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DRAFT
ENVIRONMENTAL IMPACT STATEMENT

Decommissioning of Eight Surplus Production Reactors at the Hanford Site, Richland, Washington

March 1989

U.S. DEPARTMENT OF ENERGY
WASHINGTON, D.C. 20585

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DECOMMISSIONING OF EIGHT SURPLUS PRODUCTION REACTORS AT THE HANFORD SITE, RICHLAND, WASHINGTON

March 1989

U.S. Department of Energy
Washington, D.C. 20585

COVER SHEET

RESPONSIBLE AGENCY: U.S. Department of Energy

TITLE: Draft Environmental Impact Statement, Decommissioning of Eight Surplus Production Reactors at the Hanford Site, Richland, Washington

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ABSTRACT: The purpose of this Draft Environmental Impact Statement (DEIS) is to provide environmental information to assist the U.S. Department of Energy (DOE) in the selection of a decommissioning alternative for the eight surplus production reactors at the Hanford Site, Richland, Washington.

Five alternatives are considered in this DEIS: 1) No Action, in which the reactors are left in place and the present maintenance and surveillance programs are continued; 2) Immediate One-Piece Removal, in which the reactor buildings are demolished and the reactor blocks are transported in one piece on a tractor-transporter across the Site along a predetermined route to an onsite low-level waste burial area; 3) Safe Storage Followed by Deferred One-Piece Removal, in which the reactors are temporarily stored in a safe, secure status for 75 years, after which the reactor buildings are demolished and the reactor blocks are transported in one piece on a tractor-transporter across the Site along a predetermined route to an onsite low-level waste-burial area; 4) Safe Storage Followed by Deferred Dismantlement, in which the reactors are temporarily stored in a safe, secure status for 75 years, after which they are fully dismantled and any remaining radioactive waste is transported to a low-level waste-burial area on the Hanford Site; and 5) In Situ Decommissioning, in which the reactors remain at their present locations, contamination is immobilized, major voids are filled, potential pathways (openings such as large pipes, air ducts, and doors) are sealed, and an engineered mound of building rubble, earth, and gravel is constructed over the decommissioned reactor to act as a long-term protective barrier against human intrusion, water infiltration, and water and wind erosion. A second No Action alternative of closing the facilities and doing nothing further is neither responsible nor acceptable and is not considered further.

COMMENTS: To provide comments to the DOE on the DEIS, either send written comments to Ms. Karen J. Wheeless at the above address, or present comments orally or in writing at one of the scheduled public hearings. The locations, dates, and times of the public hearings can be obtained by calling the DOE Richland Operations Office [(509) 376-7378]. Locations, dates, and times of public hearings will also be advertised in selected Northwest newspapers. To ensure consideration in preparation of the final EIS, all comments must be provided to the DOE Richland Operations Office within 90 days after the date of the Federal Register notice of publication.

FOREWORD

This draft environmental impact statement (EIS) presents analyses of potential environmental impacts of decommissioning the eight surplus production reactors at the Hanford Site near Richland, Washington.

In 1980, the U.S. Department of Energy (DOE) issued an Environmental Assessment (EA) of the F-Area Decommissioning Program (DOE/EA-0120), which addressed the dismantlement of the F Reactor and disposal of radioactive materials in burial grounds in the 200 Areas of the Hanford Site. Four alternatives were considered at that time: layaway, protective storage, entombment, and dismantlement. Based on the EA, a finding of no significant impact for the dismantlement alternative was published in the Federal Register on August 22, 1980 (45 FR 56125).

Subsequent to that action, the DOE concluded that it would be more appropriate to consider and implement a consolidated decommissioning program for all eight of the surplus production reactors located at Hanford, and decided to examine all reasonable decommissioning alternatives in greater depth. Accordingly, on May 16, 1985, the DOE published in the Federal Register (50 FR 20489) a "Notice of Intent to Prepare an Environmental Impact Statement on Decommissioning the Eight Shutdown Production Reactors Located at the Hanford Site Near Richland, Washington." The notice of intent presented pertinent background information on the proposed scope and content of the EIS. The scope of the draft EIS includes only the disposition of the eight reactors, associated fuel storage basins, and the buildings used to house these systems. Decommissioning of the N Reactor is not within the scope of this EIS. Thirty-five comment letters were received in response to the notice of intent; all comments were considered in preparing the draft EIS.

This draft EIS was prepared in accordance with the requirements of the National Environmental Policy Act of 1969 (NEPA), as amended, and the implementing regulations of the Council on Environmental Quality (CEQ) in 40 CFR 1500-1508, as well as the DOE guidelines for implementation of the CEQ Regulations set forth in 52 FR 47662. The draft EIS is being written early

in the decision-making process to ensure that environmental values and alternatives are fully considered before any decisions are made that might lead to unacceptable environmental impacts or that might limit the choice of reasonable alternatives. To comply with the NEPA requirement for early preparation of environmental documentation, this draft EIS has been prepared before final optimized engineering plans for decommissioning the reactors are available. As with any major action, it is expected that once a decommissioning alternative is selected, detailed engineering design will be carried out that may improve upon the conceptual engineering plans presented here. However, the engineering design will be such as to result in environmental impacts not significantly greater than those described here.

Decommissioning is dependent on future federal funding actions, and the actual start date cannot be predicted at this time. However, in the interim, the DOE is conducting a comprehensive program of surveillance and maintenance to control the radionuclide inventory in the reactors.

This draft EIS is being made available to appropriate federal, state, and local officials and units of government, environmental organizations, and the general public to provide all interested parties with the opportunity to review and comment on the document. All comments received will be assessed and considered by the DOE in preparation of the final EIS. The content of the EIS will be revised as appropriate. The final EIS will be sent to those who received this draft EIS, will be made available to members of the public, and will be filed with the U.S. Environmental Protection Agency (EPA). A notice of availability of the final EIS will be published by the DOE in the Federal Register. The DOE will make a decision on the proposed action not earlier than 30 days after the EPA's notice of filing of the final EIS is published in the Federal Register. The DOE will record its decision in a Record of Decision published in the Federal Register.

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DRAFT ENVIRONMENTAL IMPACT STATEMENT

DECOMMISSIONING OF EIGHT SURPLUS PRODUCTION
REACTORS AT THE HANFORD SITE, RICHLAND, WASHINGTON

1.0 SUMMARY

This is a summary of the draft environmental impact statement (DEIS) prepared by the U.S. Department of Energy (DOE) on the decommissioning of eight surplus plutonium production reactors located at the Hanford Site near Richland, Washington (see Figure 1.1). The objectives of the summary are to state the major results of the environmental analyses and to serve as a guide to the body of the DEIS. Section numbers and headings in this summary correspond to section numbers in the body of the DEIS (e.g., Section 1.3.4 of the summary corresponds to Section 3.4 of the body of the DEIS).

1.1 INTRODUCTION

Nine water-cooled, graphite-moderated plutonium production reactors were constructed along the Columbia River by the U.S. government at the Hanford Site near Richland, Washington, between the years 1943 and 1963. Eight of these reactors (B, C, D, DR, F, H, KE, and KW) are now retired from service, have been declared surplus by the DOE, and are available for decommissioning. One reactor (N) is in standby for the production of plutonium and for the production of steam to generate electricity. Decommissioning of the N Reactor is not within the scope of this EIS.

1.2 PURPOSE OF AND NEED FOR ACTION

The proposed action is to decommission the eight surplus production reactors. Facilities included within the scope of the proposed action are the eight surplus reactors, their associated nuclear fuel storage basins, and the buildings that house these systems. The purpose of decommissioning is to isolate any remaining radioactive or hazardous wastes in a manner that will minimize environmental impacts, especially potential health and safety impacts on the public. No future long-term use of any of the eight surplus

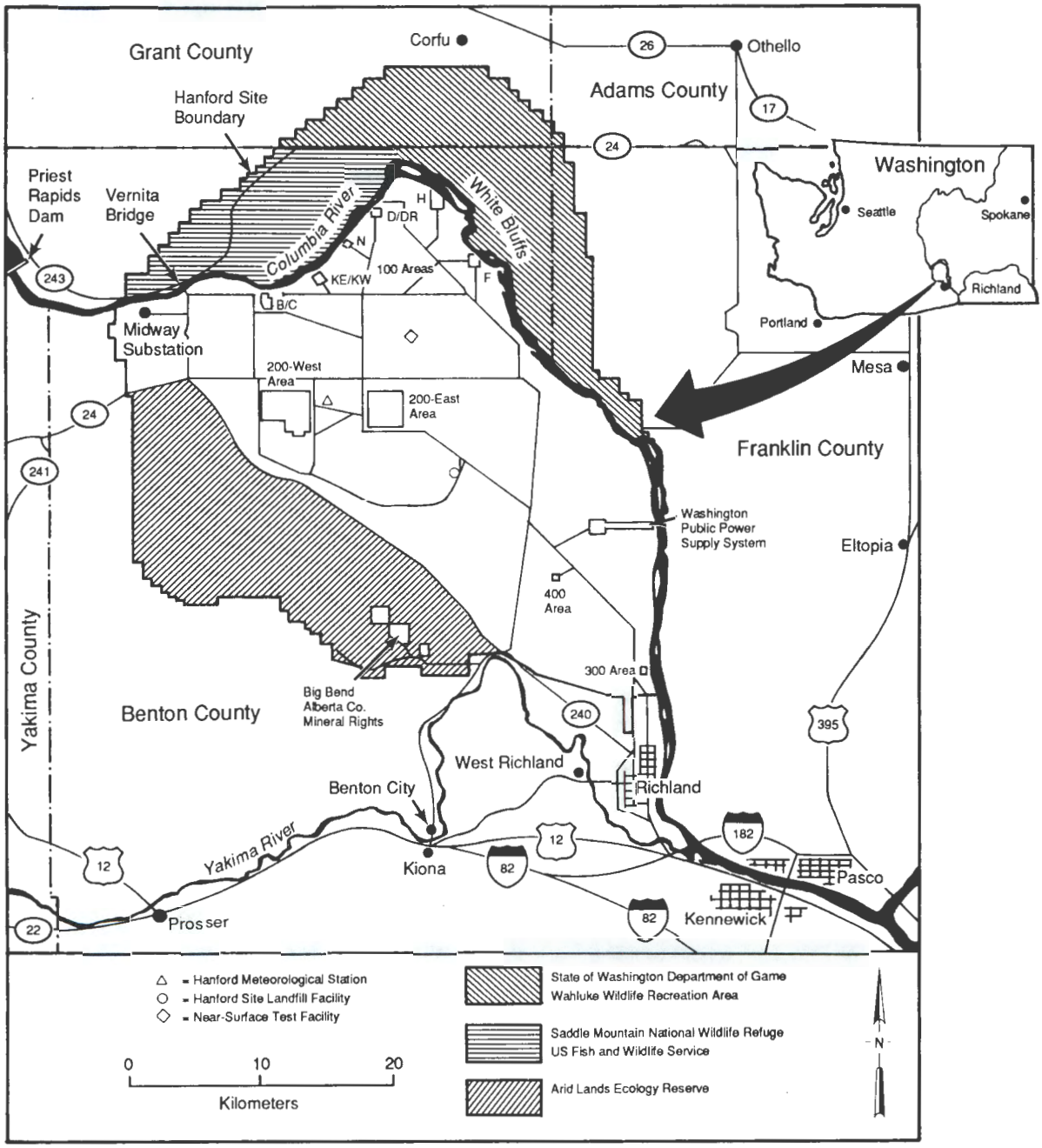


FIGURE 1.1. The Hanford Site and Surrounding Region

production reactors has been identified by the DOE. Because the reactors contain irradiated reactor components and because the buildings that house the reactors are contaminated with low levels of radioactivity, the DOE has determined that there is a need for action and that some form of decommissioning or continued surveillance and maintenance is necessary.

1.3 DESCRIPTION AND COMPARISON OF DECOMMISSIONING ALTERNATIVES

Alternatives considered in this DEIS are no action, immediate one-piece removal, safe storage followed by deferred one-piece removal, safe storage followed by deferred dismantlement, and in situ decommissioning. Evaluation of the alternatives has been carried out on the basis of several conditions and assumptions, the more important of which are listed below:

- The reactors are similar in design, construction, and radiological condition. The differences are noted in the EIS but are not significant for decommissioning purposes.
- The residual radioactive materials within the surplus facilities are low-level radioactive wastes (Low-Level Radioactive Waste Policy Act), which are suitable for disposal at Hanford by shallow-land burial. Waste disposal will be in the Hanford 200-West Area for the removal and dismantlement alternatives, and in the Hanford 100 Areas for the in situ decommissioning alternative.
- Each disposal site, whether located in the 100 Areas or 200-West Area, will have a protective barrier, a ground-water monitoring system, and a marker system. The 200-West Area disposal site may be provided with a liner/leachate collection system. The protective barrier is designed to limit the infiltration of water and is assumed to limit infiltration to 0.1 centimeter per year.
- Costs are estimated on the basis of efficient, overlapping work schedules, and are given in 1986 dollars.

The reactors and their associated fuel storage basins are briefly described in the following paragraphs (see Appendix A in the DEIS for a detailed description).

The eight surplus production reactors were constructed during the period 1943 to 1955 in the Hanford 100 Areas adjacent to the Columbia River, where the large volume of water necessary for reactor cooling was available. All of the surplus production reactors have been inactive since 1971. The reactors are similar in design, except that the newer KE and KW Reactors differ from the others in the number, size, and types of process tubes; the size of the moderator (graphite) stack; and the type of reactor-block shielding employed. While noted in the EIS, these differences are not significant for decommissioning purposes.

Each reactor building, designated as a 105 building, contains a reactor block, a reactor control room, a spent-fuel discharge area, a fuel storage basin, fans and ducts for ventilation and recirculating inert gas systems, water cooling systems, and supporting offices, shops, and laboratories. A typical reactor facility is a reinforced concrete and concrete-block structure approximately 76 meters long, by 70 meters wide, by 29 meters high. Outside the reactor block, the building has massive reinforced concrete walls (0.9 meter to 1.5 meters thick) that extend upward to the height of the reactor block to provide shielding, with lighter construction above. Roof construction is primarily precast concrete slab or poured insulating concrete. The reactor block is located near the center of the building. Horizontal control-rod penetrations are on the left side of the reactor block (when facing the reactor front face), and vertical safety-rod penetrations are on top of the reactor. Process tubes, which held the uranium fuel and carried the cooling water, penetrate the block from front to rear. Fuel discharge and storage areas are located adjacent to the rear face of the reactor. Experimental test penetrations are located on the right side of most of the reactors.

A typical reactor block (Figure 1.2) consists of a graphite moderator stack encased in a thermal shield surrounded by a biological shield. The entire block rests on a massive concrete base and foundation. Each older reactor-block assembly (graphite stack, thermal shield, biological shield, and base) weighs approximately 8,100 tonnes, and has overall dimensions of

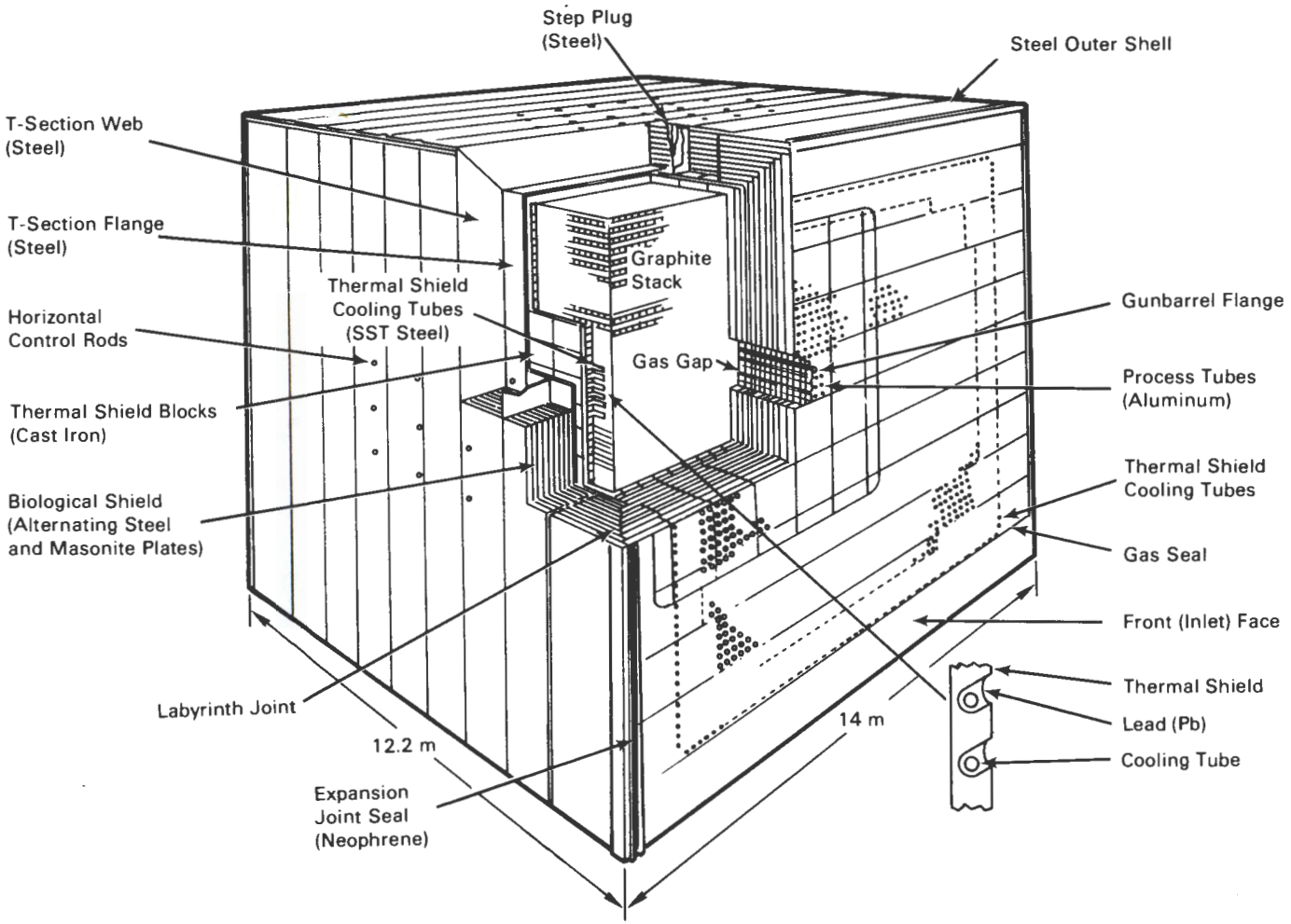


FIGURE 1.2. Reactor-Block Construction (base not shown)

14 meters wide, 12.2 meters deep, and 14 meters high. The K Reactor blocks are larger than the older reactor blocks and weigh approximately 11,000 tonnes each.

The graphite moderator stack consists of individual graphite blocks 10.6 centimeters square by 121.9 centimeters in length. The 105-F Reactor contains 8,240 graphite blocks. The full, six-sided thermal shield is composed of a single layer of approximately 3,300 cast-iron blocks. The biological shield (outside of the thermal shield) is 132 centimeters thick and forms an integral casement on the top and four sides. In the older reactors, the biological shield is constructed of alternate layers of steel and masonite, and in the K Reactors, the biological shield is composed mainly of concrete.

The fuel storage basins are concrete structures 6 meters deep, varying in area from 650 to 929 square meters. The top of each basin is at ground level. The typical fuel storage basin has a fuel discharge area adjacent to the reactor rear face, a large storage area, and a transfer area. The fuel storage basins at 105-KE and 105-KW are currently being used to store N Reactor fuel, which will be removed before decommissioning begins. The basins at 105-F and 105-H contain residual sludge and are filled with rubble and dirt. The transfer pits at 105-B and 105-C also contain some residual sludge from a previous clean-up operation. This sludge is low-level waste and will be removed or left in place, depending on the decommissioning alternative finally selected.

Radioactive inventories have been estimated for all of the surplus production reactors. The C Reactor has the largest inventory of the older reactors, and the KE Reactor has the largest inventory of the K Reactors. Radionuclides of primary interest (described in terms of their half-lives and total curie amounts in all eight reactors as of March 1985) include tritium (12.3 years, 98,100 curies), carbon-14 (5,730 years, 37,400 curies), chlorine-36 (300,000 years, 270 curies), cobalt-60 (5.3 years, 74,400 curies), cesium-137 (30.2 years, 267 curies), and uranium-238 (4.5 billion years, 0.013 curies). Cobalt-60 and cesium-137 are of importance because they contribute to the dose received by decommissioning

workers. Carbon-14, chlorine-36, and uranium-238 are of importance because of their long half-lives and because of their contribution to long-term individual and population public doses. Tritium is not of particular importance either with respect to worker doses or to public doses, but it is mentioned here because it is present in large amounts.

The Hanford Site was proposed for inclusion on the National Priorities List (NPL) for cleanup under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) on June 24, 1988. This designation includes the 100 Areas in general and a number of known inactive waste-disposal sites in particular. If in situ decommissioning is chosen, the barriers covering the reactors and fuel storage basins may cover 16 of these inactive waste-disposal sites. These sites are being evaluated by the DOE within the scope of the DOE's responsibilities under CERCLA. If the in situ decommissioning alternative is selected, any additional evaluation and remedial action required for any of these 16 sites beyond the actions proposed for in situ decommissioning will be completed before decommissioning of the reactors begins. These actions are outside the scope of this EIS.

Several materials that may be considered hazardous substances under the Resource Conservation and Recovery Act (RCRA), the Toxic Substances Control Act (TOSCA), or the Clean Air Act (CAA) are or have been present in the facilities. These materials include mercury (RCRA), friable asbestos (CAA), polychlorinated biphenyls (TOSCA), cadmium (RCRA), and nonirradiated lead (RCRA). These materials are being recycled, stored, or disposed of according to applicable regulations. Irradiated lead (653 tonnes) in the thermal shields will either be left in place under the in situ decommissioning alternative, or moved to the 200-West Area low-level waste burial ground under the dismantlement or removal alternatives. The impacts of the irradiated lead are evaluated in the DEIS.

Decommissioning alternatives are discussed in the following sections.

1.3.1 No Action Alternative

For the purpose of this EIS, no action means to continue present actions indefinitely. A second no action alternative of doing nothing further is not reasonable and is not considered in detail.

1.3.1.1 No Further Action Alternative

No further action means to close the facility and to discontinue all activities related to the facility. Although no decommissioning cost would be incurred and there would be no further occupational radiation dose, this alternative is not reasonable and is not acceptable to the DOE because it would not properly isolate the remaining radioactivity in the facility from the environment, would not provide for any maintenance or repair of the structures, and would not make any other provision for the protection of human health and safety. No further action would eventually result in deterioration of the reactor buildings, potential release of radionuclides to the environment, and potential human exposure to radioactivity and to other safety hazards by intrusion. This alternative is not considered further.

1.3.1.2 Continue Present Action Alternative

Continue present action means to continue routine surveillance, monitoring, and maintenance. These activities are the same as those required during the safe-storage period of deferred decommissioning, and the annual (or unit) costs and radiation doses are similar. Over the 100-year period assumed for active institutional control (and over any successive 100-year period), the cost to continue present action is estimated to be $41 million in 1986 dollars. The occupational radiation dose over the same 100-year period for surveillance, monitoring, and maintenance is estimated to be 24 person-rem. At the end of the 100-year period of active institutional control, problems similar to those faced in the no further action alternative would be present with respect to the isolation of remaining radioactive materials from the environment and with respect to the protection of human health and safety, even though 100 years of radioactive decay would have taken place. The presence of long-lived isotopes and other safety hazards within the facilities requires further action.

Continue present action is subsequently referred to as the no action alternative because the no further action case was not evaluated as a feasible alternative.

1.3.2 Immediate One-Piece Removal Alternative

Immediate one-piece removal means to transport each reactor block, intact on a tractor-transporter, from its present location in the 100 Areas to the 200-West Area for disposal, a distance of about 5 to 14 miles, depending on the reactor. The reactor block includes the graphite core, the thermal and biological shields, and the concrete base. Contaminated areas of the associated fuel storage basins would be removed for disposal in the 200-West Area, along with other contaminated equipment and components in the buildings that house the reactors and the fuel storage basins. The uncontaminated portion of the fuel storage basins would also be removed to provide access for the tractor-transporter. Each reactor building would then be demolished and an excavation prepared under the reactor block through the former location of the fuel storage basin. Before excavation, the weight of the reactor block would be transferred to I-beams that would be inserted through holes drilled in the concrete base and grouted in place. If contaminated soil were identified during the excavation, it would be removed and transported to the 200-West Area for disposal. A tractor-transporter would then be driven under the block, and the block would be lifted from its remaining foundation by hydraulic apparatus on the transporter and carried intact on a specially constructed haul road to the 200-West Area for disposal. The complete immediate one-piece removal process would take about 2.5 years for each reactor and about 12 years for all eight reactors. Following reactor removal, the site formerly occupied by the reactor would be backfilled, graded, seeded, and released for other DOE use. (The term "other use" means that a new or alternate use is not precluded because of the presence of radioactivity.)

The estimated total cost for immediate one-piece removal of all eight reactors is about $191 million in 1986 dollars. This includes $11 million for purchase of the two tractor units and fabrication of the transporter, and about $19 million for haul-road construction.

Public radiation doses during the decommissioning period are estimated to be zero, and occupational radiation doses are estimated to be 159 person-rem for immediate one-piece removal of all eight reactors.

1.3.3 Safe Storage Followed by Deferred One-Piece Removal Alternative

Safe storage followed by deferred one-piece removal means a multidecade safe storage period during which surveillance, monitoring, and maintenance are continued, followed by the transport of each reactor block intact on a tractor transporter from its present location in the 100 Areas to the 200-West Area for disposal.

During preparation for safe storage, building components and structures are repaired as needed to ensure the security of the facility during the safe-storage period. Building security, radiation monitoring, and fire detection systems are upgraded to provide safety, security, and surveillance as long as required.

The safe-storage period used as a basis for this EIS is 75 years, which is an adequate time for decay of cobalt-60, a radionuclide that contributes significantly to occupational dose. This period permits the reactor to be decommissioned with less occupational radiation dose than in the case of immediate one-piece removal. The safe-storage period for all but the first reactor is actually longer than 75 years because the reactors would be decommissioned in sequence at estimated 1- to 2-year intervals. During the safe-storage period, surveillance, site and facility inspections, radiological and environmental surveys, and site and facility maintenance would be carried out. Major building maintenance would be performed at estimated 5-year and 20-year intervals.

At the end of the safe-storage period, deferred one-piece removal would take place. The sequence of events is the same as for immediate one piece removal. Deferred one-piece removal is estimated to take about 2.5 years for each reactor and about 12 years for all eight reactors. The entire safe storage followed by deferred one-piece removal alternative would take about 87 years for all eight reactors.

The estimated total cost for safe storage followed by deferred one-piece removal of all eight reactors is about $198 million in 1986 dollars. This includes about $34 million for safe storage and preparation for safe storage, and about $164 million for deferred one-piece removal.

Public radiation doses are estimated to be zero, and occupational radiation doses are estimated to be 51 person-rem, including 23 person-rem during the safe-storage period and 28 person-rem during deferred one-piece removal, for all eight reactors.

1.3.4 Safe Storage Followed By Deferred Dismantlement Alternative

Safe storage followed by deferred dismantlement means a multidecade safe-storage period (75 years), during which surveillance, monitoring, and maintenance are continued, followed by piece-by-piece dismantlement of each reactor, and transport of radioactive waste to the 200-West Area for burial. Piece-by-piece dismantlement is a reasonable alternative to consider at a delayed point in time, because radioactive decay, primarily of cobalt-60, will significantly reduce occupational radiation exposure compared to immediate piece-by-piece dismantlement. Activities during preparation for safe storage and during the safe storage period are the same as for the safe storage followed by deferred one-piece removal alternative, except for slightly longer storage periods for all but the first reactor in the deferred dismantlement case.

At the end of the safe-storage period, deferred dismantlement takes place. Each reactor block would be disassembled piece by piece, and all contaminated equipment and components would be packaged and transported to the 200-West Area for disposal. Contaminated structural surfaces, including contaminated surfaces of the fuel storage basins, would also be removed, packaged, and transported to the 200-West Area for disposal. Noncontaminated material and equipment would be released for salvage, or disposed of in place or in an ordinary landfill. Remaining noncontaminated structures would be demolished and the site backfilled, graded, seeded, and released for other DOE use. An estimated 6.5 years would be required for deferred dismantlement of each reactor. The entire safe storage followed by deferred dismantlement process would take about 103 years for all eight reactors.

The estimated total cost for safe storage followed by deferred dismantlement of all eight reactors is about $217 million in 1986 dollars. This includes about $36 million for safe storage and preparation for safe storage, and about $181 million for deferred dismantlement.

Public radiation doses during the decommissioning period are estimated to be zero, and occupational radiation doses are estimated to be 532 person-rem, including 23 person-rem during the safe-storage period and 509 person-rem during deferred dismantlement, for all eight reactors. The occupational radiation dose for deferred dismantlement is higher than the occupational radiation doses for immediate or deferred one-piece removal because of the need to work at the interior of the carbon block where dose rates are higher than in the work areas utilized for one-piece removal. Even after 75 years of decay, the occupational dose (i.e., the product of worker hours times dose rates, summed over all tasks), would exceed that for immediate one-piece removal. It is possible, however, that in 75 years advances in robotics would reduce the occupational radiation dose.

1.3.5 In Situ Decommissioning Alternative

In situ decommissioning means to prepare the reactor block for covering with a protective mound (barrier) and to construct the mound. Surfaces within the facility that are potentially contaminated would be painted with a fixative to ensure retention of contamination during subsequent activities. The voids beneath and around the reactor block would be filled with grout and/or gravel as a further sealant and to prevent subsidence of the final overburden. Roofs, superstructures, and concrete shield walls would be removed down to the level of the top of the reactor block. Structures surrounding the reactor shield walls would be demolished. Piping and other channels of access into the reactor building would be backfilled with grout or similar material to ensure isolation of the reactor from the surrounding environment. Finally, the reactor block, its adjacent shield walls, and the spent-fuel storage basin, together with the contained radioactivity, gravel, and grout, would be covered to a depth of at least 5 meters with a mound containing earth and gravel. The mound would include an engineered barrier designed to limit water infiltration through the barrier to 0.1 centimeter per year. Riprap on the sides of the mounds would ensure structural stability of the mounds and mitigate against the impacts of any flood that might reach the reactors. An artist's conception of the barrier configuration for one of the reactors is shown in Figure 1.3. The mounds may cover the

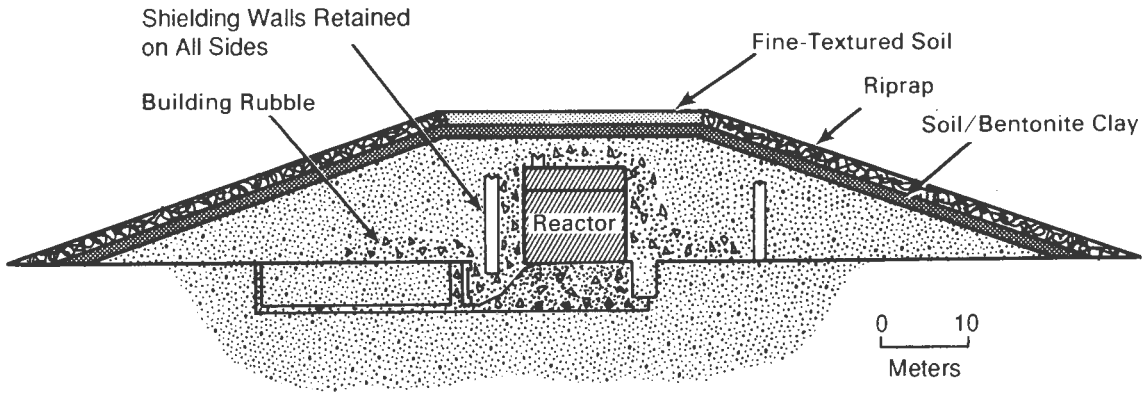


FIGURE 1.3. Barrier Configuration for In Situ Decommissioning

existing locations of 16 inactive waste-disposal sites. Necessary remedial actions for these sites will be taken prior to or in conjunction with in situ decommissioning.

In situ decommissioning of one reactor is estimated to take about 2 years, and in situ decommissioning of all eight reactors is estimated to take about 5 to 6 years. The estimated total cost for in situ decommissioning of all eight reactors is about $181 million in 1986 dollars.

Public radiation doses during the decommissioning period are estimated to be zero, and occupational radiation doses are estimated to be 33 person-rem for in situ decommissioning of all eight reactors.

1.3.6 Alternatives Considered but Not Analyzed in Detail

One major alternative, immediate dismantlement, was identified but not analyzed in detail because of its high cost (in the same range as safe storage followed by deferred dismantlement) and high occupational dose (higher than safe storage followed by deferred dismantlement because of the shorter radioactive isotope decay time). Minor variations within each decommissioning alternative also were not analyzed in detail because they offered no apparent advantages. Alternative disposal sites (i.e., other than Hanford) also were not analyzed in detail because they would result in increased costs, the possibility of increased radiation exposures to the public from cross-country transport of radioactive waste, and the possibility of transportation accidents with no compensating benefit.

1.3.7 Evaluation of Alternatives

Estimated costs of the alternatives are shown in Table 1.1, segregated to show the costs of safe storage, construction of monitoring wells, well monitoring, waste disposal, and other decommissioning costs.

The total costs and principal environmental impacts of the alternatives considered are summarized in Table 1.2. The impacts include short-term occupational radiation doses and long-term public radiation doses as a result of releases of radioactivity from the 100-Area or 200-West Area disposal sites (from Section 1.5). (A distinction is made in the DEIS between short-term impacts that occur during decommissioning operations and long-term impacts that occur following the completion of decommissioning operations to 10,000 years.) Other impacts afford little or no basis for choice among alternatives.

1.4 AFFECTED ENVIRONMENT

The affected environment includes areas both on the Hanford Site and external to the Hanford Site that might be impacted by decommissioning (see Figure 1.1). These areas are briefly described in the following sections.

TABLE 1.1. Costs of Alternatives

Activity	No Action (Continue Present Action)	Immediate One-Piece Removal	Safe Storage Followed by Deferred One-Piece Removal	Safe Storage Followed by Deferred Dismantlement	In Situ Decommissioning
Safe storage	$41.0 M	--	$33.8 M	$35.7 M	--
Decommissioning operations	--	$110.7 M	110.7	155.0	$27.7 M
Construction of wells	--	1.4	1.4	1.4	1.9
Well monitoring	--	35.1	8.1	9.6	93.6
Waste disposal/barrier	--	43.6	43.6	14.9	58.0
TOTALS	$41.0 M	$190.8 M	$197.6 M	$216.6 M	$181.2 M

TABLE 1.2. Comparison of Alternatives[a]

Alternative	Occupational Radiation Dose (person-rem)	Total Cost (millions of 1986 $)	Population Dose Over 10,000 yr[b] (person-rem)	Maximum Well Dose[c] (rem/yr)
No action (continue present action)	24	41	50,000	1.2
Immediate one-piece removal	159	191	1,900	0.04
Safe storage followed by deffered one-piece removal	51	198	1,900	0.04
Safe storage followed by deferred dismantlement	532	217	1,900	0.04
In situ decommissioning	33	181	4,700	0.03

(a) Quantities are for all eight reactors. Costs are for 100 years.
(b) The same population would receive 9 billion person-rem over 10,000 years from natural radiation.
(c) This is the maximum dose rate to a person drinking water from a well drilled near the waste form at any time up to 10,000 years.

1.4.1 Description of Impacted Portions of the 100 and 200 Areas

In early 1943, the U.S. Army Corps of Engineers selected the Hanford Site as the location for reactor and chemical separation facilities for the production and purification of plutonium for possible use in nuclear weapons. Areas of the Site that may be impacted by the decommissioning of the eight surplus production reactors are described in the following sections.

1.4.1.1 100 Areas

The 100 Areas are all on relatively flat terraces and bars near the Columbia River with elevations generally between 120 meters and 150 meters above mean sea level, and from about 11 meters to 30 meters above normal

river level. The topography is characterized by low relief and gentle slopes. Small gravel mounds to 10 meters in height are found between the 100-K and 100-D Areas.

The 100-B/C Area occupies about 263 hectares, and is the farthest upstream of the 100 Areas, at river mile 384. Essentially all facilities in the area are surplus, with the exception of the 100-B/C water system, which supplies water for the 200 Areas. The 100-K Area occupies about 55 hectares at river mile 381.5. The KE and KW fuel storage basins are in operation for the purpose of storing irradiated fuel from the N Reactor. The 100-N Area occupies about 36 hectares at river mile 380. All of its facilities are operational. The 100-D/DR Area occupies about 389 hectares at river mile 377.5. While the reactor and fuel storage basins are surplus, other facilities remain in operation at the 100-D/DR Area. Sanitary and fire-protection water is transported by pipeline from the 100-D/DR Area to the 100-H and 100-F Areas, and backup water is supplied to the 200 Areas in support of the 100-B/C water system. The 100-H Area occupies 130 hectares at river mile 372.5. All major buildings have been removed from the 100-H Area except the 105 building. The 100-F Area occupies 219 hectares at river mile 369. All facilities except the 105, 108, and 1608 buildings have been removed from the 100-F Area.

Contaminated solid and liquid wastes from the 100 Areas are buried in approximately 110 inactive waste-disposal sites in the 100 Areas. These sites are currently being reviewed by the DOE pursuant to its responsibilities under CERCLA.

1.4.1.2 <u>200 Areas</u>

The 200 Areas are located near the middle of the Hanford Site, about 11 kilometers from the Columbia River. The topography is nearly flat and varies in elevation from about 190 to 245 meters above mean sea level. Facilities and sites exist in the 200 Areas for nuclear fuel processing, plutonium separation, plutonium fabrication, high-level and transuranic radioactive waste handling and storage, and low-level radioactive waste handling and disposal.

Contaminated solids and liquids from the entire Hanford Site are buried in both inactive and active low-level waste burial grounds in the 200 Areas. Low-level wastes from the removal and dismantlement decommissioning alternatives would be buried in the 200-West Area.

1.4.2 Geology and Hydrology of the Site

The Hanford Site is located in the semiarid Pasco Basin, a structural and topographic depression within the Columbia Plateau in southeastern Washington State. The 100 Areas are located adjacent to the Columbia River on the lowest of several levels of alluvial terraces on the Site. The normal elevation of the river is 116 meters above mean sea level, and the elevations of the reactor ground-floor levels range from 125.7 to 150.6 meters. The 200 Areas are located near the center of the Site on a large bar of sand and gravel known as the 200-Area Plateau. The 200-Area Plateau ranges in elevation from 190 to 245 meters above mean sea level.

1.4.2.1 Geology of the Site

The principal stratigraphic units at the Hanford Site are the Columbia River Basalt Group with interbedded sediments of the Ellensburg Formation, which forms the bedrock beneath the Site; the Ringold Formation, consisting of semiconsolidated clays, silts, sands, and gravels lying directly over the bedrock; and the Hanford Formation, composed of a thin surface mantle of sands, gravels, and wind-blown silts overlying the Ringold Formation. The basalt is as much as 5,000 meters thick, and the Ringold and Hanford Formations are up to 360 meters and 100 meters thick, respectively.

1.4.2.2 Hydrology of the Site

The primary surface water features of the Hanford Site are the Columbia and Yakima Rivers. Surface runoff from the site to these two rivers is extremely low. The average annual flow of the Columbia River at Hanford is about 3,400 cubic meters per second, and the average annual flow of the Yakima River at Kiona (see Figure 1.1) is about 104 cubic meters per second. Normal Columbia River elevations range from 120 meters above mean sea level at Vernita, where the river enters the Site, to 104 meters at the 300 Area, where it leaves the Site. The dam-regulated probable maximum flood would

produce a flow of about 40,800 cubic meters per second in the Columbia River and would reach the elevation of the bottom of the fuel storage basins at 100-F and 100-H, but would not reach the floor of any reactor building. A 50% failure of Grand Coulee Dam would create a maximum flow of about 226,500 cubic meters per second and flood elevations of 143 to 148 meters in the 100 Areas. Parts of the 100 and 300 Areas and most downstream cities would be flooded. The 200 Areas would not be reached by this flood.

Ground water occurs under the Site in both unconfined and confined aquifers. The unconfined (upper) aquifer is contained within the glaciofluvial sands and gravels in the Ringold Formation. The bottom of the unconfined aquifer is the basalt surface of the Columbia River Basalt Group or the clay zones of the lower member of the Ringold Formation. The confined aquifer consists of sedimentary interbeds and/or interflow zones that occur between dense basalt flows in the Columbia River Basalt Group. Direct interconnections occur between the unconfined and uppermost confined aquifers. Natural recharge to the unconfined aquifer may occur in small amounts from precipitation and surface runoff. Artificial recharge to the unconfined aquifer in the 200 Areas results from the disposal of waste cooling and process water to the ground. Depth to the water table averages about 12 meters in the 100 Areas and from 55 to 95 meters in the 200 Areas.

1.4.3 Climate, Meteorology, and Seismology of the Site

The Hanford climate can be described as arid, hot in summer and cool in winter. Rainfall averages 16 centimeters per year, and average temperatures range from 1.5°C in January to 24.7°C in July. The prevailing wind is from the northwest with a secondary maximum from the southwest. Summer winds frequently reach velocities of 50 kilometers per hour. The 100-year extreme wind is estimated to have a velocity of 137 kilometers per hour. Tornado probabilities are small.

The Columbia Plateau is in an area of moderate seismicity. Swarms of small, shallow earthquakes are the predominant seismic events, with magnitudes of 1.0 to 3.5 on the Richter scale.

1.4.4 Air Quality, Water Quality, and Environmental Monitoring of the Site

Air quality in the vicinity of the Hanford Site is good except for occasional episodes of wind-blown dust from dry plowed fields and construction areas. The major industrial air pollutant release is from the PUREX and Uranium Oxide Plants, which discharge oxides of nitrogen under a Prevention of Significant Deterioration (PSD) permit issued by the U.S. Environmental Protection Agency (EPA).

The State of Washington Department of Ecology classifies the Columbia River as Class A (excellent) between Grand Coulee Dam and the mouth of the river. The DOE holds a National Pollutant Discharge Elimination System (NPDES) permit issued by the EPA for eight point source discharges into the Columbia River.

Radiological monitoring of the atmosphere, ground water, Columbia River water, foodstuffs, plants, animals, and soil is conducted routinely by the Pacific Northwest Laboratory (PNL). Measurements made in 1987 show that radionuclides have entered ground water in the 200 Areas and migrated easterly to the Columbia River. Samples collected from the Columbia River upstream and downstream from the Hanford Site indicate that tritium, iodine-129, gross alpha, and uranium concentrations were measurable at higher concentrations downstream from Hanford than upstream, but that all offsite concentrations are well within EPA drinking water standards. The major sources of radionuclides entering the river are from N Reactor liquid-disposal facilities and from 200-Area ground water moving below the Hanford Site and into the river. Foodstuffs from the area, including those irrigated with Columbia River water, were sampled and the concentrations of radionuclides were shown to be similar to the low concentrations in food stuffs grown in other adjacent areas. Some waterfowl, fish, and rabbits showed low levels of cesium-137 attributable to Hanford operations. Dose rates from external penetrating radiation measured in the vicinity of local residential areas were similar to those obtained in previous years, and no contribution from Hanford activities could be identified. Nonradiological monitoring for chemical constituents included routine sampling and a special effort involving hazardous materials. Some elevated levels of nitrate, chromium,

fluoride, and carbon tetrachloride were found in ground-water samples. Columbia River waters were within state of Washington water quality standards, with the exception of pH and fecal coliform bacteria. These latter contaminants are not attributable to Hanford Site activities.

Measured and calculated radiation doses to the general public from Hanford operations during 1987 were well below applicable regulatory limits. The calculated effective dose potentially received by a hypothetical maximally exposed individual for 1987 was about 0.05 millirem, compared with a dose of 0.09 millirem estimated for 1986. The collective effective dose to the population living within 80 kilometers of the Site estimated for 1987 was 4 person-rem, compared with 9 person-rem estimated for 1986.

These doses can be compared with the 300 millirem and 100,000 person-rem received annually by an average individual and by the surrounding population, respectively, as a result of naturally occurring radiation.

1.4.5 Ecology

The ecology of the Hanford Site is that of a cool desert or shrub steppe. Because of the arid climate, the productivity of both plants and animals is relatively low compared with that of other natural communities with higher rainfall.

1.4.5.1 Terrestrial and Aquatic Ecology

The dominant plants on the Hanford Site are large sagebrush, rabbitbrush, cheatgrass, and Sandberg bluegrass. Cottonwoods, willows, cattails, and bulrushes grow along ponds and ditches. Cheatgrass and Russian thistle invade areas where the ground surface has been disturbed. More than 300 species of insects, 11 species of reptiles and amphibians, more than 125 species of birds, and 27 species of mammals are found on the Site. Coyote, elk, and mule deer are the largest mammals observed on the Site. The Columbia River supports the most important aquatic ecosystem on the Site. Forty-five species of fish have been identified in the Hanford Reach.

1.4.5.2 Threatened and Endangered Species

No federally listed threatened or endangered plant species occur on the Site. The bald eagle and peregrine falcon are animal species federally

listed as threatened and endangered, respectively. While the bald eagle is a regular winter resident and the peregrine falcon is a casual migrant, neither species nests on the Site.

1.4.6 Socioeconomics of the Area Surrounding the Site

The Tri-Cities (Kennewick, Pasco, and Richland, Washington) and the surrounding area have been designated a Metropolitan Statistical Area (MSA) by the U.S. Bureau of the Census. About 340,000 people live within an 80-kilometer radius of the center of the Site, according to the 1980 census. About 13,000 persons are employed on DOE-related projects at Hanford.

Service amenities in the Tri-Cities are provided by various agencies and units of government and by private organizations in the MSA (e.g., schools, fire and police protection, utilities, medical facilities, parks, and shopping facilities).

Major land use in the area includes the Hanford Site, urban and industrial development in and around incorporated cities, irrigated farming, and dry farming.

Nine archaeological properties located on the Hanford Site have been identified and listed in the National Register of Historic Places, but none are within the 100 or 200 Areas. Preoperational surveys at proposed borrow-pit sites and around the reactors will be conducted in advance of any decommissioning operations to ensure that no cultural resource or archaeological site is inadvertently impacted or disturbed.

The DOE has solicited the opinion of the Washington State Historic Preservation Officer as to whether or not the B Reactor is eligible for inclusion in the National Register of Historic Places. The State Historic Preservation Officer has replied in the affirmative; however, no nomination has yet been made.

The Hanford Site is located on lands ceded to the U.S. government by the Yakima and Umatilla Indians and is near lands ceded by the Nez Perce Indians.

1.4.7 Transportation

The area is served by major interstate, U.S., and state highways; by commercial airlines; by two railroads; and by barge service on the Columbia River. DOE-owned railway and highway systems serve the Hanford Site.

1.5 ENVIRONMENTAL CONSEQUENCES

Environmental consequences other than those discussed in Section 1.3 are discussed in this section.

1.5.1 - 1.5.6 Radiological Consequences

Radiological consequences may occur as part of decommissioning operations, as a result of accidents during decommissioning, and as a result of long-term, postdecommissioning releases of radionuclides from the disposed low-level radioactive wastes. In all three cases, the radionuclide inventory described in Section 1.3 provides the basis for the calculated potential radiological impact. Occupational radiation doses are discussed in Section 1.3 (Table 1.2) and result from external exposure to gamma radiation. Accidental and long-term radiation doses are discussed below.

During decommissioning operations, the most probable source of radiation exposure to the public is inhalation of airborne radionuclides released by accidents. Several postulated accidents were analyzed. The one of largest radiological consequence was determined to be a railroad-crossing collision of a gasoline tanker with a boxcar carrying reactor graphite; this postulated accident occurred under the safe storage followed by deferred dismantlement alternative. Although the graphite would not burn, the resulting 30-minute fire would release radioactive particulates to the atmosphere sufficient to cause a lifetime dose of 0.2 rem to the maximally exposed individual member of the public.

The radiological consequences of long-term releases of radionuclides to the ground water over 10,000 years from the 200-Area disposal site and from the 100-Area in situ sites were also calculated, based on calculated release rates from the solid wastes and on estimated travel times to the Columbia River. Population doses from these releases were calculated to be about

50,000 person-rem (5 to 50 health effects) for no action (continued present action), 1,900 person-rem (0.2 to 2 health effects) for the removal and dismantlement alternatives, and 4,700 person-rem (0.5 to 5 health effects) for in situ decommissioning. During the same time period (10,000 years), the same population (410 million affected individuals) would receive 9 billion person-rem (900 thousand to 9 million health effects) from natural radiation sources.

Maximum annual individual doses over 10,000 years were also calculated for persons drinking water from wells drilled near the waste-disposal sites. These calculated doses are 1.2 rem per year for no action, 0.04 rem per year for the removal and dismantlement alternatives, and 0.03 rem per year for in situ decommissioning.

1.5.7 Impacts from Hazardous Wastes

Based on known release rates and on estimated travel times, estimates were made of the maximum concentration of lead in well water near the waste-disposal sites over 10,000 years. For the no action alternative, the maximum concentration of lead is estimated to be 6×10^{-4} milligrams per liter; for the removal and dismantlement alternatives, the concentration of lead is estimated to be 4.9×10^{-4} milligrams per liter; and for the in situ decommissioning alternative, the concentration of lead is estimated to be 1.2×10^{-4} milligrams per liter.

1.5.8 Socioeconomic Impacts

Socioeconomic impacts are caused primarily by the influx (or egress) of workers required by the project. The maximum number of workers required onsite at any one time for any decommissioning alternative is 100. This number is less than 1% of the workers presently on the Site and would produce negligible socioeconomic impacts.

1.5.9 Commitment of Resources

Resources committed to the decommissioning of the Hanford surplus reactors would include the land on which the reactors now stand and the necessary grout and fill material for in situ decommissioning; the land required for low-level waste disposal for either the one-piece removal or dismantlement

alternatives; and the energy necessary to carry out the alternative for any of the alternatives. Land commitments are discussed in the next section.

It is estimated that approximately 98,000 cubic meters of grout and 1,600,000 cubic meters of fill material would be required for in situ decommissioning of all eight reactors.

Approximately 6 million, 2 million, and 5 million liters of fuel would be consumed for one-piece removal, dismantlement, and in situ decommissioning, respectively.

1.5.10 Unavoidable Adverse Impacts

Unavoidable adverse impacts would result from each decommissioning alternative. The most important of these is occupational radiation dose, which is greatest for safe storage followed by deferred dismantlement (532 person-rem), less for immediate one-piece removal (159 person-rem) and safe storage followed by deferred one-piece removal (51 person-rem), and least for in situ decommissioning (33 person-rem). The occupational radiation dose is least for in situ decommissioning because the reactor block is neither handled nor disassembled.

Another adverse impact is the dedication of land to the disposal of radioactive waste. The land required for radioactive-waste disposal in the 200 Areas is about 6 hectares, which is offset by the 5 hectares that would become available for other DOE use in the 100 Areas following removal or dismantlement of all eight reactors. For in situ decommissioning, however, about 20 hectares of land would be occupied in the 100 Areas by the eight reactor mounds, although no land would be required in the 200 Areas for radioactive-waste disposal.

Approximately 16 hectares of land could be disrupted for excavation of earth and gravel for in situ decommissioning (depending on the depth of the excavation), but this land can be reclaimed and would remain available for other use.

1.5.11 Short-Term Versus Long-Term Use of the Environment

Each decommissioning alternative will require the use of some land for disposal of radioactive wastes and will restrict that land from other

beneficial uses for long periods of time because of the presence of long-lived radionuclides, principally carbon-14 and chlorine-36. The amount of land thus restricted was discussed in Section 1.5.10.

1.5.12 Means to Mitigate Adverse Environmental Impacts

Adverse environmental impacts that can be mitigated include occupational radiation doses, disruption to land areas, and migration of chemicals and radionuclides caused by water infiltration through waste-disposal sites.

Decommissioning workers will wear dosimeters, and radiation zones will be monitored before workers are allowed to enter. Protective shields, remotely operated tools, and contamination control envelopes will be employed when appropriate. Standard contamination monitoring devices will be used. ALARA (as low as reasonably achievable) principles will be applied in every phase of engineering planning that deals with radioactive material to reduce worker exposure.

Sites used for the acquisition of dirt and gravel will be surveyed for archaeological resources and endangered species, and will be rehabilitated when no more material need be acquired from the site.

Water migration through the waste-disposal sites (both the 200-West Area and the 100-Area sites) will be mitigated by the installation of a multi-layer, engineered barrier consisting of a capillary layer of fine-textured soil underlain by an impervious layer of soil/bentonite clay. Calculations in the DEIS are based on a water infiltration rate through the barrier of 0.1 centimeter per year.

1.5.13 Cumulative Impacts

No significant additional cumulative impact from decommissioning the surplus production reactors is expected in conjunction with existing or reasonably foreseeable future actions at the Hanford Site.

1.6 STATUTORY AND REGULATORY REQUIREMENTS

Decommissioning will be carried out in accordance with DOE's environmental policy, which is "to conduct its operations in an environmentally safe

and sound manner . . . in compliance with the letter and spirit of applicable environmental statutes, regulations, and standards."

Environmental regulations and standards of potential relevance to decommissioning are those promulgated by the EPA under the Atomic Energy Act (AEA), the Clean Air Act (CAA), Clean Water Act (CWA), Safe Drinking Water Act (SDWA), Resource Conservation and Recovery Act (RCRA), and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). State environmental regulations have also been promulgated under the authority of some of these federal statutes. Regulations of the U.S. Nuclear Regulatory Commission do not apply to the decommissioning of the surplus production reactors.

No EPA permit is expected to be required for decommissioning purposes, with the possible exception of a RCRA permit. No existing EPA standard is expected to be exceeded either by decommissioning operations or by disposal actions.

2.0 PURPOSE OF AND NEED FOR ACTION

Nine water-cooled, graphite-moderated, plutonium production reactors were constructed by the U.S. government at the Hanford Site near Richland, Washington, along the Columbia River between the years 1943 and 1963. All nine reactors are owned by the U.S. government and are managed by the U.S. Department of Energy (DOE). Eight of these reactors are now retired from service (B, C, D, DR, F, H, KE, and KW), have been declared surplus by the DOE, and are available for decommissioning. One of the reactors (N) is in standby for the production of plutonium and for the production of steam to generate electricity. Decommissioning of the N Reactor is not within the scope of this environmental impact statement (EIS). The history and status of each reactor is given in Table 2.1.

TABLE 2.1. Hanford 100-Area Reactor Status

Area	Reactor	Year Construction Started	Years of Operation	
			Start	Shutdown
100-B/C	105-B	1943	1944	1968
	105-C	1951	1952	1969
100-K	105-KW	1952	1955	1970
	105-KE	1953	1955	1971
100-N	105-N	1959	1963	Put in stand-by in 1988
100-D/DR	105-D	1943	1944	1967
	105-DR	1947	1950	1964
100-H	105-H	1948	1949	1965
100-F	105-F	1943	1945	1965

The proposed action is to decommission the eight surplus reactors. The purpose of decommissioning is to isolate securely any remaining radioactive or hazardous wastes in a manner that will reduce environmental impacts to an acceptable level, especially potential health and safety impacts on the public. No future long-term use of any of the eight surplus reactors has

been identified by the DOE, and the DOE has declared them surplus. Because the reactors contain irradiated reactor components and because the buildings that house the reactors are contaminated with low levels of radioactivity, the DOE has determined that there is a need for additional action to ensure protection of the public health and safety, and that decommissioning or continued surveillance and maintenance is necessary.

The purpose of this draft EIS is to provide environmental information that will assist the DOE in deciding which decommissioning alternative is most appropriate for the eight surplus Hanford reactors. The draft EIS was prepared in accordance with the requirements of the National Environmental Policy Act (NEPA), the regulations of the Council on Environmental Quality (40 CFR 1500-1508), and the guidelines of the DOE (52 FR 47662).

An early step in the EIS process is the publication in the Federal Register of a notice of intent (NOI) to prepare an EIS. The NOI announces the proposed action (i.e., the subject of the EIS), possible alternative actions, potential impacts to be evaluated in the EIS, and other pertinent information. The NOI also invites comments on the scope of the EIS, including suggestions for other alternatives and impacts to be evaluated. The NOI on decommissioning the eight surplus Hanford reactors appeared in the Federal Register on May 16, 1985 (50 FR 20489). The DOE received 35 letters containing comments and/or requests for a copy of the draft EIS. Each comment was carefully evaluated for additional alternatives or potential impacts to be considered in the draft EIS. Appropriate suggestions were included in the draft EIS.

Five letters of comment on the NOI recommended including 100-Area cribs, burial grounds, and settling basins within the scope of the EIS. These facilities have been considered by the U.S. Energy Research and Development Administration (ERDA 1975) with respect to the impact of flooding. Further, the DOE is presently re-evaluating these facilities within the scope of DOE's environmental review responsibilities under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA). For these

reasons, facilities in the 100 Area, other than the reactors, fuel storage basins, and buildings housing these two types of facilities, are outside the scope of this EIS.

The DOE, in accordance with 36 CFR 800, has solicited the opinion of the Washington State Historic Preservation Officer (Hunter 1986) as to whether or not the 105-B Reactor is eligible for inclusion in the National Register of Historic Places (36 CFR 60). The State Historic Preservation Officer has replied in the affirmative; however, no nomination has been made (see Appendix J).

2.1 REFERENCES

Comprehensive Environmental Response, Compensation, and Liability Act of 1980, as amended (CERCLA); Public Laws 96-510, 97-216, 97-272, and 98-45.

Federal Register, Volume 52, p. 47662 (52 FR 47662); "Compliance with the National Environmental Policy Act (NEPA); Amendments to the DOE NEPA Guidelines." (December 15, 1987.)

Federal Register, Volume 50, p. 20489 (50 FR 20489); "Intent to Prepare an Environmental Impact Statement on Decommissioning the Eight Shutdown Production Reactors Located at the Hanford Site near Richland, Washington." U.S. Department of Energy (May 16, 1985).

Hunter, J. R. 1986. Determination of Eligibility of Hanford B Reactor as a National Historic Site (Letter Report). U.S. Department of Energy Richland Operations Office, Richland, Washington.

National Environmental Policy Act of 1969, as amended (NEPA); Public Law 91-190, 42 U.S.C. 4321 et seq.

U.S. Code of Federal Regulations, Title 36, Part 60 (36 CFR 60); "National Register of Historic Places." U.S. Department of the Interior.

U.S. Code of Federal Regulations, Title 36, Part 800 (36 CFR 800); "Protection of Historic and Cultural Properties." U.S. Department of the Interior.

U.S. Code of Federal Regulations, Title 40, Parts 1500-1508 (40 CFR 1500-1508); "Regulations for Implementing the Procedural Provisions of the National Environmental Policy Act." U.S. Environmental Protection Agency.

U.S. Energy Research and Development Administration (ERDA). 1975. Final Environmental Statement on Waste Management Operations, Hanford Reservation, Richland, Washington. ERDA-1538, U.S. Energy Research and Development Administration, Richland Operations, Richland, Washington.

3.0 DESCRIPTION AND COMPARISON OF DECOMMISSIONING ALTERNATIVES

The results of the evaluation of five possible alternatives for decommissioning the eight surplus production reactors are described in this chapter. First, the scenarios for the five alternatives are briefly defined; second, assumptions and conditions are stated; third, each alternative is evaluated in terms of time commitment, overall cost, radiation dose to decommissioning workers and the public, and other impacts; and finally, the results of the evaluations are summarized. The five alternatives are defined below.

No Action--Two possible scenarios exist for the no action alternative: 1) "take no further action," which means to secure the facilities and discontinue the present surveillance, monitoring, and maintenance activities; and 2) "continue present action," which means to continue the present surveillance, monitoring, and maintenance activities for an indefinite period.

Immediate One-Piece Removal--"Immediate one-piece removal" means to remove radioactive materials and components from the facilities at an early date such that the residual levels of radioactivity at the site are sufficiently low to permit other DOE use of the site. For the surplus production reactors, this condition is achieved by removing each reactor block and transporting it overland in one piece to a DOE-owned burial location in the Hanford 200-West Area. (A reactor block consists of a graphite core, surrounding shields, and supporting base.) Other contaminated materials, equipment, and soils external to the reactor blocks would be removed, packaged, and transported to the low-level waste disposal site in the 200-West Area. Uncontaminated structures and equipment would be salvaged if usable or demolished and placed in waste areas at or near the reactor sites.

Safe Storage Followed by Deferred One-Piece Removal--"Safe storage followed by deferred one-piece removal" means to secure for safe storage for up to 75 years the areas of the site that contain radioactive materials, followed by 1) the transport of each reactor block from its present location in the 100 Areas to the 200-West Area for disposal; and 2) the removal, packaging, and transport of the remaining radioactive materials to the 200-West

Area low-level waste disposal site so that the reactor site can be made available for other DOE use. For the surplus production reactors, this condition is achieved by removing or fixing (securing) all smearable radioactive contamination within the facilities, maintaining the security and integrity of the structures during the storage period, and then removing each reactor block and transporting it over land in one piece to the 200-West Area disposal site. Remaining radioactive materials and equipment would be dismantled, packaged, and transported to the low-level waste disposal site in the 200-West Area. Uncontaminated structures and equipment would be demolished and placed in landfills in the vicinity of the reactor sites.

Safe Storage Followed by Deferred Dismantlement--"Safe storage followed by deferred dismantlement" means to secure for safe storage for up to 75 years the areas of the site that contain radioactive materials and to remove the remaining radioactive material at the end of the safe-storage period. Following the storage period, radioactive materials would be removed, packaged, and transported to the 200-West Area low-level waste disposal site so that the reactor site could be made available for other DOE use. For the surplus production reactors, this condition is achieved by removing or fixing (securing) all smearable radioactive contamination within the facilities, maintaining the security and integrity of the structures during the storage period, and then dismantling (piece-by-piece) and packaging the remaining radioactive materials and equipment, and transporting the packaged wastes to the low-level waste disposal site in the 200-West Area. Uncontaminated structures and equipment would be demolished and placed in landfills in the vicinity of the reactor sites.

In Situ Decommissioning--"In situ decommissioning" means to leave the reactor block, concrete shield walls, and fuel storage basins in place and to secure the remaining radioactivity. All of the nonradioactive structures around the reactor building would be demolished, major voids within the reactor building would be filled with gravel and/or grout, and the building would be covered with a mound of gravel and earth, thus, in effect, creating a low-level radioactive waste disposal site at each of the reactor buildings.

Each of these alternatives is evaluated in more detail in subsequent subsections. The general conditions and assumptions applied during these evaluations are listed below:

- All eight reactors are similar in design, construction, and radiological condition. Differences are described in Appendix A and are taken into account in the cost and dose calculations. These differences are not, however, very significant for decommissioning purposes.
- Costs are estimated on the basis of efficient decommissioning. The reactors would be decommissioned in overlapping sequence, with work on one reactor beginning while work on the previous reactor is still in progress. This would take advantage of worker experience, efficient equipment usage, and minimum office and engineering staff retention time. Should the reactors be decommissioned in a less-efficient manner, the estimated costs, decommissioning times, and occupational doses can be expected to be greater than those presented here.
- Costs are estimated for an assumed 100 years of active institutional control. The costs include the costs of storage before decommissioning, operations during decommissioning, and monitoring after decommissioning. The 100-year period of institutional control was selected based on EPA guidance for active institutional control of high-level radioactive wastes in 40 CFR 191. EPA guidance for active institutional control of low-level radioactive waste is not expected to be longer than 100 years.
- Estimated costs are given in constant 1986 dollars. Cost contingencies are quoted in a range from 12% to 30%. Cost and contingencies represent the best judgment of several different cost estimators (individuals and firms). Presenting the costs in 1988 dollars, given the modest inflation (approximately 5%) from 1986 to 1988, would not provide better information for distinguishing among alternatives than costs in 1986 dollars.

- The fuel storage basins at the 105-F and 105-H Reactor facilities were filled with equipment associated with the operations of the basins and with clean fill in 1969 to stabilize the residual sludge and water. Before filling the basins, the water level was lowered to allow for thorough monitoring to determine whether any high dose-rate fuel elements were remaining in the basins. None were believed to have been left at the time the fill material was placed in the basins. However, additional action is being taken before decommissioning begins (including the no action alternative) to locate and remove any fuel elements that may have been overlooked and left in the basins. For the purpose of calculations in the DEIS, all fuel storage basins are assumed to be empty and dry before decommissioning begins (including no action), except for residual sludge in the 105-B and 105-C transfer pits, which is classified as low-level waste and will be removed or left in place depending on the decommissioning alternative.
- The soil column under the KE fuel storage basin contains a significant, but not yet fully characterized, radionuclide inventory from a past leak that has been repaired. The fuel storage basin will be cleaned, and the contaminated soil column will be characterized and removed, if necessary to meet low-level waste criteria, before decommissioning begins.
- Friable asbestos, mercury, polychlorinated biphenyls, cadmium, and contaminated and noncontaminated lead either are or have been present in the facilities. Friable asbestos, mercury, and polychlorinated biphenyls are being recycled, stored, or disposed of under separate environmental documentation, according to applicable regulations. Specifically, friable asbestos is being removed, packaged, and disposed of either in the Hanford central landfill or low-level radioactive waste burial ground; mercury is being either recycled or packaged and stored for future disposal as either a hazardous or radioactive mixed waste; and polychlorinated biphenyls are being packaged and stored for later disposal. Cadmium (alloyed with lead), and contaminated and noncontaminated lead will be

removed and stored for later disposal or recycle under applicable regulations for all alternatives except no action. Impacts of no action (which are the same as for disposal in the 200-West Area) are discussed in Section 5.7.1.2. Irradiated lead, an integral compound of the thermal shields, will be left in place for in situ decommissioning, or will be placed in the 200-West Area low-level waste disposal site for the other decommissioning alternatives, in accordance with applicable regulations.

- Measurements and estimates of residual inventories (Miller and Steffes 1987) support the conclusion that the radioactive materials present within the surplus facilities are low-level radioactive wastes (Low-Level Radioactive Waste Policy Act), which are suitable for disposal at Hanford by shallow-land burial. Waste disposal will be in the Hanford 200-West Area for the removal and dismantlement alternatives, and in the Hanford 100 Areas for the in situ decommissioning alternative.

- Each in situ decommissioning site in the 100 Areas will include a barrier over the waste form, a marker system, and monitoring wells. The 200-West Area disposal site will include the same features and may include a liner/leachate collection system. The barrier is assumed to limit water infiltration to 0.1 centimeter per year.

- Ground-water monitoring systems will be constructed early in the decommissioning schedules to gather background data. Conceptual designs of the ground-water monitoring systems are described in reports prepared by PNL in support of this DEIS (Smith 1987). Monitoring designs, construction costs (including installation and project administration and reporting), and annual monitoring costs are contained in that report. Where applicable, the results of the report are included in the schedules and cost estimates for the decommissioning alternatives contained in this chapter. The ground-water monitoring system's applicability to the various decommissioning alternatives is summarized in Table 3.1. As shown in Table 3.1, costs are estimated for ground-water monitoring for

TABLE 3.1. Ground-Water Monitoring System Applicability for the Various Decommissioning Alternatives (assuming 100 years of active institutional control)

Alternative	Active Decommissioning Period (yr)	Location of Monitoring System	Approximate Monitoring System Period (yr)
No action (continue present action)	100	NA[a]	NA
Immediate one-piece removal	12	200 Areas	97.5
Safe storage followed by deferred one-piece removal	87	200 Areas	22.5
Safe storage followed by deferred dismantlement	103	200 Areas	26.5
In situ decommissioning	5	100 Areas	98.3

(a) NA = not applicable.

up to the full 100 years of assumed institutional control, because of the long-term nature of the releases from the waste forms.

Other assumptions specific to individual decommissioning alternatives are described in the appropriate sections.

3.1 NO ACTION

Consideration of no action is required by the regulations of the Council on Environmental Quality that implement the National Environmental Policy Act (NEPA). No action has two possible meanings: either to discontinue present actions and do nothing further, or to continue present actions indefinitely.

3.1.1 No Further Action

With no further action, the facility would be closed and all related activities would be discontinued. Although this alternative has no cost, it

is not reasonable because it does not properly isolate the remaining radioactivity in the facility from the environment, does not provide for any maintenance or repair of the structures, and does not make any other provision for protection of human health and safety. No further action would result in deterioration of the reactor buildings, potential release of radionuclides to the environment, potential human exposure to radioactivity by intrusion, and potential safety hazards to intruders. No further action is not the DOE's interpretation of no action. This alternative is not analyzed further.

3.1.2 Continue Present Action

Present action consists of comprehensive surveillance, monitoring, and maintenance. These activities are the same as those required during the safe storage period of the safe storage followed by deferred decommissioning alternatives. The annual (or unit) costs and radiation doses are similar. Initial repairs are estimated to cost about $903,800 per reactor; major building repairs are estimated to cost about $228,800 per reactor every 20 years; minor repairs are estimated to cost about $73,000 per reactor every 5 years; and routine surveillance, monitoring, and maintenance activities are estimated to cost about $22,500 per reactor annually. For 100 years of continued present action, the cost is estimated to be $41 million in 1986 dollars, including a 20% contingency. The occupational radiation dose for these activities is estimated to be 24 person-rem over 100 years. At the end of 100 years, problems similar to those faced with no further action would still be present with respect to the isolation of remaining radioactive materials from the environment and the protection of human health and safety, even though 100 years of radioactive decay would have occurred. In this DEIS a time period of 100 years is assumed for active institutional control of the Hanford Site; however, the DOE intends to maintain active institutional control of the Site in perpetuity.

In this DEIS, continue present action is subsequently referred to as the no action alternative.

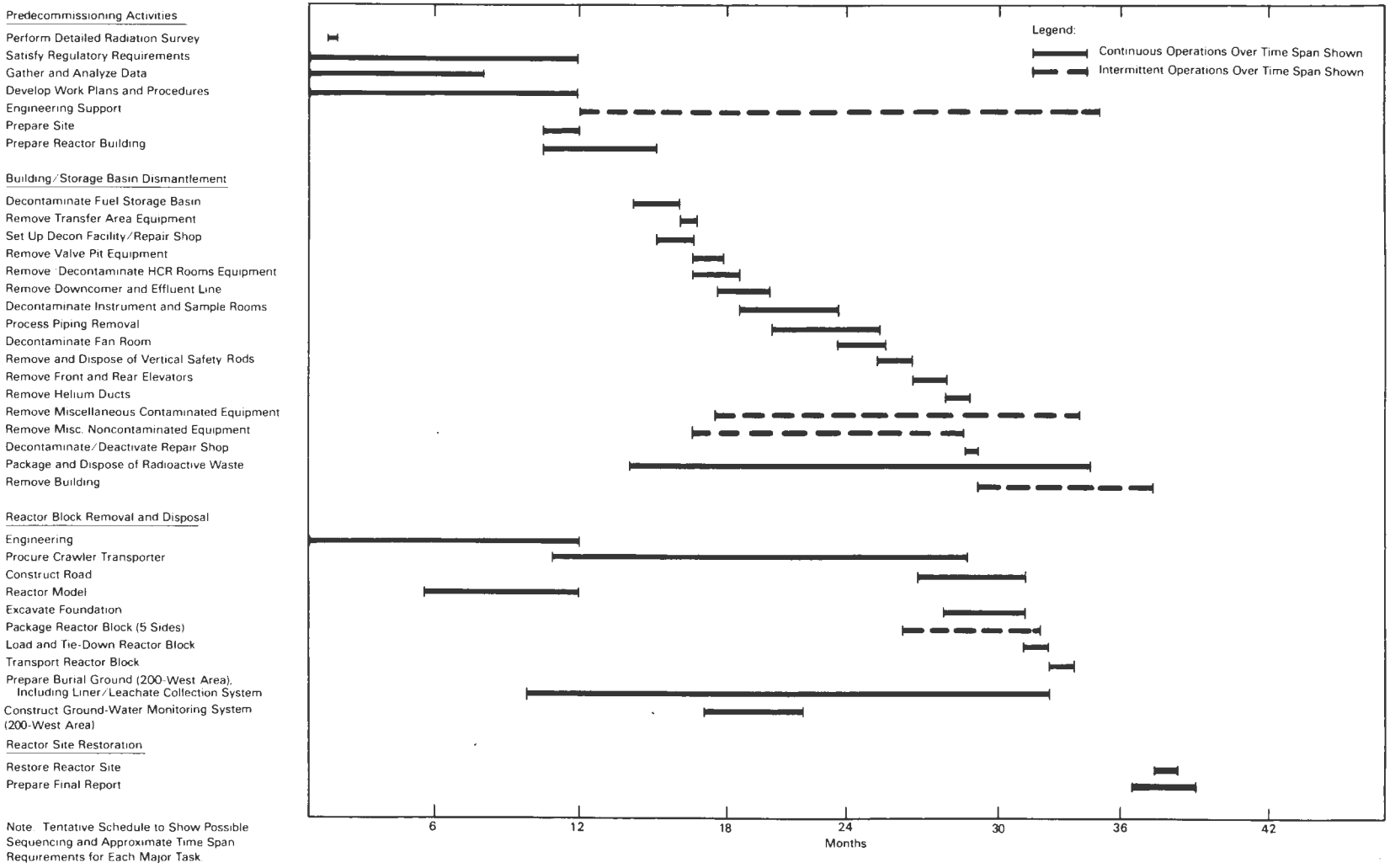
3.2 IMMEDIATE ONE-PIECE REMOVAL

Immediate one-piece removal means the removal of the surplus production reactors (in one piece) and their respective spent-fuel storage basins from their existing sites. This would include all piping, equipment, components, structures, and wastes having radioactivity levels greater than those permitted for the sites to be available for other DOE use. The immediate one-piece removal alternative calls for the following activities: 1) removing each reactor block (graphite core, surrounding shielding, and support base) in one piece and transporting it on a tractor-transporter over specially constructed haul roads to a DOE-owned burial location in the 200-West Area; 2) dismantling and removing remaining contaminated materials, equipment, and soils; and 3) demolishing and disposing of all uncontaminated equipment and structures.

3.2.1 Work Plan and Schedule

The proposed schedule for immediate one-piece removal tasks is shown in Figure 3.1. As shown in the figure, removal of the first reactor would take about 3 years. The detailed schedule includes the initial engineering and preparation of the work plan, construction and operational testing of the ground-water monitoring systems at the 200-West Area burial ground, procurement of the tractor-transporter and other necessary equipment, mobilization of the decommissioning team, construction activities at the 200-West burial ground, and construction of the haul road from the reactor sites to the burial ground. The schedule is subject to change if detailed engineering studies reveal a more efficient sequence of activities. The activities would begin with a detailed radiation survey of the reactor facility to provide current information for use in planning the work. At the same time, engineering drawings would be retrieved from storage, and working drawings would be developed for use in the work packages. Detailed work packages would be developed for use by the decommissioning teams to ensure that the activities are carried out in the proper sequence and to the appropriate conclusion. A training team would be created to assemble and train the appropriate decommissioning teams before initiating the tasks.

A conceptual schedule for decommissioning all of the eight surplus production reactors is shown in Figure 3.2. Other than the first reactor the



Note: Tentative Schedule to Show Possible Sequencing and Approximate Time Span Requirements for Each Major Task

FIGURE 3.1. Immediate One-Piece Removal Tasks and Schedule for First Reactor

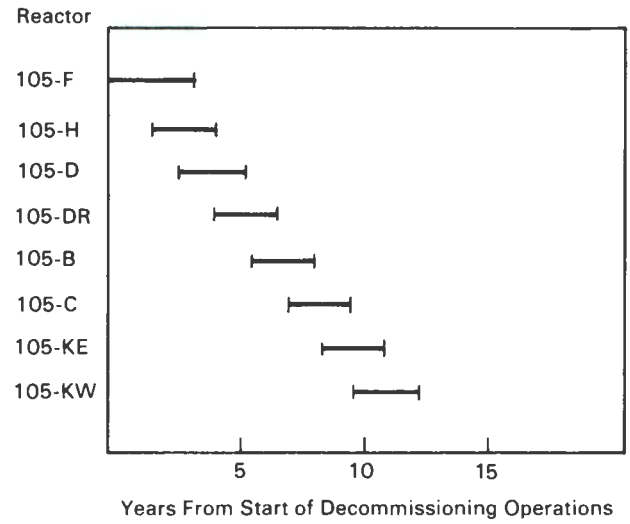


FIGURE 3.2. Estimated Schedule for Immediate One-Piece Removal of the Eight Surplus Production Reactors

remaining seven reactors are estimated to require 2.5 years per reactor for decommissioning. When decommissioning of one reactor has progressed to the midpoint of its overall schedule, work on the next reactor would begin, thus permitting efficient use of workers and equipment resources. Decommissioning costs for the first reactor would be greater than for subsequent reactors because of the tractor-transporter procurement cost and the construction cost of the haul road that would be utilized by the transporter for carrying the reactor block to the 200-West burial ground.

3.2.2 Costs of Immediate One-Piece Removal

A summary of estimated costs for immediate one-piece removal is given in Table 3.2. The costs shown are for movement of the eight intact reactor blocks by tractor-transporter overland to the 200-West Area burial ground and the dismantlement and removal of the remaining components and structures. In all cases, shipping and burial costs are based on disposal at Hanford in the low-level burial site in the 200-West Area.

The total estimated cost for immediate one-piece removal of all eight surplus production reactors is about $191 million in 1986 dollars. This estimate includes a 25% service charge on labor, equipment, and materials, a 20% contingency allowance on dismantlement costs and construction of

TABLE 3.2. Summary of Estimated Costs for Immediate One-Piece Removal of the Eight Surplus Production Reactors[a] (thousands of 1986 $)

Cost Category	Reactor 105-F	105-H	105-D	105-DR	105-B	105-C	105-KE	105-KW	Totals
Labor	3,371.18	2,691.98	2,691.98	2,691.98	2,735.18	2,735.18	2,691.98	2,691.98	22,301.44
Equipment/materials	595.90	595.90	595.90	595.90	603.10	603.10	595.90	595.90	4,781.60
Service charge (25%)	991.77	821.97	821.97	821.97	834.57	834.57	821.97	821.97	6,770.76
Subtotal	4,958.85	4,109.85	4,109.85	4,109.85	4,172.85	4,172.85	4,109.85	4,109.85	33,853.80
One-piece removal	12,856.50[b]	2,106.50	2,097.50	1,917.50	2,112.86	1,932.86	2,088.42	1,908.50	27,020.64
Subtotal	17,815.35	6,216.35	6,207.35	6,027.35	6,285.71	6,105.71	6,198.27	6,018.35	60,874.44
Contingency (20%)	3,563.07	1,243.27	1,241.47	1,205.47	1,257.14	1,221.14	1,239.65	1,203.67	12,174.88
Subtotal	21,378.42	7,459.62	7,448.82	7,232.82	7,542.85	7,326.85	7,437.92	7,222.02	73,049.32
Building removal[c]	2,757.90	2,265.23	2,265.23	2,265.23	2,265.23	2,265.23	2,265.23	2,265.23	18,614.51
Road construction[d]	14,600.00	1,891.12	491.68	491.68	378.25	378.25	378.25	378.25	18,987.48
Ground-water monitoring system and operation[e]	4,569.00	4,569.00	4,569.00	4,569.00	4,569.00	4,569.00	4,569.00	4,569.00	36,552.00
Burial ground[f]	5,447.34	5,447.34	5,447.34	5,447.34	5,447.34	5,447.34	5,447.34	5,447.34	43,578.72
TOTAL COSTS	48,752.66	21,632.31	20,222.07	20,006.07	20,202.67	19,986.67	20,097.74	19,881.84	190,782.03

(a) Notes: 1) shipping and burial costs are based on disposal at Hanford; 2) no salvage credit is taken; and 3) water flushes, high-pressure water lance, concrete scarfing, and selected manual techniques are the decontamination methods assumed to be used. Costs are deliberately not rounded for computational accuracy.
(b) Includes total cost of transporter.
(c) Adapted from Kaiser (1983) report, and includes 30% contingency as well as selected adjustment factors for a fixed-price contractor.
(d) Includes 25% contingency.
(e) Includes 20% contingency.
(f) Includes 12% contingency.

monitoring wells, a 30% contingency allowance on building removal, a 25% contingency allowance on road construction, and a 12% contingency on burial-ground costs. The application of a 25% contingency to road-construction activities is based on and consistent with the Kaiser (1986) report. The 30% contingency is based on the Kaiser (1983) report. The 12% contingency is based on a conceptual design study conducted by Westinghouse Hanford Company for this EIS (Adams 1987). The estimated costs do not include any additional allowance for inflation to account for either the work not beginning immediately or for the work extending over several years. This method of presenting the cost estimate permits useful comparisons to be made among the costs of all alternatives.

Reductions in planning and preparation costs are estimated for the second and subsequent reactors to account for the elimination of some planning activities that do not need to be repeated and for reduced site-preparation costs when two reactors are located at the same site. Haul-road construction costs are greatest for the 105-F Reactor because it would be decommissioned first and because it is farthest from the 200-West burial ground. Short haul-road extensions that tie into the main haul road are constructed for subsequent reactor-block transport operations as required, resulting in significantly lower haul-road construction costs for these latter reactors. Fuel storage basin decontamination costs are higher for the 105-B and 105-C Reactors than for the other six reactors because contaminated sludge must be removed from the fuel-storage transfer pits of these two reactors.

Estimated costs (in 1986 dollars), person-years of effort, and upper-bound estimates of radiation dose to workers for immediate one-piece removal of a "typical" reactor are shown in Table 3.3. Average costs per reactor are used when estimating costs of radioactive waste packaging and disposal, building removal, engineering, and road construction. However, other costs such as the tractor-transporter are one-time costs starting with the first reactor and cannot be accurately represented by averaging. Still other costs, such as satisfying regulatory requirements and developing work plans and procedures, are greatest for the first reactor and are substantially less

TABLE 3.3. Estimated Costs, Person-Years, and Occupational Radiation Dose for Immediate One-Piece Removal of a Typical Reactor

Activity	Cost (thousands of 1986 $)[a]	Person-Yr	Occupational Dose[b] (person-rem)
Predecommissioning			
Satisfy regulatory requirements	74.68[c]	1.21	0
Gather and analyze data	46.49[c]	0.71	0.01
Develop work plans and procedures	112.50[c]	1.71	0
Engineering support	247.00	5.48	0.02
Prepare site	292.50[c]	(d)	0
Prepare reactor building	389.40	3.77	0.09
Perform detailed radiation survey	3.80	--	0.001
Building/Storage Basin Dismantlement			
Decontaminate fuel storage basin	93.45	0.92	1.52
Remove transfer area equipment	34.20	0.59	0.37
Set up decon facility/repair shop	132.80	0.92	0.07
Remove valve pit equipment	46.40	0.92	0.02
Decontaminate/remove HCR rooms equipment	106.28	1.04	0.51
Remove downcomer and effluent line	72.88	0.63	3.81
Decontaminate instrument and sample room	111.05	1.54	0.05
Remove process piping	261.62	2.96	4.89
Decontaminate fan room	88.40	0.88	0.06
Remove/dispose of vertical safety rods	99.18	0.69	0.45
Remove front and rear elevators	92.33	0.81	1.38
Remove helium ducts	28.80	0.62	0.09
Remove miscellaneous contaminated equipment	141.30	0.31	0.01
Remove miscellaneous noncontaminated equipment	33.20	0.69	0.01
Decontaminate/deactivate repair shop	27.25	0.23	0.004
Package radioactive waste	541.89[c]	6.69	5.61
Remove building	2,326.81[c,e]	16.12	0
Reactor Block Removal, Disposal, and Monitoring			
Engineering	77.51[c]	1.60	0
Acquire tractor-transporter	1,343.75[c]	(d)	0
Construct road	1,898.75[c]	(d)	0
Construct reactor model	18.00	(d)	0
Excavate foundation	1,169.85[c]	(d)	0
Package reactor block (5 sides)	20.40	0.23	0.08
Load/tie down reactor block	66.00	0.77	0.06
Transport reactor block	24.75[c]	0.53	0.01
Burial ground (200-West Area), including protective barrier	4,863.70[c]	(d)	0.015
Construct ground-water monitoring system (200-West Area)	151.25[c,f]	(d)	0
97.5-yr ground-water monitoring system operating cost	3,656.25[c,f]	(d)	0
Reactor Site Restoration			
Restore reactor site	25.80	(d)	0
Prepare final report	45.60	0.7	0
Conduct radiation monitoring	299.00	5	0.39
Quality assurance/quality control	105.21	2.5	0
Supervision and secretarial	512.20	7.5	0.39
Services (25% of labor, material, and equipment costs)[g]	985.49	--	--
Contingency (25%)	593.36	--	--
Contingency (20%)[e]	761.50	--	--
Contingency (12%)[e]	583.60	--	--
TOTALS	22,606.18	68.27[h]	19.9

(a) Includes labor, equipment, waste disposal, and contractor costs for each activity.
(b) Except as noted, doses are based on a letter report from R. A. Winship, UNC Nuclear Industries, to W. L. Templeton, Pacific Northwest Laboratory (Winship 1986).
(c) This cost is a calculated fractional allocation of about one-eighth the total cost of this task for all eight reactors.
(d) Involves all or a significant portion of the work by a contractor.
(e) The 20% contingency applies to all activity costs in the table except building removal, road construction, and burial-ground work. The former activity utilizes a 30% contingency as well as other adjustment factors adapted from KEH-R-83-14 (Kaiser 1983). Based on the Rockwell Hanford (1985) report, a 25% contingency is utilized for road construction. Burial-ground work activity utilizes a 12% contingency, based on the Adams (1987) report.
(f) Based on a Smith (1987) cost estimate.
(g) Services include items obtained from other onsite contractors, such as laundry, utilities, fire protection and patrol, transportation, medical aid, etc.
(h) Does not include the number of person-years by contractors because these numbers were not provided in the various estimates given by the contractors. These workers are subject to little or no radiation, and thus their numbers are not required for occupational dose calculations.

for subsequent reactors. Nevertheless, the total cost given in Table 3.3 is intended to be representative of decommissioning a typical reactor by immediate one-piece removal. Table 3.3 is shown for the purpose of presenting more detail than Table 3.2.

The estimated costs and work requirements for planning and preparation activities that precede actual decommissioning operations are included in Table 3.3. Work requirements are included in the table to account for such functions as supervision, radiation monitoring, and engineering support. The occupational radiation dose estimates from Section 3.2.4 are also included in the table.

Kaiser estimates that the tractor-transporter (see Section 3.2.5 for details) could be purchased for $10.75 million (Kaiser 1986). The transporter would have a specially designed deck that would support the base of the reactor. The transporter would also have a built-in jacking capability that would allow the transporter, from beneath the reactor block, to raise the reactor block from its reinforced foundation and to lower the reactor block onto its new foundation in the 200-West Area burial ground.

3.2.3 Waste Volumes and Waste Disposal

Estimated volumes of radioactive waste from immediate one-piece removal of the first reactor are shown in Table 3.4. The volumes shown in the table are assumed to be typical for the remaining seven reactors as well. The estimated waste disposal volumes include the volume of the waste itself and the volume of packaging. Spalled concrete and contaminated equipment would be packed and shipped by truck to the disposal site. The reactor block would

TABLE 3.4. Summary of Radioactive Waste Disposal Volumes for Immediate One-Piece Removal of a Surplus Production Reactor

Material	Quantity of Waste (m^3)	Number of Shipments: Trucks	Number of Shipments: Tractor-Transporter
Spalled concrete	334.04	65	
Contaminated equipment	1,072.78	74	
Reactor block	2,761.82		1
TOTALS	4,168.64	139	1

be placed on a tractor-transporter (see Section 3.2.5 for details) in one piece and transported overland on a specially constructed haul road to a DOE-owned burial location in the 200-West Area. In addition to the single trip required for transport of the intact reactor block, an estimated 139 truck shipments per reactor are required for disposal of the contaminated wastes from the reactor (see Table 3.4).

The 200-West Area burial-site costs for the reactor blocks are presented in Table 3.5. The table summarizes the costs associated with using 1) a protective barrier and warning marker systems, and 2) a liner/leachate collection system, but does not include the costs of road construction to the 200-West Area burial site from the individual reactor sites.

TABLE 3.5. Estimated Construction Costs for Burial of Reactor Blocks with Liner/Leachate Collection System in the 200-West Area[a]

Item	Costs (thousands of 1986 $) Per Block	Total for 8 Blocks
Direct costs:		
Excavation	452.4	3,619
Foundations[b]	335	2,680
Hauling of soils/sand/gravel	277.9	2,223
Installation of soil clay mix	839	6,712
Installation of geotextile	205.3	1,642
Installation of geomembrane	178.6	1,429
Backfilling	721.4	5,771
Revegetation	5.6	45
Installation of subsurface markers	41.4	331
Installation of surface markers	300	2,400
Contractor overhead & markup	503.5	4,028
Total construction	3,860.1	30,880
Construction management	308.8	2,470
Contract management	308.8	2,470
Engineering design & inspection	386	3,088
Escalation	0	0
Contingency (12%)	583.6	4,669
TOTALS	5,447.3	43,577

(a) From Adams (1987), except as noted otherwise.
(b) Adapted from Rockwell (1985), Table 2.

Noncontaminated wastes are disposed of by onsite burial. Costs for disposal of these nonradioactive wastes are anticipated to be quite small compared with total project costs.

3.2.4 Radiation Doses to Workers and the Public

A recent survey of one of the surplus production reactors resulted in measured dose rates in normally accessible areas within the facility ranging from 0.01 millirem per hour to 0.28 millirem per hour (Winship 1986). Based on this dose-rate information, the occupational doses to decommissioning workers were estimated for immediate one-piece removal (see Table 3.3). The following two assumptions were used as bases for those dose estimates:

- Personnel directly engaged in decommissioning operations spend a maximum of 6 hours in a radiation zone during an 8-hour workday.
- Supervisors, radiation monitors, and other support personnel doing work in a radiation zone are subjected to an average dose rate that is one-half the average dose rate experienced by decommissioning workers.

These assumptions are believed to result in conservative occupational dose estimates. The occupational doses were estimated by multiplying the appropriate dose rate by the estimated worker-hours to complete each task, and then summing the products. The total occupational dose is estimated to be about 20 person-rem for immediate one-piece removal of a "typical" reactor and about 159 person-rem for all eight reactors. Special industrial safety precautions would be required during some phases of transport of the intact reactor blocks, but those activities are not anticipated to adversely affect occupational dose.

The location of the surplus reactors on the Hanford Site (isolated from the general public) and the confined nature of decommissioning activities suggest that there would be no radiation dose to the public from routine decommissioning operations. Any doses to the public would be the result of

an accident during removal activities or transport of the reactor block (or other radioactive materials) to the 200-West Area burial site (see Section 5.3.1).

3.2.5 Transporter Shipment of the Reactor Blocks

Two studies were conducted to determine the feasibility of moving a reactor block in one piece. The first study was conducted by Rockwell (1985) to develop preliminary cost estimates of route preparation and burial of the surplus production reactors. Three potential routes were analyzed for moving the intact reactor blocks. The estimated costs for preparing the routes associated with hauling the intact reactor blocks ranged from a low of $19.0 million to a high of about $20.4 million, including a 25% contingency. The least expensive route was selected for purposes of the cost estimates used in this DEIS. The total decommissioning time for all eight reactors is approximately 12 years. Therefore, it is assumed in this DEIS that by appropriate and timely scheduling of new road construction, road maintenance and upkeep costs can be minimized. The new haul roads would be either on existing roadways or would be immediately adjacent to existing roadways, thus minimizing impacts of construction, maintenance, and use. The Rockwell study did not address a preferred route or the schedules associated with either of these tasks. Before the commencement of decommissioning, additional definitive studies would be made on these issues.

The second study was conducted by Kaiser Engineers Hanford (Kaiser 1986) to determine the structural feasibility of moving the surplus production reactor blocks intact from their present locations in the 100 Area to permanent low-level burial grounds in the 200-West Area. The following conclusions were drawn from that report:

- It is technically feasible to move the eight surplus production reactors at Hanford from their present locations near the Columbia River to the 200-Area burial grounds, at an average cost of about $2.5 million (see Table 3.6), not including demolition of surrounding building structures, construction of roadways for transporting the reactor blocks, cost for transport to the burial site, or 200-Area burial site preparation.

TABLE 3.6. Summary of Costs for Transporters and Removal of Eight Surplus Production Reactors[a]

Cost Category	Estimated Costs (1988 $)
Transporters, two (2)	10,000,000
Tax at 7.5%	750,000
Total Transporter Cost	10,750,000
CPAF[b] construction:	
• Direct construction cost	
• Excavation and concrete removal	7,226,700
• Pressure grout holes	138,100
• Steel supports	776,200
Total Direct Construction Cost	8,141,000
Indirect costs:	
• General overhead[c]	
- Small tools at 2.5% labor	3,760
- Contractor indirects and fees at 18% of labor	27,090
- Radiation and health protection at 3% of labor	4,520
• Technical services	36,000
• General requirements	2,900
• Subcontractor administration	1,078,500
• Bid package plus badging	15,000
• Constructability review	20,000
Subtotal Indirect Cost	1,217,770
TOTAL	20,109,000[d]

(a) Based on Kaiser 1986, Appendix A. The cost estimate is for construction only and does not include engineering, escalation, or contingency.
(b) Cost Plus Award Fee (CPAF).
(c) The estimated cost of each subcategory is the product of the total labor cost ($150,000) times the percentage given for that item (Kaiser 1986).
(d) Total cost is rounded to the nearest $1,000.

- To load a typical reactor block onto the transporter, a major structural upgrade of the reactor foundation would be required.
- The transporter for the reactor blocks would require a load capacity of 11,000 tonnes, as determined from weight calculations on the KE and KW Reactor blocks. The transporter apparatus would consist of two or more separate transporter units joined by steel framework.

The transporter costs given in Table 3.6 were estimated by Kaiser (1986). Figure 3.3 is a photograph for illustrative purposes of a Neil F. Lampson, Inc., tractor-transporter used primarily for moving heavy cranes.[a] Higher weight capacity tractor-transporters would be required to move the reactor blocks. These units are individually controlled. Therefore, where two or more such transporters are required, an intercommunication method is utilized. In addition, because of the very large weight per unit volume involved in lifting a reactor block, the technique and the exact design of the transporter are uncertain at this time. Recommendations concerning additional definitive engineering studies are given in the Kaiser (1986) report.

The Kaiser (1986) report postulates a removal method for the 105-K Reactors, beginning with the demolition of all structures around the reactor block (e.g., buildings, trenches, etc.). Next, the land surrounding the reactor would be excavated to the bottom of the reactor foundation, and holes for support beams would be drilled through the foundation beneath the 0.635-centimeter plate. Each beam would be grouted in place in the hole as it is installed. When all beams are in place, a 10.67-meter-wide opening in the foundation would be excavated to allow transporter entry (see Figure 3.4).

(a) Reference herein to any specific commercial product, process, or service by tradename, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States government or any agency thereof.

FIGURE 3.3. Lampson 4-Engine Drive 4,000-Ton Capacity Tractor-Transporter

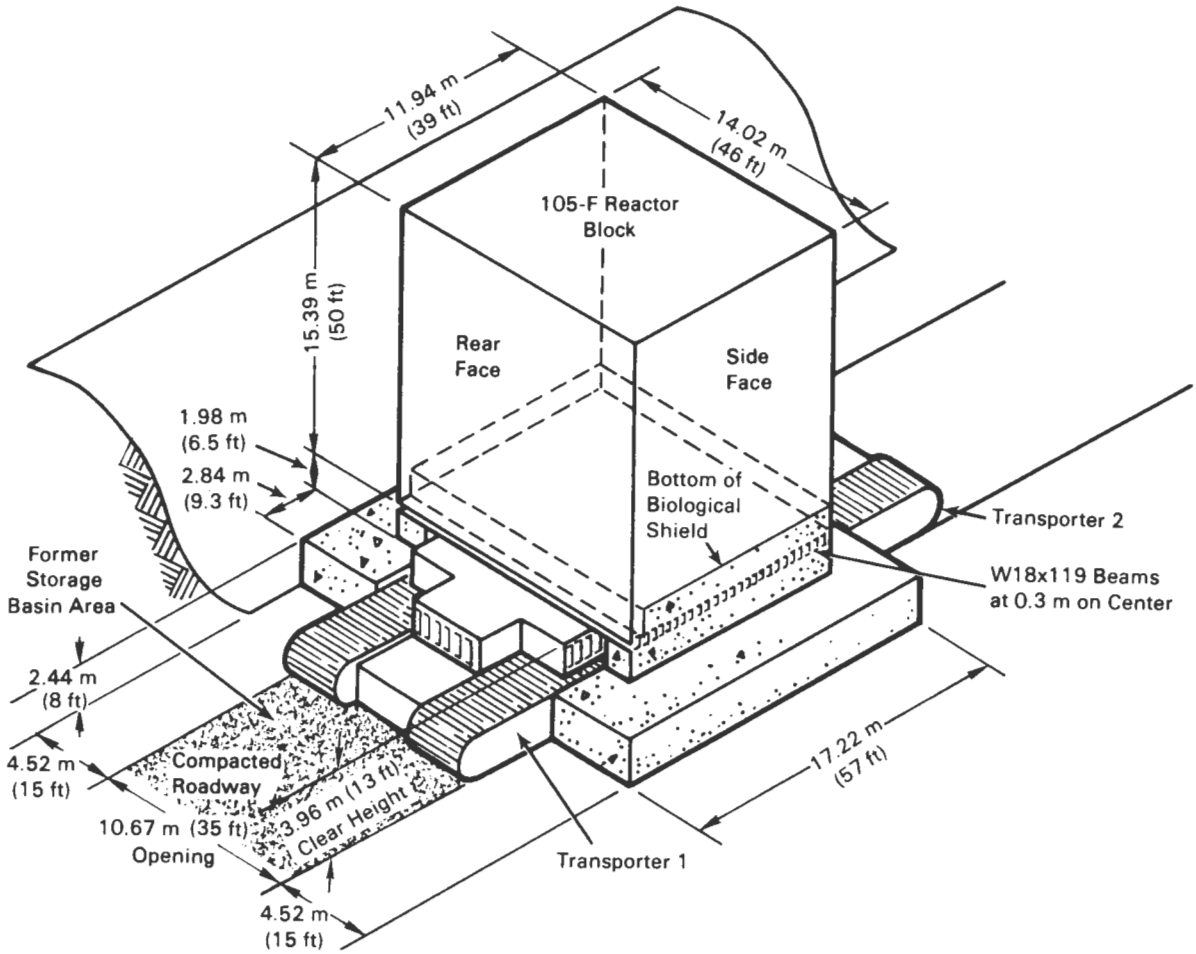


FIGURE 3.4. Isometric Illustration of the Transporter in the Excavated Opening Under the Reactor Block

The tractor-transporter would then be positioned under the reactor, and the transporter platform would be elevated to lift the reactor block from its foundation and support its weight. With the reactor block secured aboard the transporter, the transporter would be driven out of the excavation and to the 200-Area low-level burial site on a specially constructed haul road. Roadway preparations and coordination with escort services, utility districts, and the Hanford patrol would be required. Overhead power lines along the route would have to be cut or lifted temporarily. At the 200-West Area disposal site, the block would be driven down into its burial pit position and lowered

by the transporter onto engineered supports. After placement of the reactor blocks, the burial pit would be backfilled and covered with the protective barrier.

Finally, the reactor foundation site in the 100 Areas would be backfilled with clean rubble and dirt, and then graded and seeded to blend with the natural surrounding terrain.

3.3 SAFE STORAGE FOLLOWED BY DEFERRED ONE-PIECE REMOVAL

Safe storage followed by deferred one-piece removal includes three distinct operational phases: preparation for safe storage, the safe-storage period, and deferred one-piece removal.

During preparation for safe storage, building components and structures would be repaired as needed to ensure that radioactive materials are contained during the safe-storage period. Building security, radiation monitoring, and fire-detection systems would be upgraded to provide safety and security controls and regulated surveillance during the safe-storage period.

The safe-storage period assumed for these analyses is 75 years. Routine surveillance operations during this time would include periodic patrol inspections, radiological and environmental surveys, site maintenance, fence repairs, and operational testing of building security, radiological-monitoring, and fire-detection systems. Major building maintenance would be performed at 5-year and 20-year intervals to preserve the confinement capability of the reactor buildings.

At the conclusion of the safe-storage period, this alternative calls for 1) removing each reactor block (graphite core, surrounding shielding, and support base) in one piece and transporting it on a tractor-transporter over specially constructed haul roads to a burial site in the 200-West Area; 2) dismantling and removing all remaining contaminated materials, equipment, and soils; and 3) demolishing and disposing of all uncontaminated equipment and structures. The site would be backfilled, graded, seeded, and released for other use.

Safe storage has the advantage of allowing time for the decay of short- and intermediate-half-life radionuclides, thus reducing the occupational dose rate to workers during deferred one-piece removal.

3.3.1 Work Plan and Schedule

A safe-storage program designed to contain radionuclides has been conducted at the surplus production reactors since they were shut down. Continued repairs and maintenance must be carried out if the safe-storage period is to be extended for an additional 75 years. Initial repairs to the reactor buildings to place them in a long-term, safe-storage mode include the following actions:

- Remove salvageable, uncontaminated equipment.
- Remove as much wall- and roof-mounted equipment as possible, and cap the resulting holes with painted steel sheets.
- Remove built-up roofing material to bare decks.
- Repair or replace roof decks as needed.
- Spray-apply a membrane roofing material to the roof decks.
- Repoint concrete-block wall joints and seal the walls with a protective sealant.
- Regrout or reseal construction and expansion joints, and apply protective coating.
- Remove wooden doors and replace them with painted steel sheets.
- Scrape and paint all metals doors and other exposed metal components.
- Repair fences.
- Upgrade building security, radiation monitoring, and fire-detection systems.

During the safe-storage period, building components would be inspected and repaired on 5-year and 20-year cycles. Building maintenance procedures performed at 5-year intervals would include the following:

- Repaint all exposed metal trim, doors, stairs, ladders, metal sheets and any other exposed equipment.
- Repoint concrete-block wall joints; apply a new coating of protective sealant.
- Inspect concrete walls and foundations.
- Regrout or reseal construction and expansion joints as needed; apply a new coating of protective sealant.
- Repair membrane roof, flashing, and roof edge trim.
- Paint roof edge trim.

Major roof maintenance would take place at 20-year intervals and would include the following actions:

- Repair or replace roof decks as required.
- Replace membrane roofing.

A 75-year, safe-storage period would allow cobalt-60 to decay to less than one ten-thousandth of its initial quantity. This would allow decommissioning workers to remove reactor components with minimal remote handling and at greatly reduced radiation dose rates. After 75 years, the radiation exposure is mainly from cesium-137.

Deferred one-piece removal would start when the safe-storage period ends. The activities would begin with a detailed radiation survey of the reactor facility to provide current information for use in planning the work. At the same time, engineering drawings would be retrieved from storage, and working drawings would be developed for use in the work packages. Detailed work packages would be developed for use by the decommissioning teams to ensure that the activities are carried out in the proper sequence and to the appropriate conclusion. The work packages would include engineering drawings and detailed procedures, together with appropriate quality assurance checklists. A training team would be created to assemble and train the appropriate decommissioning teams before initiating the tasks.

The proposed schedule for the deferred one-piece removal tasks is the same as that previously described for immediate one-piece removal decommissioning tasks (see Figure 3.1). The same basic activities that are performed during the immediate one-piece removal decommissioning alternative (see Section 3.2 for details) are performed during deferred one-piece removal. It is assumed that a work force of essentially the same size as that needed for the immediate one-piece removal decommissioning alternative would be needed for deferred one-piece removal, and for the same period of time.

An overall schedule for safe storage followed by one-piece removal is shown in Figure 3.5. The schedule shown in Figure 3.5 is based on the assumption that those buildings currently in greatest need of roof repairs are given priority in the scheduling process. Initial repairs to upgrade the

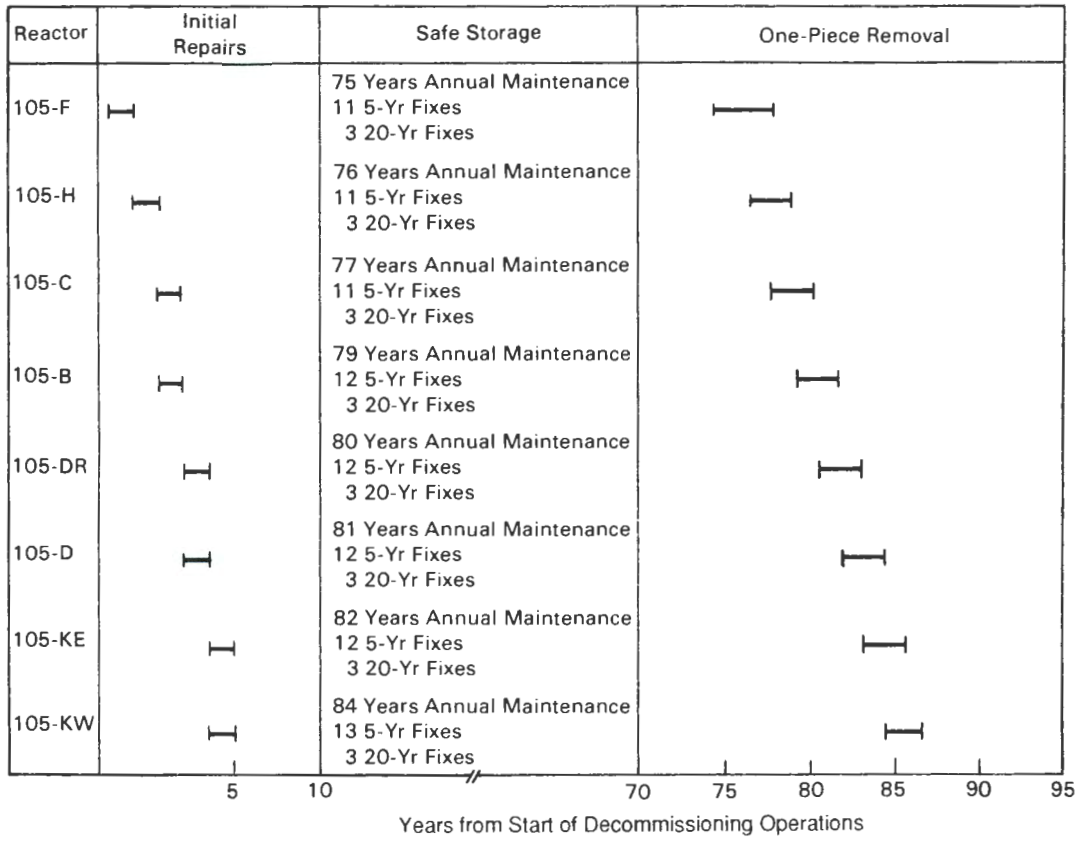


FIGURE 3.5. Schedule for Safe Storage Followed by One-Piece Removal of Eight Surplus Production Reactors

confinement capability of the reactor buildings and major roof repairs performed on a 20-year cycle would not be completed at all reactor facilities during the same year. Efficient use of personnel and equipment requires that major building upgrades be performed in a sequential fashion. The most cost-effective approach would be to complete the repairs to the buildings in one geographic area during the same work-effort period (i.e., during the same year).

Similar to the schedule for immediate one-piece removal, deferred one-piece removal of the first reactor would take about 3 years. The remaining seven reactors are estimated to require 2.5 years per reactor for decommissioning. The 3-year schedule for the first reactor includes the initial engineering and preparation of the work plan, construction and operational testing of the ground-water monitoring systems at the 200-West Area burial ground, procurement of the tractor-transporter and other necessary equipment, mobilization of the decommissioning team, construction activities at the 200-West Area burial ground, and construction of the haul roads leading from the reactor sites to the burial ground. The schedule is subject to change if detailed engineering studies reveal a more efficient sequence of activities.

When removal of one reactor has progressed to the midpoint of its overall schedule, work on the next reactor would begin, thus permitting efficient use of workers and equipment resources. As shown in Figure 3.5 removal of the first reactor would begin after 75 years of safe storage, but removal of the eighth reactor would not begin until 9 years after the start of dismantlement of the first reactor. This would result in an 84-year safe-storage period for the eighth reactor.

3.3.2 Costs of Safe Storage Followed by Deferred One-Piece Removal

A summary of estimated costs for safe storage followed by deferred one-piece removal is given in Table 3.7. The storage costs shown are corrected for the safe-storage period that varies from 75 to 84 years. The deferred removal costs shown in the table are for removal of the eight intact reactor blocks by tractor-transporter overland to the 200-Area burial ground and the dismantlement and removal of the remaining components and structures. In all

TABLE 3.7. Summary of Estimated Costs for Safe Storage Followed by Deferred One-Piece Removal of the Eight Surplus Production Reactors (thousands of 1986 $)[a]

Cost Category	Reactor 105-F	105-H	105-C	105-B	105-DR	105-D	105-KE	105-KW	Totals
Safe Storage									
Initial repairs	1,436.40	1,519.10	790.40	404.00	1,017.40	345.10	256.80	256.80	6,026.00
Annual maintenance and surveillance[b]	1,410.00	1,428.80	1,447.60	1,485.20	1,504.00	1,552.80	1,541.60	1,579.20	11,949.20
5-yr maintenance	795.30	817.30	523.60	765.60	1,286.40	1,071.60	189.60	205.40	5,654.80
20-yr roof repairs	555.00	579.60	737.10	519.90	721.20	646.80	408.60	408.60	4,576.80
Subtotal	4,196.70	4,344.80	3,498.70	3,174.70	4,529.00	3,616.30	2,396.60	2,450.00	28,206.80
Contingency (20%)	839.34	868.96	699.74	634.94	905.80	723.26	479.32	490.00	5,641.36
Total Safe Storage Costs	5,036.04	5,213.76	4,198.44	3,809.64	5,434.80	4,339.56	2,875.92	2,940.00	33,848.16
Deferred Removal									
Labor	3,371.18	2,691.98	2,735.18	2,735.18	2,691.98	2,691.98	2,691.98	2,691.98	22,301.44
Equipment materials	595.90	595.90	603.10	603.10	595.90	595.90	595.90	595.90	4,781.60
Service charge (25%)	991.77	821.97	834.57	834.57	821.97	821.97	821.97	821.97	6,770.76
Subtotal	4,958.85	4,109.85	4,172.85	4,172.85	4,109.85	4,109.85	4,109.85	4,109.85	33,853.80
One-piece removal	12,855.50[c]	2,106.50	1,932.86	2,112.86	1,917.50	2,097.50	2,088.42	1,908.50	27,020.64
Subtotal	17,815.36	6,216.35	6,105.71	6,285.71	6,027.35	6,207.35	6,198.27	6,018.35	60,874.44
Contingency (20%)	3,563.07	1,243.27	1,221.14	1,257.14	1,205.47	1,241.47	1,239.65	1,203.67	12,174.88
Subtotal	21,378.42	7,459.62	7,326.85	7,542.85	7,232.82	74,485.82	7,437.92	7,222.02	73,049.32
Building removal[d]	2,757.90	2,265.23	2,265.23	2,265.23	2,265.23	2,265.23	2,265.23	2,265.23	18,614.51
Road construction[e]	14,600.00	1,891.12	378.25	378.25	491.68	491.68	378.25	378.25	18,987.48
Ground-water monitoring system installation & operation[f]	1,194.00	1,194.00	1,194.00	1,194.00	1,194.00	1,194.00	1,194.00	1,194.00	9,552.00
Burial ground[g]	5,447.34	5,447.34	5,447.34	5,447.34	5,447.34	5,447.34	5,447.34	5,447.34	43,578.72
Total Deferred Removal Costs	45,377.66	18,257.31	16,611.67	16,827.67	16,631.07	16,847.07	6,722.74	16,506.84	163,782.03
TOTAL COSTS	50,413.70	23,471.07	20,810.11	20,637.31	22,065.87	21,186.63	19,598.66	19,446.84	197,630.19

(a) Notes: 1) shipping and burial costs are based on disposal at Hanford; 2) no salvage credit is taken; and 3) water flushes, high-pressure water lance, concrete scarfing, and selected manual techniques are the decontamination methods assumed to be used. Costs are deliberately not rounded for computational accuracy.
(b) Based on letter report by Hughes (1986).
(c) Includes total cost of tractor-transporter.
(d) Adapted from Kaiser (1983) report and includes 30% contingency as well as selected adjustment factors for a fixed-price contract. The higher removal cost for the 105-F Reactor includes the cost of a mobile crane that would also be used for demolition of the other seven reactors.
(e) Includes 25% contingency.
(f) Includes 20% contingency.
(g) Includes 12% contingency.

cases, shipping and burial costs are based on disposal at Hanford in the low-level burial site in the 200-West Area. The total estimated cost for safe storage followed by deferred one-piece removal is about $198 million.

The application of a 25% contingency on road construction costs is based on the Kaiser (1986) report. The 12% contingency on burial-ground construction costs is based on the Adams (1987) report. The 30% contingency applied to building-removal costs is based on the Kaiser (1983) report. The estimated costs do not include any additional allowance for inflation, either to account for the work not beginning immediately or to account for the work extending over several years. This method of presenting the cost estimate allows useful comparisons to be made among the costs of all alternatives.

Reductions in planning and preparation costs are estimated for the second and subsequent reactors to account for the elimination of some planning activities that do not need to be repeated and for reduced site-preparation costs when two reactors are located at the same site. Haul-road construction costs would be greatest for the 105-F Reactor because it would be decommissioned first and because it is farthest from the 200-West Area burial ground. Short haul-road extensions that connect with the main haul road would be constructed for subsequent reactor-block transport operations as required, resulting in significantly lower haul-road construction costs for these latter reactors. In addition, fuel storage basin decontamination costs would be higher for the 105-B and 105-C Reactors than for the other six reactors because contaminated sludge must be removed from the fuel storage transfer pits of these two reactors.

Estimated costs (in 1986 dollars) and person-years of effort for deferred removal of a "typical" reactor are the same as those shown previously in Table 3.3 for immediate one-piece reactor block removal. Average costs per reactor are used when estimating costs of radioactive-waste packaging and disposal, building removal, engineering, and road construction. However, other costs, such as the tractor-transporter, are one-time costs starting with the first reactor and cannot be accurately represented by averaging. It is estimated by Kaiser (1986) that the tractor-transporter (see Section 3.2.5 for details) could be purchased for $10.75 million. Still other

costs, such as satisfying regulatory requirements and developing work plans and procedures, are greatest for the first reactor and are substantially less for subsequent reactors. Nevertheless, the total cost given in Table 3.3 is intended to be representative of decommissioning a typical reactor by deferred one-piece removal.

The estimated costs and work requirements for planning and preparation activities that precede actual decommissioning operations are also included in Table 3.3. Work requirements are included in the table to account for such functions as supervision, radiation monitoring, and engineering support. The occupational radiation dose estimates given in Table 3.3 are based on a recent 105-DR reactor radiation survey conducted by UNC Nuclear Industries (Winship 1986). However, the occupational radiation dose estimates presented in Table 3.3 must be decay-corrected for the deferred one-piece removal alternative (see Section 3.3.4 for details).

3.3.3 Waste Volumes and Waste Disposal

As previously discussed, the same schedule, basic activities, and staffing are proposed for deferred one-piece removal as were utilized in the immediate one-piece removal decommissioning alternative. Likewise, the estimates of the waste volumes of contaminated and radioactive materials that must be packaged and shipped for burial are anticipated to be the same as were previously estimated for the immediate one-piece removal alternative (see Section 3.2.3 for details).

Spalled concrete and contaminated equipment would be packed and shipped by truck to the disposal site. The reactor block would be placed on a tractor-transporter in one piece (see Section 3.2.5 for details) and transported overland on a specially constructed haul road to the burial ground in the 200-West Area. In addition to the single trip required for transport of the intact reactor block, an estimated 139 truck shipments per reactor would be required for disposal of the contaminated wastes from the reactor (see Table 3.4).

Noncontaminated wastes would be disposed of by onsite burial. Costs for disposal of these nonradioactive wastes are anticipated to be quite small compared with total project costs.

3.3.4 Radiation Doses to Workers and the Public

One of the key assumptions associated with deferred one-piece removal is that essentially all of the same jobs would be performed in approximately the same way as for immediate one-piece removal, using the same techniques and equipment. The occupational radiation exposure accumulated during deferred one-piece removal would be proportional to that accumulated during immediate one-piece removal, reduced by the decay of the controlling radionuclide over the safe-storage period. For this analysis, cesium-137 is anticipated to be the controlling radionuclide present at the end of the 75-year safe-storage period. Therefore, occupational dose rates for deferred one-piece removal are based on the decay of this isotope.

Detailed estimates, based on measured dose rates, were previously made of the external occupational radiation doses that are expected to be accumulated by the workers for immediate one-piece removal (Table 3.3). Those estimates are used in this analysis as the point of reference for developing occupational doses for deferred one-piece removal. The measured dose rates are assumed to be from cobalt-60 and cesium-137, but the fraction of each is not known. Therefore, it is conservatively assumed for deferred one-piece removal that all of each measured dose rate is from cesium-137. The dose rates are then decayed according to the half-life of cesium-137. The total decay-corrected external occupational radiation dose for typical deferred one-piece removal of one reactor is then calculated to be about 3.5 person-rem.

The occupational dose for safe storage of a single reactor is estimated to be about 2.9 person-rem, including 0.1 person-rem for initial building repairs, 0.2 person-rem for roof repairs during safe storage, and 2.6 person-rem for 75 years of routine maintenance and surveillance. The occupational dose for safe storage is anticipated to be small because most maintenance and surveillance operations are carried out at locations outside the reactor

building or in areas inside the building that have very low levels of radioactive contamination. Together with the occupational dose of 3.5 person-rem for deferred one-piece removal of a single reactor, this results in a total occupational dose of about 6.4 person-rem for safe storage followed by one-piece removal of a single reactor, or about 51 person-rem for all eight reactors.

The location of the surplus production reactors on the Hanford Site (isolated from the general public) and the contained nature of the dismantlement activities ensure that routine decommissioning operations would result in little or no radiation dose to the public. Any doses to the public would have to be the result of an accident during one-piece removal of the reactor block or during transport of the reactor block or other radioactive materials to the 200-West Area for burial (see Section 5.4.1).

3.4 SAFE STORAGE FOLLOWED BY DEFERRED DISMANTLEMENT

Safe storage followed by deferred dismantlement includes three distinct operational phases: preparation for safe storage, the safe-storage period, and deferred dismantlement.

During preparation for safe storage, building components and structures are repaired as needed to ensure that radioactive materials are contained during the safe-storage period. Building security, radiation monitoring, and fire detection systems would be upgraded to provide safety and security controls and regulated surveillance during the safe-storage period.

The safe-storage period assumed for these analyses is 75 years. Routine surveillance operations during this time include periodic patrol inspections; radiological and environmental surveys; site maintenance; fence repairs; and operational testing of security, monitoring, and fire-detection systems. Major building maintenance would be performed at 5-year and 20-year intervals to preserve the confinement capability of the reactor buildings.

At the conclusion of the safe-storage period, the reactor block would undergo piece-by-piece dismantlement. The contaminated material would be packaged and transported to the 200-West Area for disposal as low-level waste. Contaminated equipment and contaminated structural surfaces would

also be removed, packaged as low-level waste, and transported to the 200-West Area for disposal. Noncontaminated equipment would be released for salvage or disposed of onsite as ordinary demolition waste. Remaining noncontaminated structures would be demolished, and the site would be backfilled, graded, seeded, and released for other use.

Safe storage has the advantage of allowing time for the decay of short- and intermediate-half-life radionuclides, thus reducing the occupational dose rate to workers during deferred dismantlement (relative to immediate dismantlement). For the surplus production reactors, the decay of cobalt-60 during the safe storage period would make piece-by-piece dismantlement of the reactor block possible without the need for extensive remote-handling techniques to remove the reactor block components. This would reduce the time, cost, and complexity of piece-by-piece dismantlement operations. However, this alternative would result in the highest occupational exposure and largest cost of any alternative. The highest occupational exposure results from the necessity to work within the reactor block where initial dose rates are high, and the largest cost results from piece-by-piece dismantlement, instead of one-piece removal.

3.4.1 Work Plan and Schedule

A safe-storage program designed to contain radionuclides has been conducted at the surplus production reactors since they were shut down. Continued repairs and maintenance must be carried out if the safe-storage period is to be extended for an additional 75 years. Initial repairs to the reactor buildings to place them in a long-term, safe-storage mode are postulated to be the same as those described previously in Section 3.3.1. Likewise, 5- and 20-year inspections and repairs, as discussed in Section 3.3.1, would be carried out.

Deferred dismantlement starts when the safe-storage period ends. Dismantlement consists of piece-by-piece removal of the reactor block and all contaminated materials in the surrounding building, shipment of the contaminated waste to a low-level waste disposal site in the 200-West Area, demolition of the remaining noncontaminated structures, and restoration of the site to its natural state for other DOE use.

A 75-year, safe-storage period would allow cobalt-60 to decay to less than one ten-thousandth of its initial quantity. This would allow decommissioning workers to remove reactor components with minimal remote handling and at greatly reduced radiation dose rates. Cesium-137 would be the dominant radionuclide.

The activities begin with a detailed radiation survey of the reactor facility to provide current information for use in planning the work. At the same time, engineering drawings would be retrieved from storage, and working drawings would be developed for use in the work packages. Detailed work packages would be developed for use by the decommissioning teams, to ensure that the activities are carried out in the proper sequence and to the appropriate conclusion. The work packages would include engineering drawings and detailed procedures, together with appropriate quality assurance checklists. A training team would be created to assemble and train the appropriate decommissioning teams before initiating the tasks.

Piece-by-piece dismantlement of the reactor block begins with the removal of the horizontal control rods and vertical safety rods, process tubes, gunbarrels, and miscellaneous piping from the block. A "greenhouse" type of contamination control envelope would be set up to control release of radionuclides to the environment. The top biological shield would be removed first, followed by the top thermal shield, exposing the graphite block. The graphite block and thermal and biological shields would be removed, starting from the top and working downward. Removal of these materials may require some remote work techniques, particularly the biological shield. Equipment and techniques employed in segmenting the shield material would be state of the art at the time of deferred dismantlement.

Following block dismantlement, contaminated surfaces in the reactor building would be decontaminated or removed, including activated concrete in the reactor block foundation. The clean building structure would then be demolished to at least 1 meter below grade. Cavities created during dismantling would be backfilled with clean rubble and earth. Finally, the site

would be graded, covered with topsoil, and seeded with indigenous plant species. After a final radiation survey, the site would be released for other DOE use.

An overall schedule for safe storage and deferred dismantlement of the eight surplus production reactors is shown in Figure 3.6. Initial repairs to upgrade the confinement capability of the reactor buildings and major roof repairs performed on a 20-year cycle would not be completed at all reactor facilities during the same year. Efficient use of personnel and equipment requires that major building upgrades be performed in a sequential fashion. The most cost-effective approach is to complete the repairs to the buildings in one geographic area during the same work effort period (i.e., during the same year). The schedule shown in Figure 3.6 is based on the assumption that those buildings currently in greatest need of roof repairs are given priority in the scheduling process.

As shown in Figure 3.6, dismantlement of the first reactor would begin after 75 years of safe storage, but dismantlement of the eighth reactor would not begin until 21 years after the start of dismantlement of the first reactor. This results in a 96-year safe-storage period for the eighth reactor. Deferred dismantlement of a single reactor is postulated to require approximately 6.5 years for completion. When dismantlement of one reactor has progressed to the stage that piece-by-piece dismantlement of the reactor block can begin (approximately 3 years into the dismantlement schedule), work on a second reactor would begin. This staggered dismantling would result in efficient use of personnel and equipment resources. Safe-storage costs for the second and subsequent reactors are greater than costs for the first reactor because of the longer safe-storage periods and the increase in the number of 5- and 20-year maintenance operations required to maintain containment integrity during the longer safe-storage periods.

A detailed dismantlement schedule for a single reactor, listing the individual tasks and their sequencing, is shown in Figure 3.7. This schedule is based on the activities and work sequence for the piece-by-piece dismantlement of the F Reactor. The tasks and sequence shown in Figure 3.7 are assumed to be representative of the requirements for piece-by-piece

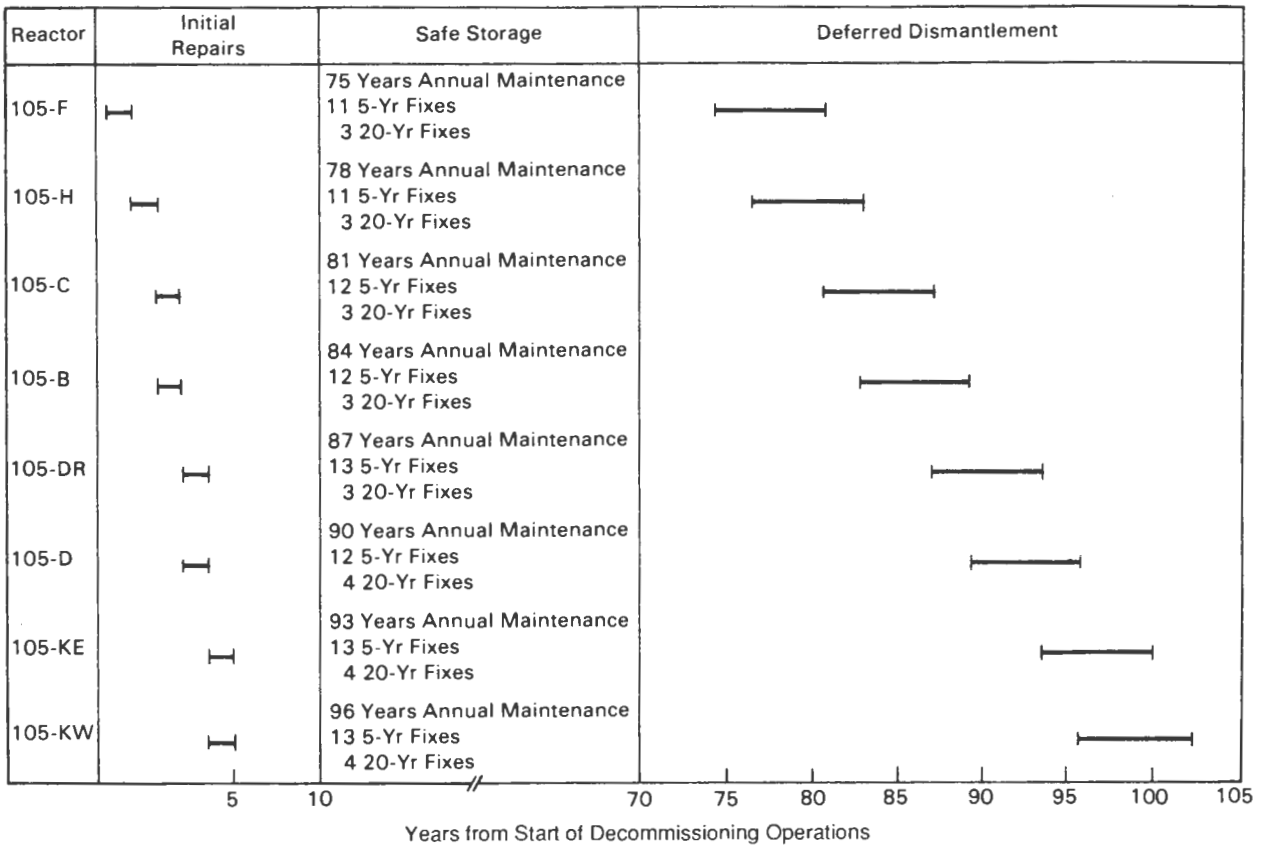


FIGURE 3.6. Schedule for Safe Storage Followed by Deferred Dismantlement of Eight Surplus Production Reactors

dismantlement of each of the surplus production reactors. The schedule shown in Figure 3.7 also gives the initial preparation activities, such as engineering and work plan preparation, procurement of necessary equipment, mobilization of the basic decommissioning team, repair of rail spurs, and site and building preparation activities that must precede the actual dismantlement operations.

In addition to the decommissioning activities shown in Figure 3.7, preparatory activities in the 200-West Area burial ground include construction and operational testing of the ground-water monitoring systems, and installation of a liner/leachate collection system. Disposal of the radioactive wastes includes installation of the protective barrier.

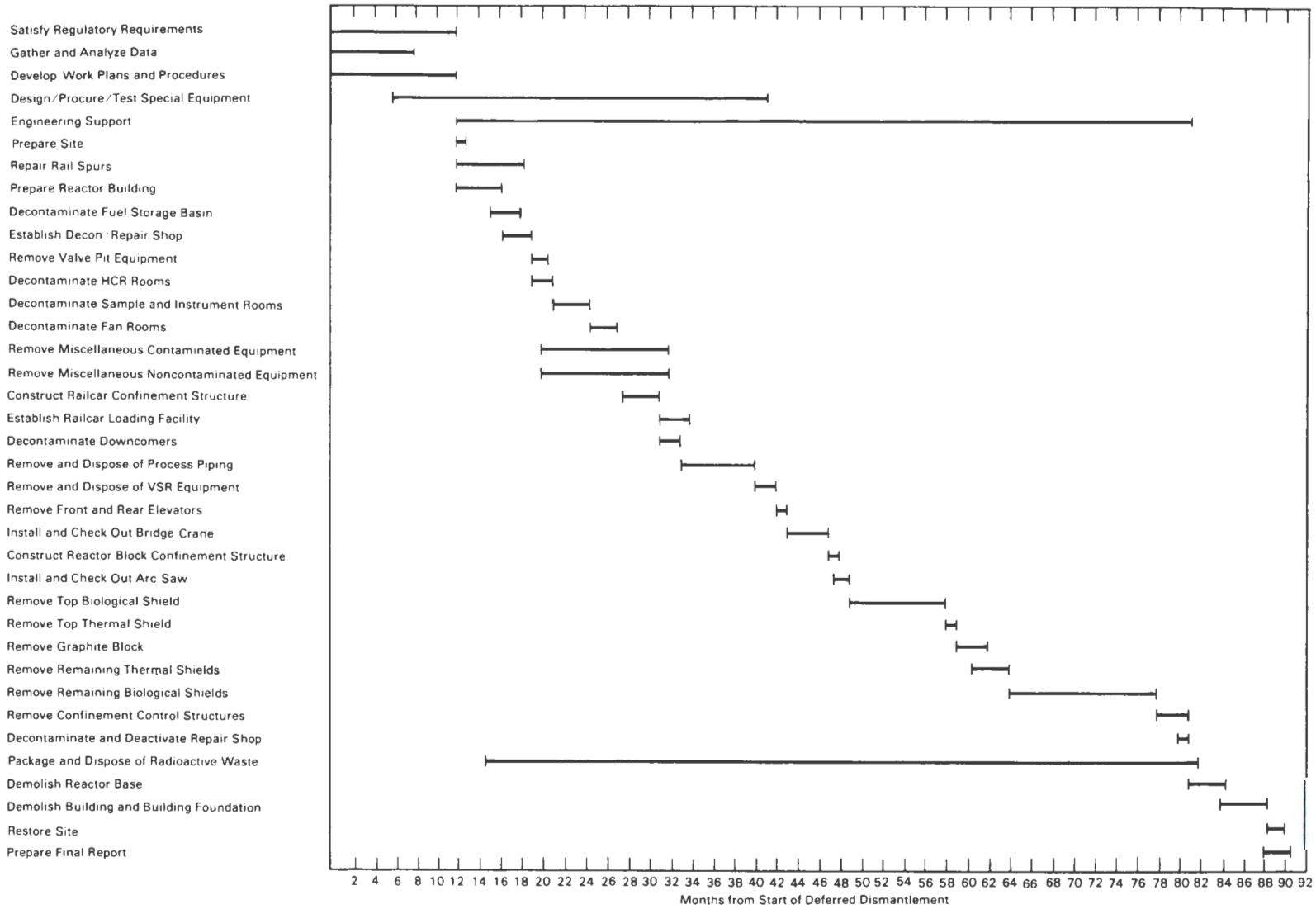


FIGURE 3.7. Deferred Dismantlement Schedule for a Single Reactor

3.4.2 Costs of Safe Storage Followed by Deferred Dismantlement

Estimated costs for safe storage followed by deferred dismantlement of the eight surplus production reactors, corrected for the safe-storage period that varies from 75 to 96 years, are summarized in Table 3.8. The total cost for all eight reactors is about $217 million. Estimated costs, person-years of effort, and upper-bound estimates of radiation dose to workers for deferred dismantlement of the first reactor, shown in Table 3.9, are assumed to be typical of the remaining seven reactors.

Reductions in planning and preparation costs are assumed for the second and subsequent reactors to account for the elimination of some planning activities that do not need to be repeated and for reduced site-preparation costs when two reactors are located at the same site. Fuel storage basin decontamination costs are higher for B and C Reactors than for the other reactors because of the contaminated sludge that must be removed from the fuel storage transfer pits of these reactors. Waste-disposal costs, shown in Tables 3.10 and 3.11, are higher for KE and KW Reactors than for the other reactors because their reactor blocks are larger. This results in higher deferred dismantlement costs for the KE and KW Reactors.

3.4.3 Waste Volumes and Waste Disposal

Estimated volumes of radioactive waste are shown in Table 3.10 for the deferred dismantlement of B, C, D, DR, F, and H Reactors, and in Table 3.11 for the deferred dismantlement of KE and KW Reactors.

The 200-West Area burial-site costs for the dismantled reactor blocks are presented in Table 3.12. The table summarizes the costs associated with constructing 1) a protective barrier, 2) a warning marker system, and 3) a liner/leachate collection system.

Spalled concrete and contaminated equipment are assumed to be packaged and shipped by truck to the disposal site. Wastes from piece-by-piece dismantlement of the biological and thermal shields and the reactor block would be placed in modified maritime containers and shipped on railroad flatcars to the disposal site. An estimated 226 truck shipments and 58 railcar shipments would be required for disposal of the dismantlement wastes

TABLE 3.8. Summary of Costs for Safe Storage Followed by Deferred Dismantlement for Eight Surplus Production Reactors (thousands of 1986 $)

Cost Category	Reactor								
	105-F	105-H	105-C	105-B	105-DR	105-D	105-KE	105-KW	Totals
Safe Storage									
Initial repairs	1,436.4	1,519.1	790.4	404.0	1,017.4	345.1	256.8	256.8	6,026.0
Annual maintenance and surveillance[a]	1,410.0	1,466.4	1,522.8	1,579.2	1,635.6	1,692.0	1,748.4	1,804.8	12,859.2
5-yr maintenance	795.3	817.3	571.2	765.6	1,393.6	1,071.6	205.4	205.4	5,825.4
20-yr roof repairs	555.0	579.6	737.1	519.9	721.2	862.4	544.8	544.8	5,064.8
Subtotals	4,196.7	4,382.4	3,621.5	3,268.7	4,767.8	3,971.1	2,755.4	2,811.8	29,775.4
Contingency (20%)	839.3	876.5	724.3	653.7	953.6	794.2	1,551.1	562.4	5,955.1
Total Safe-Storage Costs	5,036.0	5,258.9	4,345.8	3,922.4	5,721.4	4,765.3	3,306.5	3,374.2	35,730.5
Deferred Dismantlement									
Preparation	2,851.3	1,606.4	1,606.4	1,426.4	1,606.4	1,426.4	1,606.4	1,426.4	13,556.1
Dismantlement	12,265.4	12,265.5	12,351.4	12,351.4	12,265.5	12,265.5	13,170.2	13,170.2	100,105.1
Subtotals	15,116.7	13,871.9	13,957.8	13,777.8	13,871.9	13,691.9	14,776.6	14,596.6	113,661.2
Contingency (20%)	3,023.3	2,774.3	2,791.5	2,755.5	2,774.3	2,738.3	2,955.3	2,919.3	22,731.8
Building removal costs[b]	2,757.9	2,265.2	2,265.2	2,265.2	2,265.2	2,265.2	2,265.2	2,265.2	18,614.3
Ground-water monitoring system installation and monitoring[c]	1,374.0	1,374.0	1,374.0	1,374.0	1,374.0	1,374.0	1,374.0	1,374.0	10,992.0
Burial-ground costs, including liner/leachate collection system[d]	1,861.7	1,861.7	1,861.7	1,861.7	1,861.7	1,861.7	1,861.7	1,861.7	14,893.6
Total Deferred Dismantlement Costs	24,133.6	22,147.1	22,250.2	22,034.2	22,147.1	21,931.1	23,232.8	23,016.8	180,892.9
TOTAL COSTS	29,169.6	27,406.0	26,596.0	25,956.6	27,868.5	26,696.4	26,539.3	26,391.0	216,623.4

(a) Based on letter report by Hughes (1986).
(b) Adapted from Kaiser (1983) report and includes 30% contingency as well as selected adjustment factors for a fixed price contract. The higher removal cost for the 105-F Reactor includes the cost of a mobile crane that is subsequently utilized for demolition of the other seven reactors as well.
(c) Includes 20% contingency based on a 1987 cost estimate supplied by Smith (1987).
(d) Includes 12% contingency; see Westinghouse 1987 for details.

TABLE 3.9. Estimated Costs, Person-Years, and Occupational Doses for Deferred Dismantlement of a Surplus Production Reactor

Activity	Cost[a] (thousands of 1986 $)	Person-Yr	Occupational Dose[b] (person-rem)
Predecommissioning Activities			
Satisfy regulatory requirements	74.7	1.21	0
Gather and analyze data	135.3	2.08	0.05
Develop work plans and procedures	327.4	4.83	0
Design/procure/test special equipment	431.4	8.67	0
Prepare site	360	(b)	0
Prepare reactor building	389.4	3.92	0.08
Repair rail spur	615.2	1.00	0
Decontaminate fuel storage basin	74.8	0.96	1.26
Establish decon/repair shop	133.2	0.96	0.02
Building Equipment Removal			
Remove valve pit equipment	46.8	0.96	0.02
Decontaminate HCR rooms	111	1.08	0.49
Decontaminate sample and instrument rooms	97.2	1.28	0.03
Decontaminate fan rooms	92	0.92	0.06
Remove miscellaneous contaminated equipment	114.1	0.32	0.01
Remove miscellaneous noncontaminated equipment	37.6	0.8	0.01
Construct railcar confinement structure	565.4	1[c]	0.25
Establish railcar loading facility	109	0.72[c]	0.1
Decontaminate downcomers	81.4	0.72	1.08
Remove and dispose of process piping	674.8	9.76	6.47
Remove and dispose of VSR equipment	102.8	0.72	0.43
Remove front and rear elevators	104.4	0.84	1.32
Reactor Block Dismantlement, Disposal, and Monitoring			
Install and inspect bridge crane	346.2	0.52[c]	0.25
Construct reactor block confinement structure	48.6	0.36	0.06
Install and inspect arc saw	463.2	0.64[c]	0.1
Remove top biological shield	297.4	3.6	2.7
Remove top thermal shield	39.3	0.4	3
Remove graphite block	814	0.64	7
Remove remaining thermal shields	106.6	0.88	7.76
Remove remaining biological shields	792.8	5.2	3.36
Remove confinement control structures	121	1.76	0.06
Decontaminate and deactivate repair shop	26.6	0.24	0.01
Package radioactive waste	1,164.8	16.08	16.08
Burial ground (200-West Area), including protective barrier and liner/leachate collection system	1,861.7[d]	(b)	<0.01
Construct ground-water monitoring system (200-West Area)	151.3	(b)	0
26.5-yr ground-water monitoring system operating cost	993.8	(b)	0
Building Demolition/Restoration			
Demolish reactor base	205.2	2.56	0.24
Demolish building and building foundation[e]	2,326.8	16.12	0
Restore site	31.2	0.36	0
Generic Activities			
Engineering support	1,230	18	0.1
Radiation monitoring	747.5	13	5.58
Quality assurance/quality control	263	6.5	0
Supervision and secretarial	1,280.5	19.5	5.58
Services[f] (25% of labor, material, and equipment costs)	2,272.6		
Prepare final report	45.6	0.75	0
Subtotals	20,307.6	149.86	63.56
Contingency (20%)[g]	3,223.9		
TOTAL COST FOR DEFERRED DISMANTLEMENT	23,531.5		

(a) Includes labor, equipment, waste disposal, and contractor costs for each activity.
(b) Work performed by contractor.
(c) Additional work performed by contractor.
(d) This activity utilizes a 12% contingency (Adams 1987), and the contingency is included in the activity cost presented in the table.
(e) The activity utilizes a 30% contingency as well as other adjustment factors adapted from KEH R-83-14 (Kaiser 1983), and these costs are included in the activity cost presented in the table.
(f) Services include items obtained from other onsite contractors such as laundry, utilities, fire and patrol protection, transportation, medical aid, etc.
(g) The 20% contingency applies to all activity costs in the table except building demolishing and removal and burial-ground costs; see also footnotes (d) and (e).

TABLE 3.10. Summary of Radioactive Waste-Disposal Requirements for Deferred Dismantlement of B, C, D, DR, F, and H Reactors (per reactor)

Material	Quantity of Waste (m^3)	Number of Shipments Truck	Number of Shipments Railcar
Spalled concrete	679.5	136	
Contaminated equipment	1,159.9	90	
Thermal and biological shields	1,466.0		28
Reactor graphite	1,541.3		30
TOTALS	4,846.7	226	58

TABLE 3.11. Summary of Radioactive Waste-Disposal Requirements for Deferred Dismantlement of KE and KW Reactors (per reactor)

Material	Quantity of Waste (m^3)	Number of Shipments Truck	Number of Shipments Railcar
Spalled concrete	679.5	136	
Contaminated equipment	1,159.9	90	
Thermal and biological shields	2,406.8		46
Reactor graphite	2,391.9		46
TOTALS	6,638.1	226	92

from each of the B, C, D, DR, F, and H Reactors. An estimated 226 truck shipments and 92 railcar shipments would be required for disposal of the dismantlement wastes from each of the KE and KW Reactors.

3.4.4 Radiation Doses to Workers and the Public

A recent survey (Winship 1986) of one of the surplus production reactors resulted in measured dose rates in normally accessible areas within the facility ranging from 0.01 millirem per hour to 0.28 millirem per hour. Dose rates within the reactor block are anticipated to be substantially higher. However, after 75 years of safe storage, the cobalt-60 would have decayed to very low levels, leaving cesium-137 as the principal contributor to occupational dose during deferred dismantlement.

TABLE 3.12. Estimated 200-West Area Burial-Site Costs Associated with Burial of the Dismantled Reactor Blocks[a]

Item	Cost (thousands of 1986 $) Per Block	Total for 8 Blocks
Direct costs:		
Excavation	115.4	923
Hauling of soils/sand/gravel	126.4	1,011
Installation of soil/clay mix	360.3	2,882
Installation of geotextile	99.3	794
Installation of geomembrane	71	568
Backfilling	151.6	1,213
Revegetation	2.3	18
Installation of subsurface markers	21	168
Installation of surface markers	200	1,600
Contractors overhead & markup	171.1	1,377
Total construction	1,319.3	10,554
Construction management	105.5	844
Contract management	105.5	844
Engineering design & inspection	131.9	1,055
Escalation	0	0
Contingency (12%)	199.5	1,596
TOTALS	1,861.7	14,893

(a) From the Adams (1987) report.

Estimated occupational doses from deferred dismantlement were given in Table 3.9. The following two assumptions and the assumption in Section 3.3.4 regarding the dose-rate fraction from cesium-137 are used as bases for these dose estimates:

- Personnel directly engaged in decommissioning operations spend a maximum of 6 hours in a radiation zone during an 8-hour workday.
- Supervisors, radiation monitors, and other support personnel doing work in a radiation zone are subjected to an average dose rate that is one-half the average dose rate experienced by decommissioning workers.

These assumptions are believed to result in conservative occupational dose estimates. The occupational doses were estimated by multiplying the appropriate dose rate by the estimated worker-hours needed to complete each task, and then summing the products.

The occupational dose for safe storage of a single reactor is estimated to be about 2.9 person-rem, including 0.1 person-rem for initial building repairs, 0.2 person-rem for roof repairs during safe storage, and 2.6 person-rem for 75 years of routine maintenance and surveillance. The occupational dose for safe storage is anticipated to be small because most maintenance and surveillance operations are carried out at locations outside the reactor building or in areas inside the building that have very low levels of radioactive contamination.

The occupational dose for deferred dismantlement of a single reactor is estimated to be 63.6 person-rem, which results in a total occupational dose of about 66.5 person-rem for safe storage followed by deferred dismantlement of a single reactor, and about 532 person-rem for all eight. It should be noted that advances in robotics over the next 75 years might permit remote dismantlement of a single reactor at an occupational radiation dose of substantially less than 63.6 person-rem.

The location of the surplus production reactors on the Hanford Site, isolated from the general public, and the contained nature of dismantlement activities ensure that there would be little or no radiation dose to the public from routine decommissioning operations. Any doses to the public would have to be the result of an accident during dismantlement of the reactor block or during transport of the radioactive materials to the 200-West Area for burial (see Section 5.5.1).

3.5 IN SITU DECOMMISSIONING

Decommissioning of a surplus production reactor by in situ decommissioning is the least complex of the proposed decommissioning alternatives. Those surfaces within the facility that are contaminated would be painted with a fixative to ensure retention of the contamination during subsequent activities. Roofs and other superstructures and surrounding concrete shielding walls above the reactor block would be removed. Major voids beneath and around the reactor block would be filled with grout and/or gravel to prevent subsidence of the final overburden. Structures surrounding the reactor shielding walls would be demolished. Piping and other channels of access

into the reactor building would be cut and backfilled with grout or similar material to ensure isolation of the reactor from the surrounding environment. Finally, the reactor block and its adjacent shield walls, together with the contained radioactivity, gravel, and grout, would be covered with an engineered mound of additional gravel, earth, and riprap (see Appendix H for a discussion of mound design). The mound would be designed with a protective barrier and an impervious layer of soil and bentonite clay to retard infiltration of rainwater, and with riprap on the sides to protect against erosion and to mitigate the impact of any flood that might reach the reactors. The top of the mound would be seeded with grasses native to the area to inhibit surface erosion from weathering. The final mound configuration for one of the surplus reactors is illustrated in Figure 3.8.

The Hanford Site, including the 100 Areas, was proposed for the EPA's National Priorities List (NPL) on June 24, 1988 (53 FR 23988-23998). Over 110 waste disposal areas in the 100 Areas were identified in the investigation leading to this proposal. Sixteen of these waste disposal areas may be covered by the in situ mounds at the B, C, D, KE, and KW Reactor sites. These sites are being evaluated as required pursuant to the NPL listing and the requirements of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). If the in situ decommissioning alternative is selected, evaluation and any remedial action required for any of these 16 sites will be completed before decommissioning begins. These CERCLA activities are outside the scope of this EIS.

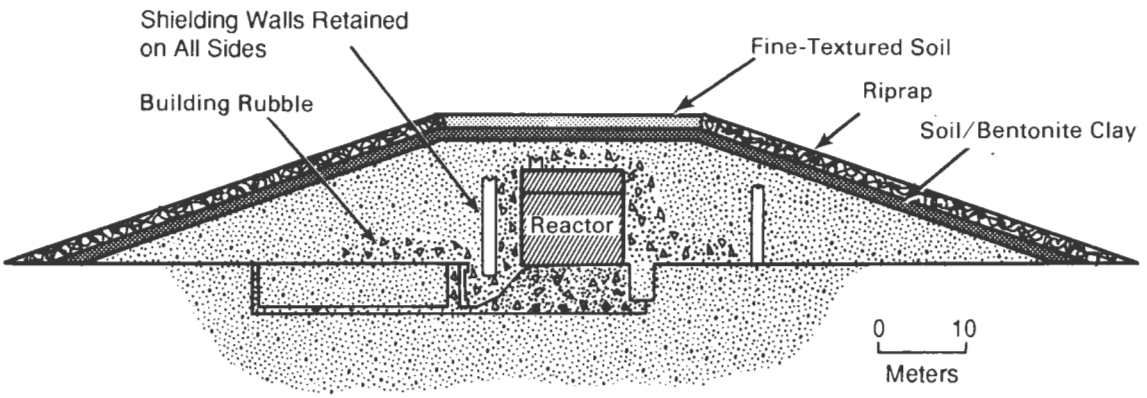


FIGURE 3.8. Barrier Configuration for In Situ Decommissioning

The analyses presented in the following subsections are based on cost estimates developed by 1) Kaiser (1985) for UNC Nuclear Industries and from the detailed worksheets that support that Kaiser document, 2) Westinghouse (Adams 1987) for the DOE, and 3) PNL in letter reports by Smith (1987). For this analysis, the detailed estimates developed by Kaiser and by Westinghouse were averaged over all reactors to obtain values for each task for the "average" reactor. Costs are adjusted to account for dollar escalation from late 1984 to 1986, where applicable. Additional staffing has been incorporated to provide such functions as radiation monitoring, quality assurance, and an appropriate level of supervision during the operations.

3.5.1 Work Plan and Schedule

The in situ decommissioning plan is designed to facilitate completion of disposal of all eight surplus plutonium production reactors in the shortest reasonable time by decommissioning several reactors simultaneously. Because the tasks to be performed at each reactor are essentially identical, teams would be developed that specialize in particular tasks. As a given task is completed at one reactor, that team would proceed to the next reactor to repeat that task, and so on until that task has been completed at all reactors. The overall schedule for disposal of all reactors illustrating this sequencing is shown in Figure 3.9.

A more detailed schedule showing the individual tasks and their sequencing for the first reactor is shown in Figure 3.10. This schedule includes the initial preparations necessary to begin the total decommissioning sequence for all reactors, such as the initial engineering and preparation of the work plan, procurement of the necessary equipment, and the mobilization of the basic team.

The activities would begin with a detailed radiation survey of the reactor facility to provide current information for use in planning the work. At the same time, engineering drawings would be retrieved from storage, and working drawings would be prepared for use in the work packages. Detailed work packages would be developed for use by the decommissioning teams to ensure that the activities are carried out in the proper sequence and to the appropriate conclusion. The work packages would include engineering drawings

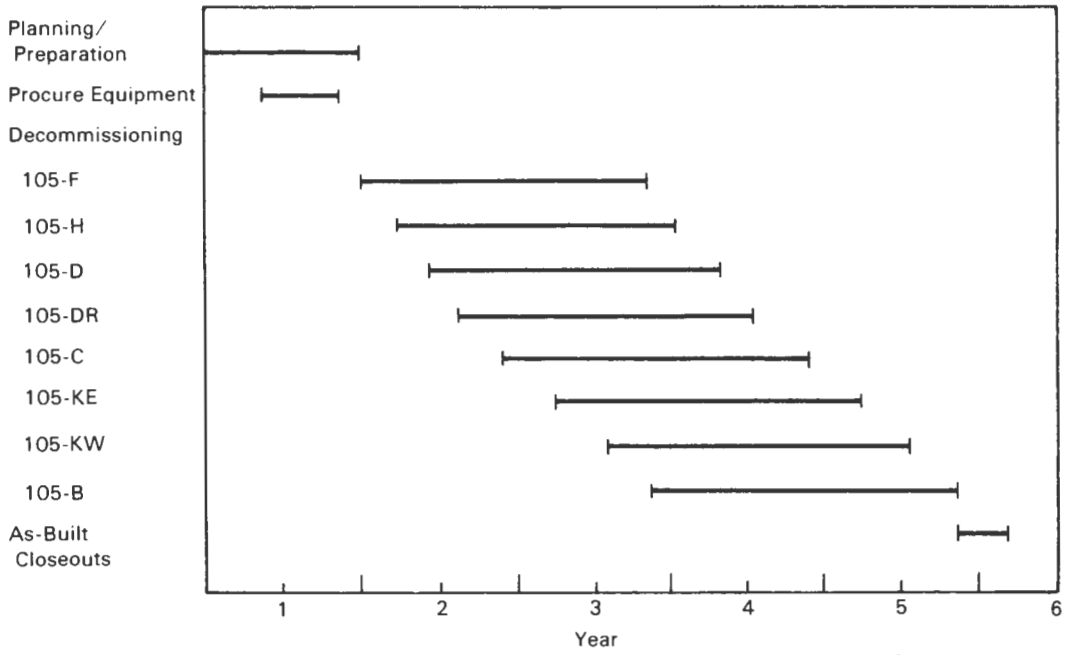


FIGURE 3.9. In Situ Decommissioning Schedule for All Eight Reactors (derived from Kaiser 1985)

and detailed procedures, together with appropriate quality assurance checklists. A training team would be created to assemble and train the appropriate decommissioning teams before initiating the tasks.

Actual decommissioning would begin with fixing of contamination within the reactor building, using liquid fixatives sprayed on the surfaces. Next, major voids beneath the reactor block and elsewhere within the building would be filled with gravel and/or grout, and then roof structures and other superstructures would be removed. The shielding walls above the upper level of the reactor block would be demolished, and all remaining voids within the building would be filled with gravel. The surrounding area would be built up with an engineered mound to cover the residual structures to a depth of at least 5 meters.

3.5.2 Costs of In Situ Decommissioning

The estimated costs, person-years of effort, and upper-bound estimates of radiation dose to workers are summarized in Table 3.13. The costs shown in the table are based on three separate costs estimates: 1) the Kaiser

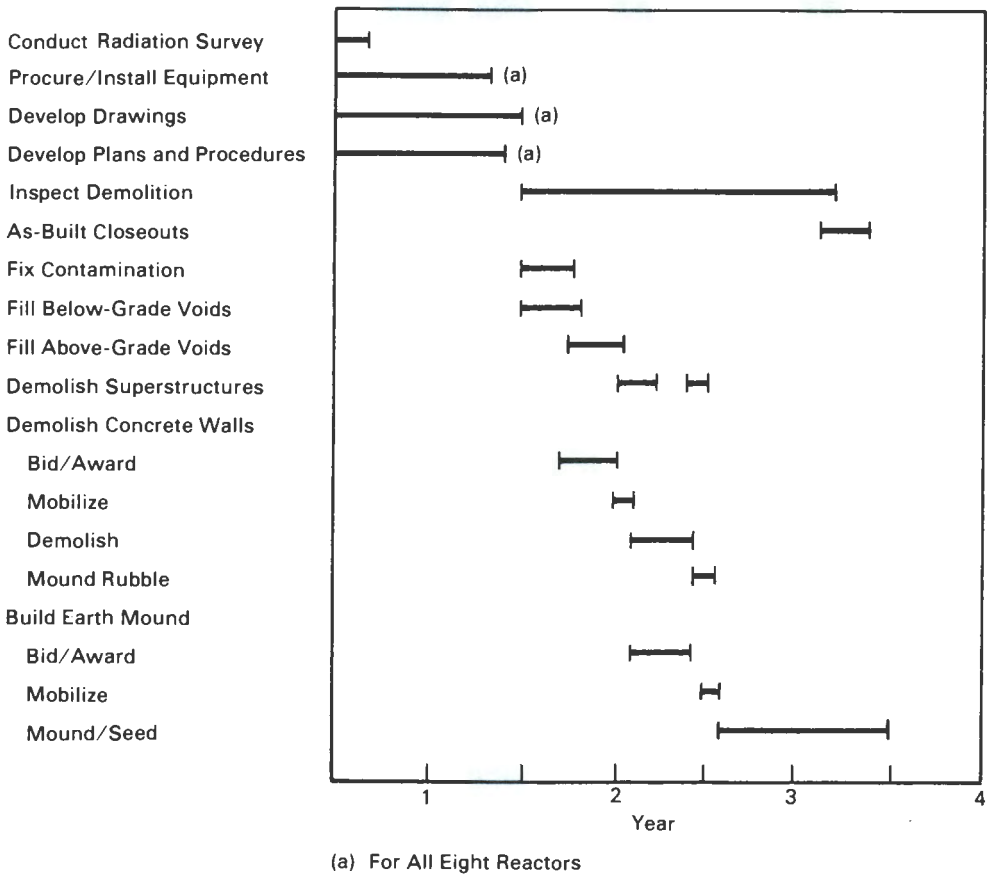


FIGURE 3.10. In Situ Decommissioning Schedule for First Reactor (derived from Kaiser 1985)

(1987) report; 2) the Adams (1987) report; and 3) a report by Smith (1987). The total cost at the bottom of the table includes site support services (25% of staff labor, materials, and equipment), and contingencies (20% of all costs, except 12% on placement of earth, gravel, and seeding). The total cost for in situ decommissioning of all eight reactors is estimated to be $181 million.

Individual and collective reactor burial mound costs are presented in Table 3.14. The table summarizes the costs associated with using a protective barrier and warning marker system, but without using a liner/leachate collection system.

TABLE 3.13. Estimated Costs, Person-Years, and Doses for In Situ Decommissioning of an "Average" Surplus Production Reactor

Activity	Cost (thousands of 1986 $)	Person-Yr	Cumulative Occupational Radiation Dose (person-rem)[a]
Predecommissioning			
Satisfy regulatory requirements	74.7	1.21	--
Perform detailed radiation survey	5.1	0.17	0.03
Develop drawings for demonstration, etc. (1/8 share)	131.5	1.54	--
Prepare work plans and procedures	50.3	0.69	--
Procure concrete batch plant, etc. (1/8 share)	72.0	--	--
Assemble mobilization/training team	27.1	0.35	
Construct ground-water monitoring system	200[b]	(c)	--
Subtotal	560.7	3.96	0.03
Decommissioning			
Fix contamination	523.5	10.09	2.02
Fill below-grade voids	160.7	1.95	0.39
Fill above-grade voids	191	1.75	0.35
Remove roofs and superstructures	493.6	(b)	--
Demolish shielding walls	12.1	0.63	0.13
Remove concrete block	117.5	1.99	0.40
Mound/gravel/seed	6,472.5	(c)	--
Engineering surveillance and closeout (1/8 share)	42.1	0.55	--
Radiation monitoring	73.8	1.25	0.25
Supervision	96.2	1.76	0.35
QA	52.7	1.25	0.25
Support services (25% of staff labor, materials, equipment cost)	440.9		
Subtotal	8,676.6	21.22	4.14
Postdecommissioning			
97.5-yr monitoring system operating cost	9,750[b]	(c)	--
Subtotal	18,987.3	25.18	4.17
State sales tax (at 7.1% on purchased materials/equipment usage, etc.)	83.2		
Contingency (20%)	2,800.2		
Contingency (12%)[d]	776.6		
TOTAL AVERAGE COST FOR IN SITU DECOMMISSIONING	22,647.3		

(a) Only those activities occurring in probable radiation zones are included (person-yr).
(b) Based on a cost estimate by Smith (1987).
(c) Activities performed by fixed-price contractors; no staffing estimates are available. However, these workers are subject to little or no radiation, and their numbers are thus not required for occupational dose calculations.

TABLE 3.14. Estimated Burial-Site Costs for the In Situ Decommissioning Alternative[a]

Item	Cost (thousands of 1986 $) Per Block	Total for 8 Blocks
Direct costs:		
Hauling of soils/sand/gravel	1,026.9	8,215
Installation of riprap	607.1	4,857
Installation of soil/clay mix	895.8	7,166
Installation of geotextile	329.4	2,635
Revegetation	0.8	6
Installation of subsurface markers	7	56
Installation of surface markers	1,600	12,800
Contractors overhead & markup	670	5,360
Total construction	5,136.9	41,095
Construction management	411	3,288
Contract management	411	3,288
Engineering design & inspection	513.6	4,109
Escalation	0	0
Contingency (12%)	776.6	6,213
TOTALS	7,249.1	57,993

(a) From the Adams 1987 report.

3.5.3 Waste Volumes and Waste Disposal

With in situ decommissioning, each reactor facility would be left in place. No wastes would be removed and transferred to another disposal location; therefore, no costs for waste disposal would be incurred.

3.5.4 Radiation Doses to Workers and the Public

A recent radiation survey of one of the surplus production reactors has shown that the radiation dose rates in essentially all areas within the facility that must be occupied by workers during the in situ decommissioning effort are very low, ranging from 0.01 millirem per hour to 0.28 millirem per hour, with most of the areas having dose rates considerably less than 0.1 millirem per hour (Winship 1986). Therefore, to provide a conservative estimate of worker radiation dose, the dose rate in all work areas is postulated to be equal to 0.1 millirem per hour and to remain constant during the decommissioning effort. The occupational radiation dose is estimated by multiplying this dose rate by the work-hours expended in radiation areas and

summing the products. For the "average" reactor, approximately 21 person-years of effort in radiation fields are estimated to be required to complete the in situ decommissioning (see Table 3.13). The cumulative radiation dose to workers is estimated to be less than 5 person-rem per reactor, or about 33 person-rem for all eight reactors.

No radiation dose to the public from these activities is expected because of the remote location of the surplus reactors on the Hanford Site and because of the limited handling of radioactive materials that is needed for in situ decommissioning.

3.6 ALTERNATIVES CONSIDERED BUT NOT ANALYZED IN DETAIL

No other major decommissioning alternatives were proposed for detailed analysis. However, some variations in the alternatives described in detail in this EIS were considered. Each of these is described briefly below.

3.6.1 Immediate Dismantlement

Immediate dismantlement means to remove a reactor piece by piece, without a safe storage period. The structures surrounding the reactor block would be decontaminated, demolished, and removed, and the reactor block would be flooded with water to provide shielding (Adams et al. 1984). The reactor would then be dismantled piece-by-piece, underwater, from the top down by remote techniques, and the pieces transported by railcar to the 200-West Area. The disadvantages of this alternative would be a significant increase in occupational radiation exposure; increased costs of design, fabrication, and use of special remote handling and viewing equipment; and the necessity of special contamination control equipment, shielding, and water cleanup techniques. Should an accident occur during transport of this material to the 200-West Area, increased radiation exposures to the general public could be anticipated. No environmental benefits would be expected. Therefore, this alternative of immediate dismantlement was not considered further.

3.6.2 Safe Storage Followed by Deferred Dismantlement

In this alternative, a variation in the safe-storage procedure was considered (Adams et al. 1984). The 105 reactor building would be

decontaminated and demolished; and a large steel dome would be installed over the reactor block, covered with earth, and left standing for approximately 75 years. The advantage of this procedure would be that the steel dome would provide a stable intrusion barrier. However, this is unnecessary since it is planned that the 100 Areas will be under active institutional control for at least 100 years. The disadvantages of this alternative are the higher costs and more worker injuries that would be associated with the construction of the dome. No environmental benefits would be expected.

3.6.3 In Situ Decommissioning

In this alternative, other variations were considered, including (Adams et al. 1984):

1. The 105 reactor building would be decontaminated and demolished and the reactor block moved into a below-grade pit at its present location. No advantages were identified. The disadvantages would be an increase in occupational exposures, placement of the reactor block closer to the ground-water table in the 100 Areas, reduction in the seismic stability offered by the existing massive foundation of the reactor, and higher costs. No environmental benefits would be expected.
2. The 105 building would be decontaminated and demolished and the reactor block sealed with a fiber-glass-reinforced plastic before mounding gravel and soil over the reactors. No environmental advantages over in situ decommissioning were identified. Higher costs would be incurred.

3.6.4 Alternative Disposal Sites for the Decommissioned Reactors

Alternative sites (other than Hanford) were also considered for the disposal of the reactors. These are not reasonable alternatives considering the existence of ample onsite disposal facilities for low-level waste at the Hanford Site. Use of alternative disposal sites (other than at Hanford) would

- increase substantially the costs of cross-country and/or barge transport

- increase significantly the probability of transportation accidents
- increase public radiation exposures from offsite transportation
- increase the probability of public radiation exposures from transportation accidents
- eliminate one-piece removal from consideration because the size and mass of the reactor blocks would make transport on public highways both difficult and very costly.

3.7 EVALUATION OF THE ALTERNATIVES

The proposed action is to decommission the eight surplus production reactors. The five decommissioning alternatives were described earlier in this chapter. The principal impacts of interest for the five alternatives are presented for comparison in Tables 3.15, 3.16, and 3.17. A cost comparison of the alternatives is presented in Table 3.18 to show the separate costs of safe storage, active decommissioning, waste disposal, and subsequent monitoring. An overall evaluation of the five alternatives is presented in this section.

In considering the alternatives for decommissioning the surplus production reactors, it should be noted that these facilities are located on the Hanford Site, an area owned and controlled by the federal government, closed to the public, and dedicated to activities associated with both the production of special nuclear materials and the disposal of radioactive waste materials. Previously disposed wastes on the Hanford Site will require essentially continuous active institutional control.

No Action (Continue Present Action)

The surveillance and maintenance activities associated with the no action (continue present action) alternative are estimated to cost about $41 million and to incur an occupational radiation dose about 24 person-rem over the 100-year period of assumed institutional control. At the end of the 100-year period, the structures would still be there, presenting a continuing expense and potential hazard. Additional storage costs at the same rate would be incurred if present action were continued beyond 100 years.

TABLE 3.15. Comparison of Decommissioning Impacts[a]

Alternatives	Active Decommissioning Period (yr)	Occupational Radiation Dose (person-rem)	Total Cost (millions of 1986 $)	10,000-yr Population Dose[b] (person-rem)
No action (i.e., continue present action)	100	24	41	50,000
Immediate one-piece removal	12	159	191	1,900
Safe storage followed by deferred one-piece removal	87	51	198	1,900
Safe storage followed by deferred dismantlement	103	532	217	1,900
In situ decommissioning	5	33	181	4,700

(a) Quantities are for all eight reactors. Costs are for 100 yr.
(b) The same population would receive 9 billion person-rem over 10,000 yr from natural radiation.

Immediate One-Piece Removal

Immediate one-piece removal would result in the reactor sites being released for other DOE use about 12 years after the initiation of decommissioning. The reactor block would be removed intact and placed in the 200-West Area low-level waste burial ground. The estimated cost is about $191 million, and the estimated occupational radiation dose is about 159 person-rem.

Safe Storage Followed by Deferred One-Piece Removal

The safe storage followed by deferred one-piece removal alternative is the same as the no action (continue present action) alternative for the first 75 years. After 75 years, the alternative becomes similar to the one-piece removal alternative. The estimated cost is $198 million, and the estimated occupational radiation dose is 51 person-rem.

TABLE 3.16. Short-Term Environmental Consequences of Decommissioning Operations

Environmental Consequences	No Action	Immediate One-Piece Removal	Safe Storage Followed by Deferred One-Piece Removal	Safe Storage Followed by Deferred Dismantlement	In Situ Decommissioning
Occupational radiation dose (person-rem)	24	159	51	532	33
Public radiation dose	very small	very small	very small	very small	very small
Accident radiation dose:					
Maximum individual (rem)	NP	0.08	0.08	0.2	NP
Public (person-rem)	NP	300	300	800	NP
Impact on air quality	Very small	Some fugitive dust	Some fugitive dust	Some fugitive dust	Some fugitive dust
Impact on water quality	No liquid discharges to public waterways	No liquid discharges to public waterways	No liquid discharges to public waterways	No liquid discharges to public waterways	No liquid discharges to public waterways
Ecological and socio-economic impacts	Minimal adverse impacts	Minimal adverse impacts	Minimal adverse impacts	Minimal adverse impacts	Minimal adverse impacts
Resource commitments	Minimal	A small fraction of national resource use	A small fraction of national resource use	A small fraction of national resource use	A small fraction of national resource use

NP = no scenario postulated.

TABLE 3.17. Long-Term Environmental Consequences from Decommissioning Wastes

Environmental Consequences	No Action	Immediate One-Piece Removal	Safe Storage Followed by Deferred One-Piece Removal	Safe Storage Followed by Deferred Dismantlement	In Situ Disposal
Dose from long-term migration to the Columbia River:					
Average individual lifetime dose (rem)	2.4×10^{-4}(a)	1.1×10^{-5}(b)	1.1×10^{-5}(b)	1.1×10^{-5}(b)	2.2×10^{-5}(c)
Public dose (person-rem)(d)	50,000	1,900	1,900	1,900	4,700
Concentration from long-term migration to the Columbia River, lead (mg/L)	2×10^{-10}	2×10^{-10}	2×10^{-10}	2×10^{-10}	2×10^{-10}
Drinking water dose from well water (rem/yr)	1.2(e)	0.04(f)	0.04(f)	0.04(f)	0.03(g)
Concentration in well water, lead (mg/L)	6×10^{-4}	4.9×10^{-4}	4.9×10^{-4}	4.9×10^{-4}	1.2×10^{-4}
Public dose from complete immersion of one reactor in the Columbia River (person-rem)	6,200	NA	NA	NA	6,200

(a) 2,590 years after disposal.
(b) 8,190 years after disposal.
(c) 3,430 years after disposal.
(d) Over 10,000 years.
(e) 140 years after disposal from B and C thermal shields.
(f) 6,160 years after disposal.
(g) 1,120 years after disposal from B and C reactor blocks.
NA = not applicable.

TABLE 3.18. Costs of Decommissioning Alternatives[a]

Activity	No Action	Immediate One-Piece Removal	Safe Storage Followed by Deferred One-Piece Removal	Safe Storage Followed by Deferred Dismantlement	In Situ Decommissioning
Safe storage	41.0	--	33.8	35.7	--
Mound/barrier		--	--	--	58.0
Waste disposal/barrier		43.6	43.6	14.9	--
Construct ground-water monitoring wells		1.4	1.4	1.4	1.9
Ground-water monitoring		35.1	8.1	9.6	93.6
Other decommissioning costs		110.7	110.7	155.0	27.7
TOTALS	41.0	190.8	197.6	216.6	181.2

(a) Costs are for 100 years, in millions of 1986 dollars.

Safe Storage Followed by Deferred Dismantlement

The safe storage followed by deferred dismantlement alternative is the same as the no action (continue present action) alternative for the first 75 years. At the end of the 75-year period, the radioactive materials would be removed and placed in the 200-West Area low-level waste burial ground, and the sites would become available for alternate DOE use. An estimated cost of $217 million for this alternative is the largest of the four decommissioning alternatives considered. The dismantlement activities would extend over a period of nearly 30 years and would result in an estimated occupational radiation dose of over 532 person-rem (also the largest of the four decommissioning alternatives).

In Situ Decommissioning

The in situ decommissioning alternative requires the shortest period of decommissioning activity and the shortest period of exposure to casual or deliberate intrusion--less than 6 years once decommissioning is initiated. The estimated cost of $181 million and the estimated occupational radiation dose of 33 person-rem are the lowest for the four decommissioning alternatives. Monitoring costs comprise one half of the $181 million, because they are estimated on the basis of monitoring continuing at its initial level for the entire 100 years of active institutional control. The protective mounds are resistant to casual intrusion and would necessitate a significant effort by a deliberate intruder to penetrate the shielded reactor block within the mound. The structure of the mound would be designed to withstand erosive actions of the weather without exposing any radioactive material to the environment. The mounds and the monitoring system would be maintained for an institutional control period of at least 100 years (the DOE has no intention of relinquishing active institutional control of the Hanford Site).

Environmental Consequences

Environmental consequences of each of the alternatives are discussed in Chapter 5.0 and summarized in Tables 3.16 and 3.17 on the bases of: 1) short-term impacts from decommissioning operations, and 2) long-term impacts from the disposed wastes.

Decommissioning operations would have minimal adverse impacts on air and water quality. No radiological consequences to the general public as a result of normal decommissioning operations are anticipated. The postulated operational accident of most consequence is a collision between a gasoline tanker and a railcar at a railroad crossing followed by a fire during the transport of reactor components to the 200-West Area in the deferred dismantlement alternative. The 50-year maximum committed radiation dose to the closest individual in the general public is estimated to be 200 millirem. The dose to the general public within 80 kilometers is estimated to be 800 person-rem. The decommissioning effort for each of the alternatives would be classed as "minor activity" in construction terms and would have an acceptable impact. No significant adverse ecological, socioeconomic, or resource impacts were identified for any alternative.

The long-term, postdecommissioning radiation doses to the general public downriver from the Hanford Site for each of the alternatives are discussed in Chapter 5.0 and Appendix G. These doses arise from leaching of the disposed wastes. The methods for calculating radiation doses are described in Appendix E, and the method for relating these doses to impacts on humans (e.g., health effects) is described in Appendix F. The projected doses are all a small fraction of the radiation dose from natural background. The total number of health effects from each of the decommissioning alternatives (other than no action) is estimated to be less than five to the downriver population over 10,000 years. Radiation doses to a small number of individuals who are postulated to conduct a variety of activities on the Site after the assumed loss of active institutional control were estimated and are discussed in detail in Chapter 5.0 and Appendix G. As noted previously, the DOE intends to maintain institutional control of the Hanford Site.

Climatic changes that alter the flow of the Columbia River could result in long-term erosion under a reactor in the 100 Areas and eventual immersion of that reactor in the river. The dose to the general public is estimated to be 6,200 person-rem from a reactor building that is postulated to be washed into the riverbed as a result of bank erosion.

Impact of Timing Assumptions on Decommissioning Costs

An examination of Table 3.18 is instructive with respect to an understanding of the impact of various timing assumptions on decommissioning costs. These timing assumptions include the EPA's guideline of 100 years for reliance on active institutional control (at which time cost accumulations are ended for the purposes of the EIS), the safe storage period of 75 years (a shorter time period might be just as effective in reducing worker dose rate from cobalt-60), and a well-monitoring period that is either continued to the end of the active institutional control period (beyond the minimum 30-year monitoring period specified in EPA's RCRA regulations), or is truncated at less than 30 years by the assumed 100 years of active institutional control. These timing assumptions all conspire to make the costs shown in Table 3.18 subject to interpretation.

An inspection of the table shows immediately that the annual cost of ground-water monitoring in the 200 Areas ($35.1 M ÷ 90 yr) is approximately equal to the annual cost of safe storage ($41.0 M ÷ 100 yr), and that the annual cost of ground-water monitoring in the 100 Areas ($93.6 M ÷ 95 yr) is approximately twice the annual cost of safe storage and also is approximately twice the annual cost of ground-water monitoring in the 200 Areas. Thus, at the end of the 100-year period of active institutional control, ground-water monitoring costs for in situ decommissioning are accumulating at twice the rate ground-water costs are accumulating for disposal in the 200 Areas. From a cost perspective, there is little to be gained by increasing or decreasing the time of safe storage for disposal in the 200 Areas. However, safe storage for 75 years before decommissioning by in situ decommissioning would decrease the cost of in situ decommissioning by approximately $52 million ($33.8 M + $8.1 M - $93.6 M).

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4.0 AFFECTED ENVIRONMENT

This chapter provides a general description of the Hanford Site and surrounding areas, emphasizing environmental attributes that could potentially be affected by the decommissioning of the surplus production reactors or that are important in the analysis of environmental impacts. More detailed environmental site descriptions for the Hanford Site are given in DOE (1982a, 1984, 1987), ERDA (1975), Jamison (1982), Rogers and Rickard (1977), and Stone et al. (1983). The surplus production reactors are described in Appendix A.

4.1 DESCRIPTION OF IMPACTED PORTIONS OF THE 100 AND 200 AREAS

In early 1943, the U.S. Army Corps of Engineers selected the Hanford Site as the location for production reactors and chemical separation facilities for the production and purification of plutonium for possible use in nuclear weapons (Manhattan Project) (ERDA 1975). Eight graphite-moderated reactors using Columbia River water for once-through cooling and one dual-purpose reactor (N Reactor) using recirculating-water cooling were built along the Columbia River.

4.1.1 100 Areas

The plutonium production reactors were built in the 100 Areas, bordering directly on the Columbia River in the northernmost portion of the Hanford Site (see Figure 4.1). At one time, in the early 1960s, all nine production reactors were operating. Currently, only the N Reactor is operational.

The 100 Areas are all on relatively flat terraces and bars with elevations generally between 120 and 150 meters above mean sea level and from about 11 to 30 meters above normal river level (Brown 1962). The topography is characterized by low relief and gentle slopes. Small to moderate gravel mounds, up to 10 meters in height, are found between the 100-K and 100-D Areas. In addition to the surplus reactors and their associated facilities, approximately 110 inactive waste-disposal sites exist in the 100 Areas (DOE 1986). These waste-disposal sites are being evaluated under the DOE's

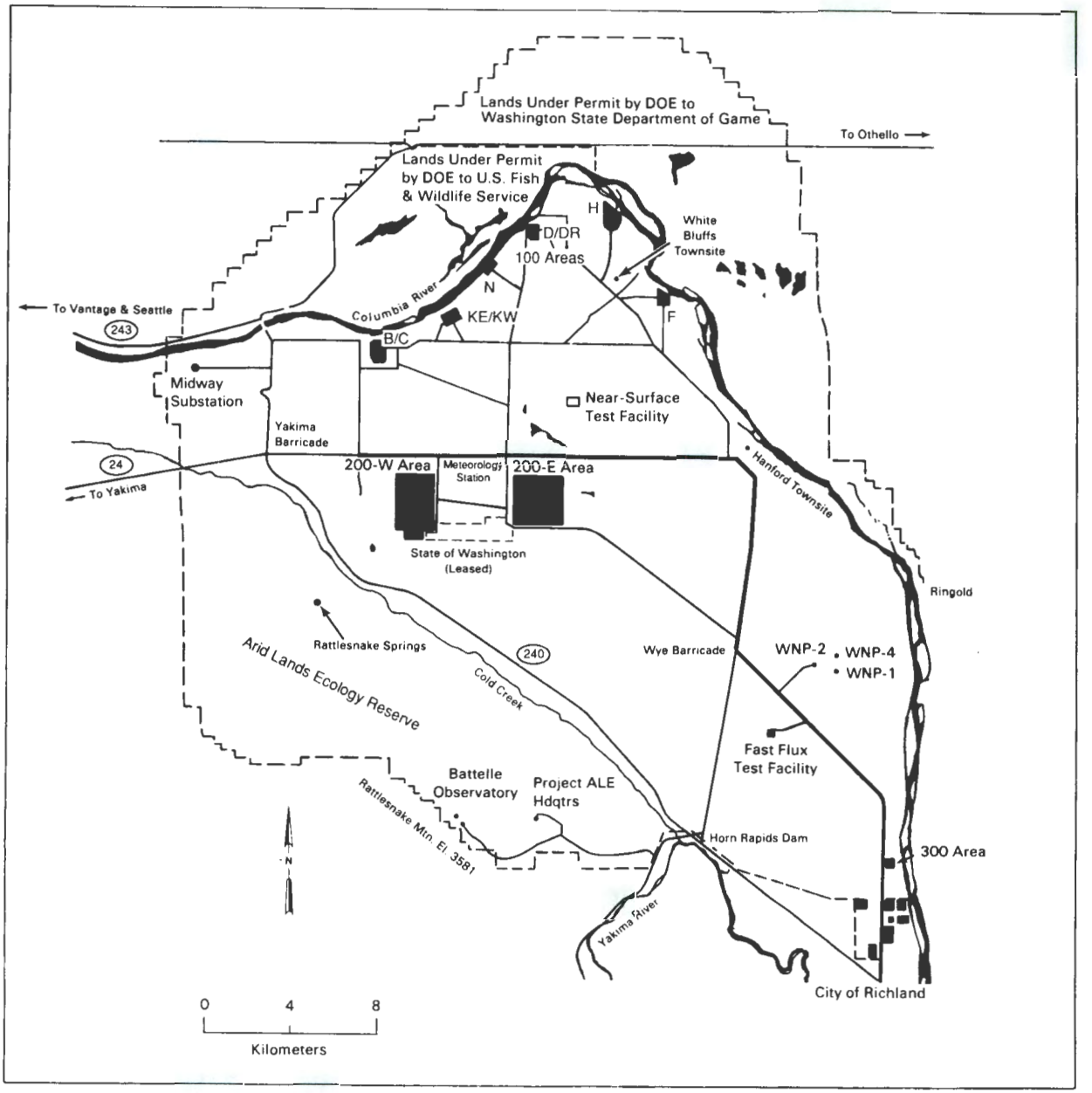

FIGURE 4.1. Hanford Site Map

responsibilities under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA).

4.1.1.1 B and C Reactor Area (100-B/C)

The 100-B/C Area occupies about 263 hectares and is the farthest upriver of the six 100 Areas, at river mile 384 (i.e., 384 miles from the mouth of the river). The Area contains two reactors, 105-B and 105-C. Very few personnel are currently assigned to the Area. Essentially all facilities in the Area are surplus, with the exception of the B/C water system, which provides all the water supply for the 200 Areas. An electrical substation in the Area taps power for the pumps providing the 200-Area water. Figure 4.2 is an aerial photograph showing the current condition of the 100-B/C Area.

4.1.1.2 K Reactor Area (100-K)

The 100-K Area, occupying about 55 hectares, is almost 4 kilometers immediately downriver from the 100-B/C complex (at river mile 381.5) and contains two reactors--105-K East and 105-K West (KE and KW, respectively). Some use is still made of the shut-down 100-K Area; therefore, partial services and utilities are in operation.

4.1.1.3 N Reactor Area (100-N)

The 100-N Area, occupying 36 hectares, is 2.4 kilometers immediately downriver from the 100-K Area (at river mile 380), and contains 43 buildings, including the N Reactor and the Washington Public Power Supply System generating plant. N Reactor is the only Hanford reactor still available for operation for the production of plutonium. The reactor is a dual-purpose unit designed to provide low-pressure steam for the 860,000-kilowatt Washington Public Power Supply System generating plant nearby.

4.1.1.4 D and DR Reactor Area (100-D/DR)

The 100-D/DR Area, which occupies about 389 hectares, is located 4 kilometers immediately downriver from the 100-N Area (at river mile 377.5). This Area is extensively used, and its utilities and services are in operation. The electrical substation serves as backup supply for the 100-N Area. Sanitary and fire protection water is provided to the 100-H and 100-F Areas

9 2 1 2 4 6 1 0 7 2 1

FIGURE 4.2. Aerial Photograph of 100-B/C Area

by way of a water export line. The water system in the 100-D Area is also a backup for systems from 100-B Area supplying the 200 Areas.

4.1.1.5 H Reactor Area (100-H)

The 100-H Area is located about 8 kilometers downriver from the 100-D/DR Area (at river mile 372.5) and occupies about 130 hectares. Very little activity continues in this Area. All major buildings, except the 105 building, have been removed. Portions of the settling basins were once used as evaporation basins for low-level chemical waste from the 300 Area and are currently being emptied and stabilized.

4.1.1.6 F Reactor Area (100-F)

The 100-F Area is located 5.6 kilometers downriver from 100-H (at river mile 369) and occupies about 219 hectares. It is the reactor area closest to Richland, Kennewick, and Pasco (the Tri-Cities). All major buildings, except the 105, 108, and 1608 buildings, have been removed. The 108 building is currently used as office space for N-Plant engineering activities. The aerial photograph of the 100-F Area (Figure 4.3) shows the facilities at this location.

4.1.2 200 Areas

The two 200 Areas, where the fuel and waste processing and waste storage and disposal activities occur, are near the center of the Hanford Site, about 11 kilometers from the Columbia River. The 200 Areas are located on what is generally referred to as the "200-Area Plateau" (Tallman et al. 1979). The topography is nearly flat with only local and low relief. Elevation varies from about 190 meters to 245 meters above mean sea level (DOE 1987).

Contaminated solids from the entire Hanford Site have been buried on the 200-Area Plateau since the start of chemical processing operations. These wastes consist of "dry waste" (solid clothing, laboratory supplies, tools, etc., packed in cardboard, wood, or metal containers) and industrial waste (primarily items of failed process equipment packaged in heavy metal or concrete boxes). Transuranic-bearing waste has been packaged in sealed metal

FIGURE 4.3. Aerial Photograph of 100-F Area

containers and segregated in burial trenches since May 1, 1970. The contaminated wastes are buried in both inactive and active sites on the 200-Area Plateau (DOE 1986).

The radioactive waste from decommissioning the 100-Area reactors would be buried in the 200-West Area if one of the removal or dismantlement alternatives is chosen for decommissioning.

Figure 4.4 shows facilities on the 200-West Area and the location of the 200-West Area burial grounds.

4.2 GEOLOGY AND HYDROLOGY OF THE SITE AND IMPACTED AREAS

The DOE's Hanford Site lies within the semiarid Pasco Basin, part of the Columbia Plateau in southeastern Washington State (Figure 4.5). The Site occupies an area of about 1,450 square kilometers and is about 50 kilometers north to south, and 40 kilometers east to west. This land area is restricted to public access, providing a buffer for the smaller areas currently used for operations, waste storage, and waste disposal. Adjoining lands to the west, north, and east of the Site are principally range and agricultural land. The Tri-Cities (Kennewick, Pasco, and Richland) compose the nearest population center and are located southeast of the Site.

The following sections contain a general description of the geologic and hydrologic features of the Hanford Site. The geology and hydrology of the 100 and 200 Areas are also discussed because of the significance of these features to decommissioning activities.

4.2.1 *Geology*

The terrain of the central and eastern parts of the Site is relatively flat (DOE 1984). The northern and western parts of the Site have moderate to steep topographic ridges composed of basalt and sediments. The central part of the Site, including the 200-Area Plateau, has undergone minimal erosion since formation by floodwaters about 13,000 years ago.

The Hanford Site overlies the structural low point of the Pasco Basin and is bounded to the southwest, west, and north by large ridges that trend eastwardly and southeastwardly from the Cascade Range, enter the Pasco Basin,

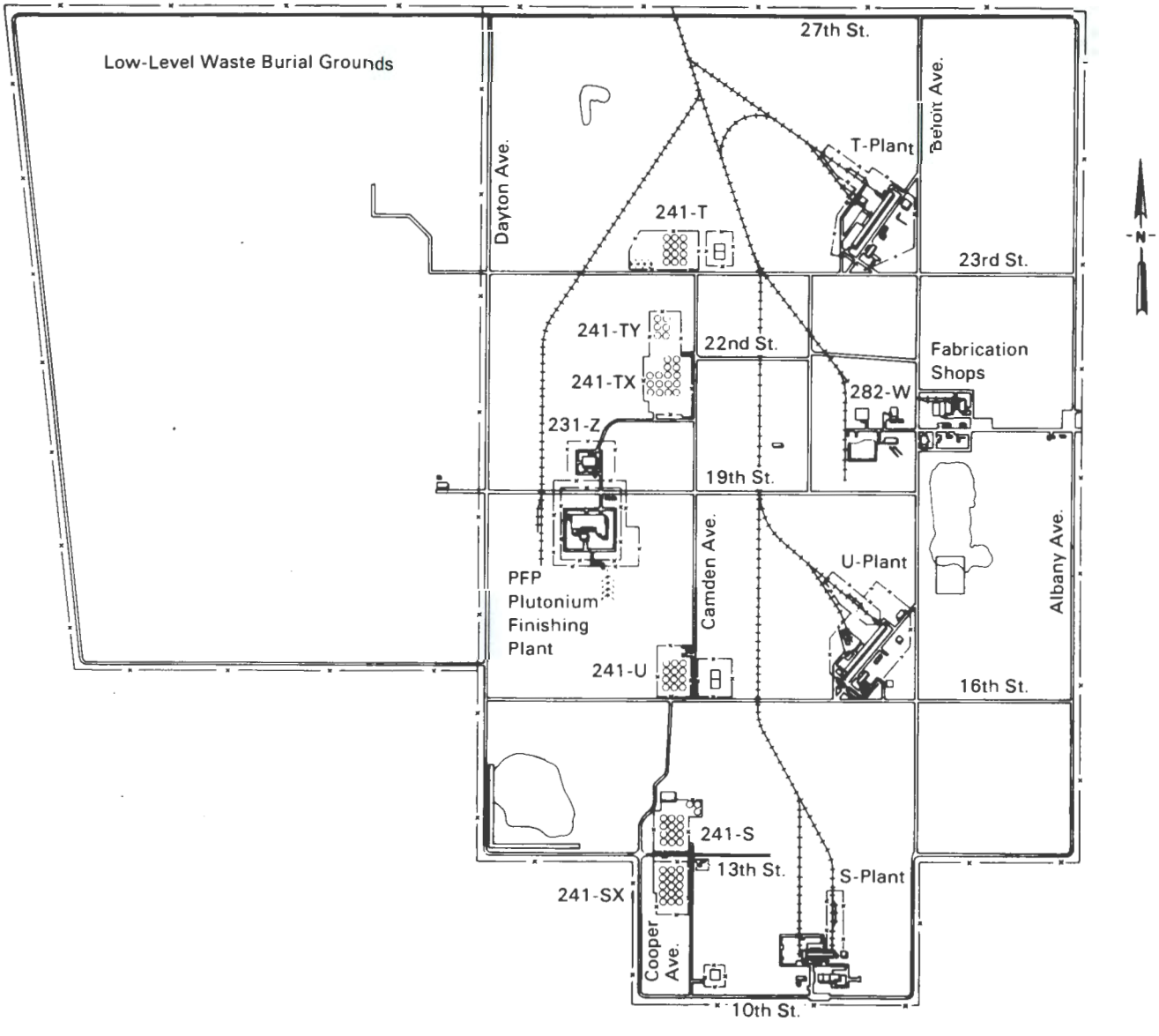

FIGURE 4.4. 200-West Area Facilities

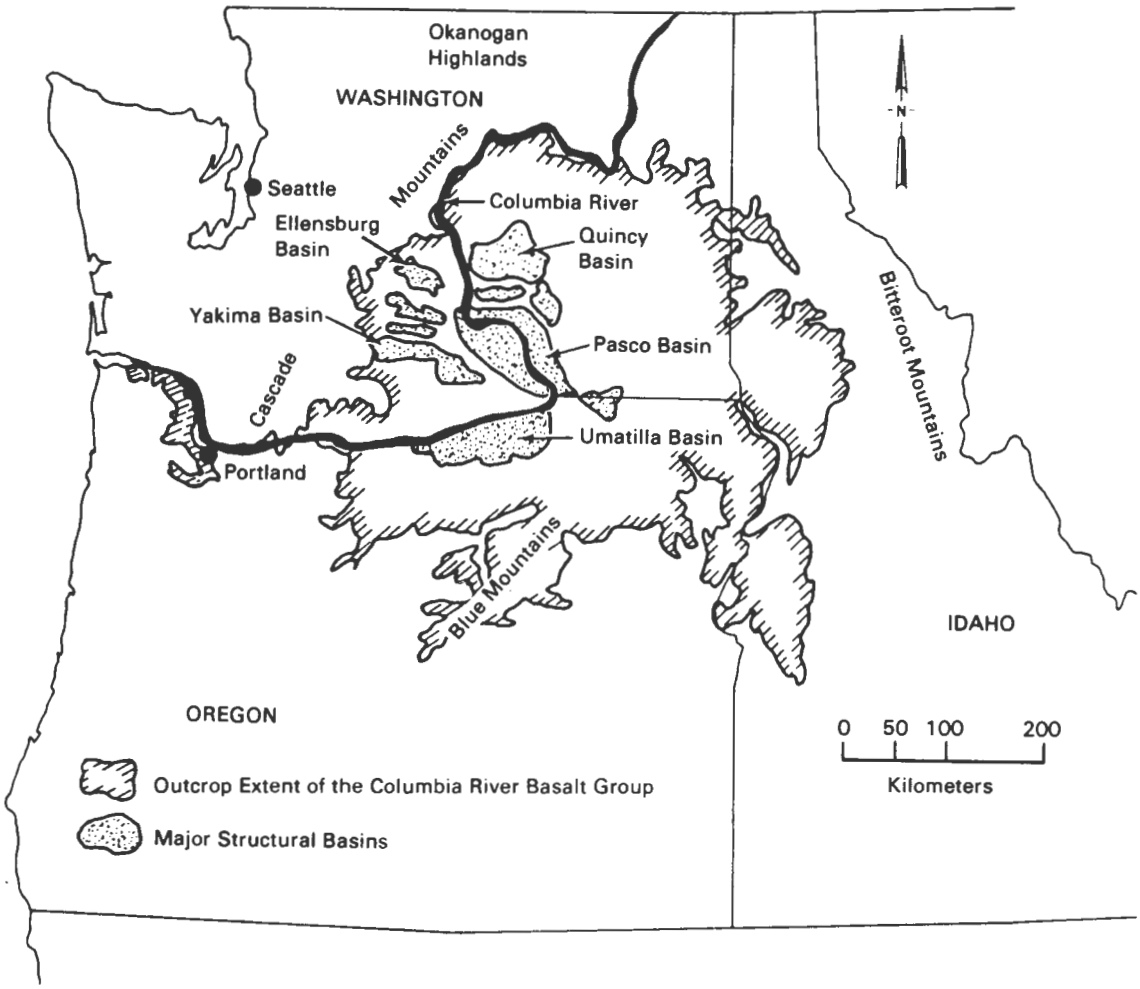

FIGURE 4.5. The Setting of the Pasco Basin Within the Columbia Plateau (Tallman et al. 1979)

and die out within its confines. The Site is bounded to the north and east by the Columbia River and the steep bluffs of the Ringold Formation.

The elevation of the alluvial plain that covers much of the site ranges from 105 meters above mean sea level in the southeast corner to 245 meters in the northwest. The 200-Area Plateau, where most of the radioactive waste is stored, ranges in elevation from 190 to 245 meters. The highest point is on Rattlesnake Mountain (1,093 meters) on the southwestern border of the Site.

The principal stratigraphic units at the Hanford Site are the Columbia River Basalt Group with interbedded sediments of the Ellensburg Formation, which forms the bedrock beneath the Site; the Ringold Formation, consisting of semiconsolidated clays, silts, sands, and gravels lying directly over the bedrock; and the Hanford Formation, composed of silts, sands and gravels overlying the Ringold Formation (DOE 1984). The basalt formations range in age from 6 to 17 million years. The basalt is as much as 5,000 meters thick, and the Ringold and Hanford Formations are up to 360 meters and 100 meters thick, respectively (Tallman et al. 1979).

Overlying the Columbia River Basalt Group are the fluvial/floodplain sediments of the Ringold Formation, deposited some 3.7 to 8.5 million years ago (Myers et al. 1979). These sediments have locally been divided into four textural units: 1) sand and gravel of the basal Ringold unit; 2) clay, silt, and fine sand with minor gravel lenses of the lower Ringold unit; 3) occasionally cemented sand and gravel of the middle Ringold unit; and 4) silt and fine sand of the upper Ringold unit. A wind-deposited silt and fine sand with relatively high caliche content (the Plio-Pleistocene unit) overlies the Ringold Formation in the western part of the Hanford Site (Tallman et al. 1979).

The Hanford Formation lies on the eroded surface of the Plio-Pleistocene unit, the Ringold Formation, and the basalt and its interbedded sediments. These sediments were deposited by catastrophic floods when glacial dams in western Montana and northern Idaho were breached, and massive volumes of glacial melt water spilled across eastern and central Washington. The last major deposition sequence from such flooding has been dated at about 13,000 years ago. These sediments have been divided into two main facies: 1) the "Pasco Gravels" facies, composed of poorly sorted clasts deposited in a high-energy environment; and 2) the "Touchet Beds" facies, comprising rhythmically bedded sequences of graded silt, sand, and minor gravel units of a slack-water environment (Myers et al. 1979).

The surface of the Hanford Site is locally veneered with alluvium, colluvium, and loess, including both active and inactive sand dunes. The

geologic units are discussed in detail by DOE (1982a, 1984), Myers et al. (1979), and Tallman et al. (1979).

A detailed discussion of the several members that make up the Columbia River Basalt Group and the overlying sediments is given in DOE 1982a and 1984.

4.2.2 Hydrology

The following discussion of the Hanford Site's hydrology contains a brief description of both surface-water and ground-water resources.

4.2.2.1 Surface Water

The Hanford Site occupies approximately one-third of the land area within the Pasco Basin. Primary surface-water features associated with the Hanford Site are the Columbia and Yakima Rivers. Several surface ponds and ditches are present and are generally associated with fuel and waste processing activities. A detailed description of surface waters in the 200 Areas is given in DOE 1987.

Flow from approximately two-thirds of the Hanford Site is considered to drain directly into the Columbia River, although runoff is extremely low, if not zero. The section of the Columbia River along the Hanford reach, which extends from the headwaters of Lake Wallula to Priest Rapids Dam, has been inventoried and is described in detail by the U.S. Army Corps of Engineers (DOE 1984). Flow along this reach is controlled by Priest Rapids Dam. Several drains and intakes are also present along this reach. Most notably, these include irrigation outfalls from the Columbia Basin Irrigation Project and Hanford Site intakes for the onsite water export system.

Cold Creek and its tributary, Dry Creek, are ephemeral streams within the Yakima River drainage system along the southern boundary of the Hanford Site (Cold Creek is shown on Figure 4.1). Both streams drain areas to the west of the Hanford Site. Surface flow, when it occurs, disappears into sediments in the western part of the Site. Approximately one-third of the Hanford Site is drained by the Yakima River system.

Both the Columbia and the Yakima rivers are important sources of industrial, agricultural, and domestic water for the region. Recorded flow rates

of the Columbia River have ranged from 4,500 to 18,000 cubic meters per second during the runoff in spring and early summer, and from 1,000 to 4,500 cubic meters per second during the low flow period of late summer and winter (Jamison 1982). The average annual Columbia River flow in the Hanford reach, based on 65 years of record, is about 3,400 cubic meters per second (DOE 1987). Minimum flows of 117 cubic meters per second have been recorded. For a period of 57 years of record, the average annual flow of the Yakima River is about 104 cubic meters per second, with monthly maximum and minimum flows of 490 and 4.6 cubic meters per second, respectively. Maximum Columbia River floods of historical record occurred in 1894 and 1948, with flows of 21,000 and 19,600 cubic meters per second, respectively (DOE 1987). The likelihood of floods of this magnitude recurring has been reduced by the construction of several flood-control/water-storage dams upstream from the Site. Normal river elevations within the Site range from 120 meters where the river enters the site near Vernita to 104 meters where it leaves the Site near the 300 Area.

The probable maximum flood (the flood discharge that may be expected from the most severe combination of meteorological and hydrologic conditions reasonably possible in the region) would produce a flow rate of 40,800 cubic meters per second. Flood elevations would be about 129 meters at the 100-N Area and 117 meters at the 300 Area (ERDA 1976). This flood would reach the elevation of the fuel storage basins at 100-F and 100-H, but would not reach the elevation of the 105-F or 105-H Reactor buildings or the fuel storage basins at the other reactor sites (see Appendix B).

An estimate has been made of flood magnitudes that would result if 25% and 50% of the center section of Grand Coulee Dam were instantaneously destroyed (ERDA 1976). A 50% flood would create a maximum flow of brief duration of about 226,500 cubic meters per second and flood elevations of 143 to 148 meters in the 100 Areas. Part of the 100 Areas and the 300 Area and most downstream cities adjacent to the river would be flooded (see Appendix B). The 200-Area Plateau would not be impacted by the 50% flood.

The potential for flash flooding from the Cold Creek drainage has been examined (Skaggs and Walters 1981), and a maximum flood depth of 2.3 meters

was estimated along the southwestern part of the 200-Area Plateau and extending to the 200-West Area. No recurrence interval of the probable maximum flood was defined, but a 100-year peak-stage flood, estimated to be about 1 meter above the Cold Creek Valley floor, would not reach the 200 Areas.

The 200-Area Plateau has numerous manmade ponds and ditches, mostly wasteways for process and cooling water. Effluents discharged to these ponds and ditches sometimes contain small quantities of radionuclides, both fission products and transuranics, and constitute an artificial source of ground-water recharge. Rattlesnake Springs, located on the western part of the Site, forms a small surface stream that flows for about 3 kilometers before disappearing into the ground. The Yakima River recharges the unconfined aquifer in the southeastern part of the Site.

When the reactors were in operation, radionuclides, chiefly from neutron activation of constituents in cooling water and in reactor piping, were detected in marine organisms and sediments in the Pacific Ocean along the Oregon and Washington coasts (DOE 1987). With only the N Reactor operating (with a closed-cycle cooling system), the discharge of radionuclides to the Columbia River is very low. A discussion of radioactivity in river sediments downstream from the Hanford Site can be found in DOE 1987.

4.2.2.2 Ground Water

Ground water under the Site occurs under unconfined and confined conditions. The unconfined aquifer is contained within the glaciofluvial sands and gravels and the Ringold Formation. It is dominated by the middle member of the Ringold Formation, consisting of sorted sands and gravels of varying hardness. The bottom of the aquifer is the basalt surface or, in some areas, the clay zones of the lower member of the Ringold Formation. The confined aquifers consist of sedimentary interbeds and/or interflow zones that occur between dense basalt flows in the Columbia River Basalt Group. The main water-bearing portions of the interflow zones occur within a network of interconnecting vesicles and fractures of the flow tops or flow bottoms. Erosional "windows" through the confining beds (the dense basalt flows of the Saddle Mountain Basalt Formation) north of the 200-East Area provide direct interconnections between the unconfined and the uppermost confined aquifers.

The most complete area of erosion is located in the vicinity of West Lake, where all but the last member (the Umatilla Member) of the Saddle Mountain Basalt was completely removed. Graham et al. (1984) defined the hydrologic relationships between the uppermost confined aquifer (the Rattlesnake Ridge aquifer) and the unconfined aquifer in an area surrounding Gable Mountain and B Ponds. Detailed descriptions of the geohydrology of the Hanford Site and references are given in DOE 1987.

Sources of natural recharge to the unconfined aquifer are rainfall and runoff from the higher bordering elevations, water infiltrating from small ephemeral streams, and river water along influent reaches of the Yakima and Columbia rivers. The movement of precipitation through the unsaturated (vadose) zone is of considerable interest, as it represents a potential mechanism for transfer of materials from shallow-land burial sites to ground water. Studies have been conducted at several locations on the Hanford Site to define the movement of water in the vadose zone.

Conclusions from these studies are varied depending on the location studied. Some investigators conclude that no downward percolation of precipitation occurs on the 200-Area Plateau where soil texture is varied and is layered with depth, and that all the moisture penetrating the soil is removed by evaporation. Others have observed downward water movement below the root zone in tests conducted near the 300 Area, where soils are coarsely textured and precipitation was above normal (DOE 1987).

In coarsely textured, unvegetated soils, precipitation can drain through the vadose zone to the ground water. Based on bare-soil lysimeter studies near the 300 Area, Jones and Gee (1984) estimated the annual recharge rate of precipitation to ground water to range from 0 to 5 centimeters per year at that location. Ground-water recharge rates are affected by differences in soil texture (especially if layered), permeability characteristics, and variation in climate. Natural recharge from precipitation to the 200-Area Plateau has not been quantified.

From the recharge areas to the west, the ground water flows downgradient to the discharge areas, primarily along the Columbia River. This general west-to-east flow pattern is interrupted locally by the ground-water mounds

in the 200 Areas. From the 200 Areas, ground water also flows to the north between Gable Mountain and Gable Butte. These flow directions represent present conditions; the aquifer is dynamic, responding to changes in natural and artificial recharge. (See Appendix C for a discussion of the modeling of ground-water pathways.)

4.2.3 Geology and Hydrology of the 100 and 200 Areas

Because the surplus reactors are located in the 100 Areas and may be disposed of in the 200 Areas, a brief, specific description of the geohydrology of these areas is provided in the following sections.

4.2.3.1 100 Areas

The 100 Areas are located adjacent to the Columbia River on the lowest of several levels of alluvial terraces and bars on the Hanford Site. The ground surface is nearly flat to gently undulating, with low-relief hills and dunes in places. Gravel mounds and closed depressions form a mounded land surface in areas south of 100-K and 100-D.

Bedrock under the 100 Areas consists of dense, hard, dark gray lava flows of the Columbia River Basalt Group. In the eastern part of the 100 Areas, near 100-H and 100-F, the upper basalt contains numerous interbeds of sand, gravel, clay, and volcanic ash, while in the western part, near 100-B and 100-K, the upper 30 meters do not contain interbeds (Brown 1962). The basalt bedrock was originally nearly flat, but was later warped and folded into anticlinal ridges (Newcomb et al. 1972).

Immediately overlying the basalt bedrock is the Ringold Formation. Thickness of the Ringold Formation originally may have been up to about 360 meters; but in the 100 Areas, the upper portions have been removed by erosion, and the Ringold Formation is considerably thinner (for example, about 100 meters at 100-H) (Brown 1962).

The uppermost aquifer in the 100 Areas is the unconfined aquifer, with the water table or top of the saturated zone marking its upper surface. Depth to the water table varies from 10 meters or less to about 30 meters and averages about 20 meters in the 100 Areas (McGhan et al. 1985).

Recharge to the unconfined aquifer is from precipitation and runoff from higher areas to the south and southwest of the 100 Areas, infiltration from ephemeral streams, and locally from the Columbia River. Some recharge from precipitation probably occurs in the 100 Areas where the surface materials are coarsely textured and the water table is close to the surface. Flow is toward the river in general, although the unconfined aquifer is hydraulically connected to the river, and reversals in flow can occur at high river stage. The water table fluctuates with changes in river level for up to several miles inland from the river (Newcomb et al. 1972). No ground water is currently being used at any of the 100 Areas.

4.2.3.2 <u>200 Areas</u>

The 200 Areas are located near the center of the Hanford Site in the interior of the Pasco Basin. Elevation varies from 190 to 245 meters. The geomorphology is dominated by flood bars and channels formed by catastrophic flooding during Pleistocene time. Eolian (wind) deflation and deposition have modified the landscape to a minor extent since the flooding.

Basement rocks underlying the thick basalts of the Pasco Basin are not well known or characterized, and the basalt lava flows are essentially the bedrock in the 200 Areas. An eolian deposit of very fine sand and silt, up to 15 meters in thickness, overlies an eroded Ringold surface in the western part of the 200 Areas. In other parts of the 200 Areas, the glaciofluvial sands and gravels of the Hanford Formation overlie the Ringold Formation or, where the Ringold is not present, the basalt. Thickness varies from about 25 meters in the western part of the 200 Areas to more than 100 meters in the east.

Wind-blown silt and sand form a veneer over most of the 200 Areas, varying in thickness from 0 to about 8 meters, and small sand dunes occur in the southern part of the 200 Areas.

Ground water under the 200 Areas occurs under unconfined and confined conditions. The water table, representing the upper limit of the unconfined aquifer, ranges from 55 to 95 meters beneath the ground surface in the 200 Areas. The aquifer is up to 61 meters thick in some areas and thins to

zero thickness along the flanks of the bordering basalt formations within the Site that extend above the water table, such as Gable Mountain and Gable Butte.

Artificial recharge to the unconfined aquifer results from the disposal of waste-cooling and process water to the ground in the 200 Areas. U Pond, B Pond, and Gable Mountain Pond have been the major sources of the artificial recharge (DOE 1987). Beneath these disposal ponds, ground-water mounds have developed in response to the artificial recharge. U Pond was deactivated in March 1985; Gable Mountain Pond, the largest, was emptied, decommissioned, and stabilized in 1987. B Pond has been enlarged, and a contingency pond was constructed nearby. These changes will affect the configuration of the artificial recharge to ground water. West Lake, a natural depression located about 1.7 kilometers north of Gable Mountain Pond, contained water intermittently before liquid-waste disposal operations began. West Lake now contains water perennially as a result of the higher water table induced by the artificial recharge.

Confined aquifers are known to underlie the 200 Areas to a depth of 1,700 meters. Additional aquifers may exist at greater depths. Flow in the confined aquifers is generally to the southeast across the Pasco Basin with discharge to the Columbia River. However, in the 200 Areas the flow is toward the Gable Mountain and Gable Butte areas (DOE 1987).

4.3 CLIMATE, METEOROLOGY, AND SEISMOLOGY OF THE SITE

The following sections contain a summary of the climate, meteorological conditions, and seismology of the Hanford Site and surrounding area. Historical conditions are described as they are known, and current conditions are summarized.

4.3.1 Climate and Meteorology

Climatological data are available for the Hanford Meteorological Station, which is located between the 200 Areas. Data have been collected at this facility since 1945. Temperature and precipitation data are also available from nearby locations for the period 1912 through 1943. A summary of these data, through 1980, has been published by Stone et al. (1983). Data

from the Hanford Meteorological Station are assumed to be representative of the present general climatic conditions for the region.

4.3.1.1 Wind

Wind data are collected routinely at the Hanford Meteorological Station. In addition to surface wind data (2.1 meters above the ground), wind data are collected at the 15.2-, 30.5-, 61.0-, 91.4-, and 121.9-meter levels of a 125-meter tower at the station. More than 20 telemetry stations distributed on and around the Hanford Site provide supplementary data for defining wind patterns.

Prevailing wind directions are from the northwest in all months of the year. Secondary maxima occur for southwesterly winds. Summaries of wind direction indicate that winds from the northwest quadrant occur most frequently during the winter (December, January, February) and summer (June, July, August). During the spring and fall, the frequency of southwesterly winds increases, with a corresponding decrease in northwest flow. Winds blowing from other directions (e.g., northeast) display minimal variation from month to month.

Monthly and annual joint frequency distributions of wind direction versus wind speed are given by Stone et al. (1983). Monthly average wind speeds are lowest during the winter months, averaging 10 to 11 kilometers per hour, and highest during the summer, averaging 14 to 16 kilometers per hour. Wind speeds that are well above average are usually associated with southwesterly winds. In the summer, high-speed winds from the southwest are responsible for most of the dust storms experienced in the region.

High winds are also associated with afternoon drainage winds and thunderstorms. The summertime drainage winds are generally northwesterly and frequently reach 50 kilometers per hour. On the average, 10 thunderstorms occur each year. They are most frequent during the summer, but they have occurred in each month. The winds during thunderstorms do not have a directional consistency. Estimates of the extreme winds, based on peak gusts observed from 1945 through 1980, are given by Stone et al. (1983).

Tornados are infrequent and generally small in the northwest portion of the United States. Grazulis (1984) lists no violent tornados for the region surrounding Hanford (DOE 1987). The Hanford Meteorological Station climatological summary (Stone et al. 1983) and the National Severe Storms Forecast Center data base list 22 separate tornado occurrences within 161 kilometers of the Hanford Site from 1916 through August 1982. Two additional tornados have been reported since August 1982.

The area expected to be directly impacted by a tornado in the Hanford region is about 1.5 square kilometers. The probability of a tornado striking a point at Hanford is estimated to be 9.6×10^{-6} per year.

4.3.1.2 Temperature and Humidity

Diurnal and monthly averages and extremes of temperature, dewpoint, and humidity are reported by Stone et al. (1983). For the period 1912 through 1980, the average monthly temperatures range from a low of -1.5°C in January to a high of 24.7°C in July. The annual average relative humidity at the Hanford Meteorological Station is 54%, with maxima during the winter months averaging about 75% and minima during the summer averaging about 35%.

4.3.1.3 Precipitation

Average annual precipitation at the Hanford Meteorological Station is 16 centimeters. Most of the precipitation takes place during the winter with nearly half of the annual amount occurring in the months of November through February. Days with greater than 1.3 centimeters of precipitation occur less than 1% of the year. Rainfall intensities of 1.3 centimeters per hour persisting for 1 hour are expected once every 10 years. Rainfall intensities of 2.5 centimeters per hour for 1 hour are expected only once every 500 years. Winter monthly average snowfall ranges from 0.8 centimeter in March to 13.5 centimeters in January. The record snowfall of 62 centimeters occurred in February 1916.

4.3.1.4 Dispersion Conditions

Atmospheric dispersion is a function of wind speed, atmospheric stability, and mixing depth. Dispersion conditions are generally good when winds are moderate to strong, when the atmosphere is of neutral or unstable

stratification, and when there is a deep mixing layer. Good dispersion conditions associated with neutral and unstable stratification exist about 57% of the time during the summer. Less favorable dispersion conditions occur when the wind speed is light and the mixing layer is shallow. These conditions are most common during the winter when moderately to extremely stable stratification exists about 66% of the time. Less favorable conditions also occur periodically for surface and low-level releases in all seasons, from about sunset to about an hour after sunrise, as a result of ground-based temperature inversions and shallow mixing layers.

Occasionally, poor dispersion conditions associated with stagnant air in stationary high-pressure systems persist for extended periods. Stone et al. (1972) estimated the probability of extended periods of poor dispersion conditions. The probability of an inversion period extending more than 12 hours varies from a low of about 10% in May and June to a high of about 64% in September and October. These probabilities decrease rapidly for durations greater than 12 hours.

4.3.2 Seismology

Earthquake records for the Pacific Northwest extend back to about 1850; however, the early records are highly qualitative. Earthquakes occurring before 1969, when a network of seismographs was installed on the Columbia Plateau, were documented mainly from reports of tremors that were felt (DOE 1987). The distribution and intensity of historical earthquakes indicates that the Columbia Plateau is in an area of moderate seismicity. Earthquakes within the central Columbia Plateau have been instrumentally located since 1969. While seismic activity above magnitude 3.0 on the Richter scale has occurred in this region, activity above magnitude 3.5 is most commonly found around the northern and western portions of the plateau, with a few events occurring along the border between Washington and Oregon (DOE 1984).

Swarms of small, shallow earthquakes are the predominant seismic events of the Columbia Plateau (DOE 1987). Earthquake swarms (as detected by the regional seismograph network) may contain from four to more than 100 earthquakes of magnitude 1.0 to 3.5. These swarms typically last a few days to several months and occur within areas typically 2 by 5 kilometers and at

depths of 3 to 5 kilometers (DOE 1984). Earthquake swarms characteristically do not follow a typical mainshock-aftershock sequence. The earthquakes within swarms gradually increase and decay in frequency, but not in magnitude.

Shallow-earthquake swarm activity in the central Columbia Plateau is concentrated principally north and east of the Hanford Site. Here earthquakes of magnitude greater than 3.0 also occur. The swarm event of perhaps the largest magnitude was recorded instrumentally on December 20, 1973, as a magnitude 4.4 earthquake located in the Royal Slope area north of the Hanford Site (DOE 1984).

Earthquakes occur to a depth of 28 kilometers in the central Columbia Plateau, although these occur at much lower frequencies than the shallower swarm events. This 28-kilometer depth is the approximate thickness of the earth's crust beneath this portion of Washington state, as determined by seismic refraction studies (Caggiano and Duncan 1983). Deep seismic activity generally occurs randomly and is not associated with known geologic structures or with patterns of shallow seismicity (DOE 1984).

Seismic activity and related phenomena, such as liquefaction, fault rupture, and subsidence, are not believed to be events that could plausibly and directly cause a release of waste from DOE facilities.

4.4 AIR QUALITY, WATER QUALITY, AND ENVIRONMENTAL MONITORING

The following sections present a summary description of air and water quality, background radiation levels, and surveillance programs by which these are monitored at the Hanford Site. More complete descriptions can be found in Cline et al. 1985, Price et al. 1985, Price 1986, and Jaquish and Mitchell 1988.

4.4.1 Air Quality

Air quality in the vicinity of the Hanford Site is generally classified as quite good. The Benton-Franklin-Walla Walla Counties Air Pollution Control Authority routinely monitors concentrations of total suspended

particulates at the Hanford Meteorological Station. No other pollutants are routinely monitored by this agency.

Wind-eroded dust from plowed fields and arid terrain with sparse vegetation is an occasional problem in the area. On a short-term basis, the dust storms that occur can produce high concentrations of total suspended particulates. The atmospheric conditions that produce the dust are otherwise favorable to pollutant transport and diffusion.

The description of air quality in the Skagit/Hanford Draft Environmental Statement (NRC 1982) reflects the current conditions in the Columbia Basin, except for nitrogen oxides. The PUREX facility, which releases nitrogen oxides, was inactive from 1972 until resuming operation in November 1983 (DOE 1982b). This facility releases nitrogen oxides under the terms of a Prevention of Significant Deterioration permit.

Ambient nitrogen oxide measurements made by the Hanford Environmental Health Foundation (HEHF) before the restart of PUREX indicated that the background concentration was less than 7 parts per billion. Monitoring is continuing; the maximum annual average concentration for 1987 was less than 8 parts per billion.

4.4.2 Water Quality

This section discusses the quality of surface water (Columbia River) and ground water at the Hanford Site.

4.4.2.1 Columbia River

The State of Washington Department of Ecology classifies the Columbia River as Class A (excellent) between Grand Coulee Dam and the mouth of the river near Astoria, Oregon (DOE 1984). The Class A designation requires that industrial uses of this water be compatible with other uses, including drinking water, wildlife, and recreation (Price 1986). The Hanford reach of the Columbia River is the last free-flowing portion of the river in the United States, although the flow is regulated by Priest Rapids Dam immediately upstream from the Hanford Site.

PNL conducts routine monitoring of the Columbia River for both radiological and nonradiological water-quality constituents. A yearly summary of results has been published since 1973 (e.g., Jaquish and Mitchell 1988). Numerous other water-quality studies have been conducted on the Columbia River relative to the impact of the Hanford Site over the past 37 years. The DOE currently holds a National Pollutant Discharge Elimination System (NPDES) permit for the discharge of nonradioactive liquids into the Columbia River.

Radiological monitoring shows low levels of radionuclides in samples of Columbia River water. Hydrogen-3 (tritium), iodine-129, and uranium were found in slightly higher concentrations downstream from the Hanford Site than upstream in 1987 (Jaquish and Mitchell 1988).

4.4.2.2 Unconfined Aquifer

Water quality data for the unconfined aquifer in the Pasco Basin were obtained from the U.S. Geological Survey (USGS) (Graham et al. 1981). These data are from samples collected from wells outside the Hanford Site. Chemical analyses are available for well samples collected at Hanford between the years 1974 and 1979 by the USGS. These analyses are reported in PNL documents (e.g., Price 1986; Jaquish and Mitchell 1988).

Radionuclides have been introduced into the ground water as a result of various liquid-waste disposal activities. Nitrate, tritium, and total-beta contaminations have migrated away from these sites in a general west-to-east direction. Some longer lived radionuclides, such as strontium-90, technitium-99, cesium-137, and iodine-129, have reached the ground water, primarily through cribs. Minor quantities of longer lived radionuclides have reached the water table via a failed ground-water monitoring well casing, and through reverse well injection, a disposal practice discontinued at Hanford in 1947 (Smith 1980). The occurrence and consequences of leaks from waste storage tanks and the occurrence of radioactive materials in soils have been described elsewhere (ERDA 1975). These occurrences have not resulted, and are not expected to result, in radiation exposure to the public (ERDA 1975; DOE 1987).

Ground water is routinely and extensively monitored to trace the movement of contaminants and to determine any impact on the public (Graham et al. 1981). Ground-water monitoring results are reported annually (e.g., Cline et al. 1985; Price 1986; Jaquish and Mitchell 1988).

Studies have been conducted to determine whether or not any contaminants have migrated from the unconfined aquifer to the upper, confined aquifer (Strait and Moore 1982; Graham et al. 1984). These studies indicate that some migration occurred south and east of Gable Mountain Pond, but that contamination levels were well below limits of the drinking-water standards. Also, under present ground-water flow conditions, any contaminants in the upper, confined aquifer will eventually discharge back to the unconfined aquifer in the vicinity of West Lake (Graham et al. 1984).

4.4.2.3 Confined Aquifer

Ground water in the confined aquifer beneath the Hanford Site can be characterized by areal and stratigraphic changes in the ground-water chemistry (Graham et al. 1981). The stratigraphic position of these changes is believed to delineate flow-system boundaries and to identify chemical evolution taking place along ground-water flow paths. Some potential mixing of ground waters has also been identified using these data. However, the rate of any mixing is unknown. Overall, waters in the shallow basalts are of a sodium-bicarbonate chemical type; those in the deep basalts are of a sodium-chloride chemical type (DOE 1984).

4.4.3 Environmental Monitoring

The DOE has conducted an environmental monitoring program at the Hanford Site for the past 44 years. Monitoring results have been recorded since 1946 in quarterly reports; since 1958, the results have been available as annual reports (compiled by Soldat et al. 1986). Beginning in 1985, the offsite and onsite monitoring results were combined in a single report. Results from the 1987 report (Jaquish and Mitchell 1988) are briefly summarized here.

Radioactive materials in air were sampled continuously in 1987 on the Hanford Site, at the Site perimeter, and in nearby and distant communities at

50 locations. In 1987 the annual average Hanford onsite or perimeter concentrations of tritium, krypton-85, uranium, plutonium-239 and -240, and iodine-129 were numerically greater than levels measured at distant monitoring stations. However, the effective dose equivalent to the hypothetical maximally exposed individual from these emissions was calculated to be 0.03 millirem for 1987, as compared with the EPA standard of 25 millirem per year (40 CFR 61.92). Nitrogen dioxide data collected in 1987 indicated that the highest annual average perimeter concentration was 0.008 parts per million, as compared with the EPA average annual ambient air quality standard of 0.05 parts per million (40 CFR 50.11).

During 1987, ground water was collected from 563 onsite monitoring wells that sample both the confined and unconfined aquifers under the Hanford Site. Radiological monitoring results indicate that gross alpha, gross beta, tritium, cobalt-60, strontium-90, technetium-99, ruthenium-106, antimony-125, iodine-129, iodine-131, cesium-137, and uranium concentrations near operating areas were at levels above the EPA's drinking water standard (40 CFR 141 and EPA 1976). Tritium continued to move slowly with the general ground-water flow and discharge to the Columbia River. Nitrate concentrations resulting from Site operations exceeded the drinking-water standard at isolated locations in the 100, 200, and 300 Areas and in the 600 Area southwest of the old Hanford townsite. Chromium concentrations were above the drinking-water standard in the 100-D and 100-H Areas, fluoride was above the drinking-water standard in a few wells in the 200-West Area, and carbon tetrachloride was above the drinking-water standard in the 200-West Area. None of these wells is used for drinking-water purposes. Ground-water concentrations of radionuclides in three well systems on the Hanford Site used for drinking-water purposes do not exceed radiological drinking-water standards.

Measurements of Columbia River water in 1987 showed concentrations of radionuclides and other hazardous substances to be well below drinking-water standards. Tritium, gross alpha, uranium, and iodine-129 are measurable in higher concentrations downstream from Hanford than upstream. The calculated effective dose equivalent to the hypothetical maximally exposed individual

from the Columbia River water pathway for 1987 was 0.02 millirem per year, as compared with the EPA standard of 4 millirem per year from drinking water alone.

Low levels of radionuclides attributable to worldwide fallout were found in several foodstuff and farm product samples during 1987. Concentrations in samples collected near the Hanford Site, including those irrigated with water taken from the Columbia River downstream from the Site, were similar to concentrations measured in samples collected away from the Site.

Deer, fish, game birds, waterfowl, and rabbits on the Site and from offsite locations were analyzed for radionuclides. Levels of radionuclides in both onsite and offsite samples generally were similar and attributable to worldwide fallout, although slightly elevated amounts of cobalt-60, strontium-90, and cesium-137 were observed in bass collected from sloughs in the 100-F Area. Also, waterfowl collected from B Pond and rabbits collected near the 100 and 200 Areas contained low levels of cesium-137.

Measured external radiation exposures and calculated radiation doses to the public from 1987 Hanford operations were well below applicable regulatory standards. The calculated effective dose potentially received by the maximally exposed individual was about 0.05 millirem for 1987, compared with a dose of 0.09 millirem estimated for 1986. The collective effective dose to the population residing within 80 kilometers of the Site was 4 person-rem for 1987, compared with 9 person-rem for 1986. These doses may be compared with the approximately 300 millirem per year and 100,000 person-rem per year received by an average individual and the surrounding population, respectively, as a result of naturally occurring radiation.

4.5 ECOLOGY

The Hanford Site consists of mostly undeveloped land with widely spaced clusters of industrial buildings located along the western shoreline of the Columbia River and at several locations in the interior of the 1.450-square-kilometer Site. The industrial buildings are interconnected by roads, railroads, and electrical transmission lines. Most of the Site has not experienced tillage or livestock grazing since the early 1940s. The Columbia River

flows through the Site, and although the river flow is not directly impeded by artificial dams, the historic daily and seasonal water fluctuations have been changed by dams elsewhere along the river (Rickard and Watson 1985). The Columbia River as it flows through the Hanford Site is accessible for public recreational use and commercial navigation.

4.5.1 Terrestrial Ecology

The Hanford Site is located in the semiarid sagebrush vegetation zone of eastern Washington (Daubenmire 1970). In the early 1800s, the dominant plant was big sagebrush (*Artemisia tridentata*), with an understory of perennial bunchgrasses, especially Sandberg bluegrass (*Poa sandbergii*) and bluebunch wheatgrass (*Agropyron spicatum*). With the advent of settlement that brought livestock grazing and crop raising, the natural vegetation mosaic was opened to a persisting invasion by alien annuals, especially cheatgrass (*Bromus tectorum*). Today, cheatgrass is the dominant plant on cultivated fields that were abandoned 40 years ago. Cheatgrass is also well established on rangelands at elevations below 244 meters (Rickard and Rogers 1983).

Although the dryland areas of the Hanford Site were treeless in the years before land settlement, trees were planted and irrigated on farms to provide windbreaks and shade for several decades before 1943. When these farms were abandoned in 1943, some of the trees died but others have persisted, presumably because their roots are deep enough to contact ground water. Today these trees serve as nesting platforms for hawks, owls, ravens, magpies, and great blue herons, and as night roosts for wintering bald eagles (Rickard and Watson 1985).

The release of water used as industrial process coolant streams at Hanford Site facilities has created several semipermanent artificial ponds at places that had never before supported ponds. Some of these have now been in place for two decades (Rickard et al. 1981). Over the years, the ponds developed stands of cattails (*Typha latifolia*), reeds (*Scirpus* spp.), and trees, especially willow (*Salix* spp.), cottonwood (*Populus* sp.), and Russian olive (*Eleagnus angustifolia*). The ponds attract waterfowl during autumn and spring migrations, and they also support nesting populations of American

coots (Fulica americana). These ponds are ephemeral features of the landscape and would quickly disappear should the industrial releases of water be terminated.

4.5.2 Aquatic Ecology

Two kinds of natural aquatic habitats occur on the Hanford Site--the Columbia River, and small, spring streams located in the Rattlesnake Hills. The spring streams are remotely located from the industrial operations on the Hanford Site and have never received aqueous discharges from Hanford facilities.

The Columbia River has received aqueous discharges from operating nuclear reactors since the 1940s (Rickard and Watson 1985). Over the past 40 years, the Hanford reach of the Columbia River has supported spawning populations of chinook salmon. Fall-spawning chinook salmon reached their greatest densities in the years 1980 to 1985. The increase in spawning activity is attributed to fisheries management practices purposefully designed to compensate for the loss of salmon reproduction caused by four decades of intensive hydroelectric development along the mainstream Columbia River and its tributaries.

The Hanford reach continues to provide sports fishing for salmon, steelhead, smallmouth bass, channel catfish, yellow perch, black crappie, rocky-mountain whitefish, carp, walleyed pike, and sturgeon. The fisheries resource is also exploited by great blue herons, Forster's terns, gulls, and other fish-eating birds, including the white pelican and the bald eagle.

A major factor in the general decline of native plants and animal populations characteristic of the semiarid sagebrush zone of eastern Washington has been the land uses that converted large tracts of former wild lands to dryland wheat and irrigated crops. Over the past 150 years, these changes have resulted in diminished populations of native animals, especially sagebrush voles, sage sparrows, sage thrashers, sage grouse, burrowing owls, pygmy rabbits and Merriam's shrews. Today the Hanford Site is one of the largest remnants of undeveloped sagebrush land in eastern Washington.

4.5.3 Threatened and Endangered Species

Some species of plants and animals exist throughout the world in such small numbers that they are in danger of becoming extinct by human-induced habitat changes, by direct human exploitation, by introduction of aggressive or competitive alien species, by introduction of disease, or by the introduction of efficient predators.

The U.S. Fish and Wildlife Service is the federal agency responsible for identifying and listing those plants and animals whose populations in the United States are so small that they are in danger of extirpation or extinction. The Washington state agencies responsible for species lists are the Department of Game (non-game species) and the Department of Natural Resources (Natural Heritage Program). The Department of Game lists animal species, and the Natural Heritage Program lists plant species. Lists of plant and animal species are in various stages of preparation and publication and are subject to change as new information is obtained. Sometimes species are added to existing lists, and sometimes species are removed. Federally listed and candidate species appear in an attachment to a recent letter from the U.S. Fish and Wildlife Service (Appendix I).

None of the plants occurring at Hanford are included on the federal list of endangered and threatened species. However, three plant species that are candidates for consideration for future listing are known to occur on the Hanford Site. These are Astragalus columbianus, Rorippa calycina columbiae, and Lomatium tuberosum. Astragalus columbianus occurs on dryland benches along the Columbia River in the vicinity of Priest Rapids Dam, and Rorippa calycina columbiae and Lomatium tuberosum occur in the wetted zone of the water's edge along the Hanford reach of the Columbia River.

Several plant species that are listed by the Washington State Natural Heritage Program (1986) as "sensitive" probably occur on the dryland areas of the Hanford Site. These are Erigeron piperianus, Chaenactis douglasii var. glandula, and Cryptantha leucophea. Other state-listed sensitive species that are likely to occur along the shoreline of the Columbia River are Cyperus rivularis and Lindernia anagallidae.

The U.S. Fish and Wildlife Service lists two animal species as threatened or endangered on the Hanford Site. These are the American peregrine falcon (Falco peregrinus), endangered; and the bald eagle (Haliaeetus leucocephalus), threatened. The American peregrine falcon is not known to nest on the Hanford Site. Its presence on the Hanford Site is as a casual migrant. The bald eagle is a regular winter resident, but it also is not known to nest on the Hanford Site. Eagles forage on dead salmon and prey upon waterfowl along the Hanford reach of the Columbia River, with occasional foraging flights onto the Hanford Site. Over the past 20 years, the number of bald eagles wintering along the Hanford reach has increased from less than 10 to about 35 (Rickard and Watson 1985). The state of Washington issued bald eagle protection rules in 1986 (WAC 232-12-292). These rules provide for the preparation of a management plan to mitigate eagle disturbance in cooperation with the Washington State Department of Game and the U.S. Fish and Wildlife Service.

Two candidate invertebrate species occur in the Hanford reach of the Columbia River: the great Columbia River limpet (Fisherola nuttalli) and the great Columbia River spire snail Lithoglyphus columbiana).

The Washington State Game Department lists animal species in three categories: sensitive, threatened, and endangered. The bird and mammal species listed that are known to occur or thought to have a potential to occur on the Hanford Site are listed in Table 4.1.

4.5.4 Game Birds and Mammals of the Hanford Site

Resident game birds and mammals are valuable resources that belong to the citizens of Washington state, but reside on the Hanford Site either permanently or temporarily. Their management is the responsibility of the DOE and is coordinated with the Washington State Department of Game.

The Hanford Site supports populations of chukar partridge (Alectoris chukar), gray partridge (Perdix perdix), and sage grouse (Centrocercus urophasianus). The greatest concentrations of these birds are in the Rattlesnake Hills. The sage grouse population is very small and appears to be confined entirely to the slopes of the Rattlesnake Hills. The mourning dove (Zenaidura macroura) nests throughout the Hanford Site. Small, isolated

TABLE 4.1. Sensitive, Threatened, and Endangered Animal Species on the Hanford Site (Washington State Department of Game 1985)

Sensitive Species	Threatened Species	Endangered Species
Northern goshawk *Accipiter gentilis*	Bald eagle *Haliaeetus leucocephalus*	American white pelican *Pelecanus erythrorhynchus*
Swainson's hawk *Buteo swainsoni*	Ferruginous hawk *Buteo regalis*	Sandhill crane *Grus canadensis*
Golden eagle *Aquila chrysaetos*	Pygmy rabbit *Sylvilagus dahoensis*	American peregrine falcon *Falco peregrinus*
Burrowing owl *Athene cunicularia*		Merriam's shrew Sorex *merriami*
Western bluebird *Sialia mexicana*		Pallid bat *Antrozous pallidus*
Sage thrasher *Oreoscoptes montanus*		Long-eared myotis *Myotis evotis*
Loggerhead shrike *Lanius ludovicianus*		
Sage sparrow *Amphispiza belli*		
Giant Columbia River limpet *Fisherola nuttali*		
Columbia River spire snail *Lithoglyphus columbianus*		

populations of Chinese ring-necked pheasants (*Phasianus colchicus*) and California quail (*Lophortyx californica*) live along the Columbia River and near the spring streams in the Rattlesnake Hills.

The Columbia River serves as a major resting area for migrant waterfowl. The greatest concentrations of waterfowl (ducks and geese) occur in the autumn months, and waterfowl hunting is a popular recreational activity along the Hanford reach of the Columbia River. Hunting is permitted on the Columbia River (but not on the Site) between Richland and the upstream powerline crossing at the abandoned Hanford townsite.

The Hanford reach of the Columbia River is an important nesting habitat for the western Canada goose (Branta canadensis moffitti). Geese have regularly nested on the sparsely vegetated sand and cobble islands over the past 40 years (Fitzner and Rickard 1983). The nesting goose population appears to be stable. Coyotes are a major contributor to the absence of goose nests from islands that formerly supported as many as 100 nests.

Elk (Cervus elaphus) and mule deer (Odocoileus hemionus) are year-round residents of the Hanford Site. The herd of wild, free-roaming elk (currently about 70 animals) is increasing. The herd range is centered almost entirely on the Arid Lands Ecology (ALE) reserve, a part of the Hanford Site established in 1968 as an environmental research study area. Mule deer range throughout the Hanford Site, but most of the population is centered along the Columbia River. Some of the deer born on the Hanford Site travel beyond the boundary of the restricted access area of the Hanford Site, and some are killed by hunters.

Coyote, badger, and bobcat are the important fur-bearers of the dryland habitats. Beaver, skunk, mink, muskrat, and raccoon are present along the Columbia River.

The cottontail rabbit (Sylvilagus nuttalli) is widely distributed throughout all dryland habitats of the Hanford Site. Black-tailed jackrabbits (Lepus californicus) are scattered throughout the lower elevations of the Hanford Site, but major populations are concentrated around the 200-Area Plateau.

4.5.5 Self-Revegetation of Previously Plowed Land

Small irrigated fields on the Hanford Site were abandoned in the early 1940s following the relocation of the former private land owners. These fields were promptly invaded by cheatgrass in the first years of abandonment. Cheatgrass has maintained a plant cover on these fields that has been resistant to wind and water erosion for 40 years (Rickard and Rogers 1983).

4.5.6 Ecological Research and Education

The ALE reserve is a protected part of the Hanford Site. It is completely fenced to exclude stray livestock and is patrolled by aircraft to

discourage off-road vehicular trespassing that can be damaging to native vegetation and disruptive to wildlife. The major land use of the ALE reserve is as a study area for short- and long-term ecological research. The National Environment Research Park at Hanford provides administrative mechanisms for university and college students and faculty to use the land-biotic resources and facilities of the Hanford Site and especially the ALE reserve for environmental research and educational purposes.

4.6 SOCIOECONOMICS OF THE AREA SURROUNDING THE SITE

The extensive nuclear-related development work begun at Hanford in 1943 has been a major factor in the socioeconomy of the surrounding area. The Tri-Cities (Kennewick, Pasco, and Richland) and the remainder of Benton and Franklin Counties are the areas that potentially would be most affected by future decommissioning activities on the Site. This area has been designated as a Metropolitan Statistical Area (MSA)[a] by the Bureau of the Census. A detailed review of area socioeconomics is given in DOE 1987.

4.6.1 Economy and Work Force

The primary economic bases of the Tri-Cities MSA are Hanford operations, agriculture services industries, wholesale and retail trade, and manufacturing (DOE 1987). Dominant sectors of the economy in 1983 include services (27% of nonagricultural employment), wholesale and retail trade (20%), manufacturing (18%), and government (17%). The contract construction work force declined from 13,550 in 1981 (21% of the nonagricultural total) to 5,620 (10% of the nonagricultural total) in December 1983. Much of this decline resulted from the completion, deferral, or cancellation of nuclear power plant construction. The Washington Public Power Supply System, the major non-DOE-related employer at Hanford, had about 1,600 employees in 1986. About 13,000 persons are employed on DOE-related projects at Hanford. Agricultural employment in Benton and Franklin Counties varies seasonally from a

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(a) An MSA, consisting of a designated population nucleus and surrounding areas, is part of the same economic and social structure. It comprises a single city of population 50,000 or more, plus the surrounding associated areas, or it is a generally urbanized area of population more than 100,000. The MSA usually follows county boundaries.

low of about 2,000 to a high of about 6,000 (DOE 1987). The small size of the projected work force for the surplus reactor decommissioning, estimated at 100, would probably not have a significant effect on the Tri-Cities area.

The average annual per capita income, including agricultural payrolls, was about $8,300 in 1982. As of September 1985, unemployment within the Tri-Cities was 7.8%, compared with 7.2% for the state and 6.9% for the nation (DOE 1987).

From 1970 to 1982, housing units increased 94.3%, following increased population and employment that accompanied Washington Public Power Supply System projects in the mid-1970s (Watson et al. 1984). The number of housing units grew at an annual average rate of 7.8% from 1973 through 1981. Richland, Pasco, and Kennewick all have experienced sharp declines in housing growth since 1981 (Watson et al. 1984). Housing units in 1982 in the Tri-Cities totaled about 58,000, with 69% being single-family units, 20% multi-family units, and 11% mobile homes. The total vacancy rate in the Tri-Cities MSA in 1983 was about 8.6%, or 5,000 vacant housing units (Watson et al. 1984).

4.6.1.1 Population

There were about 340,000 people residing within an 80-kilometer radius of the 200 Areas according to estimates based on the 1980 census (see Figure 4.6). The projected population within an 80-kilometer radius of the 200 Areas for 1990 is about 420,000.

The estimated population trend of Benton and Franklin Counties from 1981 to 1990 varies from a decline of about 8% to an increase of about 8%, depending on different assumed economic factors. These factors include the restart of construction of Washington Public Power Supply System reactors, possible changes in agricultural growth, or the start of new DOE-related projects (Watson et al. 1984). The fact that the N Reactor was recently placed in standby will undoubtably lead to a decline in Hanford's employment base.

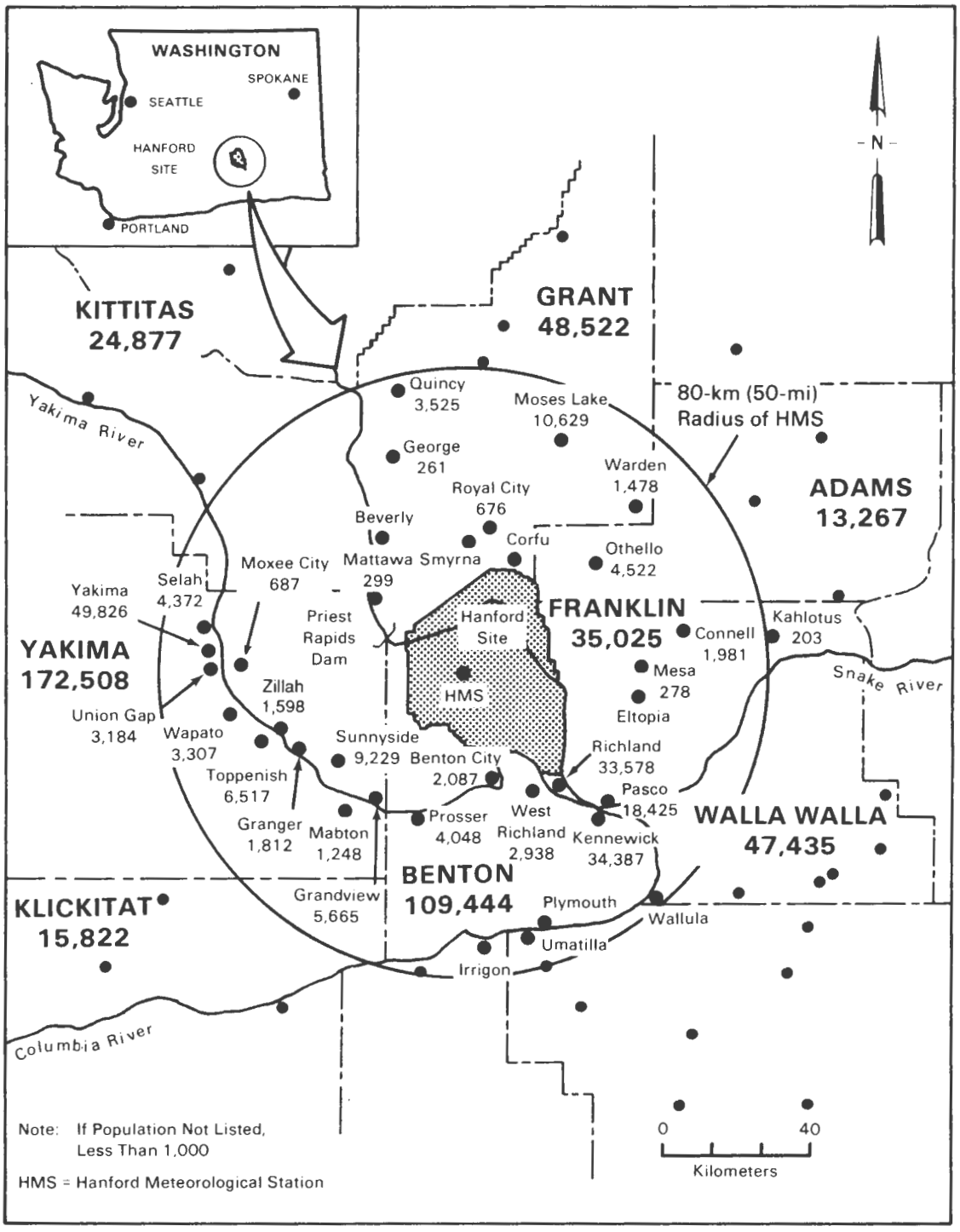

FIGURE 4.6. Populations of Cities Within 80 Kilometers of the Hanford Meteorological Station, According to the 1980 U.S. Census and Other More Current Estimates (Washington State Human Rights Commission 1984; DOE 1987)

4.6.1.2 Services

The several services provided to the Tri-Cities are described below.

Education. All school districts in the Tri-Cities MSA offer first through twelfth-grade education. The 1984 spring enrollment was about 26,300 students; the Kennewick school district is the largest, with about 10,000 students. Two elementary schools and one junior high school were closed in Richland in 1983 because of declining school population. The Tri-Cities generally has no shortage of school facilities.

Schools of higher education in the Tri-Cities include Columbia Basin College in Pasco and the Tri-Cities University Center in Richland. Enrollment at Columbia Basin College in the fall of 1984 was about 5,000, with about 54% part-time students. The number of students at Columbia Basin College has been fairly constant over the past several years. The enrollment at the Tri-Cities University Center is about 1,000.

Fire and Police Protection. Each of the Tri-Cities maintains a full-time fire protection staff; other municipalities and rural fire districts typically have one full-time person aided by volunteer personnel. Mutual aid agreements exist among the municipal and rural fire departments and the Hanford Fire Protection Department (operated by Westinghouse Hanford Company). These provide for better fire protection for each jurisdiction by making backup personnel and equipment available from neighboring units.

The combined staff of the Richland, Kennewick, and Pasco police departments is about 120; the smaller cities and the sheriffs' departments of Benton and Franklin Counties have another 40 police personnel. In addition, there are about 350 persons on the Hanford Site security force, administered by Westinghouse Hanford Company.

Water, Sewer, and Solid Wastes. The Columbia River is the source of part or all of the municipal water supplies for each of the Tri-Cities. Each city operates its own treatment and distribution system. Richland directly uses about 15.6 million cubic meters of Columbia River water annually for its domestic supply. An additional 10.4 million cubic meters per year are pumped from the river for the recharge of wells that provide domestic water and for

the irrigation of the Tri-Cities University Center campus and adjacent land. Kennewick withdraws about 4.7 million cubic meters of water directly from the river for domestic supply during April through October. A well-collector system located near the Columbia River at Kennewick adds to this amount during the April through October period and is the sole source of city water from November through March. Pasco withdraws about 7.6 million cubic meters of water directly from the river annually.

In addition to the use of Columbia River water by the Tri-Cities, water is pumped from the river for irrigating agricultural lands downstream from the Hanford Site. The withdrawal of Columbia River water for agriculture in the region, from the Hanford Site to 130 kilometers downstream, is about 585 million cubic meters annually. The combined annual withdrawal of this irrigation water and the domestic supplies for the Tri-Cities is about 623 million cubic meters. The urban population along this section of the river was about 91,000 during the 1980 census (Rand McNally 1985). The estimated number of people using Columbia River water within about 130 kilometers downstream from the site, including the unreported rural population along the river, is about 100,000.

Each of the Tri-Cities operates its own plant for primary and secondary sewage treatment. A new sewage-treatment plant went into operation in Richland in October 1985. Pasco is nearing the limit of its system; Kennewick's system has some reserve capacity.

Solid refuse is disposed of in sanitary landfills. The City of Richland operates its own fill, while Kennewick and Pasco contract for this service with private operators. The capacity of existing landfills is adequate for existing and anticipated future needs through 1990.

Regulation of municipal water, sewer, and solid waste is carried out by the Washington State Department of Ecology, the Washington State Department of Social and Health Services, and local health districts.

Medical Facilities. Four general hospitals, located in Richland, Kennewick, Pasco, and Prosser, serve the region. Their combined capacity is about 320 beds, which exceeds current demand. The area also has seven nursing homes with a combined capacity of 411 beds, the Mid-Columbia Mental

Health Center, and several minor emergency aid centers. Expansion of Pasco's hospital was recently completed. Kennewick General Hospital is remodeling its existing facility. Richland, Pasco, and Kennewick are also exploring the possibility of consolidating medical facilities to serve the Tri-Cities and to avoid unnecessary duplication of services and facilities.

Parks and Recreation. The Tri-Cities area has 67 federal-, state-, county-, and city-maintained park facilities covering almost 50 square kilometers. Most of these parks are located along the Columbia and Snake rivers and provide camping, boating, swimming, and picnic facilities.

4.6.2 Noise

Background noise was not measured for this DEIS and is usually not evaluated because of the remoteness of most Hanford activities and the isolation from most receptors that are covered by federal or state statutes. However, background noise measurements were conducted by Puget Sound Power and Light Company for the Skagit/Hanford Nuclear Project (NRC 1982). Ambient noise levels on the Hanford Site do not exceed federal or state of Washington noise standards.

4.6.3 Historic, Archaeological, and Cultural Resources

The Hanford Site currently has nine archaeological properties listed in the National Register of Historic Places (National Register) (Rice 1985). Three other archaeological properties and one historic site are being nominated or have been nominated to the National Register. Most of these are located on the islands and shorelines of the Columbia River (DOE 1987), or on rocky ridges in the center of the Hanford Site. In all, 133 archaeological sites have been identified on Hanford, including Indian open camps, fishing stations, housepit sites, cemeteries, hunting blinds and traps, and places where stone tools were made. Seventeen sites are located just north of the 200 Areas, near Gable Mountain and Gable Butte. A survey of the 200 Areas has revealed no such sites. The historic White Bluffs freight road, which is being considered for nomination to the National Register, traverses the 200-West Area and passes northeastward to the old White Bluffs ferry landing. Three National Register Archaeological Districts, one listed site, and numerous as-yet unevaluated archaeological sites are located near the 100 Areas.

A detailed description of some of these sites can be found in Rice 1985 and ERDA 1975. The 100 Areas themselves have not yet been surveyed for cultural resources. B Reactor, in the opinion of the Washington State Historic Preservation Officer, is eligible for listing in the National Register.

The decommissioning of surplus production reactors may have an impact on archaeololgical or cultural properties that may be found within the 100 Areas, and/or the 100-B Reactor. Whenever earth-disturbing activities or decommissioning of structures is contemplated, a review is carried out by the Hanford Cultural Resources Laboratory. This includes literature and records search and field inspection components.

4.6.4 Land Use

The entire 1,450-square-kilometer area of the Hanford Site is a controlled area and is expected to remain so for the foreseeable future. Within this controlled area are several DOE operational areas where access is restricted further (see Figure 4.7).

The areas designated for the ALE reserve, U.S. Fish and Wildlife Refuge, and Washington State Department of Game total about 660 square kilometers and provide a buffer zone around the areas of government activity.

Land use in the surrounding area includes urban and industrial development, irrigated and dryland farming, and grazing. Principal agricultural crops include hay, wheat, potatoes, corn, apples, soft fruit, hops, grapes, and vegetables. In recent years, wine grapes have gained importance. Industries in the nearby Tri-Cities are mainly those related to agriculture and energy production.

4.6.5 Indian Tribes

The Hanford Site is located on lands ceded to the U.S. government by the Yakima and Umatilla Indians, who now live on reservations near the Hanford Site (DOE 1987). The Wanapum band, a nontreaty group, resided on what is now the Hanford Site before 1943. They now live at Priest Rapids Dam (Relander 1986). Other Indian tribes in the region whose ceded lands do not include any portion of the Hanford Site are the tribes of the Nez Perce Indian reservation, the Spokane Indian reservation, and the Colville Indian reservation.

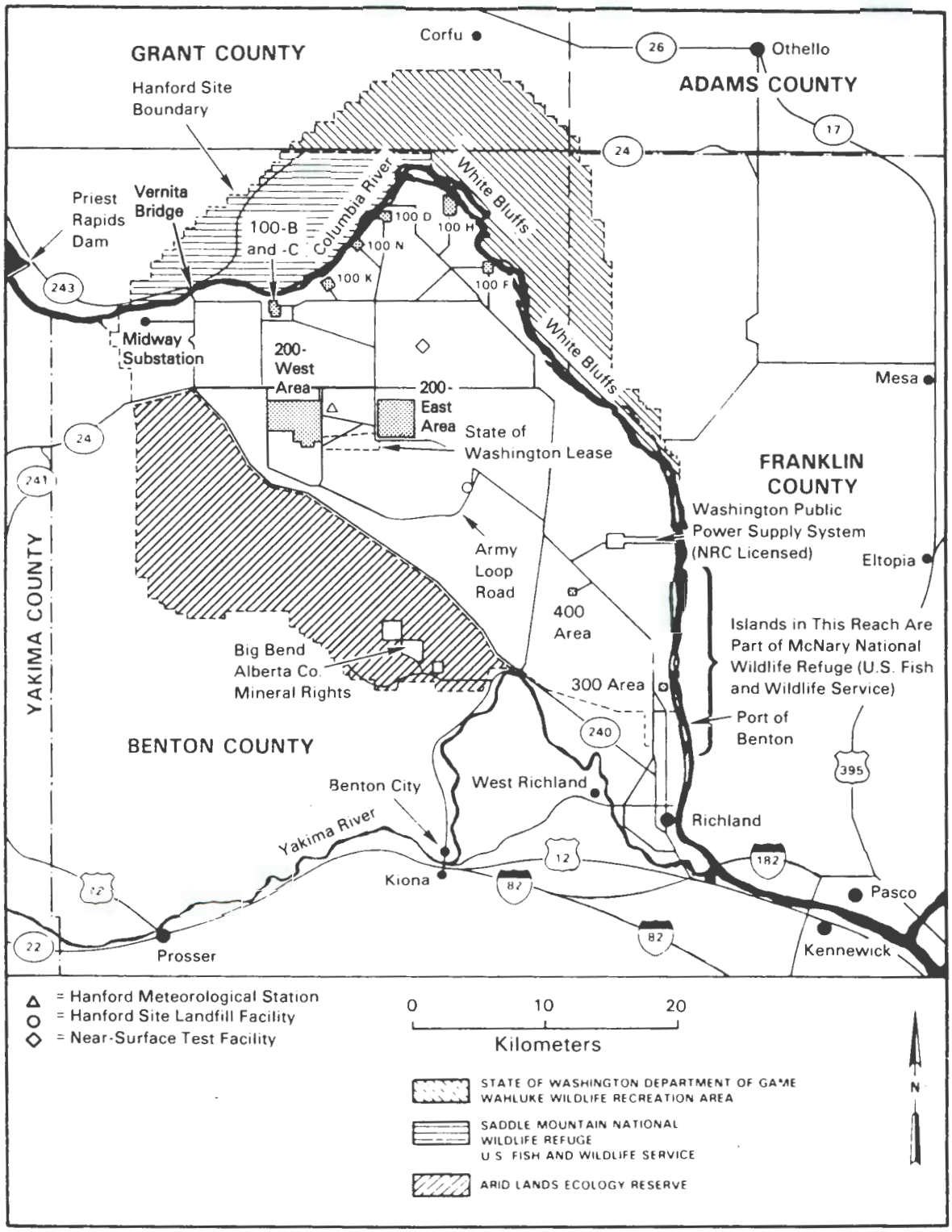

FIGURE 4.7. Land Use at the Hanford Site (DOE 1984)

As part of their treaty agreements, the Yakima and Umatilla Indians were generally assured of the right to fish at all their usual and accustomed places. Residents of the Yakima and Umatilla reservations and the Wanapum band consider portions of the Hanford Site to be sacred. Specific places important to them are Gable Mountain, Gable Butte, Goose Egg Hill, Coyote Rapids, and numerous cemeteries. Some of these places figure in their stories of creation, and some are important to the conduct of certain religious ceremonies. Consultation with Indian religious leaders may be necessary if the potential exists for abridgement of religious freedom.

4.7 TRANSPORTATION FOR THE SITE AND SURROUNDING AREA

Most of the transportation activities associated with decommissioning of the surplus production reactors would take place within the Hanford Site boundaries. Use would be made of the existing transportation network shown in Figure 4.8 for truck or rail transport of decommissioning wastes, or of specially constructed haul roads shown in Figure 4.9 for one-piece transport of the reactor blocks.

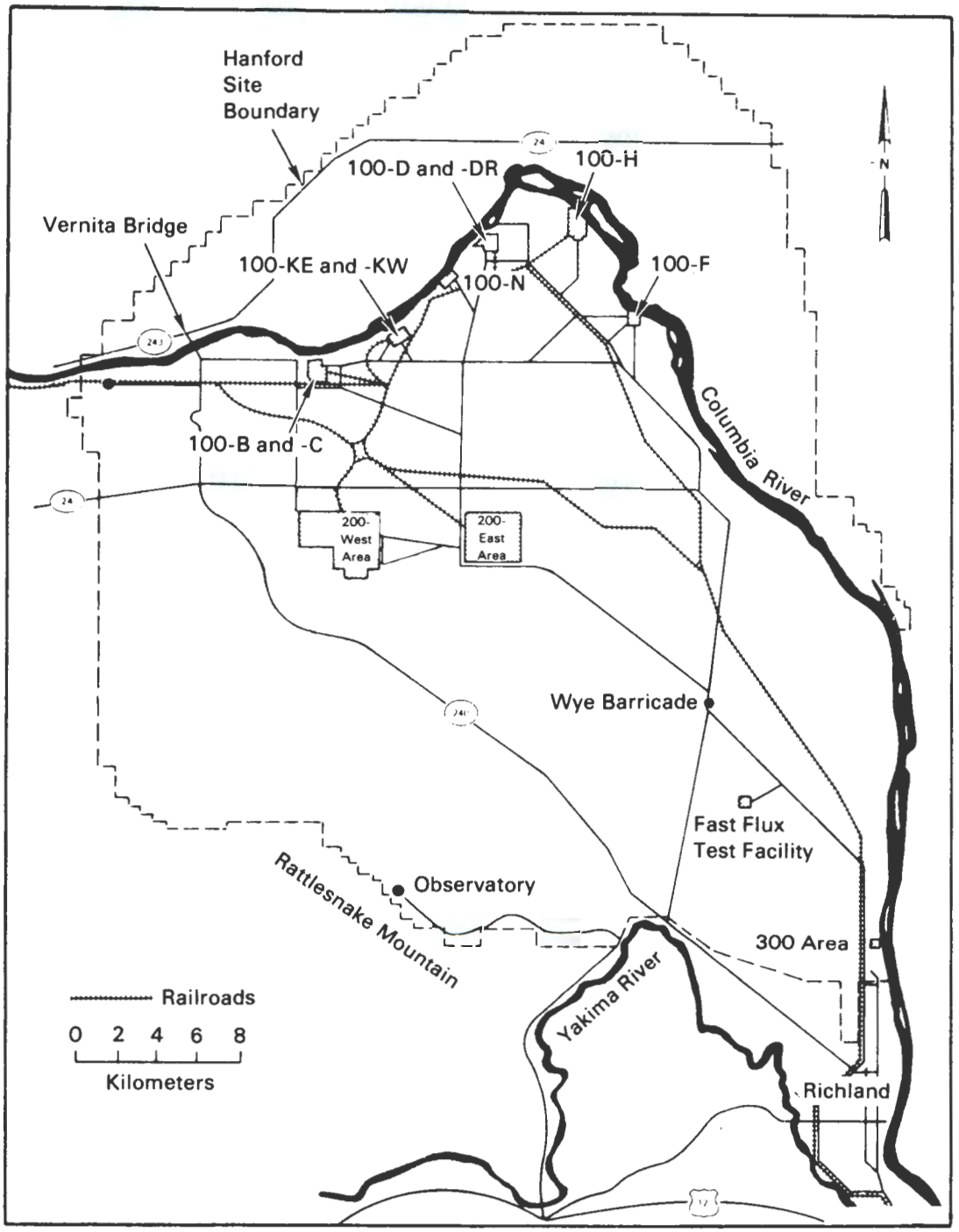

FIGURE 4.8. Transportation Network on the Hanford Site (DOE 1984)

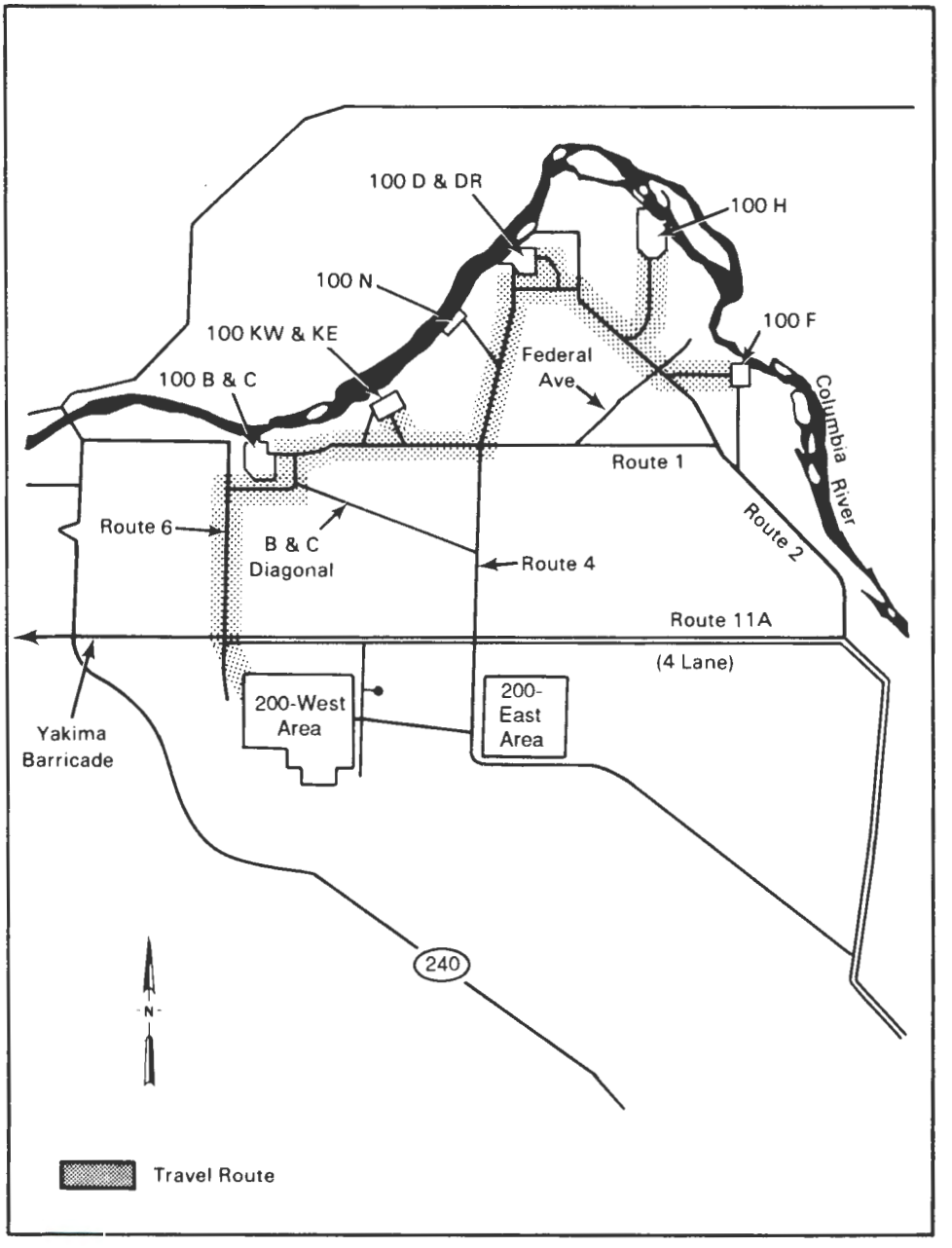

FIGURE 4.9. Projected Haul Roads to be Used for Reactor-Block Transport

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5.0 ENVIRONMENTAL CONSEQUENCES

This chapter contains a discussion of the environmental consequences that could result from implementation of the decommissioning alternatives described in Chapter 3.0. The alternatives analyzed are

- no action
- immediate one-piece removal
- safe storage followed by deferred one-piece removal
- safe storage followed by deferred dismantlement
- in situ decommissioning.

Alternatives considered but not discussed in detail in Chapter 3.0 were not evaluated.

Each of the decommissioning alternatives was evaluated for environmental consequences associated with both normal and abnormal operations and events. Modeling assumptions and accident scenarios used in the evaluation are conservative. The analyses were conducted such that the predicted environmental impacts should exceed those actually expected or experienced. Accident conditions chosen describe the most serious incidents that could be reasonably postulated to occur.

Potential impacts were assessed during two time periods for each of the alternatives: the active decommissioning period and the postdecommissioning period. For the active decommissioning period, the following types of impacts were considered:

- radiation doses to the work force during decommissioning operations (Chapter 3.0)
- radiation doses to the public from postulated routine releases and from radiological accidents (Sections 5.2 through 5.6)
- ecological impacts (Sections 5.2 through 5.6)
- socioeconomic impacts (Section 5.8)
- resource commitments (Section 5.9)
- costs (Chapter 3.0).

For the postdecommissioning period, the following types of impacts were considered:

- long-term impacts from decommissioning wastes under present climatic and otherwise undisturbed conditions (Section 5.7)
- long-term impacts from decommissioning wastes under changed climatic or otherwise disturbed conditions (Section 5.7).

5.1 ANALYSIS APPROACH

To describe postdecommissioning impacts in terms of public health and safety, possible human-induced events and natural processes that could result in the long-term release of radionuclides and hazardous substances from the wastes resulting from decommissioning operations were identified and evaluated. Their potential impacts are reported. (The assessment of potential long-term impacts is presented in detail in Appendix G; pertinent results are summarized in this chapter.) Most potential natural events and human activities acting on or near the waste-disposal sites are not expected to significantly affect disposal-system performance. Some events, such as catastrophic floods associated with glaciation or a breach of Grand Coulee Dam, would in themselves create such an overwhelming environmental impact as to likely obliterate or obscure any impacts from released hazardous substances or radionuclides.

To evaluate bounding postdecommissioning impacts, it was assumed that the Hanford Site would be abandoned after 100 years (i.e., it was assumed that active institutional control cannot be relied upon to ensure safety from residual radionuclides or hazardous substances beyond 100 years). Abandonment of the Hanford Site was assumed for analysis and comparison purposes only and does not represent a present or projected plan. The DOE has no intention of terminating active management and surveillance of the Hanford Site.

5.1.1 Inventories

Quantities of radionuclides and hazardous substances considered in determining the environmental consequences reported in this chapter are presented in Appendix A.

5.1.2 Routine and Accidental Releases

Routine releases of radioactivity and public exposures were not analyzed for any alternative. Routine waterborne releases are unlikely because very little water will be used in decommissioning. Routine airborne releases are also unlikely because few areas to be demolished (except for the deferred dismantlement alternatives) are contaminated with radioactivity. Those areas that are contaminated will be demolished within contamination control envelopes.

Radiological accidents were analyzed for all alternatives considered. Radionuclide source terms for accident analyses were determined using the inventories provided in Appendix A, modified by appropriate delay times (decay) and by appropriate release fractions for the specific accident scenarios identified in the discussions for each decommissioning alternative.

Impacts of accidents involving hazardous materials have not been addressed because all hazardous materials (such as friable asbestos, mercury, polychlorinated biphenyls, cadmium, and contaminated and noncontaminated lead) except irradiated lead will have been removed from the decommissioning site and will have been either recycled, stored, or disposed of. No accident scenario involving irradiated lead was identified.

The accident analysis and dose evaluation included the following steps: 1) identify potential accidents and release mechanisms for each disposal/handling process, 2) determine accidents that could breach the radionuclide containment systems and provide a pathway of escape for the radionuclides to the biosphere, 3) estimate the fraction of radionuclides released, 4) calculate doses from the estimated releases using established models as described in Appendix E, and 5) consider significant mitigating factors. The key assumptions used in developing the accident scenarios, the release fractions

used in the accident analysis, and general considerations used in performing the dose calculations are described in subsequent sections.

The following accidents were analyzed, because they were considered to be the most credible, to result in the largest individual doses, and to bound the range of expected impacts:

- In the immediate one-piece removal and safe storage followed by deferred one-piece removal alternatives, it is postulated that the reactor block falls off the tractor-transporter, breaking the shielding, and releases powdered graphite, which is resuspended by wind action for 8 hours before recovery crews cover the block. (A small fraction of the graphite will be in the form of powder, caused by thermal expansion and contraction and by past removal of some of the metal channel liners that extend through the graphite block.) This scenario bounds a number of smaller radiological accidents that could occur during the transport of intact reactors or during the transport of dismantled reactor graphite in railcars in the safe storage followed by deferred dismantlement alternative.
- In the case of safe storage followed by deferred dismantlement, it is postulated that severe weather during the dismantlement of the reactor removes the roof and displaces the temporary confinement structure over the reactor building, resulting in a release of powdered graphite and subsequent suspension of the graphite powder by wind action.
- During transport of the dismantled reactor graphite blocks by railcar between the 100 Areas and the 200-West Area in the safe storage followed by deferred dismantlement alternative, it is postulated that a collision occurs at a railroad crossing with a vehicle transporting a flammable liquid such as gasoline. While the graphite would not burn, the impact results in powdered graphite being resuspended within the updraft caused by the fire.

No credible accidents resulting in the release of radioactive materials were identified for the no action and in situ decommissioning alternatives. Potential long-term environmental impacts for these two alternatives represent the bounding environmental impacts.

5.1.2.1 Downwind Transport and Dose Assessment Methods

The radiological impact on the general public from any of the potential accidents considered is dependent on the quantity and type of radioactive material released. The estimates of fractional airborne releases of radionuclides resulting from each of the accidents described are based on previously published data on common industrial accidents, including fires, explosions, and container ruptures.

Doses to the population and the maximally exposed individual were calculated for each accident scenario postulated to result in a significant release of radioactive material. The assumptions, models, and input parameters required for the calculation of the maximally exposed individual and population dose are described below.

Three accident scenarios were developed. The dose analysis considered only those resulting in a release of radioactive material to the offsite environment. The duration of a release during an accident can significantly affect the radiological consequences of the event. In this DEIS, all releases are postulated to be of short duration (about 8 hours). The short duration is postulated because of the presence onsite of firefighting crews and other emergency-response crews who would quickly bring the accident under control. Even with short-term (also known as acute) releases, the radionuclides can continue to expose the population long after the release has been terminated. For example, in a typical accident scenario, a cloud (or plume) of contaminated material is postulated to be released. As the plume travels offsite, members of the public may be exposed to radiation from the radionuclides contained in the cloud. If they inhale some of the radioactive material from the cloud as it passes, they will receive an additional exposure. If some of the radioactive material deposits on plants or on the ground, long-term exposure to people residing in the area can result. The standard method for evaluating the radiological impact of a release is to estimate the dose to the maximally exposed individual (the individual receiving the highest dose from the release) and to the entire exposed population as a whole. The doses are reported in rem for the maximally exposed individual, and in person-rem for the population. The dose calculated for the analysis of

operational accidents is the 50-year committed dose. The 50-year committed dose is calculated based on 1-year exposure to the material in the environment. For additional discussion of this topic, see Appendix E.

The computer programs used to calculate doses to the maximally exposed individual and to the regional population are discussed in Appendix E. The dose calculations rely on the use of meteorological data to estimate the manner in which radioactive material would most likely disperse following an accidental release to the atmosphere. Demographic data also play an important role in the calculation of radiation dose. It is the combination of meteorological and demographic information that indicates which population group would receive the highest exposure from radioactive releases. In the case of accidental releases from the 100 Areas of the Hanford Site, the population projected to receive the greatest exposure lives 16 to 80 kilometers southeast of the site. The population data used in the assessment of potential accidents and their dose consequences were obtained from Sommer et al. (1981).

To bound the consequences of an accident, the releases were assumed to be from the area closest to the Site boundary, 100-F, thereby maximizing the dose to the maximally exposed individual and the general public.

Data required for the dose programs include dietary and recreational preferences and habits in the general population, as well as agricultural practices in the general region. The standard Hanford Site terrestrial pathway data used as part of the dose calculations are given in Appendix E. Standardized input for Hanford Site environmental documentation is summarized by McCormack et al. (1984).

The potential radiation doses to the maximally exposed individual and the general public are given for the accident scenarios, where applicable, in the section describing the potential environmental impacts for each alternative considered.

5.1.2.2 Fire Consideration

The surplus production reactors in the 100 Areas are made of large blocks of graphite. A major fire involving the graphite is not considered to

be a credible scenario. The reactors in their current condition cannot be exposed to sufficient energy to cause the graphite itself to ignite. In two instances, fires were reported to have occurred in the graphite moderators of operating reactors; these reactors were Windscale No. 1, in October 1957, and Chernobyl No. 4, in April 1986. In both cases, however, combustion of the graphite was initiated after other reactions supplied sufficient energy to heat the graphite to very high temperatures. In the case of the Windscale incident, excessively rapid heating of the uranium fuel elements caused them to fail and catch fire (Committee of Inquiry 1957); temperatures as high as 1,300°C were measured in the reactor (and localized temperatures may have been higher). Several times during the course of the accident, air was circulated through the reactor; the air flow tended to cool the graphite, but led to increased discharge of fission products. Therefore, water was finally used to cool the reactor. At Chernobyl (MacLachlan 1986), the power-generation rate rapidly increased from 200 megawatts to over 20,000 megawatts (more than six times the design power), the fuel temperatures reached about 3,000°C, and the resultant steam explosion ruptured piping in the core. The exothermic steam-zirconium reaction (the pressure tubes and fuel cladding were a zirconium alloy) then heated the graphite to very high temperatures, with concurrent exposure to air. An estimate of 25% of the graphite was consumed in the following 2 days; however, it is not known if the graphite fire would have been self-sustaining, even under these extreme conditions. In the surplus production reactors, there are no credible sources for the energy needed to heat the graphite to the temperatures required to sustain combustion. Because no credible sources of sufficient energy can be postulated, a major fire in the graphite block of each of the surplus production reactors was not evaluated further. Smaller fires are discussed in appropriate sections below.

5.1.3 Supporting Material

Discussions of the modeling of radionuclide release and movement in the ground water beneath the Hanford Site and into the Columbia River are provided in Appendices C and D. Details of methods used for calculating radiation dose and conversion to health effects are given in Appendices E and F, respectively.

5.2 NO ACTION

Under the no action alternative as described in Section 3.1, the DOE would continue present action. This alternative includes continued surveillance, monitoring, and maintenance of the surplus Hanford production reactors, but does not include implementation of a long-term solution for permanent disposal of the contained radioactive materials. No mechanisms were identified for routine release of the surplus reactor-contained radionuclides offsite, and, therefore, no analyses were performed for operational radiological impacts to the offsite population.

Potential long-term environmental impacts are discussed in Section 5.7.

5.2.1 Radiological Consequences from Postulated Accidents

Accidents were considered for the no action (continue present action) alternative, but none were identified that would result in radiation doses to the offsite population. Therefore, no population doses were estimated for the no action case.

5.2.2 Ecological Impacts

Ecological impacts from the no action alternative would essentially be unchanged from present conditions.

5.3 IMMEDIATE ONE-PIECE REMOVAL

In the immediate one-piece removal alternative (described in Section 3.2), each surplus production reactor block and all other remaining contaminated materials, including any sludges associated with the reactor's fuel storage basin, would be removed from the 100 Areas and disposed of in a 200-West Area near-surface burial ground. No mechanisms were identified for routine release of radionuclides offsite, and, therefore, no analyses are provided for operational radiological impacts to the offsite population.

Potential long-term environmental impacts are discussed in Section 5.7.

5.3.1 Radiological Consequences from Postulated Accidents

Handling and transporting the surplus Hanford production reactors for immediate one-piece removal would create the possibility for accidents. Of

the possible accidents, only the block-drop accident was analyzed in detail because it is the accident involving resuspended graphite powder that would yield the largest potential radiological consequences.

The operations for one-piece removal of the reactor block from the reactor sites to the burial ground in the 200-West Area would involve securing the block on a tractor-transporter and moving it to the burial ground. In any of these steps, the block would be supported above ground with relatively little confinement other than the surrounding shielding. The potential exists for partial or total dropping of the block onto the ground.

As a maximally credible case, it is assumed that the reactor block drops, crushing one edge. About 1% of the total block volume (about 10 cubic meters) is assumed to be reduced to a fine powder. Of this, approximately 1% is assumed to be resuspended by wind action over 8 hours before recovery operations stabilize the material. These values are very conservative when compared with the values provided by the EPA (1976, 1977) for fugitive emissions from a number of industries in the United States. Because the outer edges of the block are not as highly contaminated (not as highly irradiated) as the center portions, a 10-to-1 peak-to-average ratio was used for the radionuclides contained in the graphite crushed by the drop. Therefore, to obtain the release fraction used in the dose calculations, these three factors (1%, 1%, and 10%) were multiplied to obtain a total quantity released of 1×10^{-5} of the graphite block inventory.

This scenario bounds a number of smaller radiological accidents that could occur during the transport of either the intact reactor blocks or other low-level radioactive wastes.

Table 5.1 provides estimated radiation dose commitments to the public from a postulated accident in which the reactor block falls off the transporter. The doses are presented for four possible times of occurrence: in winter, in spring, in summer or in autumn just before the harvest of most crops. The resultant doses can vary as a function of the time of the accident. This is because the radionuclides carbon-14 and tritium would behave as would natural carbon and water, reaching a peak value in the vegetation during the course of the accident, but being transpired back to

the atmosphere after the plume passes. In the autumn, it is assumed that the vegetation is harvested and stored before these processes occur, and the doses are thus maximized. The maximally exposed individual dose is around 80 millirem. The total projected maximum population dose is about 300 person-rem, or less than one health effect. This same population currently receives 90,000 person-rem annually from naturally occurring background radiation.

TABLE 5.1. Radiation Doses to the Public from a Transporter Accident (immediate one-piece removal)

Season of Occurrence	Maximally Exposed Individual Whole-Body Dose (rem)	Population Whole-Body Dose (person-rem)
Winter	2×10^{-3}	1×10^{1}
Spring	2×10^{-3}	1×10^{1}
Summer	4×10^{-3}	2×10^{1}
Autumn	8×10^{-2}	3×10^{2}

5.3.2 Ecological Impacts

Ecological impacts from the immediate one-piece removal alternative would be minimal because much of the area under consideration has already been disturbed as a result of radioactive waste management and other nuclear-energy-related activities. Disturbance of wildlife may occur locally as a result of intermittent blasting while preparing the 105 buildings for removal. However, the impact of these noises would be minimal (see Section 5.10.3) and would not cause permanent disruption to the wildlife using the area. Transport of the reactor blocks along the potential routes to the 200-West Area would result in minimal disturbance to plant and wildlife habitats. Many of these areas have already been disturbed from the original road construction. Additional temporary impacts on plants and wildlife may occur as a result of local excavation to obtain soil for backfilling the 100 Areas after removal of the surplus reactors. The present locations of

low-level radioactive waste burial grounds at the Hanford Site have already impacted their local environment, and additional impacts on plants and wildlife are expected to be minimal.

5.4 SAFE STORAGE FOLLOWED BY DEFERRED ONE-PIECE REMOVAL

Safe storage followed by deferred one-piece removal (described in Section 3.3) would involve the same disposal operations as those required for immediate one-piece removal, but these operations would be deferred by a safe-storage period of up to 75 years. The delay would allow radioactive decay of short- and intermediate-half-life radionuclides such as cobalt-60, thereby reducing both worker radiation exposure during disposal operations and the total radionuclide inventory in the material removed. Such a delay would, therefore, also mitigate the radiological impact to the general public resulting from potential accident scenarios.

No mechanisms were identified for routine release of radionuclides offsite, and, therefore, we performed no analyses of operational radiological impacts to the offsite population.

Potential long-term environmental impacts are discussed in Section 5.7.

5.4.1 Radiological Consequences from Postulated Accidents

Potential accidents for the safe storage followed by deferred one-piece removal alternative were analyzed. Only the potential dropped reactor block accident previously described in Section 5.3.1 was considered credible. This accident represents the bounding radiological impact to the general public for potential accident scenarios for this alternative. The estimated radiation doses to the public from the block-drop accident are given in Table 5.1; this estimate is considered conservative for the present alternative because it does not account for the reduced total radionuclide inventory resulting from radionuclide decay during the safe-storage period.

5.4.2 Ecological Impacts

Ecological impacts from the safe storage followed by deferred one-piece removal alternative would be minimal because much of the area under consideration has already been disturbed as a result of radioactive waste management

and other nuclear-energy-related activities. Temporary disturbance of wildlife may occur locally as a result of intermittent blasting while preparing the 105 buildings for decommissioning. However, the impact of the blasting would be minimal (see Section 5.10.3) and would not cause permanent disruption to the wildlife usage of the area. Additional temporary impacts on plants and wildlife may occur as a result of local excavation to obtain soil for backfilling the 100 Areas after removal of the surplus reactors. The present locations of low-level radioactive waste burial grounds at the Hanford Site have already impacted this local environment, and additional impacts on plants and wildlife are expected to be minimal.

5.5 SAFE STORAGE FOLLOWED BY DEFERRED DISMANTLEMENT

The safe storage followed by deferred dismantlement alternative (described in Section 3.4) entails piece-by-piece dismantlement of the reactors, following a delay period of up to 75 years. This delay permits radioactive decay of cobalt-60, the principal nuclide contributing to worker radiation exposure. The resultant low-level radioactive wastes would be disposed of in a 200-West Area near-surface burial ground. No mechanisms were identified for routine release of radionuclides offsite, and, therefore, no analyses of operational radiological impacts to the offsite population were performed.

Potential long-term environmental impacts are discussed in Section 5.7.

5.5.1 Radiological Consequences from Postulated Accidents

Handling and processing of the surplus Hanford production reactors for safe storage followed by deferred dismantlement would create the possibility for accidents. Of the accidents postulated for this alternative, a severe weather accident during dismantlement and a railcar accident, involving fire, during transport of radioactive wastes to the burial ground were determined to have the largest potential radiological consequences.

5.5.1.1 Severe Weather

The stepwise dismantling of the reactor blocks would normally occur within temporary confinement structures located inside the reactor building. The impacts of minor failures of the temporary confinement structures are

bounded by a scenario that results in severe damage to the building. A severe storm is postulated to damage the building roof during the dismantling operation and breach the temporary confinement structure.

A total cross section of the reactor is assumed to be exposed (i.e., one layer of the graphite, or approximately 1% of the core). The graphite blocks are hard and have high compressive strength; however, portions may be oxidized, and portions may have been converted to powder from abrasion. It was assumed that dismantlement of the reactor block would generate graphite powder. Accumulations of up to 1% of the exposed graphite as powders are assumed. If the wind is assumed to suspend 1% of the powder before controls could be reapplied, a release fraction of 1×10^{-6} of the total core inventory following 75 years of decay could result.

5.5.1.2 Railcar Accident

Transport of decommissioning wastes to the 200-West Area burial ground would require about 226 truck shipments of concrete rubble and contaminated equipment, and 58 railcar loads of reactor internals per reactor for B, C, D, DR, F, and H Reactors, and about 226 truck shipments and 92 railcar shipments per reactor for the KE and KW Reactors (see Tables 3.10 and 3.11, respectively). Of these, the highest concentrations of potentially environmentally mobile radionuclides would be in the rail shipments of reactor graphite. An accident where there is a collision at a railroad crossing between a railcar containing reactor graphite and a vehicle carrying a flammable liquid (e.g., gasoline) followed by a 30-minute fire, bounds the radiological impacts of potential transportation-related accidents for this alternative.

About 3% of the total graphite in a reactor would be involved in any single shipment. Assuming a 10-to-1 peak-to-average ratio, as much as 30% of the 75-year decayed radionuclide inventory of one reactor block could be in a single railcar. Impact forces caused by the accident are assumed to crush 1% of the shipment into a fine powder. Resuspension of 1% of the powder during the fire (ANSI N46.1, 1980) results in a release fraction of about 3×10^{-5} of the total reactor inventory (1×10^{-4} of the railcar inventory).

5.5.1.3 Radiation Doses

The projected radiation doses to the public from these postulated accidents are summarized in Table 5.2. The total projected 50-year population dose from the most severe accident (railcar) amounts to 800 person-rem, or less than one health effect. This same population currently receives 90,000 person-rem annually from naturally occurring background radiation.

TABLE 5.2. Radiation Doses to the Public from Postulated Accidents During Deferred Dismantlement

Accident Description	Season of Occurrence	Maximally Exposed Individual Whole-Body Dose (rem)	Population Whole-Body Dose (person-rem)
Severe weather blowing roof off of reactor building while core is uncovered during dismantling	Winter	2×10^{-4}	1×10^{0}
	Spring	2×10^{-4}	1×10^{0}
	Summer	4×10^{-4}	2×10^{0}
	Autumn	8×10^{-3}	3×10^{1}
Onsite transportation accident with fire involving a railcar full of reactor parts	Winter	6×10^{-3}	3×10^{1}
	Spring	8×10^{-3}	4×10^{1}
	Summer	1×10^{-2}	5×10^{1}
	Autumn	2×10^{-1}	8×10^{2}

5.5.2 Ecological Impacts

Ecological impacts from the safe storage followed by deferred dismantlement alternative would be minimal because much of the area under consideration has already been disturbed as a result of radioactive waste management and other nuclear-energy-related activities. Disturbance of wildlife may occur locally from intermittent blasting while preparing the 105 buildings for decommissioning. However, the impact of these noises would be minimal (see Section 5.10.3) and would not cause permanent disruption to the wildlife using the area. Additional temporary impacts on plants and wildlife may occur as a result of local excavation to obtain soil for backfilling the 100 Areas after removal of the surplus reactors. The present low-level radioactive waste burial grounds at the Hanford Site have already impacted the local environment. Additional impacts on plants and wildlife are expected to be minimal.

5.6 IN SITU DECOMMISSIONING

Disposal of the surplus Hanford production reactors by in situ decommissioning involves sealing the reactor blocks in place and covering them with a mound of earth and gravel, as described in Section 3.5. The mound is intended to inhibit intrusion by humans and to discourage farming, dwelling, or other human uses of the areas above or near the sites. While the mound may not prevent burrowing animals from reaching a reactor block, the biological shields would prevent burrowing animals from reaching the radioactive interior of the block. No mechanisms were identified for routine release of radionuclides offsite, and, therefore, no analyses of operational radiological impacts to the offsite population were performed.

Potential long-term environmental impacts are discussed in Section 5.7.

5.6.1 Radiological Consequences from Postulated Accidents

Potential accidents were considered for the in situ decommissioning alternative, but no credible scenarios were noted that could release portions of the radionuclide inventory that remains essentially undisturbed within the reactor blocks. Hence, no radiation doses to the public from potential accidents are projected for the in situ decommissioning alternative.

5.6.2 Ecological Impacts

Disturbance of wildlife may occur locally as a result of intermittent blasting while preparing the 105 buildings and quarrying for earth and gravel. However, the impact of these noises would be minimal (see Section 5.10.3) and would not cause permanent disruption to the wildlife using the area. The construction requirement with the greatest ecological impact is the need for fill materials (earth and gravel) for the mounds. Preoperational surveys of the fill material sites for archaeological resources and endangered plant and animal species would be conducted. The surplus production reactor sites at Hanford have already impacted their local environment, and additional impacts from in situ decommissioning on plants and wildlife would, therefore, be minimal.

5.7 ASSESSMENT OF LONG-TERM IMPACTS

Although the DOE plans to maintain active institutional control of the Hanford Site, abandonment after 100 years was assumed for population dose estimates. This is in accord with the philosophy expressed by the EPA in 40 CFR 191 that active institutional control after 100 years cannot be relied upon for control of residual radionuclides. With this fundamental loss-of-control assumption, scenarios were developed involving a limited number of intruders who could drill, excavate, examine, and/or conduct salvage operations at the alternative burial locations. Further, it was postulated that people would construct homes, drill wells, grow gardens, and farm on or near the burial locations, which maximizes the postulated population exposure to ionizing radiation. Finally, for offsite impacts, the population residing between the Hanford Site and the mouth of the Columbia River was estimated to grow to 5 million over the next 10,000 years, representing a total of 410 million affected individuals over the 10,000-year period (see Appendix G).

The analysis in this section draws upon the descriptions of the surplus production reactors in Appendix A and decommissioning alternatives in Chapter 3.0, and upon analyses of radiological consequences presented in Appendix G. Other appendices are referred to as needed, such as Appendix C (hydrologic modeling of the ground-water pathway), and Appendix D (description of modeling of release rates of radionuclides).

Key findings of the long-term impacts assessment are as follows:

- The major pathway for radionuclides and chemicals to the affected environment is via ground water.
- For wastes disposed of near the surface on the Hanford Site, the consequences to the offsite population are negligible compared with consequences from naturally occurring radiation sources. This holds true for all scenarios for any of the decommissioning alternatives and also for the no action alternative. Individual doses, however, to persons who drill wells near the waste sites and who

use the water for drinking and/or irrigation of small family farms can exceed existing drinking-water standards for community water systems.

- Intruder scenarios, developed for the case where only passive institutional controls exist for each of the decommissioning alternatives considered and where no active institutional controls exist for the no action alternative after 100 years, indicate significant adverse consequences to those who ignore warnings and intrude into the wastes for all alternatives considered. The likelihood of intrusion is considered highest in the no action alternative, after the loss of active institutional control.
- Some events, such as catastrophic floods, would in themselves have such an overwhelming environmental impact as to obliterate or obscure any impact from waste they might release.

5.7.1 Long-Term Consequences of Waste Migration

This section presents the long-term impacts associated with each decommissioning alternative. The expected impact of each alternative is presented where the disposal systems perform as predicted under present climatic conditions and without human-induced or other disruption.

The initial radionuclide inventories for the long-term consequences analyses for the no action and in situ decommissioning alternatives are those shown in Appendix A. The initial radionuclide inventories for the deferred decommissioning alternatives are those shown in Appendix A decayed to the year 2060 (allowing for 75 years of safe storage). The inventories of lead used for the long-term consequences analyses for all the alternatives are those presented in Appendix A.

The reactor waste sites in both the 100 and the 200 Areas will include protective barriers. Such protective barriers are designed to minimize water infiltration into the wastes. However, over the long time periods of interest in this analysis (chemicals do not decay and reduce their potential hazards as a function of time), the efficacy of such a system is uncertain. Thus, for these analyses, the barrier is assumed to permit a limited amount

of water infiltration and leachate transport. The limits of barrier function are not well defined. The practical limits at which infiltration rates can be measured are about 0.1 centimeter per year (DOE 1987, Appendix M). Thus, this infiltration rate was used in the analyses. This infiltration rate supplies the water that is available to react with (or leach) the waste form and to move the chemicals or radionuclides downward to the water table.

Water infiltrating through wastes below ground will generally cause the slow dissolution or release of contained materials. The rates of the dissolution or release are important to the calculation of impacts. The dissolution/release rates used in this analysis are discussed in Appendices C and D of this DEIS. Laboratory experiments were performed to verify the assumptions used on the release rates (see Section D.1).

The long times involved necessitate the postulation of future climates at the Hanford Site, and the assumption that all artificial recharge from cribs, ponds, and trenches has ceased. To bound the different water-table cases, we used two ground-water recharge rates: 0.5 centimeter per year, representing continuation of a dry climate, and 5 centimeters per year, representing a wetter climate. These recharge rates supply the water that determines the water-table elevation and the rate of horizontal ground-water flow.

Impacts are assessed as radionuclides and chemicals enter the biosphere and are released to both ground water and surface water.

5.7.1.1 Dose from Radionuclides in Ground Water

If precipitation were to infiltrate through the protective barrier and into a waste form, it could cause radionuclides and chemicals to move slowly downward from the waste site. Wastes could then migrate through the vadose zone and into the ground water. (See Appendices C and D for more information.) For the assumed case that loss of active institutional control occurs and the Hanford Site is used for other purposes, potential impacts on individuals using the water were analyzed. The maximum radiation doses are predicted to result from the full-garden scenario for well water (see Section G.1.3.2 of Appendix G). These maximum values are presented in

Table 5.3, as well as those resulting from drinking water and Columbia River pathways (Sections G.1.3.1 and G.1.3.3, respectively).

The rate of waste migration and the resulting radionuclide and chemical concentrations are dependent on the infiltration rate through the protective barrier (assumed 0.1 centimeter per year) and on climatic conditions. Considerable uncertainty exists in predicting future climatic conditions; hence, a bounding range of ground-water recharge rates was analyzed. Impacts are reported for two ground-water recharge extremes: 0.5 and 5 centimeters per year for the 200-Area Plateau. In some instances, the 5-centimeter-per-year recharge case produced a smaller dose than the 0.5-centimeter-per-year recharge case because of larger dilution in the aquifer as a result of the increased recharge. For the 100 Area alternatives, there is no difference in dose between the two recharge rates.

No Action. Long-term radiological impacts from this alternative were assessed at a well located between a reactor site and the Columbia River. The well was assumed to pick up all of the contaminated fluid leached from the source and to mix with enough ground water to irrigate the garden for the full-garden scenario in the radionuclide food pathway analysis. In this scenario, an individual who consumes water derived from the well location and consumes the food grown is predicted to receive a lifetime dose of 2.5×10^3 rem. This predicted maximum dose occurs at 140 years following loss of institutional controls and is dominated by the radionuclides cobalt-60 and strontium-90.

Immediate One-Piece Removal. Long-term radiological impacts from this alternative were assessed at a well located 5 kilometers from the 200-West Area disposal site. An individual in the full-garden scenario at this site would receive a lifetime dose of 9.5×10^1 rem. This maximum dose would occur at 6,160 years following disposal and is dominated by chlorine-36. An individual lifetime dose from natural background radiation would be about 21 rem (0.3 rem per year for 70 years).

TABLE 5.3. Summary of Maximum Radiation Doses from Calculated Ground-Water and Columbia River Radionuclide Concentrations (from Appendix G)

Scenario[a]	Maximum Individual Whole-Body Dose (rem)	Time (yr after disposal)	Dominant Radionuclide	10,000-yr Integrated Population Whole-Body Dose (person-rem)	Dominant Radionuclide
No Action Alternative					
Drinking water from well (Tables G.5, G.6):					
Annual	1.2×10^{0}	140	^{241}Am, ^{60}Co	--	--
Lifetime	8.2×10^{1}	140	^{241}Am, ^{60}Co	--	--
Full-garden scenario for well water (Table G.13, G.14):					
Annual	3.5×10^{1}	140	^{60}Co, ^{90}Sr	--	--
Lifetime	2.5×10^{3}	140	^{60}Co, ^{90}Sr	--	--
Average individual[b] Columbia River pathways (Tables G.20)	2.4×10^{-4}	2,590	^{41}Ca	5.0×10^{4}	^{41}Ca
Immediate One-Piece Removal, Deferred One-Piece Removal, and Deferred Dismantlement Alternatives, 0.5 cm/yr Recharge					
Drinking water from 5-km well (Tables G.1, G.2):					
Annual	5.0×10^{-1}	6,090	^{14}C	--	--
Lifetime	3.5×10^{1}	6,090	^{14}C	--	--
Full-garden scenario for well water at 5 km (Tables G.9, G.10):					
Annual	1.4×10^{0}	6,160	^{36}Cl	--	--
Lifetime	9.5×10^{1}	6,160	^{36}Cl	--	--
Average individual[b] Columbia River pathways (Table G.17)	1.1×10^{-5}	8,470	^{36}Cl	1.9×10^{3}	^{14}C, ^{36}Cl
In Situ Decommissioning Alternative					
Drinking water from well (Tables G.3, G.4):					
Annual	3.0×10^{-2}	1,120	^{14}C	--	--
Lifetime	2.1×10^{0}	1,120	^{14}C	--	--
Full-garden scenario for well water (Tables G.11, G.12):					
Annual	4.6×10^{-1}	1,120	^{14}C, ^{36}Cl	--	--
Lifetime	3.2×10^{1}	1,120	^{14}C, ^{36}Cl	--	--
Average individual[b] Columbia River pathways (Table G.19)	2.2×10^{-5}	3,430	^{14}C	4.7×10^{3}	^{14}C

Note: Doses are given for the 100 Area site (out of 6) that would result in the highest doses.
(a) Annual = individual maximum potential 1-yr radiation dose;
Lifetime = individual maximum potential 70-yr radiation dose.
(b) Average individual = average downriver individual, lifetime dose during peak release period.

Safe Storage Followed by Deferred One-Piece Removal. The predicted long-term radiological impacts of this alternative are the same as those predicted for the immediate one-piece removal alternative.

Safe Storage Followed by Deferred Dismantlement. The predicted long-term radiological impacts of this alternative are the same as those predicted for the immediate one-piece removal alternative.

In Situ Decommissioning. Predicted long-term radiological impacts of ground-water contamination for this alternative under the full-garden scenario are that an individual would receive a lifetime dose of 3.2×10^1 rem. This maximum dose would occur 1,120 years after disposal and is dominated by carbon-14 and chlorine-36.

5.7.1.2 Chemical Contamination of Ground Water

A hazardous substance that would be disposed of in conjunction with disposal of the low-level radioactive wastes resulting from the decommissioning alternatives is nonremovable, irradiated lead imbedded in the thermal shield of each reactor block. The largest inventory of lead is in the K Reactors, each with about 110 tonnes. The smaller reactors each contain about 73 tonnes of lead. In the no action alternative, the reactors would contain somewhat larger quantities of lead and small quantities of cadmium (see Appendix A).

The water that is assumed to percolate throughout the waste site is also assumed to reach a solubility-limited lead concentration of 0.29 milligram per liter (based on the expected solubility-controlling mineral cerussite, $PbCO_3$, the most soluble lead compound in Hanford ground water; metallic lead itself has a very low solubility in water). The transport of the lead by the ground water would be very slow; the concept of solubility-limited transport is that an equilibrium has been established throughout the soil column from the source to the ground water. The travel time of the water itself from the waste form will vary from between about 200 to 900 years for disposal in the 100 Areas to about 4,200 years for disposal in the 200-West Area (see Appendix C). The time required to reach the solubility-limited transport concentration will be significantly longer than these times. A simple estimate of the travel time of the lead to the ground water may be made on the basis of

retardation of the lead migration by a fixed distribution coefficient (K_d) of between 200 and 2,000 milliliters per gram (Baes et al. 1985; EPA 1985a; Singh and Sekhon 1977). The peak concentrations predicted would not occur for between 200 thousand and 10 million years for disposal in the 100 Areas, or between 4.5 million and 45 million years for disposal in the 200-West Area. While the transport time could vary from these simple estimates because of changes in soil pH or recharge rates over long periods of time, they serve to show that lead migration would be very slow.

Assuming that the leachate water then mixes with and is diluted by the regional ground-water system, maximum future ground-water concentrations of lead can be predicted. For the reactors disposed of in the 200-West Area (the one-piece removal and the dismantlement alternatives), the maximum calculated concentration of lead at a well located 5 kilometers away and based on a 0.5-centimeter-per-year ground-water recharge rate is predicted to be 4.9×10^{-4} milligrams per liter. An average ground-water recharge rate of 5 centimeters per year results in a predicted lead concentration of 2×10^{-4} milligrams per liter at the same location. The no action and in situ decommissioning alternatives result in predicted lead concentrations of 6×10^{-4} and 1.2×10^{-4} milligrams per liter, respectively, in a well located between the in situ decommissioning site and the Columbia River.

For the no action alternative, the inventories of lead are somewhat larger than for the other alternatives. However, because the release of lead to ground water is controlled by the solubility of lead in the leachate, the release rate would not be increased. The time over which the lead could result in contamination of the ground water would increase in proportion to the increased inventory.

Also for the no action alternative, three of the reactors (B, F, and H) would contain small quantities (32 kilograms) of metallic cadmium. The release and transport of cadmium is similar to that described for the lead (with which it is associated). The solubility limit for cadmium in Hanford ground water is 0.01 milligram per liter (in a chemical form similar to that

of the lead). The release of the cadmium could result in ground-water concentrations of about 2×10^{-5} milligrams per liter in a well located between the reactors and the river.

5.7.1.3 Dose from Radionuclides in River Water

Radionuclide concentrations in Columbia River water and doses are discussed in this section (see Table 5.3); chemical concentrations are discussed in Section 5.7.1.5.

No Action. The radiological impacts of the no action (continue present action) alternative are predicted to result in a maximum total-body radiation dose of 2.4×10^{-4} rem to an individual living along the Columbia River downstream from the reactor sites. The 10,000-year, integrated population total-body dose is predicted to be 5×10^{4} person-rem, which would be expected to produce fewer than 50 health effects.

Immediate One-Piece Removal. Migration of radioactive wastes from the 200-West Areas to the Columbia River is predicted to result in a maximum lifetime dose of 1.1×10^{-5} rem to an individual living on the river. This is equivalent to less than 2 hours of natural background radiation. The impacts to the affected human population over 10,000 years are calculated to be 1,900 person-rem, which would be expected to produce fewer than two health effects. This compares with 9 billion person-rem to the same population (410 million affected individuals) from natural background radiation (900 thousand to 9 million health effects).

Safe Storage Followed by Deferred One-Piece Removal. The radiological impacts for this alternative are the same as those for the immediate one-piece removal alternative.

Safe Storage Followed by Deferred Dismantlement. Radiological impacts for this alternative are the same as those for the immediate one-piece removal and safe storage followed by deferred one-piece removal alternatives.

In Situ Decommissioning. In this alternative, the reactors would remain in the 100 Areas, close to the Columbia River. Transport of radionuclides to the river is predicted to result in a maximally exposed individual lifetime dose of 2.2×10^{-5} rem. This dose is less than an individual would

receive from 2 hours of exposure to natural background radiation. Over 10,000 years, the cumulative dose downstream from the reactor site would be 4,700 person-rem, which would be expected to produce fewer than five health effects. Again, this can be compared to 9 billion person-rem to the same population (410 million affected individuals) from natural background radiation (900 thousand to 9 million health effects).

Total Health Effects. Table 5.4 presents the predicted health effects over the next 10,000 years, based on the doses reported in the previous discussion and from Appendix G. Health effects are based on projections outlined in Appendix F. Values of less than one effect may be considered to be the probabilities of one effect.

TABLE 5.4. Estimated Total Health Effects over 10,000 Years to the Downriver Population from Each Alternative

Alternative	Total Estimated Health Effects[a]
No action	5 - 50
Immediate one-piece removal	0.2 - 2
Safe storage followed by deferred one-piece removal	0.2 - 2
Safe storage followed by deferred dismantlement	0.2 - 2
In situ decommissioning	0.5 - 5

(a) Based on a range of 100 to 1,000 health effects per 10^6 person-rem. See Appendix F for details.

It can be seen from Table 5.4 that no alternative is predicted to produce a significant number of health effects. Natural background radiation over the next 10,000 years is estimated to produce from 900 thousand to 9 million health effects to the downstream population.

5.7.1.4 Global Impacts of Carbon-14

Carbon-14 is formed naturally in the upper atmosphere by reaction of neutrons of cosmic-ray origin with nitrogen and, to a lesser extent, with oxygen and carbon. Carbon-14 has also been released to the atmosphere as a

result of nuclear weapons testing. The average specific activity of carbon-14 in the atmosphere from production by cosmic rays is about 6 picocuries of carbon-14 per gram of carbon, corresponding to an atmospheric inventory of 3.8 megacuries. About 9.6 megacuries of carbon-14 is estimated to have been injected into the atmosphere by weapons tests.

In addition, all nuclear reactors produce carbon-14 from capture of neutrons by nitrogen, carbon, or oxygen present as components of the fuel, moderator, structural hardware, or as impurities. Most of the carbon-14 formed in the coolant and moderator of light-water reactors and in the deuterium oxide moderator and annulus gas of heavy-water reactors will be converted to a gaseous form and will be released from the reactor site (NCRP 1985). The emission of carbon-14 from each United States commercial nuclear power reactor averages about 7.5 to 9.5 curies per year (Davis 1977).

The total atmospheric inventory of carbon-14 currently contributes less than 1% of the average annual total-body dose of 300 millirem resulting from natural background radiation.

However, unlike the other radionuclides and chemical elements considered in these analyses, carbon constitutes a significant fraction of the elemental composition of the human body and human diet. Thus, transport processes through the different environmental pathways and within plants, animals, and humans that apply to trace quantities of other radionuclides, where the corresponding stable elements are present in such quantities that saturation effects are significant, do not necessarily apply to radionuclides such as carbon-14 (EPA 1985b).

For global impacts of carbon-14, a factor of from 6.3×10^{-2} to 6.3×10^{-1} fatal cancers per curie of carbon-14 released to the environment may be used (see Section E.2.5 of Appendix E). These values yield a predicted global impact of 2,400 to 24,000 fatal cancers over the next 10,000 years if the entire inventory of all the carbon-14 contained in Hanford surplus production reactors is assumed to be released to the accessible environment over a short period of time. However, the release mechanisms for carbon-14 that have been identified are slow, constant processes, and the impacts from these releases would be distributed over a

period of about 23,000 years (see Appendix C). The global impacts would be the same for all alternatives and approximately the same as for the more rapid release rate.

For comparison purposes, one can estimate the total number of fatal cancers from all causes in the United States and worldwide, and compare these estimates to the scenario presented above. Given constant population size and the 1986 United States cancer fatality rate (American Cancer Society 1987), 4 billion cancer fatalities will occur in the United States over the next 10,000 years. Using the same cancer-fatality rate and a constant world population of 4.2 billion leads to an estimate of 170 billion cancer fatalities worldwide over the next 10,000 years, a number which greatly exceeds that predicted on the basis of the release of the total carbon-14 inventory contained in the Hanford surplus production reactors.

5.7.1.5 Chemical Contamination of the Columbia River

As chemicals enter the ground water on the Hanford Site, their ultimate destination is the Columbia River. Concentrations of lead in river water from the reactor decommissioning wastes were evaluated. For wastes buried in the 100 or 200 Areas, the maximum concentration of lead would be 2×10^{-10} milligrams per liter of river water. As described in Section 5.7.1.2, this would not be expected to occur for many thousands of years.

Also as described in Section 5.7.1.2 under the no action alternative, three of the reactors (B, F, and H) would contain small quantities of metallic cadmium. Release of this cadmium via ground water could result in concentrations in the Columbia River of around 1×10^{-11} milligram per liter.

5.7.2 Consequences of Postulated Human Disruptive Events

Postulated human-induced events that might disrupt the disposed wastes were analyzed for each alternative. These events are identified in Appendix G. Not all postulated events are credible for all of the decommissioning alternatives. This is because the disposal actions differ for each alternative; thus, some intrusion scenarios are not possible and were not analyzed. Only the bounding scenario for each alternative is presented here. Radiation doses are summarized in Table 5.5.

TABLE 5.5. Summary of Radiation Doses from Human Activities Postdecommissioning (from Appendix G)

Scenario/Time	Whole-Body Dose (rem/yr)
Immediate One-Piece Removal and Deferred One-Piece Removal and Dismantlement Alternatives	
Well-drilling (Table G.22):	
100 yr	5×10^{-3}
1,000 yr	2×10^{-3}
Excavation (Table G.23):	
100 yr	5×10^{-1}
1,000 yr	3×10^{-1}
Residence and garden on burial site (Table G.27):	
100 yr	2×10^{1}
1,000 yr	2×10^{1}
Residence and garden, postdrilling (Table G.28):	
100 yr	2×10^{0}
1,000 yr	2×10^{0}
In Situ Decommissioning and No Action Alternatives	
Deliberate intruder--salvage or archaeology (Table G.25):	
100 yr	1×10^{1}
1,000 yr	8×10^{0}
Casual intruder (Table G.26):	
100 yr	6×10^{-2}
1,000 yr	4×10^{-2}

The EPA's philosophy, as expressed in 40 CFR 191, is that active institutional controls are not to be relied on for environmental protection for more than 100 years after disposal. Thus, passive institutional controls such as covers, markers, and public records are the only mechanisms to inhibit intrusion onto the Hanford Site and into waste sites after 100 years. The intruder scenarios used are based on the 100-year assumption and should be viewed as speculative, highly unlikely scenarios. The risks associated with them should be viewed in the same context. Federal ownership and presence on the Hanford Site is planned to be continuous.

There is little likelihood for the intruder scenarios to result in the offsite population becoming exposed to significant quantities of radiation. Rather, the dose is received by only the intruder(s) and, in some cases, by the intruder's family.

The intrusion scenarios analyzed (Appendix G) include the following:

- exploratory drilling that penetrates a waste disposal site and brings contaminated drilling mud to the surface, resulting in radiation exposure of the drilling crew
- the preceding drilling scenario, followed soon by individuals residing on or near the contaminated drilling mud and consuming garden produce raised in the contaminated soil
- excavation activity such as constructing a basement for a home (radiation exposure is calculated for the worker excavating the waste)
- deliberate intrusion such as activity associated with an archaeologist or salvager
- casual intrusion that involves a person discovering the disposal site and then leaving the site
- a home-garden scenario where a person resides over the inactive disposal site.

The inventory used for the analysis represents the maximum inventory for a single reactor. This maximum inventory from Appendix A for the KE Reactor was used for all intrusion scenarios (except the home-garden scenario, which uses the inventories of all the reactors).

No Action. If the reactors were to be left in their current state, they might attract salvagers. Doses similar to those presented in the in situ decommissioning alternative would apply to this alternative.

Immediate One-Piece Removal. Following loss of active institutional control of the Hanford Site, it is postulated that individuals may move onto the disposal site. In the immediate one-piece removal alternative, the

highest dose results from farming activities at this site. This habitation scenario is predicted to result in a total-body dose of 20 rem per year at 100 years to this individual.

Safe Storage Followed by Deferred One-Piece Removal. The predicted radiological impacts of this alternative are the same as those for the immediate one-piece removal alternative.

Safe Storage Followed by Deferred Dismantlement. The intrusion impacts for this alternative are the same as for the immediate one-piece removal and safe storage followed by deferred one-piece removal alternatives. This results from similar disposal in the 200-West Areas of the Hanford Site.

In Situ Decommissioning. The largest predicted radiation dose for this alternative results from the activities of a deliberate intruder (e.g., an archaeologist or salvager). For bounding purposes, it is assumed that the in situ mound presents a peculiar land form that might invite investigation. This intentional intruder is postulated to dismantle a portion of the reactor and is predicted to receive a dose of 10 rem per year at 100 years after disposal (see Section G.4 for assumptions used in predicting doses).

Impacts of Human Disruptive Events on Ground-Water Releases. For each of the disposal alternatives, a barrier would be constructed to preclude moisture infiltration. Should this barrier be disrupted by human activities, the potential exists for increased water infiltration over a portion of the wastes. This could result in enhanced transport of materials under the barrier to the ground water. Because the release of the major constituents (carbon-14, lead) are controlled by release rate and solubility constraints, the consequences of such disruptive events are bounded by the calculated consequences of the no action alternative. Radionuclide and lead concentrations could range from the values indicated for each disposal alternative to as high as those shown for the no action alternative, as presented in Section 5.7.1. The degree of barrier degradation would control the amount of recharge reaching the waste. In no case could results exceed those of the no action alternative, because essentially all of the available natural precipitation is used in the no action analyses.

5.7.3 Natural Disruptive Events

We postulated numerous natural events that might have an impact on the disposal of the reactors. Events such as a returning ice age or volcanic and seismic activity are expected to produce large impacts of their own that would overshadow the release of radionuclides from Hanford.

The Hanford Site is located in a Zone 2 area (U.S. seismic risk area), as defined by the U.S. Coast and Geodetic Survey (ERDA 1975), where moderate damage might occur from earthquakes. The largest historical earthquake to occur within the Columbia Basin, the 1936 Milton-Freewater earthquake, had an intensity of VII on the Modified Mercalli Scale. The Modified Mercalli Scale is a qualitative description of damage that might occur in an earthquake. An intensity of VII would cause moderate damage to unreinforced structures. The largest potential fault near Hanford is the postulated Rattlesnake-Wallula lineament, which is located at the southeast end of the Rattlesnake Hills and about 24 kilometers from the 100-B and C Areas, which are the closest reactor areas to the fault. A detailed seismic analysis of the consequences of an earthquake equivalent in intensity to the largest historical earthquake to occur in the Columbia Basin has not been conducted. However, the radiological consequences to the public of such an earthquake are not expected to exceed those of other accidental releases previously discussed.

Although it is reasonable to expect that the total failure of Grand Coulee Dam is in the realm of incredible, to assess the consequences if a portion of the dam failed, a scenario was postulated in which a 50% dam failure occurs, resulting in high river flows in the Hanford reach of the Columbia River. River elevations and flow velocities from this scenario would not impact either waste buried in the 200-West Area, or riprap-protected reactors in the 100 Areas (see Appendix H). It is also not likely that the volume of water from this short-duration flood would be sufficient to undermine any reactor. However, it can be postulated that climatic changes could alter the flow of the Columbia River, resulting in the erosion of the present river banks and the immersion of a reactor in the river from erosion under the reactor. For the no action and in situ decommissioning

alternatives, the dose from this event to the downstream population over the next 10,000 years from immersion of a single reactor in the Columbia River would be about 6,200 person-rem (see Section G.7 of Appendix G).

The elevation of the dam-regulated probable maximum flood will reach the elevation of the bottom of the H and F fuel storage basins. Any downriver population dose would, however, be a small fraction of the 6,200 person-rem estimated for complete immersion of one reactor, in approximate ratio to the radionuclide inventories presented in Appendix A.

Severe weather, such as tornados, might impact the actual disposal activities. Accidents of this type have been addressed earlier in this chapter. Once the reactors have been disposed of, severe weather would not impact the wastes.

5.8 SOCIOECONOMIC IMPACTS

Socioeconomic impacts are influenced primarily by the number and scheduling of workers required for each alternative. The timetable and work force estimates for the operations to implement each alternative are given in Chapter 3.0. The size of the projected work force at any given time for any one of the alternatives is estimated at about 100 (see Section 4.6), which is small compared to the present work force of about 13,000 persons currently employed on DOE-related projects at the Hanford Site. If all workers in-migrate and bring two dependents, this activity could increase the Tri-Cities area population by as many as 300 persons, or approximately 0.4%. The impacts on the Tri-Cities area from a 0.4% population increase would be negligible; increases of less than 5% of the present labor force have been determined to have little effect on an existing community (U.S. Department of Housing and Urban Development 1976). Many of the decommissioning jobs would likely be filled by existing staff, or from the unemployed work force of the area (7.8% in September 1985). Hence, actual population increases are expected to be less than this amount. Decommissioning of the surplus production reactors on the Hanford Site would not have a significant impact on employment, population, community services, housing, local transportation, education, utilities, or other services.

5.9 IRREVERSIBLE AND IRRETRIEVABLE COMMITMENT OF RESOURCES

The major irreversible and irretrievable commitment of resources to the decommissioning of the Hanford surplus production reactors include 1) the land on which the reactors are presently located if in situ decommissioning is chosen; 2) the land required for low-level waste disposal if either immediate one-piece removal, safe storage followed by deferred one-piece removal, or safe storage followed by deferred dismantlement is chosen; and 3) grout and fill material. These and other required resources are discussed in the next four subsections.

5.9.1 Materials

Each decommissioning alternative, except the no action alternative, would require fill material at each surplus production reactor site. The in situ decommissioning alternative would require the greatest quantity of fill material (estimated to require 1,600,000 cubic meters). The fill material would be obtained from excavations on the Hanford Site, and its excavation and use would not significantly impact current Hanford Site land usage.

Concrete in the amount of 6,000 cubic meters would be required for support of the reactor blocks in the 200-West Area low-level waste burial ground if either the immediate one-piece removal or the safe storage followed by deferred one-piece removal alternatives were selected. The in situ decommissioning alternative would require an extensive amount of grout, approximately 98,000 cubic meters, if it were selected. The amount of grout required for the in situ decommissioning alternative is equivalent to the amount of concrete in several miles of interstate highway. However, concrete requirements for recent interstate highway construction in the local and regional area were easily met without major impact. Thus, concrete and grout requirements could also be met without significant impact on area resources.

Construction of the tractor-transporters required for either of the one-piece removal alternatives would not require any materials in short supply. The tractor-transporters would be available for other large construction jobs following their use in the decommissioning effort, but their

use on other subsequent projects is not ensured. If no additional use were identified, the tractor-transporters would be sold as surplus or for scrap material recovery.

Numerous expendable materials would either be consumed during the decommissioning operations or would become radioactively contaminated and require disposal as low-level waste. Such materials include protective clothing, material for contamination control envelopes and temporary confinement structures, some tools, explosives for removing portions of structures, materials for waste-disposal containers, and liners and barriers in the low-level burial ground or present reactor sites. None of these materials are in short supply and they do not represent a substantial commitment of resources; the quantities required would have no significant effect on local or national supplies.

5.9.2 Energy

Most of the energy resources needed for the decommissioning of the surplus production reactors will be in the form of gasoline and diesel fuel. Gasoline or diesel oil would be used for truck or rail transport of radioactive waste, for one-piece removal of the reactor blocks on tractor-transporters, or for excavation and placement of fill material. Approximately 6 million, 2 million, and 5 million liters of fuel would be consumed for one-piece removal, dismantlement, and in situ disposal, respectively. Electrical energy would be used for lights, existing bridge cranes, and existing elevators for any decommissioning alternative. The quantities of either petroleum fuels or electrical energy would not impact available supplies. Costs for such energy usage are included in the cost estimates listed for each alternative considered in Chapter 3.0.

5.9.3 Water

Only small quantities of water would be required for any of the decommissioning alternatives. Any contaminated water resulting from decommissioning efforts would be transported to the 200 Areas for processing and disposal.

5.9.4 Land

The land required for radioactive waste disposal in the 200 Areas is about 6 hectares for all eight reactors. This land commitment would be offset by the 5 hectares that would become available for other DOE use in the 100 Areas following removal of all eight reactor blocks and fuel storage basins. For the in situ disposal alternative, about 20 hectares of land would be occupied in the 100 Areas by the eight reactors and their mounds, but no land would be required in the 200 Areas for radioactive-waste disposal for this alternative. For the no action alternative, the 100 Areas and the 200 Areas would both retain their present land use.

Approximately 16 hectares of land could be disrupted for excavation of earth and gravel for the in situ decommissioning alternative, but this land would be reclaimed and remain available for other DOE use. The quarry sites either have been or would be surveyed for archaeological resources and endangered species before operations begin. A much smaller land use is required to obtain fill material for the immediate one-piece removal, safe storage followed by deferred one-piece removal, or the safe storage followed by deferred dismantlement alternatives. The entire Hanford Site occupies about 150,000 hectares, and about 2,065 hectares are currently committed in the 200 Areas for processing-plant and waste-management activities. Thus, the disturbed land area would be insignificant in relation to these totals.

5.10 UNAVOIDABLE ADVERSE IMPACTS

Each of the decommissioning alternatives would expose workers to radiation and industrial accidents. These exposures and accidents, although adverse, are all within accepted radiological and industrial operating limits. These impacts are discussed in the following sections, but in general, they are few and limited; none could be identified that would significantly impact workers. Long-term impacts to the general public and cumulative impacts are discussed in Sections 5.7 and 5.13, respectively.

5.10.1 Occupational Radiation Doses

Occupational radiation doses total 24, 159, 51, 532, and 33 person-rem for the no action, immediate one-piece removal, safe storage followed by deferred one-piece removal, safe storage followed by deferred dismantlement, and the in situ decommissioning alternatives, respectively, for all eight reactors (see Table 3.15). The dose is highest for the safe storage followed by deferred dismantlement alternative because of contact dismantling of the reactor blocks. The dose is lowest for the no action and in situ decommissioning alternatives because the reactor block is neither dismantled nor handled. However, the no action alternative is not viewed as a recommended action because it does not remove the structures and contents from being a continued potential hazard.

5.10.2 Occupational Safety

Occupational safety refers to industrial-type accidents that are independent of radioactivity. These accidents would not directly involve members of the general public because all decommissioning activities, including transport, would take place on the Hanford Site. Accident rates would be comparable to those experienced in industry, and may be less because accident rates in the nuclear industry have traditionally been less than national industrial rates.

5.10.3 Noise Impacts

The remoteness of the reactor sites from human habitation would mitigate the effects of noise levels from drilling, demolition, and transportation. For removal, concrete structures would be drilled and blasted to rubble using small charges of explosives. These events would occur intermittently for each of the alternatives. However, wildlife species nesting and residing near the 100 Areas may be impacted by the noise. Noise may adversely affect the behavior of wildlife (Fletcher and Busnel 1978). Standard practice would include the use of muffler systems on heavy demolition and transportation equipment during the demolition of the 105 buildings and transport of waste material to the 200 Areas, and would minimize adverse environmental impacts. Impact on members of the general public would be minimal, as noise levels would meet the requirements of the Noise Control Act of 1972.

5.10.4 Land Dedication and Disruption

Land dedication and disruption are addressed in Section 5.9.4.

5.11 SHORT-TERM VERSUS LONG-TERM USE OF THE ENVIRONMENT

Each decommissioning alternative would require the use of some land for disposal of radioactive wastes and would remove that land from other beneficial uses indefinitely because of the presence of long-lived radionuclides, principally carbon-14 and chlorine-36. However, as discussed in Section 5.9.4, the quantity of land required for radioactive-waste disposal, including that required for the in situ decommissioning alternative, is insignificant compared with that available on the Hanford Site or that already dedicated to processing and waste-management activities in the 200 Areas. Both waste-disposal activities and the temporary disruption of land areas to obtain fill material would be followed by land surface restoration and reseeding of the area with native grasses to control erosion. Such actions would return the land surface to a condition similar to that of its original condition.

5.12 MEANS TO MITIGATE ADVERSE ENVIRONMENTAL IMPACTS

Adverse environmental impacts that can be mitigated include occupational radiation doses, accidents, noise, disruption of land areas, and migration of chemicals and radionuclides as a result of water infiltration through the waste-disposal sites. Mitigation of these impacts has been incorporated into each of the alternative courses of action to the extent practicable.

Decommissioning workers would wear dosimeters to monitor individual doses. Radiation zones would be monitored before workers are allowed to enter. Protective shields, remotely operated tools, and contamination-control envelopes would be employed when appropriate. Standard contamination monitoring devices, such as personnel hand and shoe counters, would be used. ALARA (as low as reasonably achievable) principles would be applied in every phase of engineering planning that deals with radioactive material to reduce worker exposure.

Monitoring of the disposal sites for releases would be continued by the sitewide monitoring and surveillance program as long as active institutional control remains intact.

Potential accidents between a gasoline truck and a railcar carrying reactor-block graphite would be eliminated by guarding all grade crossings during reactor-block graphite transport and possibly by other precautions, such as scheduling reactor-block graphite and gasoline transport on different days.

Control measures would be instituted to minimize the impacts of noise on wildlife. These include the use of mufflers on engines, the possible use of blasting mats to muffle sounds during blasting, and possible restricted operations. Disturbance of winter-roosting and foraging bald eagles and nesting long-billed curlews as a result of the proximity of human presence may be significant, and decommissioning activities would be restricted to the immediate vicinity of the reactor site as much as possible. Vehicular traffic would be limited to already established main roads. The DOE will work with the U.S. Fish and Wildlife Service and the Washington State Department of Game to mitigate disturbance of eagles.

Sites used for the acquisition of earth and gravel and areas around the reactors will be surveyed for archaeological resources and endangered species before operations begin, and will be restored to an environmentally acceptable condition when operations are completed.

Water infiltration through the waste-burial sites will be mitigated by the installation of a multi-layer engineered barrier consisting of a capillary layer of fine-textured soil underlain by an impervious layer of soil/bentonite clay. Calculations in the DEIS are based on a water infiltration rate through the barrier of 0.1 centimeter per year.

5.13 CUMULATIVE IMPACTS

Cumulative impacts from operations on the Hanford Site outside the scope of this DEIS can be assessed by examining monitoring records of current activities and by considering future activities to be conducted at the Hanford Site. No significant additional socioeconomic or radiological

cumulative impacts are expected from decommissioning the surplus production reactors in conjunction with other existing or potential future actions at the Hanford Site.

Hanford Site activities currently taking place, or reasonably anticipated, that are not within the scope of this DEIS and that might increase the overall cumulative impacts of the proposed action include

- operation of the dual-purpose N Reactor for production of special nuclear materials and steam used by the Washington Public Power Supply System to produce electricity
- operation of the PUREX Plant and related facilities
- construction and operation of the Process Facility Modifications Project
- operation of the Supply System's Number 2 nuclear power plant and possible operation of one or more additional units
- operation of U.S. Ecology's commercial low-level waste-disposal site
- disposal of defense high-level, transuranic, and tank wastes
- disposal of low-level liquid wastes to the ground and cribs, and disposal of solid low-level waste in near-surface burial grounds, including decommissioned naval submarine reactors and the Shippingport Atomic Power Station reactor
- eventual decontamination and decommissioning of the remainder of Hanford's surface facilities.

5.13.1 Socioeconomic Impacts

At the Hanford Site, cumulative sociological impacts are expected to be within the ability of the community to absorb them. The unanticipated termination of work on the two incomplete Supply System power plants on the Hanford Site has left the surrounding communities with excess resources. Impacts to the communities similar to those experienced as a result of termination of the Supply System power plant construction would be experienced if operation of the N Reactor were to be permanently terminated (with the

subsequent termination of its associated fuel-fabrication and fuel-processing operations). The N Reactor was placed in a standby mode in February 1988. The short-term impact on employment at Hanford is currently unknown, but it is likely that the action will result in the termination of a significant fraction of the Hanford Site work force in the next 1 to 2 years. The activities associated with decommissioning and disposal of the eight surplus production reactors would absorb some of the existing excess resources in the area.

5.13.2 Radiological Impacts

The following discussion addresses the potential short-term and long-term cumulative radiological impacts to the general public.

5.13.2.1 Short-Term Radiological Impacts

The magnitude of short-term radiological impacts is determined principally by the Hanford sitewide monitoring program (Jaquish and Mitchell 1988). Radiological monitoring data from 1987 operations at the Hanford Site are presented in Section 4.4 of this DEIS.

The overall radiological impact of 1987 Hanford Site operations was calculated to be 0.05 millirem (effective dose equivalent) to a hypothetical, maximally exposed person residing off site, and 4 person-rem to the population within 80 kilometers. These doses are in addition to those received from natural background radiations (which produce individual, total-body, annual doses of about 0.3 rem, and about 100,000 person-rem to the same 80-kilometer population).

The 1987 airborne concentrations of all radionuclides associated with Hanford Site operations were far below levels that would produce an individual dose exceeding the EPA standard of 0.025 rem per year (40 CFR 61) from airborne pathways. Very low levels of radionuclides from Hanford operations were detected in the Columbia River; however, downstream levels were far below concentrations that would produce an individual dose exceeding the EPA standard (40 CFR 141) of 4 millirem per year for community drinking-water systems.

Samples of foods grown close to the Hanford Site have been examined annually for radionuclides since the mid 1940s. The low levels found in most 1987 samples are attributable to worldwide fallout in the atmosphere resulting primarily from previous testing of nuclear weapons. There is no indication that any samples contained radionuclides associated with Hanford Site operations. Samples of deer, rabbits, game birds, water fowl, and fish were also collected near operating Hanford Site facilities and at other locations where the potential for radionuclide uptake was most likely. Although cobalt-60, strontium-90, and cesium-137, probably from Hanford Site operations, were found in some samples, concentrations were low enough that any radiation dose acquired from eating such fish or animals would be within applicable radiation protection standards.

Impacts from completion and operation of the Supply System's Plant Number 1 are estimated to approximate those from the Supply System Plant Number 2 (which is operating). Current Supply System monitoring records show that radiological impacts from Plant Number 2 are low compared with those from natural background radiation.

Project radiological impacts from ongoing Hanford Site operations and reasonably anticipated operations are summarized in Table 5.6. The impacts are very small compared with impacts from natural background radiation (which is about 0.3 rem per year). No health effects would be expected from population doses such as those presented in Table 5.6.

5.13.2.2 Long-Term Radiological Impacts

Long-term cumulative radiological impacts are those that might occur in the distant future after Hanford's operating plants have been decommissioned and long after active institutional control is assumed to be absent. A principal source of impacts would be from low-level waste disposal sites. The term "low-level waste" (as used here) includes all low-level radioactive defense wastes (some 400 individual sites) other than wastes from decommissioning; high-level, transuranic, and tank wastes; and secondary wastes (such as grouted waste produced during waste processing). Long-term cumulative radiological impacts of low-level waste disposal, Hanford Site defense waste-disposal alternatives, and decommissioning alternatives are given in

TABLE 5.6. Cumulative Short-Term Radiological Impacts for Existing Hanford Site Operations and Reasonably Foreseeable Waste Disposal

Activity	Maximum Annual Individual Whole-Body Cumulative Dose (rem)[a]	Annual Population Whole-Body Dose (person-rem)[b]
Existing Hanford Site Operations:[c]		
N Reactor, PUREX Plant, defense LLW disposal	0.00005	4
Supply System #2[d]	0.002	1
U.S. Ecology LLW disposal[e]	0	0
Additions from Reasonably Foreseeable Operations:		
Process facility modifications[f]	0	0
Additional Supply System nuclear power units[d]	0.002	1
Implementation of HDW-EIS Alternatives:[g]		
Geologic	<0.001	30
In-place	<0.001	0.03
Reference	<0.001	0.05
Preferred	<0.001	0.03 - 30
No disposal action	<0.001	0.006

(a) For perspective, the annual dose to such an individual from natural background radiation would be 0.3 rem.
(b) For perspective, the dose to the same population for the same period from natural background would amount to about 100,000 person-rem.
(c) Based on The Hanford Annual Environmental Monitoring Report for 1987 (Jaquish and Mitchell 1988).
(d) Performance of additional units assumed to be the same as reported for Supply System #2 (DOE 1986, p. 5.53).
(e) Average annual dose rate including background at U.S. Ecology site fence was 0.18 rem; at corners of site, 0.11 rem; hence, dose from facility at Hanford Site boundary would be essentially zero.
(f) See DOE/EIS-0115D (DOE 1986, p. 5.53).
(g) See DOE/EIS-0113 (DOE 1987).

Table 5.7. The impacts given in Table 5.7 are to downstream users of the Columbia River. Impacts from Hanford defense wastes were calculated for two different ground-water recharge rates (0.5 and 5 centimeters per year) and for the cases in which the protective barriers fail (15 centimeters per year infiltration over 10% of the barrier) and in which they remain intact (zero

TABLE 5.7. Cumulative Long-Term Radiological Impacts from Existing Hanford Site Waste Disposal and Reasonably Foreseeable Waste Disposal

Activity	Integrated Population Whole-Body Dose Over 10,000 yr (person-rem)[a]	
	Barriers Effective/Current Climate[b]	Barrier-Failure Scenario/Wetter Climate[c]
Existing Hanford site operations:		
N Reactor, PUREX Plant, Supply System #2	(d)	(d)
Defense LLW disposal (no barriers)	2,000	6,000
U.S. Ecology LLW disposal	(e)	(e)
Additions from reasonably foreseeable operations:		
Process facility modifications project	(d)	(d)
Additional Supply System nuclear power units	(d)	(d)
HDW-EIS disposal alternatives:[f]		
Geologic	2	200
In Place	10	600
Reference	10	600
Preferred[g]	9 - 10	300 - 600
No disposal action (no barriers)	20,000	4,000,000
Decommissioning surplus production alternatives:		
No Action	(h)	50,000
Immediate one-piece removal	(h)	1,900
Safe storage followed by deferred one-piece removal	(h)	1,900
Safe storage followed by deferred dismantlement	(h)	1,900
In situ decommissioning	(h)	4,700

(a) Values rounded to one significant digit. For perspective, if the population within 80 km of Hanford remained constant for 10,000 years, the integrated population dose from natural background would amount to 1,020,000,000 person-rem.
(b) Assumed average ground-water recharge rate of 0.5 cm/yr.
(c) Assumed average ground-water recharge rate of 5 cm/yr.
(d) Long-term radiological impacts would be associated with decommissioning wastes.
(e) Values not known, but because of waste characteristics, they would be expected to be much less than those for defense LLW disposal.
(f) See DOE/EIS-0113 (DOE 1987).
(g) Radiological impacts are shown as a range because disposal decisions have not been made for single-shell tank waste, TRU contaminated soil sites, or pre-1970 buried TRU solid waste.
(h) The scenario of a completely effective barrier (zero infiltration) was not used for this DEIS; the best comparison with DOE/EIS-0113 (DOE 1987) is with the barrier-failure scenario.

infiltration). For bounding purposes, two impacts are provided: when the recharge rate is the greatest and protective barriers fail; and when the recharge rate is lower and protective barriers remain intact.

As shown in Table 5.7, long-term radiological impacts from low-level waste disposal on the Hanford Site are larger than for high-level, transuranic, and tank wastes as disposed of according to the alternatives presented in the Hanford defense waste EIS (DOE 1987). Radiological impacts from low-level waste disposal, however, are smaller than those associated with the

Hanford defense waste no disposal action alternative (the principal reasons for large impacts from the no disposal action alternative are the assumptions that tank waste remains in liquid form and no barriers are placed over the wastes).

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U.S. Code of Federal Regulations, Title 40, Part 141 (40 CFR 141); "National Interim Primary Drinking Water Regulations." U.S. Environmental Protection Agency.

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6.0 STATUTORY AND REGULATORY REQUIREMENTS

The U.S. government owns the eight surplus production reactors at the Hanford Site, and the U.S. Department of Energy (DOE) is the federal agency responsible for the Site and for decommissioning the surplus reactors. Decommissioning will be carried out in accordance with the DOE's environmental policy, which is "to conduct its operations in an environmentally safe and sound manner . . . in compliance with the letter and spirit of applicable environmental statutes, regulations, and standards" (DOE Environmental Policy Statement DOE N 5400.2). Statutory, regulatory, and potential permit requirements relevant to decommissioning are discussed in this chapter.

Federal regulations that apply to or may be relevant to the decommissioning of the Hanford surplus reactors have been promulgated under the Clean Air Act (CAA); the Clean Water Act (CWA); the Safe Drinking Water Act (SDWA); the Resource Conservation and Recovery Act (RCRA) as amended by the Hazardous and Solid Waste Amendments (HSWA); the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) as amended by the Superfund Amendments and Reauthorization Act (SARA); the Atomic Energy Act (AEA); and other federal statutes. Provisions in the CAA, CWA, SDWA, RCRA, and CERCLA also require federal agencies to comply with applicable state and local regulations. Regulations promulgated at the federal level under these statutes are, for the most part, administered by the U.S. Environmental Protection Agency (EPA). In Washington state, the state regulations are administered by the Washington Department of Ecology (WDOE) or by the Department of Social and Health Services (DSHS). The more important environmental regulations, together with potential permit requirements, are discussed below. The federal regulations appear in the U.S. Code of Federal Regulations (CFR), and the Washington state regulations appear in the Washington Administrative Code (WAC). The federal law from which each regulation derives is noted in the section heading.

6.1 AIR QUALITY (CAA)

- 40 CFR 50, "National Primary and Secondary Ambient Air Quality Standards"; 40 CFR 60, "Standards of Performance for New Stationary

Sources." EPA regulations in 40 CFR 50 set national ambient air quality standards. EPA regulations in 40 CFR 60 provide standards for the control of the emission of pollutants to the atmosphere. Construction or modification of an emissions source may require a Prevention of Significant Deterioration of Air Quality (PSD) permit under 40 CFR 52. Standards in 40 CFR 50 and 40 CFR 60 are not expected to be exceeded as a result of decommissioning activities. No air pollutants are expected to be emitted during decommissioning operations that would require a PSD permit.

- 40 CFR 61, "National Emission Standards for Hazardous Air Pollutants" (NESHAP). EPA hazardous emission standards in 40 CFR 61 Subpart H provide for the control of the emission of radionuclides to the atmosphere from DOE facilities. The regulations include both standards and approval requirements. Standards in 40 CFR 61 are not expected to be exceeded as a result of decommissioning activities. No air pollutants are expected to be emitted during decommissioning operations that would require NESHAP approval.

- WAC 173-400 through WAC 173-495, Washington state Air Pollution Control Regulations; General Regulation 80-7, Benton-Franklin-Walla Walla Counties Air Pollution Control Authority. WDOE air pollution control regulations, promulgated under the Washington Clean Air Act, appear in WAC 173-400 through 173-495. These regulations include both emission standards and ambient air quality standards. The State of Washington has delegated most of its authority under the Washington Clean Air Act to the Benton-Franklin-Walla Walla Counties Air Pollution Control Authority. General Regulation 80-7 contains emission standards and authorization requirements for nonradioactive air pollutants. Standards in WAC 173-400 through 173-495 or in General Regulation 80-7 are not expected to be exceeded as a result of decommissioning activities. No air pollutants are expected to be emitted during decommissioning operations that would require approval under WAC 173-400 through 173-495 or under General Regulation 80-7.

- WAC 402-80, "Monitoring and Enforcement of Air Quality and Emission Standards for Radionuclides." DSHS regulations in WAC 402-80 contain standards and permit requirements for the emission of radionuclides to the atmosphere from DOE facilities based on WDOE standards in WAC 173-480, "Ambient Air Quality Standards and Emission Limits for Radionuclides." These standards are equivalent to those in 40 CFR 61. Standards in WAC 173-480 and 402-80 are not expected to be exceeded as a result of decommissioning activities. No radionuclides are expected to be emitted during decommissioning operations that would require a permit under WAC 402-80.

6.2 WATER QUALITY (CWA, SDWA)

- 40 CFR 141, "National Primary Drinking Water Regulations." The EPA drinking water standards in 40 CFR 141 apply to water supplied by public water systems, including systems drawing Columbia River water downstream from the Hanford Site. The ability of public water systems to meet these standards is not expected to be adversely affected as a result of decommissioning activities.
- 40 CFR 122, "National Pollutant Discharge Elimination System." EPA regulations in 40 CFR 122 require a National Pollutant Discharge Elimination System (NPDES) permit for the discharge of pollutants from any point source into waters of the United States. No liquids are expected to be discharged into the Columbia River from decommissioning operations. Thus, no NPDES permit is expected to be required for decommissioning operations.
- WAC 173-218, "Underground Injection Control Program." WDOE regulations in WAC 173-218 provide standards and permit requirements for the disposal of fluids by well injection. No waste disposal by this method is planned as a part of decommissioning.

6.3 SOLID WASTES (AEA, RCRA, CERCLA)

- 40 CFR 193 (pending), "Environmental Radiation Protection Standards for Management and Land Disposal of Low-Level Radioactive Wastes."

The EPA has announced its intent to promulgate environmental radiation protection standards for low-level radioactive waste disposal in 40 CFR 193. When promulgated by the EPA, these standards may affect the disposal of low-level radioactive waste owned by the DOE. At present, however, only an advance notice of proposed rulemaking has been published by the EPA. No proposed rule has been published in the Federal Register.

- 40 CFR 260-268 and 270-272, "Hazardous Waste Management." EPA RCRA regulations in 40 CFR 260-268 and 270-272 apply to the treatment, transport, storage, and disposal of hazardous wastes (but not to purely radioactive wastes) and to the hazardous component of radioactive mixed wastes (but not to the radioactive component of radioactive mixed wastes) owned by the DOE.

  Source, special nuclear, and byproduct materials are specifically exempted from the definition of solid waste in RCRA. RCRA also provides that the provisions in RCRA shall not apply to, nor authorize regulation of, any activity or substance that is subject to the AEA, except to the extent that such application or regulation is not inconsistent with the requirements of the AEA. Thus RCRA provides for the resolution of any inconsistencies between the requirements of RCRA and those of the AEA.

- WAC 173-303, "Washington Dangerous Waste Regulations." The EPA has authorized the State of Washington through the WDOE to conduct its own dangerous-waste regulation program in lieu of major portions of the RCRA interim and final status permit program for hazardous wastes. WDOE is also authorized to conduct its own dangerous-waste program in lieu of the RCRA program for radioactive mixed wastes. However, the EPA has retained its authority to administer those sections of the hazardous-waste program mandated by the Hazardous and Solid Waste Amendments to RCRA. The state regulations include both standards and permit requirements and may apply to the disposal of irradiated lead in the thermal shields.

- 40 CFR 300, "National Oil and Hazardous Substances Pollution Contingency Plan." The EPA CERCLA regulations in 40 CFR 300 apply

to the cleanup of inactive hazardous-waste disposal sites and to the cleanup of hazardous substances released into the environment. Hazardous substances under CERCLA include radionuclides. On June 24, 1988 (53 FR 23988), the EPA proposed the Hanford Site for inclusion on its National Priorities List (NPL). This list was established for the purpose of identifying hazardous-waste sites that are eligible for and require cleanup under CERCLA. The 100 Areas at Hanford are specifically included in the proposed listing, based on review of specific disposal sites within the 100 Areas. Those specific disposal sites within the 100 Areas that may be impacted by in situ decommissioning, together with their inventories, are listed in Appendix A. The CERCLA regulations may also apply to any further disposition of irradiated lead in the reactor thermal shields.

6.4 APPLICABILITY OF RCRA AND CERCLA REQUIREMENTS

As noted previously, the EPA has proposed that certain areas of the Hanford Site be designated on the National Priorities List (NPL), including the 100 Areas on which the eight surplus production reactors are located. The DOE is working with the EPA and the State of Washington to develop agreements addressing the program that the DOE will implement to comply with the requirements of CERCLA. In recognition of the importance of addressing future waste management, disposal, and remedial and corrective actions in a unified and comprehensive manner, the DOE has proposed that the agreements comprehensively address both CERCLA and RCRA activities at Hanford.

This EIS is not intended to be a RCRA permit application nor a CERCLA remedial investigation/feasibility study. It is also not intended to be a vehicle to resolve questions regarding the specific applicability of the requirements of RCRA or CERCLA. Notwithstanding these questions, the EIS includes conceptual designs for disposal site barriers, liner/leachate collection systems (except for the in situ decommissioning alternative), marker systems, and ground-water monitoring systems (see Section 5.7 and Appendix H). These systems are intended to meet the requirements of RCRA or

CERCLA to mitigate the near- and long-term potential for contaminant migration into ground water or the Columbia River.

The DOE intends to continue discussions with the EPA and the State of Washington to resolve the specific applicability of particular requirements of RCRA or CERCLA to decommissioning.

6.5 U.S. NUCLEAR REGULATORY COMMISSION AND OTHER FEDERAL REGULATIONS

The DOE reactors at Hanford are not subject to the regulations of the U.S. Nuclear Regulatory Commission (NRC). Therefore, the NRC's regulations (53 FR 24018, June 27, 1988) on the decommissioning of licensed nuclear facilities and the NRC's regulations in 10 CFR 61 on the licensing requirements for disposal of low-level radioactive wastes are not directly applicable. However, the EPA regulations in 40 CFR 193 are expected, when issued, to establish general standards for low-level radioactive waste disposal that utilize radiation protection goals somewhat similar to those of the NRC regulations in 10 CFR 61. Therefore, the DOE is using the standards in 10 CFR 61 as guidance in anticipation of similar EPA standards in 40 CFR 193 that may have to be met at the time of decommissioning.

Regulations of the U.S. Department of Transportation in 49 CFR 171-179, "Hazardous Materials Regulations," apply to the handling, packaging, labeling, and shipment of hazardous materials off site, including radioactive wastes.

Requirements of the National Historic Preservation Act in 36 CFR 800, the Archaeological Resources Protection Act and the American Indian Religious Freedom Act in 43 CFR 7, and the American Antiquities Act in 43 CFR 3 and 25 CFR 261, apply to the protection of historic and cultural properties, including both existing properties and those discovered during construction. Historic, archaeological, and cultural properties on the Hanford Site are discussed in Chapters 4.0 and 5.0.

Species protection requirements of the Endangered Species Act in 50 CFR 402, the Bald and Golden Eagle Protection Act in 50 CFR 22, and the Migratory Bird Treaty Act in 50 CFR 10, 13, and 21 apply to the protection of

these species during decommissioning activities. Threatened and endangered species on the Hanford Site are discussed in Chapters 4.0 and 5.0.

Presidential Executive Orders 11988 and 11990 apply to activities that might impact floodplains or wetlands. The DOE regulations in 10 CFR 1022 establish policies and procedures for compliance with these executive orders and are discussed in Appendix B.

6.6 STANDARDS FOR PROTECTION OF THE PUBLIC

Applicable standards for protection of the public from air and water contamination and from radioactivity appear in several EPA regulations. The regulations that contain these standards are cited above, without a discussion of the standards themselves. Numerical values of the standards important to decommissioning are discussed below.

The EPA regulations in 40 CFR 61 Subpart H apply to releases of radionuclides to the atmosphere from DOE facilities and state that

> "Emissions of radionuclides to air from [DOE] facilities . . . shall not exceed those amounts that cause a dose equivalent of 25 mrem/y to the whole body or 75 mrem/y to the critical organ of any member of the public. Doses due to radon-220, radon-222, and their respective decay products are excluded from these limits."

The EPA regulations in 40 CFR 141 apply to concentrations of radionuclides and other pollutants in public drinking water supplies (i.e., community water systems using Columbia River water downstream from the Hanford Site). These regulations state in part that

> "The average annual concentrations of beta particle and photon radioactivity from man-made radionuclides in drinking water shall not produce an annual dose equivalent to the total body or any internal organ greater than 4 millirem/year."

Also, maximum contaminant levels in community water systems of 15 picocuries per liter of gross alpha particle activity, including radium-226 but excluding radon and uranium, are specified in 40 CFR 141.

40 CFR 141 also specifies a maximum concentration for lead of 0.05 milligram per liter and for cadmium of 0.01 milligram per liter in community water systems.

The EPA regulations in 40 CFR 193, when promulgated by the EPA, are expected to apply to the disposal of radioactive decommissioning wastes. In the absence of draft regulations, guidance can be taken from the NRC regulations in 10 CFR 61, which state:

> "Concentrations of radioactive material which may be released (from the disposal facility) to the general environment in ground water, surface water, air, oil, plants, or animals must not result in an annual dose exceeding an equivalent of 25 millirems to the whole body, 75 millirems to the thyroid, and 25 millirems to any other organ of any number of the public."

For any situation not covered by the EPA regulations, limits in DOE Order 5480.1A (or its successor orders) apply:

> "The effective dose equivalent to any member of the public from all routine DOE operations (natural background and medical exposures excluded) shall not exceed 500 mrem/year for occasional annual exposures and 100 mrem/year for exposures lasting, or predicted to last, longer than 5 years."

The DOE has also prepared draft derived concentration guides (DOE Order 5480.3) for concentrations of radionuclides in air and water that could be continuously consumed or inhaled without exceeding the 100-millirem-per-year limit.

7.0 LIST OF PREPARERS AND REVIEWERS

The persons who prepared this draft environmental impact statement (DEIS) are identified in this chapter. The overall effort was led by C. E. Miller, Jr., formerly Director, Surplus Facilities Management Program Office, U.S. Department of Energy Richland Operations Office (DOE-RL), and by R. D. Freeberg, Chief, Restoration Branch, DOE-RL, assisted by J. D. Goodenough, DOE-RL Surplus Production Reactors Decommissioning Project Manager. Other DOE-RL staff providing reviews of the DEIS draft materials were R. M. Carosino, P. F. X. Dunigan, P. K. Clark, K. V. Clarke, P. J. Krupin, and J. H. Slaughter.

The DEIS was prepared with the assistance of staff members of Pacific Northwest Laboratory (PNL), operated for the DOE by the Pacific Northwest Division of Battelle Memorial Institute. Program managers for the preparation of the surplus production reactor decommissioning DEIS were W. L. Templeton and J. V. Robinson. E. B. Moore was deputy program manager. PNL programmatic overview was provided by W. A. Laity, W. L. Templeton, and J. V. Robinson. PNL and DOE-RL staff contributing to the preparation of the DEIS are identified as follows:

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Foreword		W. L. Templeton
Chapter 1.0	Summary	E. B. Moore
Chapter 2.0	Purpose of and Need for Action	E. B. Moore
Chapter 3.0	Description and Comparison of Decommissioning Alternatives	R. I. Smith G. J. Konzek E. S. Murphy, Jr. E. B. Moore
Chapter 4.0	Affected Environment	R. W. Wallace W. H. Rickard
Chapter 5.0	Environmental Consequences	B. A. Napier D. H. Denham W. T. Farris E. B. Moore

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		L. G. Morgan A. E. Reisenauer W. L. Templeton
Chapter 6.0	Statutory and Regulatory Requirements	E. B. Moore
Chapter 7.0	List of Preparers and Reviewers	W. L. Templeton V. L. Brouns
Chapter 8.0	Glossary	V. L. Brouns
Appendix A	Description of the Surplus Reactors	G. J. Konzek
Appendix B	Floodplain/Wetlands Environmental Review	E. B. Moore
Appendix C	Hydrologic and Transport Modeling of the Ground-Water Pathways	A. E. Reisenauer
Appendix D	Release Rates of Radionuclides from Reactor-Block Materials	W. C. Morgan
Appendix E	Method for Calculating Radiation Dose	B. A. Napier D. H. Denham
Appendix F	Radiologically Related Health Effects	B. A. Napier D. H. Denham
Appendix G	Assessment of Long-Term Impacts of Decommissioning Alternatives	B. A. Napier W. T. Farris
Appendix H	Waste Disposal	E. B. Moore W. H. Walters
Appendix I	Endangered and Threatened Species	E. B. Moore
Appendix J	National Historic Preservation Act Requirements	K. V. Clarke (DOE-RL)
References		V. L. Brouns
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Preparers and Reviewers

Technical support was provided to DOE-RL by the staffs of UNC Nuclear Industries, Kaiser Engineers Hanford, Rockwell Hanford Operations, and Westinghouse Hanford Company. This support consisted of inventories and dose-rate data, conceptual engineering design and cost information, and transportation and radioactive waste disposal cost information.

Others providing review of this DEIS were C. D. Corbit, I. C. Nelson, T. L. Page, J. A. Stottlemyre, C. M. Unruh, and D. G. Watson of PNL.

Biographic sketches of the principal preparers follow.

William L. Templeton, Manager of NEPA Implementation and Environmental Documentation, Office of Hanford Environment

B.Sc.Hons Zoology, University of St. Andrews 1951

Mr. Templeton has over 35 years of experience in the nuclear field. He spent 15 years with the U.K. Atomic Energy Authority involved in the fate and effects of released radionuclides in the environment. He has worked for PNL since 1965 and has been responsible as a manager for technical supervision of and participation in a broad range of environmental assessments and research programs. For 3 years he was responsible for the ecological impact portion of EISs on nuclear power plants for the Energy Research and Development Administration (ERDA) and U.S. Nuclear Regulatory Commission (NRC). He was a member of the DOE ad hoc advisory committee responsible for advising the Defense Nuclear Agency on the cleanup operations of residual radioactivity in the Marshall Islands. From 1980 through 1985 he was chairperson of a Nuclear Energy Agency/Organization for Economic Co-Operation and Development (NEA/OECD) advisory group charged with the responsibility for the evaluation and development of the NEA research and surveillance program for the European low-level radioactive dump site in the northeast Atlantic Ocean. He has also advised the DOE, the U.S. Environmental Protection Agency, and the U.S. Navy on the potential radiological impacts of ocean disposal of low-level radioactive wastes, including decommissioned submarines. He is presently co-chairperson of the National Council on Radiation Protection (NCRP) Task Group developing screening models for the evaluation of radioactivity in the environment for the NCRP and the EPA.

John V. Robinson, Deputy Manager for NEPA Implementation and Environmental Documentation, Office of Hanford Environment

B.S.	Physics, Canisius College	1952
M.S.	Nuclear Physics, Rensselaer Polytechnic Institute	1955
Graduate, Oak Ridge School of Reactor Technology		1958
Graduate, Harvard Business School Club of Buffalo		1971

As Deputy Manager for NEPA Implementation and Environmental Documentation with PNL's Office of Hanford Environment, Mr. Robinson oversees National Environmental Policy Act documents on Hanford facilities. He has over 30 years of experience working for both the government and industry in research and development and consulting in the fields of nuclear power, nuclear waste, aerospace, environmental impact assessments, and pollution abatement. Before coming to PNL in 1978, Mr. Robinson worked in both research and engineering and commercial development, establishing and directing scientific, nuclear, and marketing projects.

Emmett B. Moore, Senior Research Scientist, Technology Planning and Analysis Center

B.S.	Chemistry, Washington State University	1951
Ph.D.	Physical Chemistry, University of Minnesota	1956

Before joining PNL, Dr. Moore was director of power plant siting for the Minnesota Environmental Quality Board where he managed the regulatory and environmental activities of the Board relating to power plant siting and transmission line routing. At PNL he managed preparation of PNL's portion of the NRC's Draft Generic EIS on Decommissioning of Nuclear Facilities; authored or coauthored several documents in the NRC NUREG/CR series on the technology, safety, and costs of decommissioning nuclear facilities; and managed and was principal author of the DOE EIS on Decommissioning of the Shippingport Atomic Power Station. He has conducted basic research in

chemical physics, taught physics and physical chemistry at the university level, and is an experienced environmental hearing officer.

Virginia L. Brouns, Technical Communication Specialist, Publishing and Administration Department

B.A.	Technical Communications, Eastern Washington University	1984

Since coming to PNL in 1984, Ms. Brouns has contributed technical editing and publication coordinating on projects such as the environmental assessment for a monitored retreivable storage facility, the environmental assessment on the Basalt Waste Isolation Project, the environmental impact statement on the disposal of Hanford defense wastes, and numerous other technical reports, manuals, and articles related to environmental and risk assessment.

Kevin V. Clarke, Realty Specialist, U.S. Department of Energy, Richland Operations Office

B.A.	Anthropology, California State University at Sacramento	1975
Graduate Work, Parks and Recreation Administration		1976-1977

Mr. Clarke started his career in the federal government with the Bureau of Land Management in 1976 as an outdoor recreation planner. Since 1983, he has held a realty position and had responsibility for ensuring that all land actions comply with cultural resources laws. Since joining the DOE in 1986, he has acted as the preservation officer for the Hanford Site.

Dale H. Denham, Senior Research Scientist, Environmental Pathways and Assessment Section, Geosciences Department

B.A.	Math and Physics, Williamette University	1960
M.S.	Radiological Science, University of Washington	1962

Mr. Denham has 26 years experience in applied health physics and environmental monitoring/assessment, including 16 years with PNL. Since rejoining Battelle in 1979, he has been a project manager and a major contributor to decommissioning and environmental monitoring projects with emphasis on environmental radiological characterization, dose calculations, and preparation/review of the radiological portions of environmental assessments, EISs, and safety analysis reports.

William T. Farris, Scientist, Environmental Pathways and Assessment Section, Geosciences Department

B.S.	Geological Sciences, University of Washington	1984
M.S.	Radiological Sciences, University of Washington	1987

Mr. Farris was a staff member at PNL from 1985 to 1988. While at PNL, he was involved in the evaluation of impacts associated with defense and commercial radioactive waste management and disposal programs. He was a contributor to the EIS on the disposal of Hanford defense wastes and a member of the Grout Technology Project research team.

George J. Konzek, Research Engineer, System Design Section, Waste Systems and Transportation Department

B.S.	General Studies, Eastern Oregon State College	1986

Mr. Konzek has 30 years experience in nuclear and energy-related research and development. He was the supervisor and AEC/NRC licensed senior reactor operator at the Plutonium Recycle Critical Facility for 9 years. Over a 7-year period, starting in 1976, he was a major contributor in a series of NRC studies on the technology, safety, and costs of decommissioning reference nuclear facilities, including a pressurized water reactor, a boiling-water reactor, and research and test reactors. He was a contributing member of the PNL team that prepared the decommissioning analysis for the

TMI-2 Programmatic Environmental Impact Statement. He led and was the primary author of the NRC-sponsored study on decommissioning of research and test reactors.

Larry G. Morgan, Staff Scientist, Waste Package and Performance Assessment Department

B.S.	Chemistry, Rose-Hulman Institute of Technology	1964
Ph.D.	Physical Chemistry, Oregon State University	1978

Dr. Morgan specializes in physical and inorganic chemistry, with an emphasis on those areas related to the nuclear fuel cycle. His professional experience includes studies of the chemistry of the actinides and fission products, nuclear fuel reprecessing, nuclear waste management, control of radioactive emissions to the atmosphere, and environmental documentation related to nuclear activities. At PNL, Dr. Morgan is the program manager of the studies conducted in support of the Salt Repository Project for the geologic disposal of high-level nuclear waste. He was the deputy project manager at PNL for the preparation of the environmental impact statement for the Process Facilities Modification Project proposed for the Hanford Site, and he has contributed to the preparation of other environmental documents. Dr. Morgan is a participant in a team addressing the regulatory and technical issues related to the ultimate disposal of nuclear wastes contained in single-shell tanks at the Hanford Site. He is also the program coordinator (chairperson) for the chemistry program at the Tri-Cities University Center.

William C. Morgan, Senior Research Scientist, Fuels and Materials Department

B.A.	Physics, Linfield College	1959

Mr. Morgan has over 25 years of experience in the effects of radiation on the physical and chemical behavior of nuclear graphites. He also has extensive experience in neutron dosimetry for reactor materials irradiation studies. Mr. Morgan is currently a member of the Technology Assessment Task Force for N Reactor graphite.

E. Smith Murphy, Jr., Senior Research Scientist, Chemical Technology Department

B.S.	Physics, Brigham Young University	1947
M.S.	Physics, Colorado State University	1952
Ph.D.	Physics, Colorado State University	1961

Dr. Murphy was a staff member at PNL from 1974 to 1986. His previous experience included 20 years of physics instruction at the university level. At PNL he had a broad range of experience in risk and safety assessment, waste management, transportation studies, and decommissioning. He was a member of a research team that studied the decommissioning of nuclear facilities to provide information for the NRC on the technology, safety, and costs of decommissioning these facilities. He contributed to studies of decommissioning a fuel reprocessing plant, a mixed oxide fuel fabrication plant, and light-water nuclear power reactors. He was leader for studies of the decommissioning of low-level waste burial grounds, material licensee facilities, and light-water reactors that have been involved in accidents. He prepared addenda to the reactor decommissioning studies to evaluate 1) waste-disposal alternatives in the event that licensed shallow-land burial sites are not available, and 2) the impacts of NRC waste classification criteria on the disposal of decommissioning wastes.

Bruce A. Napier, Senior Research Scientist, Health Physics Department

B.S.	Nuclear Engineering, Kansas State University	1975
M.S.	Nuclear Engineering, Kansas State University	1977

Mr. Napier has recently developed exposure scenarios and performed radiological analyses for deep geologic waste repositories; performed radiological analyses for the NRC on decommissioning boiling-water reactors, low-level waste burial grounds, and non-fuel-cycle facilities; carried out an analysis of the EPA's proposed regulation 40 CFR 191 for the Office of Nuclear Waste Isolation; and prepared a generic study on the environmental effects of proposed uranium mining in British Columbia. He also contributed

to the EIS on the management of commercially generated radioactive waste, the EIS for operation of PUREX, the environmental assessment on the Basalt Waste Isolation Project, the final EIS on double-shell tanks, and the draft EIS on disposal of Hanford defense wastes.

Andrew E. Reisenauer, Research Scientist, Hydrology Section, Geosciences Department

B.S.	Public Health, Washington State University	1951
Professional	Ground-Water Hydrologist certified by the American Institute of Hydrology	

Mr. Reisenauer has had 35 years experience at Hanford in soils and waste chemistry, soils physics, and hydrology. He was a staff member at PNL from 1965 to 1987. He has been a major contributor to the development of numerical modeling of saturated and unsaturated ground-water flow and transport. He has performed various ground-water studies throughout the United States as well as at Hanford.

William H. Rickard, Staff Scientist, Terrestrial Sciences Section, Environmental Sciences Department

B.S.	University of Colorado	
M.S.	University of Colorado	
Ph.D.	Washington State University	1957

Dr. Rickard has conducted environmental research on the Hanford Site for 27 years, with particular attention to plant and animal populations. Before coming to the Hanford Site, he worked at the Nevada Test Site evaluating the response of wild plants and animals to nuclear explosions.

Richard I. Smith, Staff Engineer, Waste Systems and Transportation Department

B.S.	Physics, Washington State University	1955
M.S.	Applied Physics, University of California at Los Angeles	1957

P.E.	Nuclear Engineering, State of Washington	1972
P.E.	Nuclear Engineering, State of California	1975

Mr. Smith has contributed to, and subsequently managed, a 6-year program sponsored by the NRC that examined the technology, safety, and costs of decommissioning licensed reference nuclear facilities. These studies, which covered reactors, fuel cycle facilities, and non-fuel-cycle nuclear facilities, are known and used worldwide. He has also contributed to and managed a variety of programs related to experimental reactor neutronics, nuclear facility decommissioning, and nuclear waste storage. He has authored over 50 formal and informal reports of research sponsored by the U.S. Atomic Energy Commission (AEC), ERDA, NRC, the Electrical Power Research Institute (EPRI), and other organizations.

Richard W. Wallace, Research Scientist, Hydrology Section, Geosciences Department

B.S.	Geology, Iowa State University	1959
M.S.	Geology, Iowa State University	1961
Ph.D.	Hydrogeology, University of Idaho	1972

Dr. Wallace has worked with proposed radioactive-waste disposal techniques, methods, and systems for the past 9 years. His work has included description and characterization of various geologic media and settings, development of release scenarios (both from natural events and from human activity), and analysis of scenarios for waste released as source terms for dose and consequences analyses.

Wallace H. Walters, Senior Research Engineer, Hydrology Section, Geosciences Department

B.S.	Civil Engineering, University of Texas at Arlington	1969
M.S.	Civil Engineering, Colorado State University	1975

Graduate Studies in Water Resources Engineering, Mississippi State University

Graduate Studies in Hydraulics, Colorado State University

Mr. Walters has had 20 years of experience in water resources research and engineering. Since joining the PNL staff in 1978, he has been involved in studies of the impact of hydrologic systems on hazardous waste disposal; the erosion, deposition, and transport of sediment in rivers; and the mathematical modeling of river systems. Before joining PNL, Mr. Walters worked with the U.S. Army Corps of Engineers as a research engineer on the Mississippi River and Tributaries Project, where he specialized in river hydraulics and geomorphology, sediment transport, and bank-erosion problems. He also worked as a research assistant at Colorado State University, analyzing flood routing and modeling flood waves.

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8.0 GLOSSARY

This glossary contains definitions of terms and a list of acronyms, abbreviations, and symbols used in this environmental impact statement. Definitions are based on general usage at the Hanford Site. The glossary also contains a list of elements and their symbols and a list of selected conversion factors.

8.1 DEFINITIONS OF TERMS

absorbed dose - the quantity of energy imparted to unit mass of material exposed to radiation, expressed in rads (100 erg/gram)

activation - the induction of radioactivity in material by irradiation with neutrons or other particles

activation products - radioisotopes formed through bombardment with neutrons or other particles; nuclides such as ^{3}H, ^{63}Ni, ^{14}C, and ^{60}Co are typically considered activation products, TRU nuclides such as ^{240}Pu are also included by strict definition

active institutional control - continued control over a site by government ownership and management; considered to last at least 100 years

activity - the number of spontaneous nuclear transformations per unit time of a radioactive material

acute - happening over a short time period, usually referring to accidents

adsorption - adhesion of atoms, ions, or molecules to the surface of liquids or solid bodies they contact

advective flow - movement of water as represented by average velocity

airborne radioactive material - radioactive aerosols, particles, mists, fumes, and/or gases transported by air

alluvial plain - rock deposit laid down by streams flowing from mountains into lowland regions

alpha decay - radioactive decay in which an alpha particle is emitted from the nucleus of an atom

alpha particle - a positively charged particle made up of two neutrons and two protons (nucleus of helium atom) emitted by certain radioactive materials

Glossary; Definitions of Terms

anticline - an up-arched fold in which the rock strata dip away from the fold's axis; opposite of syncline

aquifer - a subsurface formation containing sufficient saturated permeable material to yield significant quantities of water

atomic number (Z) - the number of protons (positive charges) in the nucleus of each chemical element

background radiation - radioactivity from naturally occurring sources; principally radiation from cosmogonic and primordial radionuclides

basalt - a dark, fine-grained, extrusive igneous rock

beta radiation - charged particles (electrons or positrons) emitted from the nuclei of atoms undergoing nuclear transformations

bioconcentration (bioaccumulation) - the process whereby an organic system selectively removes an element from its environment and accumulates that element in a higher concentration

biomass - the total mass of living and dead organisms present in an area, volume, or ecological system

biosphere - the portions of the earth, atmosphere, lithosphere, and hydrosphere that support plant and animal life; that is, the life zone

biota - the plant and animal life of a region

biotic - caused by living organisms

burial ground - land area specifically designated to receive contaminated waste packages and equipment, usually in trenches covered with overburden

caliche - an accumulation of calcareous material formed in soil or sediments in arid regions

capable (fault) - said of a fault if there is evidence of a movement at or near the ground surface during the last 35,000 years or of two or more movements during the last 500,000 years

Cenozoic - the latest of eras into which geologic time is divided; from about 65 million years before present time, to present

chemical processing - chemical treatment of materials to separate specific usable constituents; at Hanford, the separation by chemical means of plutonium from uranium and fission products resulting from the irradiation of uranium in a nuclear reactor

chronic - occurring over a long time period, or continuous, as opposed to acute

clast - a piece, fragment or grain of rock material

coliform (count, number) - a measure of the bacterial content of water; a high coliform count indicates potential contamination of a water supply by human waste

colluvium - loose, incoherent soil or rock material at the base of a slope

confined aquifer - a subsurface water-bearing region having defined, relatively impermeable upper and lower boundaries and whose pressure is significantly greater than atmospheric pressure

conservative - conservative choices of parameters or assumptions are those that would tend to overestimate rather than underestimate impacts

contamination (contaminated material) - the deposition, solvation, or infiltration of radionuclides on or into an object, material, or area; the presence of unwanted radioactive materials or their deposition, particularly where it might be harmful

crib - an underground structure designed to receive liquid waste that can percolate into the soil either directly and/or after traveling to a connected tile field

criteria - often used in conjunction with standards; criteria are general guidelines or principles from which more quantitative or definitive standards are prepared to regulate activities

curie - a unit of activity equal to 3.7×10^{10} disintegrations per second

daughter products - radioactive decay products; the nuclides formed by the radioactive disintegration of a first nuclide (parent)

decay, radioactive - a spontaneous nuclear transformation of one nuclide into a different nuclide or into a different energy state of the same nuclide by emission of particles and/or photons

decommission - to isolate securely any radioactive or hazardous waste materials remaining after permanent closure of a facility, reducing potential health, safety, and environmental impacts of surplus facilities, including activity to stabilize, reduce, or remove radioactive contamination

decontamination - the removal of radioactive contamination from facilities, soils, or equipment by washing, chemical action, mechanical cleaning, or other techniques

diastrophism - the process by which the earth's crust is deformed, producing mountains, faults, etc.

dismantlement - those actions required to disassemble and remove sufficient radioactive or contaminated materials from the facility and site in order to permit release of the property to unrestricted use

dispersion - phenomenon by which a material placed in a flowing medium gradually spreads and occupies an ever-increasing portion of the flow domain

disposal - emplacement of waste so as to ensure isolation from the biosphere without maintenance and with no intent of retrieval and requiring deliberate action to gain access after emplacement

disposal site - the area dedicated to waste disposal and related activities

distribution coefficient (or K_d) - as used here, K_d is defined as moles of solute adsorbed per gram of solid, divided by moles of solute left in solution per milliliter of solution

dose commitment - the integrated dose which results from an intake of radioactive material when the dose is evaluated from the beginning of intake to a later time (usually 50 to 70 years)

dose equivalent - the product of absorbed dose, quality factor, distribution factor, and other modifying factors necessary to evaluate the effects of irradiation received by exposed persons, so that the different characteristics of the exposure are taken into account; commonly expressed in rem

dose rate - the radiation dose delivered per unit time

ecology - the branch of biological science that deals with the study of relationships between organisms and their environment

ecosystem - an assemblage of biota (community) and habitat

environmental surveillance - a program to monitor the effects on the surrounding region of the discharges from industrial operations

eolian - related to, formed by, or deposited by wind

evapotranspiration - the combined loss of water from soil by evaporation and from the surfaces of plant structures

exposure - the condition of being made subject to the action of radiation; a measure, in roentgens, of the ionization produced in air by x ray or gamma radiation (see roentgen)

fallout - radioactive materials deposited on the earth's surface and in the atmosphere following the detonation of nuclear weapons

fault - a break in the continuity of a rock formation, caused by a shifting or dislodging of the earth's crust, in which adjacent surfaces are differentially displaced parallel to the plane of fracture

fission products - the lighter atomic nuclides (fission fragments) formed by the fission of heavy atoms; refers also to the nuclides formed by the fission fragments' radioactive decay

fixative - a substance (such as paint, asphalt, or grout) used to stabilize loose contamination

flow top - uppermost part of a basalt flow

fluence - see neutron fluence

fluvial - pertaining to or produced by rivers or streams

food chain - a linear sequence of successive utilizations of nutrient energy by a series of species

fuel (nuclear, reactor) - fissionable material used as the source of power when placed in a critical arrangement in a nuclear reactor

fuel storage basin - a water-filled facility for holding irradiated reactor fuels

gamma radiation - electromagnetic energy emitted in the process of a nuclear transition

gastrointestinal (GI) dose - the dose to the stomach and lower digestive tract of humans and animals via external exposure or via internal transport of radioactive material

genetic effects - radiation-induced effects (primarily mutations) that affect the descendants of the exposed individual; also called "hereditary" effects

glaciofluvial - pertaining to streams flowing from glaciers, or the deposits made from such streams

greenhouse - in radiation protection, a temporary structure, frequently of wood and plastic film, used as a confinement barrier between a radioactive work area and a nonradioactive area to prevent the spread of contamination

ground water - water that exists or flows below the surface (within the zones of saturation)

grout - a fluid mixture of cement, water, fly ash, and clay that sets up as a solid mass and is used for waste fixation or immobilization

habitat - the characteristics of the place where biota live

half-life - the time required for a radionuclide's activity to decay to half its value, used as a measure of the persistence of radioactive materials; each radionuclide has a characteristic constant half-life

hazardous waste - potentially dangerous materials that may include radioactive materials, depending on the legal definition; those wastes that are identified as hazardous pursuant to 40 CFR 261 or 40 CFR 300

health effects - in the context used here, health effects are delayed somatic and genetic effects that may occur in a population as a result of exposure to radiation; specifically, cancers resulting from exposure of body cells, and abnormalities in future generations resulting from exposure of germ cells

hydraulic conductivity - the parameter relating the volumetric flux to the driving force in flow through a porous medium (particularly water through soil); a function of both the porous medium and the properties of the fluid

hydraulic potential - a measure of the force present to cause ground-water flow; related to the height of the column of water above the point relative to mean sea level

immobilization - a process such as grouting or vitrification designed to inhibit mobility of waste

infiltration - flow or movement of water through the soil surface into the ground

influent - flowing into, joining

institutional control - see "active institutional control"

interbed - sedimentary material between basalt flows

interflow - between basalt flows

intruder - a person who comes in contact with radioactive waste at or near the point of disposal, either deliberately or inadvertently

inversion - a condition in which temperature increases with height in the atmosphere

irradiation - exposure to radiation by being placed near a radioactive source; usually, in the case of fuel materials, being placed in an operating nuclear reactor

isotope - nuclides with the same atomic number (i.e., the same chemical element) but with different atomic masses; although chemical properties are the same, radioactive and nuclear properties may be quite different for each isotope of an element

leach - to dissolve out the soluble components of a solid by contact with water or other solvent

leachate - the solution or product obtained from leaching

lithologic - pertaining to the characteristics and study of rocks

liquefaction - the property of certain loose granular earth material, when saturated with water and physically disturbed, to behave temporarily as a liquid

loess - a homogeneous, nonstratified, unindurated sediment, largely silt, mainly wind deposited

low-level waste (LLW) - radioactive waste not classified as high-level waste or spent nuclear fuel (as defined by the Low-Level Radioactive Waste Policy Act)

lysimeter - an instrument for measuring the water percolating through soils and determining the materials dissolved by the water

magnitude - a measure of the strength of an earthquake

marker - a surface or subsurface monument or plaque of durable material containing a warning and/or information message designed to inhibit intrusion

mass number (A) - the number of nucleons (protons and neutrons) in the nucleus of an atom

maximally exposed individual - a hypothetical member of the public whose habits tend to maximize radiation dose to a given organ; for the case where exposures from airborne radionuclides result in the highest contribution to dose, this individual is assumed to reside continuously at the location of highest airborne radionuclide concentration and to eat food grown there

Miocene - an epoch of the geologic time scale; from about 22 million to 5 million years before the present

monitoring wells - holes sunk in the ground to various depths where instruments are lowered or water samples are taken to determine presence of radioactive or hazardous substances

neutron - a particle existing in or emitted from the atomic nucleus; it is electrically neutral and has a mass about equal to that of a stable hydrogen atom

neutron activation - the process of irradiating a material with neutrons so that the material itself is transformed into a radioactive nuclide

neutron fluence - the total number of particles that have passed through a unit area in a specified length of time

nuclear radiation - particles and electromagnetic energy given off by transformations occurring in the nucleus of an atom

nuclear reactor - a device constructed of fissionable material such that a chain of fission events can be maintained and controlled to meet a particular purpose

nuclide - a species of atom having a specific mass, atomic number, and nuclear energy state

offsite - any place outside the Hanford Site boundary

onsite - within the Hanford Site boundary

organ - for purposes of this EIS, the term "organ" is used to represent the lungs, bone, thyroid, or the intestinal tract

overburden - soil used to backfill an excavation containing solid waste or a liquid-waste disposal structure

packaging - assembly of radioactive material in one or more containers

passive institutional control - control by barriers, markers, land records, etc.

pathway analysis - the study of the movement of radioactive materials from the source to locations of interest; may involve computer simulation

penetrating radiation - forms of radiation capable of passing through significant thicknesses of solid material; usually include gamma rays, x rays, and neutrons; also specifically, radiation capable of penetrating human skin and exposing internal organs

percolation - gravity flow of ground water through the pore spaces in rock or soil

periphyton - organisms that live attached to underwater surfaces

permeability - capacity of a medium for transmitting a fluid

person-rem - the product of the dose equivalent in rem and the number of people receiving that dose, a collective population dose (also "man-rem")

phytoplankton - microscopic plants that live drifting in a body of water

Pleistocene - the most recent epoch of the geologic time scale; about 1.3 million to 100,000 years before the present

population dose (population exposure) - summation of individual radiation doses received by all those exposed to the source or event being considered, expressed in person-rem

porosity - the ratio of the aggregate volume of small spaces or pores in a rock soil to its total volume

production reactor - a nuclear reactor designed for transforming one nuclide into another, usually natural uranium into plutonium

PUREX - Plutonium and Uranium Recovery through EXtraction, latest in a line of separation technologies, preceded by bismuth phosphate and REDOX

rad - a unit of measure for the absorbed dose of radiation; 1 rad equals 100 ergs absorbed per gram of material

radiation (ionizing) - particles and electromagnetic energy emitted by nuclear transformations that are capable of producing ions when interacting with matter

radiation monitoring - a term covering application of a field of knowledge including determination of dose rates, surveys of personnel, and equipment for contamination control, air sampling, exposure control, etc.

radiation survey - evaluation of an area or object with instruments to detect, identify, and quantify radioactive materials and radiation fields present

radioactive (decay) - the undergoing of spontaneous nuclear transformation in which electromagnetic energy or nuclear particles are emitted

radioactive waste - solid, liquid, or gaseous material of negligible economic value that contains radionuclides

radioactivity - the property of certain nuclides of emitting particles or electromagnetic radiation while undergoing nuclear transformations

radionuclide - a nuclide that is radioactive

raptor - bird of prey

reactor - see nuclear reactor

recharge - the net process of water percolating downward through the soil profile resulting from the individual processes of precipitation, surface runoff, and evapotranspiration

recharge rate - the net rate of downward water movement resulting from recharge; units are mass or volume per unit time per unit area ($cm^3/yr\ cm^2$)

regolith - rock "waste" or surface mantle of unconsolidated rock debris; in the Pasco Basin, the basin-fill sediments that are the parent materials of the local soils

rem - the special unit of the dose equivalent; the radiation dose equivalent in rems is numerically equal to the absorbed dose in rads at the point of interest in tissues, multiplied by a quality factor, distribution factors, and all other modifying factors; one rem approximately equals one rad for x, gamma, or beta radiation

residual radioactivity - any radioactivity remaining following contamination

riparian - related to or located along the bank of a natural water course, such as a river

riprap - broken stones that are placed irregularly in a wall to strengthen a bank of soil

river mile - distance in miles measured upstream from river mouth

roentgen - a unit of measure of ionizing electromagnetic radiation (exposure) (x and gamma rays); one roentgen corresponds to the release by ionization of 83.8 ergs of energy per gram of air

routine release - a planned, nonaccidental release of radionuclides during normal operation of a facility

saturated zone - the subsurface zone in which all interconnecting voids or pores are filled with water

seismicity - the tendency for earthquakes to occur

shallow-land burial - disposal of waste in near-surface excavations that are covered with a protective overburden

shielding - bulkheads, walls, or other constructions used to absorb radiation in order to protect personnel or equipment

sludge - primarily material collected from the bottom of fuel storage basins

somatic effects - radiation-induced effects that become manifest in the cells of an exposed individual; at low doses and dose rates, these are statistically predicted delayed cancers

source term - the quantity of radioactive material, released by an accident or operation, which causes exposure after transmission or deposition

special nuclear material - plutonium, uranium-233, uranium enriched in the isotopes 233 or 235

spent nuclear fuel - fuel that has been withdrawn from a nuclear reactor following irradiation, whose constituent elements have not been separated by reprocessing

stability (atmospheric) - a description of the atmospheric forces on a parcel of air following vertical displacement in an atmosphere otherwise in hydrostatic equilibrium; if the forces tend to return the parcel to its original level, the atmosphere is stable; if they tend to move the parcel farther in the direction of displacement, the atmosphere is unstable; if the air parcel tends to remain at its new level, the atmosphere has neutral stability

storage - retention of waste in a retrievable manner that requires surveillance and institutional control

subsidence - gradual or sudden sinking of the ground surface below natural grade level due to slow decay and compression of material or collapse of a void space

surplus facility - any facility or site (including equipment) that has no identified programmatic use and may or may not be radioactively contaminated to levels that require controlled access

surveillance - activities to ensure that site waste remains safe, including inspection and monitoring of the site, maintenance of access barriers to radioactive materials left on the site, and prevention of activities on the site that might impair these barriers

survey - an evaluation of the radiation hazards incidental to the production, use, release, disposal, or presence of radioactive materials or other sources of radiation under a specific set of conditions

syncline - a low, trough-like area in bedrock, in which rocks incline together from opposite sides

tectonic - pertaining to or designating the rock structures resulting from deformation of the earth's crust

transmissivity - a coefficient relating the volumetric flow of ground water through a unit width to the driving force (hydraulic potential); a function of the porous medium, fluid properties, and saturated thickness of the aquifer

transuranic (TRU) waste - without regard to source or form, radioactive waste that at the end of institutional control periods is contaminated with alpha-emitting transuranium radionuclides with half-lives greater than 20 years and concentrations greater than 100 nCi/g.

transuranium radionuclide - any radionuclide having an atomic number greater than 92.

200-Area Plateau - highest portion (aside from Rattlesnake and Gable Mountains) on the Hanford Site, containing most of the waste-processing and storage facilities

unconfined aquifer - an aquifer that has a water table or surface at atmospheric pressure

unrestricted release level - amount of residual radioactivity that will be allowed to remain in lands, structures, or materials following decommissioning and still permit other use of the lands, structures, or materials; based on standards to be defined in 40 CFR 194

vadose zone - the unsaturated region of soil between the ground surface and the water table

vesicle - a small cavity in a once-molten rock, formed by steam or gas during solidification of the rock

water table - upper boundary of an unconfined aquifer surface below which soil saturated with ground water occurs; defined by the levels at which water stands in wells that barely penetrate the aquifer

wind rose - a diagram designed to show the distribution of wind directions at a given location; one variation includes wind speed groupings by direction

8.2 ACRONYMS, ABBREVIATIONS, AND SYMBOLS

ALARA - as low as reasonably achievable

ALE - Arid Lands Ecology, a research reserve on the Hanford Site operated for the DOE by Pacific Northwest Laboratory

CAA - Clean Air Act

CEQ - Council on Environmental Quality

CERCLA - Comprehensive Environmental Response, Compensation, and Liability Act of 1980, as amended

CF - concentration factor

CFR - U.S. Code of Federal Regulations

Ci - curie

cm - centimeter

cm^3 - cubic centimeter

CWA - Clean Water Act

DEIS - draft environmental impact statement

DOE - U.S. Department of Energy

EIS - environmental impact statement

EPA - U.S. Environmental Protection Agency

FEIS - final environmental impact statement

ha - hectare = 10,000 m^2, equivalent to 2.47 acres

HEPA - high efficiency particulate air (filter)

HDW - Hanford defense waste, or the DOE's 1986 draft and 1987 final EIS on the disposal of Hanford defense wastes (DOE/EIS-0113)

ICRP - International Commission on Radiation Protection

K_d - distribution coefficient

L - liter

LET - linear energy transfer

LLI - lower large intestine

LLW - low-level waste

m^3 - cubic meter

mrad - millirad

mrem - millirem

mR - milli-Roentgen

MSL - mean sea level

nCi - nanocurie (1×10^{-9} Ci)

NEPA - National Environmental Policy Act of 1969

NERP - National Environmental Research Park

NESHAP - National Emission Standards for Hazardous Air Pollutants

NCRP - National Council on Radiation Protection and Measurements

NRC - Nuclear Regulatory Commission

pCi - picocurie (1×10^{-12} Ci)

pH - a measure of acidity and alkalinity

PMF - probable maximum flood

PNL - Pacific Northwest Laboratory

ppm - parts per million

PUREX - Plutonium and Uranium Recovery through EXtraction

Q - release quantity of radioactive materials, Ci

Q′ - release rate of radioactive material, Ci/sec

RCRA - Resource Conservation and Recovery Act

SDWA - Safe Drinking Water Act

SI - Systeme Internationale

SPF - standard project flood

t - tonne (metric ton) = 1,000 kg = 2,200 lb

T - standard ton

Tri-Cities - area including cities of Kennewick, Pasco, and Richland, Washington

TRU - transuranic

WNP-2 - Washington Nuclear Plant Number 2

wt - weight

χ - chi, concentration, Ci/m^3

$\bar{\chi}/Q'$ - chi-bar/Q prime, normalized annual average air concentration (Ci/m^3) per Ci/sec released, also written sec/m^3); also called the annual average atmospheric dispersion factor

8.3 ALPHABETICAL LIST OF ELEMENTS AND THEIR SYMBOLS

Element	Symbol	Element	Symbol	Element	Symbol
Actinium	Ac	Hafnium	Hf	Praseodymium	Pr
Aluminum	Al	Helium	He	Promethium	Pm
Americium	Am	Holmium	Ho	Protactinium	Pa
Antimony	Sb	Hydrogen	H	Radium	Ra
Argon	Ar	Indium	In	Radon	Rn
Arsenic	As	Iodine	I	Rhenium	Re
Astatine	At	Iridium	Ir	Rhodium	Rh
Barium	Ba	Iron	Fe	Rubidium	Rb
Berkelium	Bk	Krypton	Kr	Ruthenium	Ru
Beryllium	Be	Lanthanum	La	Samarium	Sm
Bismuth	Bi	Lawrencium	Lr	Scandium	Sc
Boron	B	Lead	Pb	Selenium	Se
Bromine	Br	Lithium	Li	Silicon	Si
Cadmium	Cd	Lutetium	Lu	Silver	Ag
Calcium	Ca	Magnesium	Mg	Sodium	Na
Californium	Cf	Manganese	Mn	Strontium	Sr
Carbon	C	Mendelevium	Md	Sulfur	S
Cerium	Ce	Mercury	Hg	Tantalum	Ta
Cesium	Cs	Molybdenum	Mo	Technetium	Tc
Chlorine	Cl	Neodymium	Nd	Tellurium	Te
Chromium	Cr	Neon	Ne	Terbium	Tb
Cobalt	Co	Neptunium	Np	Thallium	Tl
Copper	Cu	Nickel	Ni	Thorium	Th
Curium	Cm	Niobium	Nb	Thulium	Tm
Dysprosium	Dy	Nitrogen	N	Tin	Sn
Einsteinium	Es	Nobelium	No	Titanium	Ti
Erbium	Er	Osmium	Os	Tungsten	W
Europium	Eu	Oxygen	O	Uranium	U
Fermium	Fm	Palladium	Pd	Vanadium	V
Fluorine	F	Phosphorus	P	Xenon	Xe
Francium	Fr	Platinum	Pt	Ytterbium	Yb
Gadolinium	Gd	Plutonium	Pu	Yttrium	Y
Gallium	Ga	Polonium	Po	Zinc	Zn
Germanium	Ge	Potassium	K	Zirconium	Zr
Gold	Au				

8.4 CONVERSION FACTORS

Length

1 centimeter (cm) = 0.3937 inch
1 meter (m) = 3.281 feet
1 kilometer (km) = 0.6215 mile

Mass

1 kilogram (kg) = 2.2 pounds
1 metric ton = 2,200 pounds

Area

1 square centimeter meter (cm^2) = 0.155 square inch

1 square meter (m^2) = 10.76 square feet

1 square kilometer (km^2) = 0.386 square mile
= 247 acres

1 hectare (ha) = 10,000 square meters
= 2.47 acres

Volume

1 cubic meter (m^3) = 1,000 liters
= 10^6 cm^3
= 35.31 cubic feet
= 264 gallons

Multiplier	Prefix	Symbol	Equivalent
10^{12}	tera	T	trillion
10^{9}	giga	G	billion
10^{6}	mega	M	million
10^{3}	kilo	k	thousand
10^{2}	hecto	h	hundred
10^{1}	deka	da	ten
10^{-1}	deci	d	a tenth part
10^{-2}	centi	c	a hundredth
10^{-3}	milli	m	a thousandth
10^{-6}	micro	μ	a millionth
10^{-9}	nano	n	a billionth
10^{-12}	pico	p	a trillionth
10^{-15}	femto	f	one thousandth of a millionth of a millionth
10^{-18}	atto	a	one millionth of a millionth of a millionth

APPENDIX A

DESCRIPTION OF SURPLUS REACTORS

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APPENDIX A

DESCRIPTION OF SURPLUS REACTORS

This appendix describes the surplus production reactors and their respective spent-fuel storage basins for the following designated facilities: 105-B, 105-C, 105-D, 105-DR, 105-F, 105-H, 105-KE, and 105-KW. For purposes of consistency with the previously published radiological characterizations of these reactor facilities (Miller and Steffes 1987), the 105-DR Reactor facility is described as the typical or reference reactor. Reactors other than 105-DR are also used in describing a typical reactor; for example, in describing parts of the reactor block, the 105-F Reactor is utilized. Significant differences between the 105-DR Reactor and its spent-fuel storage basin and the other seven surplus production reactor facilities are described, as necessary, to facilitate the assessment and evaluation of those differences as they affect decommissioning technology, safety, and costs.

The eight surplus production reactors were constructed during the period 1943 to 1955 in five separate self-supporting complexes (100 Areas) adjacent to the Columbia River, where the large volume of water necessary for reactor cooling was readily available. The 100 Areas are located in the northern portion of the Hanford Site, as shown in Figure A.1. All of the surplus reactors have been inactive since 1971. Table 2.1 in Chapter 2.0 gives the history and status of each surplus reactor. Table A.1 gives the elevation above sea level of the ground floor of each reactor.

The surplus production reactors are quite similar in design, with the K Reactors differing from the older production reactors mainly in the number, size, and type of process tubes; the size of the graphite moderator stack; and the type of shielding employed.

Each of the eight surplus reactor facilities in the 100 Areas is divided into two major parts for descriptive purposes: 1) the nuclear reactor, and 2) its associated irradiated fuel storage basin. Both of these parts of the reactor facilities are discussed in this appendix in terms of physical

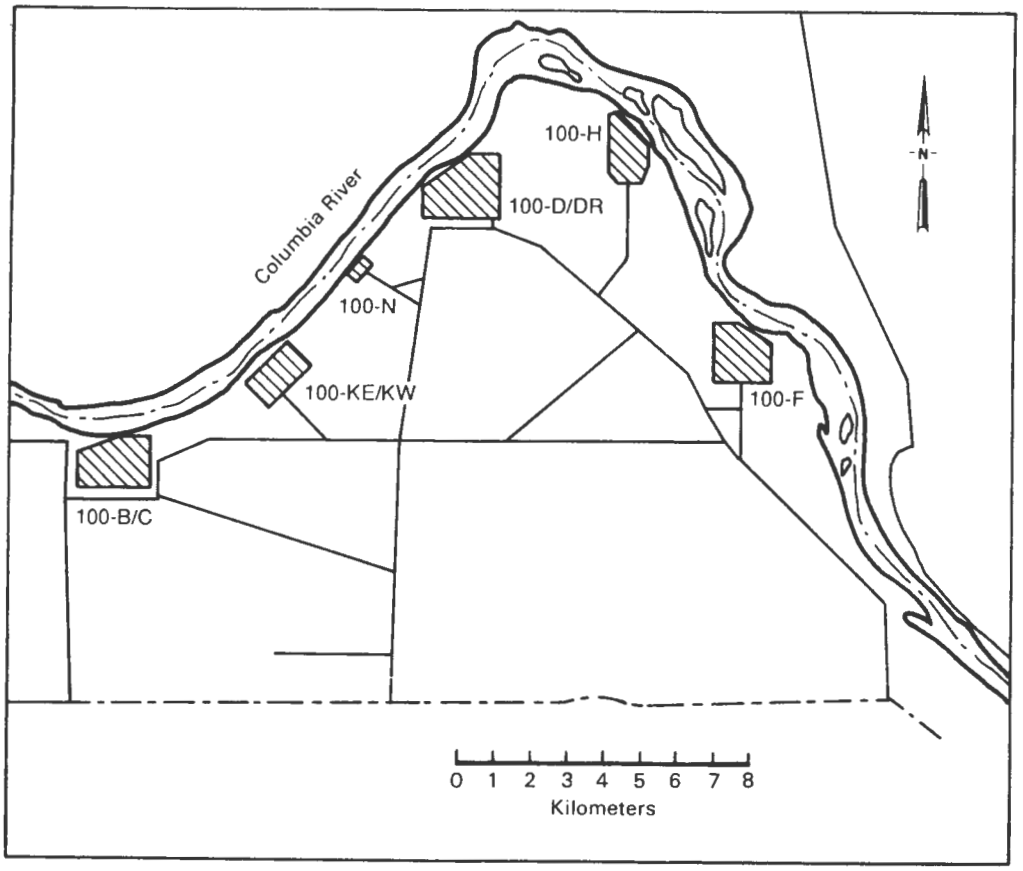

FIGURE A.1. Hanford Site 100 Areas

TABLE A.1. Elevation Above Sea Level of the Ground Floor of Each Reactor[a]

Reactor	Elevation (m)
105-B	142.8
105-C	150.6
105-KE	141.7
105-KW	141.7
105-D	142.2
105-DR	142.0
105-H	128.9
105-F	125.7

(a) The elevation of the bottom of each fuel storage basin is approximately 6.1 m beneath the elevation of the ground floor.

descriptions, significant differences between the reference 105-DR facility and the other reactor facilities, radiological characteristics, and hazardous nonradioactive materials.

A.1 PHYSICAL DESCRIPTION OF THE NUCLEAR REACTORS

The surplus production reactors, which are graphite moderated and water cooled, were used to produce weapons-grade plutonium. Each reactor building, designated as a 105 building, contains a reactor block, a reactor control room, a spent-fuel discharge area, fuel storage basin and associated fuel handling equipment, fans and ducts for the ventilation and recirculating gas systems, water cooling systems, and supporting offices, shops, and laboratories. A typical reactor facility (Figure A.2) is a reinforced concrete and concrete block structure approximately 76 meters long, by 70 meters wide, by 29 meters high. The building has massive reinforced concrete walls (0.9 meter to 1.5 meters thick) around the reactor block to provide radiation shielding, with lighter construction above (either concrete block or corrugated asbestos-cement). Roof construction is primarily precast concrete slab or poured insulating concrete. Except for the reinforced concrete portions, these buildings can be classified as light, non-airtight, industrial structures.

As shown in Figure A.2, the reactor block is located near the center of the building. Horizontal control-rod penetrations are on the left side of the reactor block (when facing the reactor front face), and vertical safety-rod penetrations are on the top of the reactor. Fuel discharge and storage areas are located adjacent to the rear face of the reactor. Experimental test penetrations are located on the right side of most of the reactors.

A.1.1 Reactor-Block Description

A typical reactor block (Figure A.3) consists of a graphite moderator stack encased in cast iron thermal shielding (20.3 to 25.4 centimeters thick) and a biological shield (alternating layers of steel plate and masonite, or heavy aggregate concrete, 101.6 to 210.8 centimeters thick). Studies have shown that some powdering of the masonite has occurred, but this

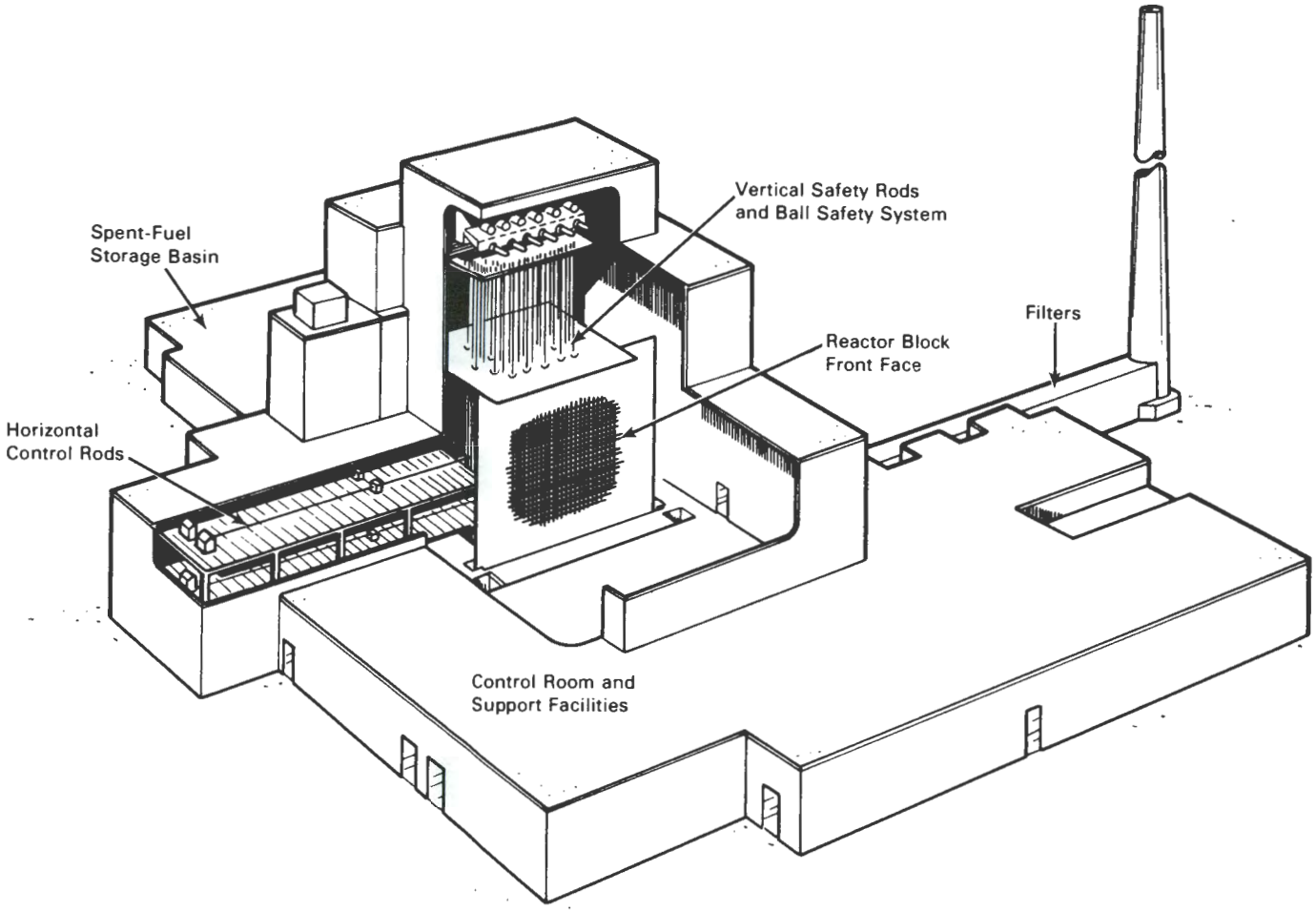

FIGURE A.2. Typical Reactor Facility

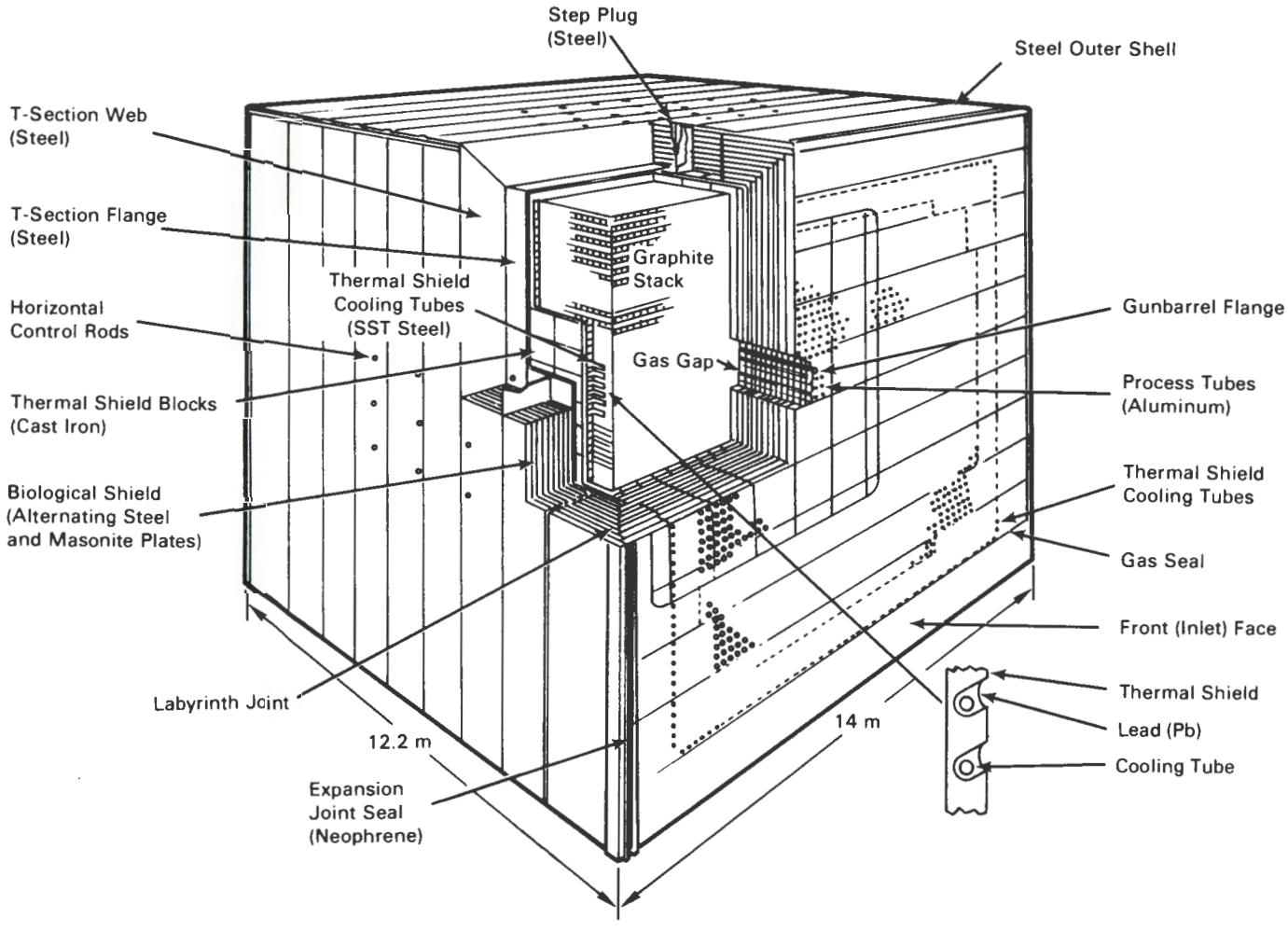

FIGURE A.3. Reactor-Block Construction

deterioriation has not reduced the structural integrity of the reactor block as a whole (Adams et al. 1984). The entire block rests on a massive concrete base and foundation. A typical reactor block assembly weighs approximately 8,117 tonnes (including the weight of the base), and has overall dimensions of 14 meters high, by 14 meters wide, by 12.2 meters deep. The principal components of a production reactor block are:

- the reactor moderator stack, an assembly of graphite blocks cored to provide channels for process tubes, control rods, and other equipment
- thermal and biological shielding, surrounded by a heavy, vault-like steel outer shell equipped with gas-tight seals for the reactor block penetrations
- the process tubes, which held the uranium fuel elements and carried the cooling water
- horizontal control rods
- vertical safety rods
- the ball 3X system, which was used for dropping neutron-absorbing steel-and-boron balls into vertical safety channels for emergency reactor shutdown
- monitoring equipment, and experimental and test equipment.

The following description pertains to the 105-F Reactor, but is considered typical of the 105-B, 105-C, 105-D, 105-DR, and 105-H Reactors as well.

A.1.1.1 Graphite Moderator Stack

The encapsulated graphite moderator stack measures 11 meters high, by 11 meters wide, by 8.5 meters long; its total volume is 1,028 cubic meters. Individual graphite blocks, stacked tightly in a criss-cross pattern, are 10.6 centimeters square by 121.9 centimeters in length. The weight of the graphite is approximately 1,636.4 tonnes.

A.1.1.2 Thermal Shield

The graphite stack is bordered underneath by a layer of 26-centimeter-thick cast-iron blocks (the bottom wall of the thermal shield). A massive steel-reinforced high density concrete base completely underlies the thermal shield, serving as a support pad. The full six-sided thermal shield is composed of a single layer of approximately 3,300 cast-iron blocks, varying greatly in size and weight. The bottom shield is made up of 136 blocks, measuring 115.6 by 82.6 by 26 centimeters. Each of the bottom blocks weighs 1.25 tonnes. The top shield consists of 144 blocks, each measuring 115.6 by 67.3 by 20.6 centimeters thick, and weighing 0.964 tonnes. The total weight of the top and bottom thermal shield blocks is 308.8 tonnes.

The two thermal shield side walls are each made up of approximately 170 cast-iron blocks, each measuring 20 by 66.4 by 94 centimeters and weighing 0.75 tonnes. Edge and corner blocks vary slightly in overall size and weight. The total weight of the two side thermal shield blocks is 255 tonnes.

The front and rear face thermal shields consist of 2,704 blocks ranging in size from 17 by 16.7 by 25.6 centimeters to 23.8 by 20.8 by 17 centimeters, and varying in weight from 39.5 to 168.2 kilograms apiece. The weight of the front and rear face thermal shield blocks is about 455 tonnes.

The top, bottom, and side thermal shields contain slots that hold cooling tubes. The cooling tubes are held in place by lead (Pb) poured into the slots around the tubes. A total of about 650 tonnes of lead is contained in the thermal shields of all eight surplus reactors.

A.1.1.3 Biological Shield

The next layer of shielding is the biological shield. It measures 132 centimeters thick, and forms an integral encasement on the top and four sides. On the top and two sides, steel plate T-section flanges (each approximately 14 meters long, 1.2 meters wide, and 1.33 meters high) form the inner wall and ribbing of the biological shield. Eight flanges per wall are situated vertically on the control rod and experimental level sides of the block,

with stems facing outward. Other flanges lie horizontally on top of the reactor, aligned with the side wall flanges.

The 1.2-meter-wide flanges adjacent to the thermal shield are 6.35-centimeter-thick steel plate. They were welded along each edge, except at the top edges, to the next adjoining T-section flange. The resulting metal-walled cells (approximately 14 meters long, by 1.2 meters wide, by 1.26 meters deep) were filled with 12 alternating layers of material: six layers of 11.43-centimeter-thick masonite, and six double-plate layers of 4.76-centimeter-thick steel. Each layer of steel plate was welded along all junctures to the cell walls. An outer shell of 0.635-centimeter steel plate was welded in place to completely seal the top and side walls of the biological shield. The total weight of the top and both side biological shields including the steel plate, masonite, and steel cover plate is about 2,455 tonnes.

The top biological shield is not welded to the side walls of the reactor block. The shield was laid in place, with edges of all four walls meeting in diagonal, stair-step labyrinth joints. All seams are enclosed by gas-tight expansion seals.

The reactor's front and rear face biological shielding was fabricated in the same alternately layered pattern of masonite and steel, but in sectioned blocks rather than solid walls. There are a total of 264 such blocks (called B-blocks), 132 on each face. Each full block weighs 7.22 tonnes, and the transition blocks each weigh 4.41 tonnes. On each face, 69 blocks were drilled and fitted with equally spaced process-tube support sleeves (gun-barrels). Two layers of 0.635-centimeter-thick steel plate horizontal tie straps were plug-welded to each row of blocks across the front and rear reactor faces. All seams between tie straps and all edges and corners of the reactor block were sealed with expansion seals. The total weight of the inlet and outlet B-blocks is about 2,002.6 tonnes.

A.1.1.4 Process Tubes

Extending through the reactor block from the front to the rear face are 2,004 symmetrically located 4.399-centimeter-diameter aluminum process tubes.

These tubes are connected to the cooling-water piping on both the front and rear face. The estimated weight of the process tubes and corresponding gun barrels is about 196.8 tonnes.

A.1.1.5 Foundation

The reactor block rests on a massive reinforced concrete foundation. The foundation is 19.51 meters long, 17.22 meters wide, and 6.858 meters deep. The concrete base of the reactor block is separated from the foundation by a 0.635-centimeter-thick steel membrane plate (see Figures A.4 and A.5). The estimated weight of the concrete in the reactor base is about 808 tonnes.

A.1.1.6 Summary of the Estimated Weights for the Reference Reactor Block Components

Table A.2 contains a list of major components of the typical reactor block and their respective weights. The estimated total weight of this typical reactor block is about 8,117 tonnes. As previously mentioned, the two K Reactors differ from the six older production reactors in several

TABLE A.2. Estimated Component Weights for the Reference Reactor Block

Component	Estimated Weight (kg)
Graphite moderator stack	1,636,364
Thermal shield blocks (top & bottom)	308,773
Thermal shield blocks (sides)	255,000
Thermal shield blocks (front & rear)	454,773
Biological shield (top & sides)	2,454,545
Biological shield (front & rear)	2,002,636
Process tubes & gunbarrels	196,818
Reactor base	807,727
ESTIMATED TOTAL WEIGHT	8,117,000[a]

(a) The estimated total weight is rounded up to the nearest 1,000 kg. This reference weight is considered applicable to the six older reactors; see text for 105-K Reactor's estimated weight.

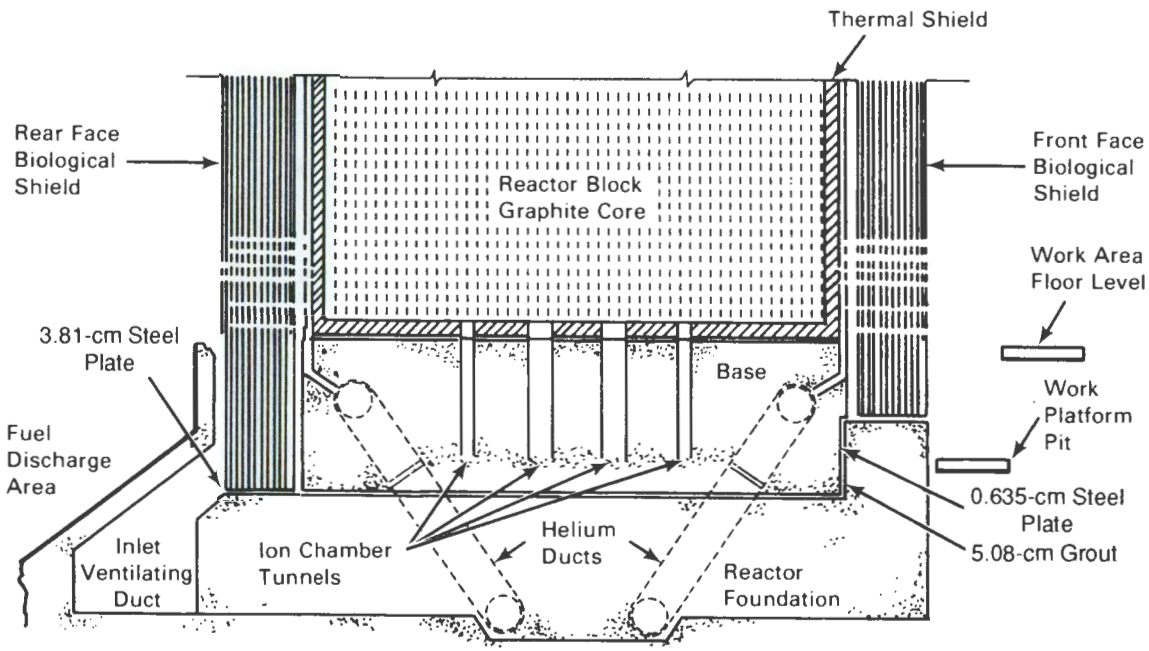

FIGURE A.4. Reactor Base (side view)

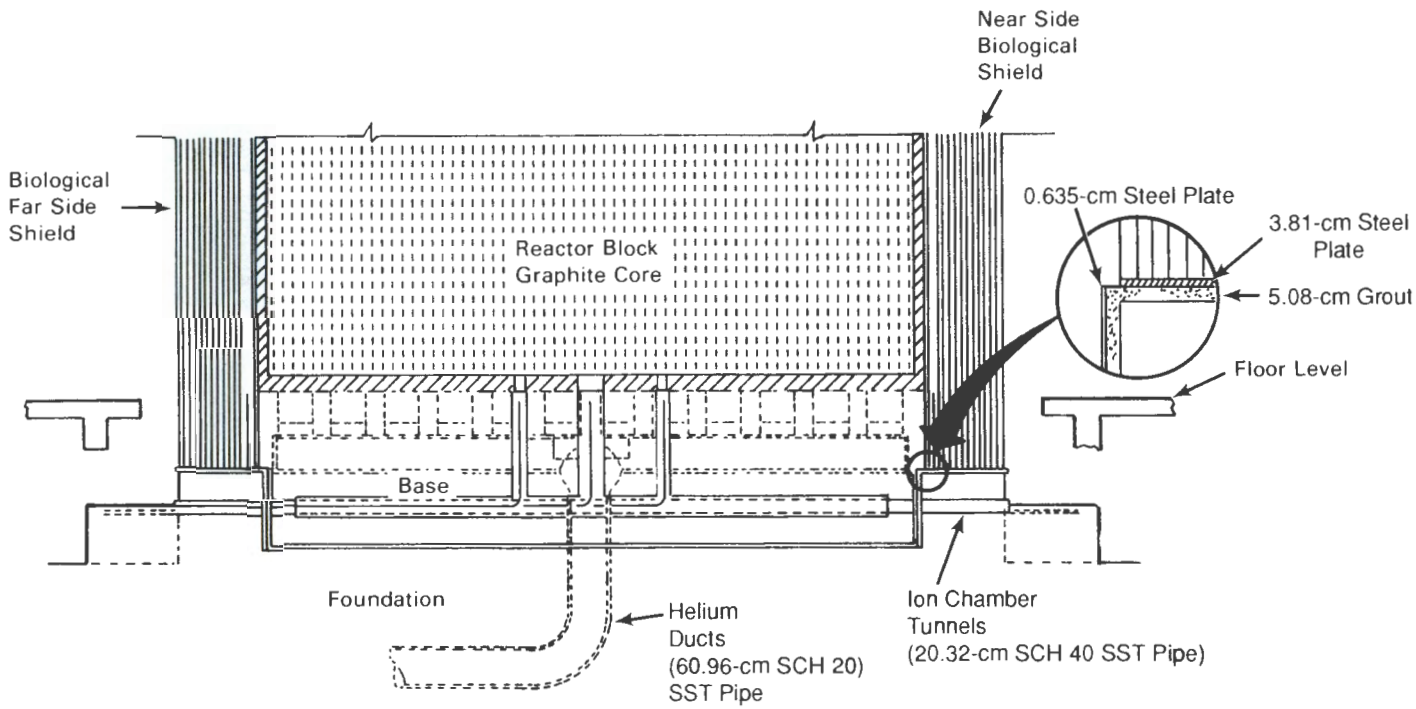

FIGURE A.5. Reactor Base (Rear View)

aspects, including the estimated total weight of their reactor blocks. The 105-K Reactor blocks are estimated to weigh approximately 11,000 tonnes each (Kaiser 1986).

A.1.2 Differences in Reactor Designs

The eight shut-down production reactors are quite similar in design, with the two K Reactors differing from the older six reactors mainly in the number, size, and type of process tubes, the size of the moderator stack, and the type of shielding employed. Information on reactor block size and construction materials used for all eight surplus reactors is given in Table A.3. Other differences for individual reactors also are described in the discussion that follows.

A.1.2.1 Differences in Reactor Block Foundation Systems

A typical reactor block rests on a massive concrete foundation. The KE/KW foundation is 6.25 meters thick. The concrete foundations for C, KE, and KW contain tunnels for the retrieval of the boron balls used for the reactor's third shut-down safety system.

A.1.2.2 Other Differences for Individual Reactors

Generic rooms and areas of interest to decommissioning operations are identified in Figure A.6 (based on the 105-F building layout). Differences for individual reactors are described below (Kaiser 1987):

- The 105-B, -D, and -F Reactors were the first of the eight reactors to be built. These three 105 buildings were constructed from the same drawings.
- The control room is located below the inner rod room floor slab, which is 0.91 meter thick. Two other rooms are between the control room and the reactor block, also beneath the inner rod room. The laboratory area adjacent to the reactor consists of a below-grade room, a concrete slab floor at ground level, and two above-grade rooms separated by a metal grating floor. A metal stairway leads up to the top of the reactor.

TABLE A.3. Hanford Production Reactor Design Data[a]

Reactors	Graphite Stack Dimensions (m)			Process Tubes			Thermal Shield		Biological Shield	
	Front to Rear	Top to Bottom	Side to Side	Number	Type	ID (cm)	Type	Thickness (cm)	Type	Thickness (m)
B, C, D, DR, F, H	8.5344	10.9728	10.9728	2,004	Aluminum	4.445[b]	Cast iron	20.32 to 25.4[d]	Steel and masonite	1.3208[c]
KE, KW	10.2108	12.4968	12.4968	3,220	Zircaloy and aluminum	4.572	Cast iron	25.4	Heavy aggregate concrete	1.143 to 2.1082

(a) From Adams et al. 1984.
(b) C Reactor has slightly larger diameter process tubes than the other reactors in this group.
(c) Layers of masonite and steel are 11.43 cm and 9.525 cm, respectively. All sides extend over the foundation forming a skirt. C Reactor top has heavy aggregate concrete, 2.1336 m thick. The biological shields are encased in a 2.54-cm steel case.
(d) Sides, 20.32-cm-thick overlapping cast-iron blocks. Top, 20.64 cm thick. Front and rear, 25.4 cm thick. Bottom, 26.035 cm thick. There is an air gap of 0.3175 cm between thermal and biological shields.

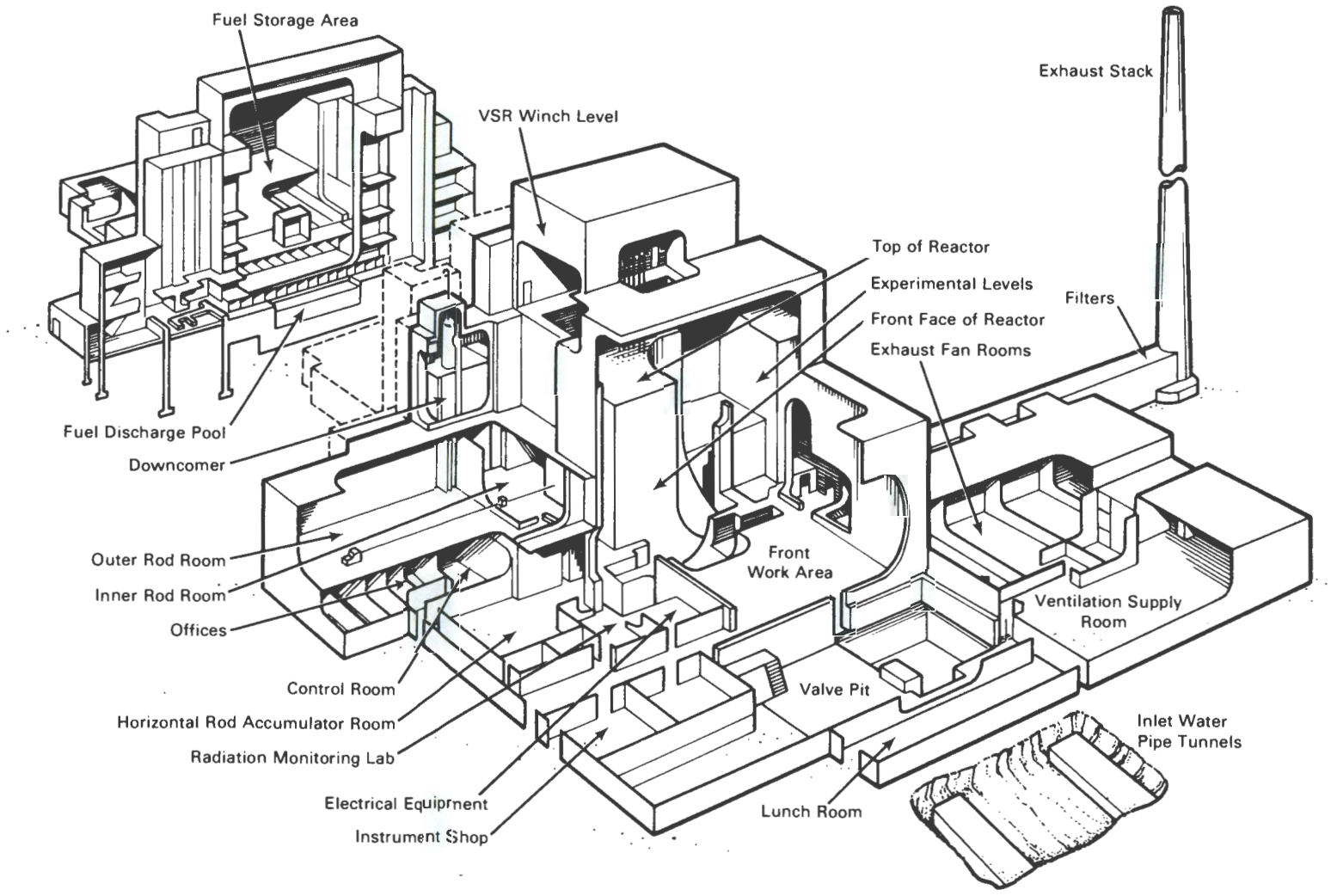

FIGURE A.6. 105 Building Layout

- The 105-DR Reactor control room and surrounding offices and rooms are located below the 1.22-meter-thick concrete slab floor of the inner and outer rod rooms. A 5.18-meter-wide tunnel runs underneath the control room area from the process area to outside the 105 building.
- The 105-C and 105-H Reactor buildings differ from the other reactors in arrangement and materials of construction:
  - Both buildings were constructed without valve pits. (More extensive tunnel networks served the same purpose.)
  - The 105-C Reactor block foundation contains narrow short tunnels for retrieving balls (3X) used as an emergency reactor shut-down method. These tunnels are inaccessible from above.
  - In 105-C, numerous rooms in the upper part of the building have cement-asbestos (transite) siding on the walls instead of concrete block.
  - The outer rod room at 105-H has poured concrete walls instead of the concrete block walls typical in the other reactors.
  - Although the fan rooms are similar to the typical reactor building, the 105-C and 105-H tunnel and underground plenums are larger, especially on 105-H. The 105-H tunnel extends far to the east under the fan room and contains numerous heavy partitions and spaces, all covered with a 0.91-meter-thick slab. The 115-H gas wing is part of the 105-H building.
- The 105-KE and 105-KW Reactor buildings were constructed using the same drawings and are, therefore, very similar. However, the KE and KW Reactors do have several deviations from the "typical" reactor in the following areas: the outer rod room, the fan rooms, the valve pit, the mechanical equipment rooms, and the miscellaneous above-grade support rooms. Brief descriptions of each of these areas follow. Storage basin differences are discussed in Section A.2.

- Outer rod room. The outer rod rooms of the 105-K Reactor buildings are constructed of 0.3048- to 0.9144-meter-thick reinforced concrete walls instead of the concrete block described for the typical reactor.
- Fan rooms. The fan rooms for the K Reactors are located on opposite ends of the building and below a reinforced concrete slab. The supply fan rooms are above-grade, and the exhaust fan rooms are below-grade. The supply fan rooms have transite walls and a reinforced concrete roof.
- Valve pit. The KE and KW Reactor valve pits are below-grade, directly under the work areas. The valve pit areas are two large rooms called piping rooms No. 1 and No. 2. These valve pits are similar to those of the typical reactor but located below the work-area floor slab.
- Mechanical equipment rooms and miscellaneous above-grade support rooms. The mechanical rooms and the miscellaneous above-grade support rooms were built with transite wall panels and reinforced concrete roofs or ceilings.

A.1.3 Radiological Characteristics of the Nuclear Reactors

The inventory of radioactivity contained in the reactors after the fuel was removed has been estimated to determine the requirements for radioactive waste packaging, shipping, and disposal, and to provide source terms for radioactivity release scenarios. A knowledge of the inventory is also necessary in estimating occupational radiation dose rates to be expected at different times from various decommissioning activities. Dose-rate measurements were made at the shut-down reactors as part of each plant's deactivation schedule in the late 1960s and early 1970s. In addition, radiation dose-rate and smear-survey data were taken at the 105-DR Reactor in January and April 1986 (Winship 1986) to evaluate the amount of radioactive decay that has taken place in that facility since shutdown in 1965. To provide accurate data for the comparison, the latter survey duplicated the earlier surveys. Results from the survey indicate that appreciable radioactive decay has taken place since the earlier surveys.

A radiological characterization program was begun in 1975 to establish radionuclide inventories and concentrations in the surplus 100-Area facilities. To quantify the radionuclide concentrations in the surplus 100-Area reactors with reasonable accuracy, representative samples of the thermal and biological shields and graphite cores were obtained. This required drilling holes through a 2.54-centimeter steel plate that encloses the biological shield, through the biological and thermal shields, and into the graphite stack. Four test holes were drilled into the DR Reactor core. Selected samples were submitted for radioisotopic analyses, and estimated inventories in the reactors and in the spent-fuel storage basins are reported (Miller and Steffes 1987).

The estimated radionuclide and hazardous chemical inventories of all eight surplus reactors are presented in the following sections. These inventories were used in the calculations of long-term consequences in Chapter 5.0.

A.1.3.1 Reactor Graphite Stack Inventory[a]

Radionuclides in the graphite originate from the carbon, the cover gas, the cooling water (from occasional tube leaks), and from the impurities present in the coke when it was processed into graphite blocks. For fission products to enter the graphite stack both a fuel element cladding failure and a simultaneous failure of the process tube are required, which would allow water, fission products, and transuranics to be carried into the graphite. The inventory from mixed fission products and transuranics remaining in the graphite stacks is made up of plutonium-239, americium-241, strontium-90, and cesium-137. Tables A.4 through A.11 show the estimated radionuclide inventories in the 100-Area reactors' graphite as of March 1985. Trace amounts of long-lived radionuclides, molybdenum-93, and niobium-94 were estimated based on impurity levels and neutron fluence.

(a) Information on radionuclide inventories has been extracted from Miller and Steffes (1987).

TABLE A.4. Estimated Radionuclide Inventory in B Reactor, as of March 1, 1985 (Ci)[a]

Radionuclide	Half-Life (yr)	Component: Graphite Stack	Thermal Shield	Process Tubes	Control System	Bio-Shield	Storage Basin	Total
^{3}H	12.3	8,300	--	--	--	--	--	8,300
^{14}C	5,730	4,500	--	--	--	--	--	4,500
^{41}Ca	1.0×10^{5}	190	--	--	--	2	--	192
^{60}Co	5.3	100	8,690	300	110	--	11	9,211
^{59}Ni	7.5×10^{4}	1	7	0.1	--	--	0.5	8.6
^{63}Ni	100	180	840	10	--	--	60	1,090
^{36}Cl	3.0×10^{5}	42	--	--	--	--	--	42
^{90}Sr	28.8	10	--	0.2	--	--	14	24.2
^{93}Zr	1.5×10^{6}	--	--	--	--	--	--	--
^{93}Mo	3,000	--	0.04	--	--	--	--	0.04
^{94}Nb	2.0×10^{4}	0.3	0.02	--	--	--	--	0.32
^{99}Tc	2.1×10^{5}	--	0.002	--	--	--	--	0.002
^{108}Ag	27	--	0.03	--	--	--	--	0.03
^{137}Cs	30.2	30	--	--	--	--	16	46
^{152}Eu	13	40	--	1.6	--	--	1.4	43
^{154}Eu	8.5	20	--	1.2	--	--	4.2	25.4
^{238}U	4.5×10^{9}	--	--	--	--	--	0.009	0.009
^{238}Pu	87.7	--	--	--	--	--	0.075	0.075
^{239}Pu	2.4×10^{4}	1	--	--	--	--	1.6	2.6
^{241}Am	433	0.3	--	--	--	--	0.5	0.8

(a) Based on Table 16 in Miller and Steffes 1987.

TABLE A.5. Estimated Radionuclide Inventory in C Reactor, as of March 1, 1985 (Ci)[a]

Radionuclide	Component: Graphite Stack	Thermal Shield	Process Tubes	Control System	Bio-Shield	Storage Basin	Total
^{3}H	8,900	--	--	--	--	--	8,900
^{14}C	4,500	--	--	--	--	--	4,500
^{41}Ca	14	--	--	--	4	--	18
^{60}Co	60	9,890	350	110	--	16	10,426
^{59}Ni	--	7	0.1	--	--	0.16	7.26
^{63}Ni	28	840	10	--	--	16	894
^{36}Cl	12	--	--	--	--	--	12
^{90}Sr	10	--	0.2	--	--	7	17.2
^{93}Zr	--	--	--	--	--	--	--
^{93}Mo	--	0.04	--	--	--	--	0.04
^{94}Nb	0.3	0.02	--	--	--	--	0.32
^{99}Tc	--	0.002	--	--	--	--	0.002
^{108}Ag	--	0.03	--	--	--	--	0.03
^{137}Cs	30	--	--	--	--	6	36
^{152}Eu	40	--	1.7	--	--	4	45.7
^{154}Eu	20	--	1.3	--	--	7	28.3
^{238}U	--	--	--	--	--	0.004	0.004
^{238}Pu	--	--	--	--	--	0.075	0.075
^{239}Pu	1	--	--	--	--	1.5	2.5
^{241}Am	0.3	--	--	--	--	0.5	0.8

(a) Based on Table 17 in Miller and Steffes 1987.

TABLE A.6. Estimated Radionuclide Inventory in D Reactor, as of March 1, 1985 (Ci)[a]

Radionuclide	Component: Graphite Stack	Thermal Shield	Process Tubes	Control System	Bio-Shield	Storage Basin	Total
^{3}H	7,700	--	--	--	--	--	7,700
^{14}C	4,300	--	--	--	--	--	4,300
^{41}Ca	150	--	--	--	2	--	152
^{60}Co	90	7,380	270	110	--	0.05	7,850.05
^{59}Ni	2	7	0.1	--	--	0.002	9.102
^{63}Ni	280	810	10	--	--	0.27	1,100.27
^{36}Cl	34	--	--	--	--	--	34
^{90}Sr	10	--	0.2	--	--	0.06	10.26
^{93}Zr	--	--	--	--	--	--	--
^{93}Mo	--	0.04	--	--	--	--	0.04
^{94}Nb	0.3	0.02	--	--	--	--	0.32
^{99}Tc	--	0.002	--	--	--	--	0.002
^{108}Ag	--	0.03	--	--	--	--	0.03
^{137}Cs	30	--	--	--	--	0.12	30.12
^{152}Eu	40	--	1.7	--	--	2	43.7
^{154}Eu	20	--	1.2	--	--	0.007	21.207
^{238}U	--	--	--	--	--	--	--
^{238}Pu	--	--	--	--	--	--	--
^{239}Pu	1	--	--	--	--	0.024	1.024
^{241}Am	0.3	--	--	--	--	0.008	0.308

(a) Based on Table 18 in Miller and Steffes 1987.

TABLE A.7. Estimated Radionuclide Inventory in DR Reactor, as of March 1, 1985 (Ci)[a]

Radionuclide	Component: Graphite Stack	Thermal Shield	Process Tubes	Control System	Bio-Shield	Storage Basin	Total
^{3}H	4,900	--	--	--	--	--	4,900
^{14}C	3,200	--	--	--	--	--	3,200
^{41}Ca	90	--	--	--	2	--	92
^{60}Co	30	4,060	200	110	--	0.23	4,400.23
^{59}Ni	1	5	0.1	--	--	0.01	6.11
^{63}Ni	95	580	10	--	--	1.25	686.25
^{36}Cl	26	--	--	--	--	--	26
^{90}Sr	10	--	0.2	--	--	0.29	10.49
^{93}Zr	--	--	--	--	--	--	--
^{93}Mo	--	0.04	--	--	--	--	0.04
^{94}Nb	0.3	0.02	--	--	--	--	0.32
^{99}Tc	--	0.002	--	--	--	--	0.002
^{108}Ag	--	0.03	--	--	--	--	0.03
^{137}Cs	30	--	--	--	--	0.81	30.81
^{152}Eu	40	--	1.3	--	--	0.23	41.53
^{154}Eu	20	--	0.9	--	--	0.05	20.95
^{238}U	--	--	--	--	--	--	--
^{238}Pu	--	--	--	--	--	--	--
^{239}Pu	1	--	--	--	--	0.024	1.024
^{241}Am	0.3	--	--	--	--	0.008	0.308

(a) Based on Table 19 in Miller and Steffes 1987.

TABLE A.8. Estimated Radionuclide Inventory in F Reactor, as of March 1, 1985 (Ci)[a]

Radionuclide	Component: Graphite Stack	Thermal Shield	Process Tubes	Control System	Bio-Shield	Storage Basin	5,260.23
^{3}H	5,800	--	--	--	--	--	5,800
^{14}C	3,700	--	--	--	--	--	3,700
^{41}Ca	140	--	--	--	2	--	142
^{60}Co	70	4,870	210	110	--	0.23	5,260.23
^{59}Ni	2	6	0.1	--	--	0.01	8.11
^{63}Ni	190	680	10	--	--	0.25	881.25
^{36}Cl	33	--	--	--	--	--	33
^{90}Sr	10	--	0.2	--	--	0.29	10.49
^{93}Zr	--	--	--	--	--	--	--
^{93}Mo	--	0.04	--	--	--	--	0.04
^{94}Nb	0.3	0.02	--	--	--	--	0.32
^{99}Tc	--	0.002	--	--	--	--	0.002
^{108}Ag	--	0.03	--	--	--	--	0.03
^{137}Cs	30	--	--	--	--	0.81	30.81
^{152}Eu	40	--	1.4	--	--	0.23	41.63
^{154}Eu	20	--	1.0	--	--	0.05	21.05
^{238}U	--	--	--	--	--	--	--
^{238}Pu	--	--	--	--	--	--	--
^{239}Pu	1	--	--	--	--	0.024	1.024
^{241}Am	0.3	--	--	--	--	0.008	0.308

(a) Based on Table 20 in Miller and Steffes 1987.

TABLE A.9. Estimated Radionuclide Inventory in H Reactor, as of March 1, 1985 (Ci)[a]

Radionuclide	Component: Graphite Stack	Thermal Shield	Process Tubes	Control System	Bio-Shield	Storage Basin	Total
^{3}H	5,500	--	--	--	--	--	5,500
^{14}C	3,500	--	--	--	--	--	3,500
^{41}Ca	54	--	--	--	2	--	56
^{60}Co	40	4,270	200	110	--	0.23	4,620.23
^{59}Ni	1	5	0.1	--	--	0.01	6.11
^{63}Ni	120	650	10	--	--	1.25	781.25
^{36}Cl	17	--	--	--	--	--	17
^{90}Sr	10	--	0.2	--	--	0.29	10.49
^{93}Zr	--	--	--	--	--	--	--
^{93}Mo	--	0.04	--	--	--	--	0.04
^{94}Nb	0.3	0.02	--	--	--	--	0.32
^{99}Tc	--	0.002	--	--	--	--	0.002
^{108}Ag	--	0.03	--	--	--	--	0.03
^{137}Cs	30	--	--	--	--	0.81	30.81
^{152}Eu	40	--	1.3	--	--	0.23	41.53
^{154}Eu	20	--	1.0	--	--	0.05	21.05
^{238}U	--	--	--	--	--	--	--
^{238}Pu	--	--	--	--	--	--	--
^{239}Pu	1	--	--	--	--	0.024	1.024
^{241}Am	0.3	--	--	--	--	0.008	0.308

(a) Based on Table 21 in Miller and Steffes 1987.

TABLE A.10. Estimated Radionuclide Inventory in KE Reactor, as of March 1, 1985 (Ci)[a]

Radionuclide	Component: Graphite Stack	Thermal Shield	Process Tubes	Control System	Bio-Shield	Storage Basin	Total
^{3}H	30,000	--	--	--	--	--	30,000
^{14}C	7,000	--	--	--	--	--	7,000
^{41}Ca	1	--	--	--	15	--	16
^{60}Co	5	17,500	190	110	--	0.23	17,805.23
^{59}Ni	--	9	13	--	--	0.01	22.01
^{63}Ni	11	1,200	1,700	--	--	1.25	2,912.25
^{36}Cl	54	--	--	--	--	--	54
^{90}Sr	10	--	0.3	--	--	0.29	10.59
^{93}Zr	--	--	11	--	--	--	11
^{93}Mo	--	0.06	0.2	--	--	--	0.26
^{94}Nb	1.1	0.03	0.6	--	--	--	0.73
^{99}Tc	--	0.003	0.03	--	--	--	0.033
^{108}Ag	--	0.04	--	--	--	--	0.04
^{137}Cs	30	--	--	--	--	0.81	30.81
^{152}Eu	40	--	2	--	--	0.23	42.23
^{154}Eu	20	--	1.6	--	--	0.05	21.65
^{238}U	--	--	--	--	--	--	--
^{238}Pu	--	--	--	--	--	--	--
^{239}Pu	1	--	--	--	--	0.024	1.024
^{241}Am	0.3	--	--	--	--	0.008	0.308

(a) Based on Table 22 in Miller and Steffes 1987.

TABLE A.11. Estimated Radionuclide Inventory in KW Reactor, as of March 1, 1985 (Ci)[a]

Radionuclide	Component: Graphite Stack	Thermal Shield	Process Tubes	Control System	Bio-Shield	Storage Basin	Total
^{3}H	27,000	--	--	--	--	--	27,000
^{14}C	6,700	--	--	--	--	--	6,700
^{41}Ca	5	--	--	--	15	--	20
^{60}Co	5	14,500	170	110	--	0.23	14,785.23
^{59}Ni	--	9	11	--	--	0.01	20.01
^{63}Ni	15	1,100	1,500	--	--	1.25	2,616.25
^{36}Cl	52	--	--	--	--	--	52
^{90}Sr	10	--	0.3	--	--	0.29	10.59
^{93}Zr	--	--	10	--	--	--	10
^{93}Mo	--	0.06	0.2	--	--	--	0.26
^{94}Nb	1.1	0.03	0.6	--	--	--	1.73
^{99}Tc	--	0.003	0.03	--	--	--	0.033
^{108}Ag	--	0.04	--	--	--	--	0.04
^{137}Cs	30	--	--	--	--	0.81	30.81
^{152}Eu	40	--	2	--	--	0.23	42.23
^{154}Eu	20	--	1.6	--	--	0.05	21.65
^{238}U	--	--	--	--	--	--	--
^{238}Pu	--	--	--	--	--	--	--
^{239}Pu	1	--	--	--	--	0.024	1.024
^{241}Am	0.3	--	--	--	--	0.008	0.308

(a) Based on Table 23 in Miller and Steffes 1987.

A.1.3.2 Reactor Thermal Shield Inventory

Cobalt-60 and nickel-63 are the primary constituents of the thermal shield's radionuclide inventories. Cobalt-60 would influence the dose for immediate dismantlement but would have decayed to manageable levels after 75 years. Other isotopes, including nickel-59, molybdenum-93, and niobium-94 are produced in stainless steel cooling tubes in the top, bottom, and sides of the thermal shield. These isotopes are included in the thermal shield inventory.

A.1.3.3 Process Tube Inventory

The aluminum process tubes in the six older reactors are made of 1100 aluminum alloy. The chemical composition specification required a minimum of 99% aluminum. Individual elemental impurities did not exceed a maximum of 1%. These impurities do not generate significant quantities of radionuclides with long half-lives. Gamma radiation spectrum measurement of aluminum samples that were present in the K Reactors for the entire operating life of the plant did not detect measurable concentrations of aluminum-26. Therefore, the only potential long-lived radionuclides generated from irradiation of the process tubes are nickel-59 and nickel-63. The fuel cladding contained 1% nickel, which combined with impurities in the process water to become part of the corrosion film in the tubes. In the KE and KW Reactors, 73% of the process tubes were made of zirconium and were in use for 7 years. Analysis of the Zircaloy-2 taken from a process tube indicated 416 parts per million of nickel, which accounts for the inventories of nickel-59 and nickel-63 shown in Tables A.10 and A.11. The inventories shown in the tables are based on impurity levels and fluence-exposure history of the tubes.

A.1.3.4 Reactor Control System Inventory

The vertical safety rods, horizontal control rods, and ball 3X safety system make up the reactor control system. Only a small segment of each safety rod was exposed to the reactor's neutron fluence. Additionally, only the reactor entry ports of the ball system were exposed.

When calculated by either time in the reactor or extrapolated from dose measurements, the cobalt-60 inventory remaining in the control system on the reference date of March 1, 1985, is estimated to be about 110 curies per reactor.

A.1.3.5 Trace Radionuclides

Impurities in the materials exposed to the neutron flux become activated during reactor operation. While the contribution of these activated impurities is small compared to the major constituents previously considered, calculations were performed to indicate the amounts of trace radionuclides that may be present in various reactor components. The calculated amounts are included in Tables A.4 through A.11.

A.1.3.6 Summary

While some variations in the radionuclide inventories are noted for specific reactor components, overall the facilities can be separated into two types: the six older reactors and the K Reactors. The average total radionuclide inventory ranges from about 19,000 curies for the older reactors to just under 55,000 curies for the K Reactors, as of March 1, 1985.

The estimates of the radionuclide inventories for both types of reactors are conservative in that they overestimate the actual inventories. The reported inventories represent more than 95% of the total inventory; the unidentified 5% is postulated to be distributed in piping, tunnels, and various other locations within the reactor buildings and in unaccounted-for inventories within the reactors or fuel storage basins. At the time of decommissioning, more specific determinations of the inventory, or total curies of each isotope in each reactor facility, may be needed to define the type and quantity of radioactivity for shipping and burial purposes.

A.1.4 Hazardous Nonradioactive Materials

Several materials that could be designated as hazardous under the Resource Conservation and Recovery Act (RCRA), the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), the Clean Air Act, or the Toxic Substances Control Act are present in the reactor buildings, including lead, mercury, friable asbestos, polychlorinated biphenyls, and

cadmium. Hazardous, nonradioactive materials were recently identified and inventoried (Miller and Steffes 1987). Mercury, friable asbestos, and polychlorinated biphenyls are presently being removed for recycle, storage, or disposal under separate environmental documentation. Nonirradiated cadmium and lead will be removed for recycle or stored for later disposal for all alternatives except no action. Irradiated lead will either be left in place for in situ decommissioning or moved to the 200-West Area low-level waste burial ground for the other decommissioning alternatives. An inventory of lead and cadmium currently in the reactor buildings is presented in Table A.12.

A.2 PHYSICAL DESCRIPTION OF THE FUEL STORAGE BASINS

Each reactor building contains a spent-fuel storage basin. The basin served as a collection, storage, and transfer facility for the fuel elements discharged from the reactor. The storage basin area is located behind the reactor. Brief physical descriptions (including significant differences) and radiological descriptions of the fuel storage basins are given in the following discussion.

TABLE A.12. Estimated Cadmium and Lead Inventories in Hanford Surplus Production Reactor Buildings[a]

Facility	Nonirradiated Cd (kg)	Nonirradiated Pb (tonne)	Irradiated Pb (tonne)
105-B	9.1	7.6	72.6
105-C	--	22.7	72.6
105-D	--	13.1	72.6
105-DR	--	12.8	72.6
105-F	13.6	12.6	72.6
105-H	9.1	29.2	72.6
105-KE	--	42.6	108.9
105-KW	--	31.8	108.9

(a) Based on information contained in Appendix G of Miller and Steffes 1987.

A.2.1 Description of Storage Basin

The typical reactor spent-fuel storage basin is divided into three zones: the spent-fuel discharge area, the storage area, and the transfer area. Each basin has a wash pad, and some have an underwater fuel-inspection facility. The storage basin above-grade structures are constructed with concrete block walls and precast concrete (panel) tile roofs, 3 meters to 12 meters in height. The below-grade portion is 6 meters deep, with reinforced concrete columns and walls. The average thickness of the outside walls of the basin is 50.8 centimeters; the bottom of the basin is about 15.24 centimeters thick. The total volume of concrete in each basin is about 573 cubic meters. The spent-fuel storage basin areas range from 650 square meters to 929 square meters, depending on the specific reactor. Side and top views for the storage basins at 105-B, -D, and -F are shown in Figure A.7.

A.2.2 Differences in Fuel Storage Basin Designs

The storage area of each basin (except for KE and KW Reactors) is equipped with 19 rows of six steel posts each used to support a slotted wooden floor over the basin. The rows are 18.3 meters long and are centered about 1.2 meters apart. The floors in the KE and KW Reactor basins consist of steel gratings suspended from the ceiling. The 105-K Reactors' above-grade walls are constructed of transite panels instead of concrete blocks. The roofs of the basins are reinforced concrete slabs above a heavy steel support structure.

The wall areas and storage basin areas of the 105-C and 105-H buildings have gypsum roofs instead of concrete tile. In addition, the 105-C building has transite siding on the above-grade storage basin areas. The storage basin for 105-C includes a metal examination facility, which is a below-ground and above-ground building about 7.9 meters by 18.3 meters, with transite siding above-grade (Kaiser 1987).

A.2.3 Radiological Characteristics of the Fuel Storage Basins

Residual radioactivity in the storage basins originated from process tube scale and from failed fuel elements that were discharged into the

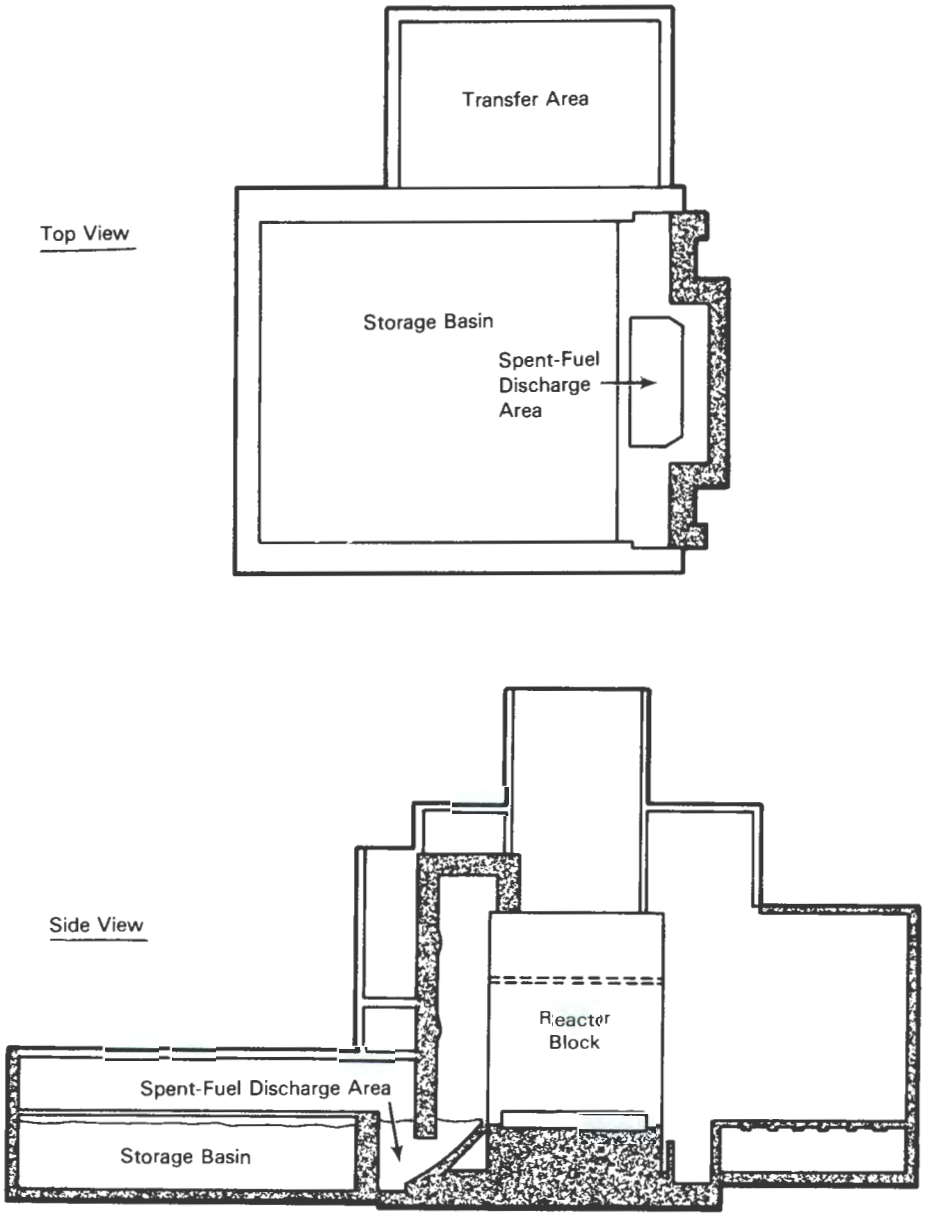

FIGURE A.7. Fuel Storage Basins in the 100 Areas: 105-B, -D, and -F

storage basins. When decommissioning begins, the B and C basin transfer pits will contain residual sludge. The residual radioactivity inventory is given in Table A.13.

A.3 LOW-LEVEL WASTE SITES COVERED BY THE IN SITU DECOMMISSIONING MOUND

Sixteen inactive waste disposal sites may be covered by the mounds at B, C, D, KE, and KW Reactor sites. These sites (along with others) are presently being evaluated by the DOE within the scope of the DOE's responsibilities under CERCLA. If the in situ decommissioning alternative is selected, evaluation and remedial action required for any of these 16 sites would be completed before decommissioning of the reactors begins (DOE 1986). The radionuclide inventory of these sites is given in Table A.14. Known chemical inventories include 1,000 kilograms of sodium dichromate, 1,000 kilograms of sodium oxalate, and 6,000 kilograms of sodium sulfamate in one of the 105-B Reactor sites; 1,700 kilograms of sodium dichromate in two of the 105-D Reactor sites; 3,000 kilograms of potassium borate in one of the 105-DR Reactor sites; and 1,000 kilograms of sodium dichromate in one of the 105-H Reactor sites.

A.4 UNACCOUNTED-FOR INVENTORIES

The inventories previously listed represent more than 95% of the total inventory; the unidentified 5% is postulated to be distributed in piping, tunnels, and various other locations within the reactor buildings and in unaccounted-for inventories within the reactors or fuel storage basins (Miller and Steffes 1987). If any presently unknown, but significant inventories are discovered during decommissioning, they will be evaluated for appropriate action including any required additional NEPA documentation.

TABLE A.13. Estimated Spent-Fuel Storage Basin Inventory, as of March 1, 1985 (Ci/Basin)[a]

Basin	^{59}Ni	^{60}Co	^{63}Ni	^{90}Sr	^{137}Cs	^{152}Eu	^{154}Eu	^{238}U	^{238}Pu	^{239}Pu	^{241}Am
B	0.5	11	60	14	16	1.4	4.2	0.009	0.075	1.6	0.5
C	0.16	16	16	7	6	4	7	0.004	0.075	1.5	0.5
D	0.002	0.05	0.27	0.06	0.12	0.02	0.007	--	--	0.024	0.008
F	0.51	11.23	61.25	14.29	16.81	1.63	4.25	0.009	0.075	1.624	0.508
H	0.51	11.23	61.25	14.29	16.81	1.63	4.25	0.009	0.075	1.624	0.508
DR	0.01	0.23	1.25	0.29	0.81	0.23	0.05	--	--	0.024	0.008
KE	0.01	0.23	1.25	0.29	0.81	0.23	0.05	--	--	0.024	0.008
KW	0.01	0.23	1.25	0.29	0.81	0.23	0.05	--	--	0.024	0.008
TOTALS	1.712	50.20	202.52	50.51	58.17	9.37	19.857	0.031	0.30	6.444	2.048

(a) From Table 15 in Miller and Steffes 1987. For computational accuracy, the total quantities are deliberately not rounded.

TABLE A.14. Estimated Radionuclide Inventory of Ground Disposal Sites Under the In Situ Decommissioning, as of March 1, 1985 (Ci/reactor site)

Reactor	Number of Sites	^{3}H	^{14}C	^{60}Co	^{90}Sr	^{137}Cs	^{152}Eu	^{238}U	^{238}Pu	^{239}Pu	Others
B	2	0.23	--[a]	4.6	0.020	0.14	0.28	0.00034	0.0012	0.006	<1
C	1	--	--	80.0	--	--	--	--	--	--	<2
D	3	1.0	--	0.21	0.29	1.6	1.0	0.0062	--	0.024	<1
DR	2	--	--	--	--	--	--	--	--	--	<1
F	2	--	--	--	--	--	--	--	--	--	<1
H	2	--	--	1.0	--	--	--	--	--	--	<1
KE	2	56.5	110	--	--	--	--	--	--	--	<1
KW	2	81.9	110	--	--	--	--	--	--	--	<1
TOTALS	16	139.6	220	85.8	0.31	1.74	1.28	0.0065	0.0012	0.03	

(a) Dash (--) means that either there is no known inventory or the inventory is much less than the inventory of the same isotope in another site.

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APPENDIX B

FLOODPLAIN/WETLANDS ENVIRONMENTAL REVIEW

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APPENDIX B

FLOODPLAIN/WETLANDS ENVIRONMENTAL REVIEW

Presidential Executive Orders 11988 and 11990, entitled, "Floodplain Management" and "Protection of Wetlands," respectively, require each federal agency to ensure that the effects of any action it may take in a floodplain are evaluated with respect to flood hazards and floodplain management, and to ensure that protection of wetlands is considered in decision making. The DOE has published regulations in 10 CFR 1022, entitled "Compliance with Floodplain/Wetlands Environmental Review Requirements," in order to meet these obligations.

Wetlands are defined in 10 CFR 1022 as

> "those areas that are inundated by surface or groundwater with a frequency sufficient to support and under normal circumstances does or would support a prevalence of vegetative or aquatic life that requires saturated or seasonally saturated soil conditions for growth and reproduction. Wetlands generally include swamps, marshes, bogs, and similar areas such as sloughs, potholes, wet meadows, river overflow, mudflats, and natural ponds."

None of the surplus production reactors are in a wetland as defined above; therefore, consideration of wetland protection is not required in decommissioning the surplus production reactors. No wetlands are involved.

Floodplain is defined in 10 CFR 1022 as

> "the lowlands adjoining inland and coastal waters and relatively flat areas and flood-prone areas of offshore islands including, at a minimum, that area inundated by a 1 percent or greater chance flood in any given year. The base floodplain is defined as the 100-year (1.0 percent) floodplain. The critical floodplain is defined as the 500-year (0.2 percent) floodplain."

The first step in a floodplain review is to determine whether the proposed action is located in either the base or critical floodplain. Because the elevation of the 500-year (critical) flood is higher than the elevation of the 100-year flood, consideration of the 500-year flood will automatically include consideration of the 100-year flood.

The U.S. Army Corps of Engineers has carried out studies of the flooding potential of the Columbia River, based on historic data and on the water-storage capacity of dams on the Columbia River (Corps of Engineers 1969); and the DOE has carried out studies of the impacts of potential flooding on facilities at Hanford (ERDA 1976). Flood elevations along the river have been estimated for the probable maximum flood (PMF), the standard project flood (SPF), and the 100-year flood, for both dam-regulated and unregulated floods. The SPF is defined as one having a recurrence interval of 500 to 1,000 years (DOE 1987) and is thus equivalent to the critical flood. The peak discharge rates at Hanford for the dam-regulated PMF, the dam-regulated SPF, and the unregulated historic flood of record have been estimated to be 40,800 cubic meters per second, 16,100 cubic meters per second, and 22,700 cubic meters per second, respectively (Puget Power 1981; ERDA 1976). From these discharge rates, flood elevations at each of the surplus reactors can be estimated from a chart prepared by the Corps of Engineers (UNC 1978). The results for the dam-regulated SPF are presented in Table B.1.

From the data presented in Table B.1, it can be seen that the elevation of the dam-regulated 500-year flood (SPF) will not reach the elevation of the first floor of any of the surplus production reactors. Nor will the elevation of the dam-regulated 500-year flood reach the elevation of the bottom of any fuel storage basin, the elevations of which are 6.1 meters below the elevations of the first floors.

TABLE B.1. Dam-Regulated Standard Project Flood (SPF) Elevations Above Sea Level at the Hanford Surplus Production Reactors

Reactor	River Mile	Reactor First-Floor Elevation (m)	SPF Elevation (m)
105-C	384	150.6	126.5
105-B	384	142.8	126.5
105-D	377.5	142.2	121.9
105-DR	377.5	142.0	121.9
105-KE	381.5	141.7	125.0
105-KW	381.5	141.7	125.0
105-H	372.5	128.9	120.4
105-F	369	125.7	118.9

Because the surplus production reactors are not in the 500-year (critical) floodplain, because decommissioning will not impact the 500-year floodplain, and because decommissioning will not be impacted by the 500-year flood, no further floodplain review is necessary under the provisions of 10 CFR 1022.

Other flooding scenarios have been evaluated by the Corps of Engineers, specifically a flood caused by a catastrophic failure of Grand Coulee Dam. A 50% catastrophic failure of Grand Coulee Dam is estimated to result in a peak discharge of approximately 226,500 cubic meters per second at Hanford (ERDA 1976). Flood elevations at the surplus production reactors for a 50% catastrophic failure of Grand Coulee Dam and for the dam-regulated PMF are given in Table B.2 (estimated from the chart in UNC 1978).

From the data presented in Table B.2, it can be seen that the elevation of the dam-regulated PMF will reach the elevation of the bottom of the fuel storage basins at the 105-H and 105-F Reactors (6.1 meters below the first-floor elevations), and that the elevation of the flood resulting from a catastrophic 50% failure of Grand Coulee Dam will reach above the first

TABLE B.2. Elevations at the Hanford Surplus Production Reactors of the Dam-Regulated Probable Maximum Flood (PMF) and the Flood Resulting from a Catastrophic 50% Failure of Grand Coulee Dam

Reactor	First-Floor Elevation (m)	Reactor PMF Elevation (m)	50% Coulee Dam Failure Elevation (m)
105-C	150.6	131.1	147.8 (0)[a]
105-B	142.8	131.1	147.8 (2.8)
105-D	142.2	127.4	143.9 (1.8)
105-DR	142.0	127.4	143.9 (1.8)
105-KE	141.7	129.5	146.3 (2.7)
105-KW	141.7	129.5	146.3 (2.7)
105-H	128.9	126.5	143.3 (1.4)
105-F	125.7	125.0	143.3 (1.4)

(a) Number in parentheses is average flow velocity in m/sec.

floor elevation of all reactors except the 105-C Reactor. Protection of the reactors from the latter flood with riprap for the in situ decommissioning alternative is discussed in Appendix H.

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APPENDIX C

HYDROLOGIC AND TRANSPORT MODELING OF THE GROUND-WATER PATHWAYS

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APPENDIX C

HYDROLOGIC AND TRANSPORT MODELING OF THE GROUND-WATER PATHWAYS

One of the potential pathways for environmental impact associated with disposal of decommissioned surplus reactor facilities is the transport of radionuclides through ground water. Whether buried on the 200-Area Plateau or in situ under a mound in the 100-Area, radionuclides could be released to infiltrating water that would migrate to the ground water and eventually to the Columbia River. This appendix describes the hydrologic and transport models used in the ground-water pathway modeling. Also considered are the forms of the buried wastes, and the mechanisms that control the release of the radionuclides from the burial grounds and their movement to ground water.

Transient events continually occur that remind us that predicting future events over thousands of years is complex. However, events associated with release and transport of radionuclides in the unsaturated (vadose) zone of the soil are known to be long-term events in the case where only natural infiltration occurs. Water travels downward at rates measured in years per meter in the Hanford environment. In the unconfined aquifer system, horizontal movement of water rates range from a fraction of a meter to hundreds of meters per year, depending on the location, ground-water potential, and the hydraulic conductivity. Consequences of actions initiated in the next 50 years may be observed centuries or millenniums from now. Therefore, all ground-water transport modeling has been done as a steady-state analysis. The assumptions include long-term averages of river flow, low and high recharge estimates, and the basic assumption that artificial recharge of waste waters on the 200-Area Plateau is discontinued. A detailed discussion of the modeling assumptions and their uncertainties is contained in the Final Environmental Impact Statement, Disposal of Hanford Defense High-Level, Transuranic and Tank Wastes (DOE 1987).

The data and model parameters used in this DEIS were selected as realistic values that would enable us to produce a realistic estimate of impacts. Where uncertainties exist, an attempt was made to select values

that would produce conservative results. A conservative value of a parameter tends to overestimate the impact, rather than underestimate it. Where reliable data provide realistic values of parameters, these values were used.

The system of an engineered barrier used in the in situ decommissioning alternative, and a barrier and a liner/leachate collection system used in the alternatives involving disposal in the 200 Areas, is designed to intercept, and thus minimize, water movement through the wastes. However, over the long time periods of interest in the analysis (10,000 years), the efficacy of a liner/leachate collection system is highly uncertain. No credit has been taken in the analyses for the liners and leachate collection systems. The functioning of the engineered moisture barrier, used in all of the disposal alternatives, is also not well defined. Theoretical analyses have shown that under most circumstances, the barriers could be up to 100% effective at preventing moisture infiltration. However, the practical limits of detection (i.e., the limit to which it can be proved that the barrier is functioning) are at infiltration rates of about 0.1 centimeter per year. Therefore, this infiltration rate was used in the analyses as a design basis, and the calculations were performed assuming a uniform rate of water infiltration through the barrier of 0.1 centimeter per year. This should be considered to be an upper bound to the expected infiltration rates through the barrier and thus to the wastes.

C.1 WASTE FORMS AND RELEASE RATES

The alternatives proposed in this study call for burial of the surplus production reactors (dismantled or in one piece) on the 200-Area Plateau or under mounds in the 100 Areas. The reactor components having distinct radionuclide-release characteristics were treated separately in these analyses. The graphite blocks, thermal and biological shielding, and other metal reactor components were treated as separate waste forms during the hydrologic and transport modeling. Another waste form is the fuel storage basins that would either be dismantled, placed in containers, and disposed of in the 200-West Area burial ground, or left in place in the 100 Areas. Although modeled separately, the results are combined in the Chapter 5.0 discussion.

C.1.1 Releases from Graphite

The rates of release of carbon-14 from graphite blocks are discussed in Appendix D. These rates are functions of time, temperature, and relative humidity. Because a relative humidity above 0.98 is normal in the soil pore atmosphere at extremely low moisture contents, saturated conditions were assumed. A normal range of soil temperatures of 17°C to 20°C exists at burial depths on the 200-Area Plateau. Because of the long-term nature of the release, a conservative constant temperature of 22°C was used to develop the release function for the carbon-14. The resulting release extends over 23,000 years.

White et al. (1984) identify leach rates for other radionuclides of interest from irradiated graphite. The incremental leach rates measured after 100 days in simulated ground water were corrected for the volume-to-surface-area ratio of the Hanford reactors' graphite to properly scale up from laboratory measurements to carbon block size. From these data a total time for complete leaching was calculated. The results are shown in Table C.1.

TABLE C.1. Release Rates for Radionuclides from Graphite

Radionuclide	Fraction of Original Inventory Released Per Day	Number of Yr for Total Release
^{3}H	1×10^{-6}	2,740
^{55}Fe	1×10^{-5}	274
^{60}Co	3×10^{-5}	91
^{134}Cs	3×10^{-5}	91
^{154}Eu	8×10^{-5}	34

Radionuclides for which measured rates are not available were assigned rates based on their similarity of chemistry to those with measured rates. Hence, the nickel isotopes were assigned the leach rate of iron-55; cesium and strontium were assigned the leach rate determined for cesium-134; plutonium and americium were assigned the leach rate for europium-154; and the chlorine-36 was assigned the leach rate for tritium (hydrogen-3).

C.1.2 Releases from Shielding and Metal Components

The iron shielding and aluminum components of the reactor contain activation products that are subject to release as corrosion occurs. To provide a release rate for these radionuclides, it was assumed that the iron would corrode at a rate of 5 mils (0.005 inch) per year. Thus, the release rate for the iron is 3.5×10^{-5} centimeters per day. Corrected for the volume-to-surface-area ratio of 5 centimeters, the radionuclides in the shielding would release over 390 years.

Aluminum components were assumed to corrode at a rate of 0.1 mil per year, yielding a release rate of 7×10^{-7} centimeters per day. Corrected for a volume-to-surface-area ratio of 0.32 centimeter, the radionuclides in the aluminum would release over 1,250 years.

C.1.3 Releases from Fuel Storage Basins and Ground Disposal Sites

The fuel storage basins associated with each reactor may be dismantled, placed in containers, and buried in the 200-West Area burial ground. If left in situ, they would be filled with soil. For these analyses it was assumed that the material covered a 50- by 50-meter area to a depth of 2 meters. Radionuclide releases from this material are based on the assumption that infiltrating water contacts the waste and releases the radionuclides by an adsorption-equilibrium control mechanism. The same release mechanism was applied to the disposal of the fuel storage basins at the 100-Areas.

C.2 SCENARIOS

For this DEIS, a postdisposal assessment period of 10,000 years was selected. This time period was selected because of the long half-lives of several radioactive isotopes in the waste inventory (including carbon-14, chlorine-36, and calcium-41) and also because 10,000 years is the longest time period, related to radioactive waste-disposal systems, mentioned in any federal regulation (40 CFR 191). The scenario assumes loss of active institutional control after 100 years.

The predictions of future climate used in the modeling are projected from data for past climatic states. The Pasco Basin was cooler and wetter

13,000 to 10,000 years ago than it is today and changed to a warmer, drier climate about 8,000 years ago (Nickmann and Leopold 1985).

Because warm, interglacial climates like the present are typical of only about 10% of the climatic record for the past one million years (Bull, in Scott et al. 1979), the most likely change will be toward a cooler and wetter climate. It is possible, however, that the greenhouse effect will produce a warmer and wetter climate at Hanford in the future. In either event, it is the wetter, not warmer or colder, climate that was assumed for a conservative estimate of potential impacts.

The ground-water pathway analyses assume 1) a continuous dry climate with an average annual ground-water recharge over the Hanford Site of 0.5 centimeter per year, and 2) a wetter climate with an average annual recharge of 5 centimeters per year. These recharge rates provide the fluid to carry the leachate horizontally in the ground water. The burial ground for all components was assumed to be in the 200-West Area for the removal or dismantlement alternatives. The depth to ground water from the bottom of the burial pit in the 200-West Area was assumed to be 64 meters under both climate conditions.

In analyzing the ground-water pathway for the in situ (100-Area) decommissioning alternative, the most obvious differences from the 200-West Area are the distance to the river and the depth of the unsaturated soil beneath the reactors (see Section 3.3). The release mechanisms are assumed to be the same.

C.3 HYDROLOGIC MODELING

The ground-water pathway analysis of the surplus reactors that would be buried on the 200-Area Plateau requires that the leachate be modeled as traveling through the unsaturated zone to the water table and then through the ground water to the Columbia River. The rate at which water can travel through the unsaturated zone is sensitive to the moisture content and texture of the soil. For a given soil, the steady-state infiltration rate will determine moisture content and the travel time below the depth affected by seasonal transients of temperature and moisture.

Travel times for water to move through a soil profile can be estimated for a given flux, q, when a unit hydraulic gradient and steady-state infiltration are assumed. For layered soils, the travel time is the summation of travel times through each layer. The equation used for determining total time, t, can be written as:

$$t = \left[\sum_{i=1}^{j} W_i(q)\ T_i \right] / q \qquad \text{(C.1)}$$

where i = the index of the soil layer
j = the number of layers
$W_i(q)$ = the water content of soil layer i for flux q
q = the assumed steady-state flux
T_i = thickness of each soil layer.

Soil data available from a site on the 200-Area Plateau were used to calculate the travel times through a layered soil system 64 meters deep to ground water for a 0.1-centimeter-per-year flux (i.e., the water flux that passes through the barrier, into the waste form, and down through the vadose zone). The thicknesses of soil layers were determined from a soil profile down to the water table. Based on these data, travel time was 4,200 years. Vadose-zone modeling performed for the sites in the 100 Areas is described in Section C.3.3.

A two-dimensional finite difference model was applied to the unconfined aquifer to determine the travel times and flow paths of ground water that could become contaminated by leachate from disposed reactor components. The steady-state version of the Variable Thickness Transient (VTT) Model (Reisenauer 1979a,b,c; Kipp et al. 1976) assumes the flow occurs as an incompressible fluid that saturates a rigid, porous soil matrix. In this model, the hydraulic conductivity is assumed to be isotropic (independent of direction) but heterogeneous (dependent upon location), and the flow is presumed to obey Darcy's law. The basic equation upon which the model is constructed is known as the Boussinesq equation. The basic formulation of the computer code assumes that a two-dimensional (areal) representation is

adequate, and that consequentially all the aquifer properties are averaged over the saturated thickness of the aquifer. The variations of the aquifer thickness are considered, however, and the free surface boundary condition with accretion is incorporated into the difference equation. The model provides a means of applying a specific set of boundary conditions to a ground-water aquifer to produce a steady-state or time-varying simulation.

The VTT model of the Hanford Site uses data on a square grid pattern of over 2,500 nodes, each node representing an area 610 meters on a side. The Columbia River bounds the region to the north and east. The western and southern sides are bounded irregularly by Umtanum, Yakima, and Rattlesnake Ridges, and are broken by two small alluvial valleys and, in the southernmost part, by the Yakima River. In the central part of the region, basaltic outcrops above the water table, such as Gable Mountain and Gable Butte, are assumed to be no-flow areas. Water entering the region from the valley alluvium is accounted for in the model by flux across the western boundary.

The spatial distribution of the hydraulic conductivity was estimated from pump-test data at wells and numerous water-level measurements through the use of a computer routine that combines these data mathematically to project the measured conductivity data throughout large areas of the Site (Cearlock et al. 1975). The unconfined aquifer bottom, a necessary input to the model, is considered to be the top of the basalt or the top of an overlying clay unit. Because field data are limited, the effective porosity is assumed to be a constant at 0.1. This conceptualization of the Hanford Site has been used with small modifications by Arnett et al. (1977), Harty (1979), and others.

C.3.1 Application of the Aquifer Model to Surplus Reactor Decommissioning on the 200-Area Plateau

The two climate scenarios to which the model was applied for this DEIS assumed postdisposal conditions with no liquid waste disposal to ground in the 200 Areas and recharge occurring from rainfall and snowmelt. In the case of the relatively dry climate scenario, which results in only 0.5 centimeter per year recharge to the aquifer, the water table drops to a near pre-1945 level. The largest influence on the direction and rate of movement comes

from water entering the aquifer from the alluvium in Cold Creek Valley. The direction from the assumed 200-Area reactor burial ground is eastward toward the Columbia River, as shown in Figure C.1. In the case of the wetter climate scenario, the 5-centimeter-per-year recharge was accumulated from the slopes of Rattlesnake Ridge and other higher elevations outside the model boundaries and applied to the model as water flowing into the edge of the unconfined aquifer in addition to the 5-centimeter-per-year recharge distributed to the surface alluvium onsite. As a result, the water table is higher and the direction of flow from the 200-Area burial ground under these conditions is to the north through the gap between Gable Mountain and Gable Butte, as shown in Figure C.2.

For each of the scenarios modeled, the travel times and path lengths of streamlines in the streamtubes were calculated from the burial ground to a hypothetical domestic water well placed 5 kilometers away, intercepting contaminated water. The water is assumed to be used for garden irrigation and drinking. Travel times and path lengths along the streamlines were also calculated to the river outflow boundary. The travel times for the relatively dry climate scenario (0.5-centimeter-per-year recharge) and the wetter climate scenario (5-centimeter-per-year recharge) are 180 years and 70 years, respectively. These data were used in the solute transport model along with the data from the release rates to calculate the environmental effects for each contaminant at both water usage points. The results are discussed in Appendix G.

C.3.2 Application of the Aquifer Model to Surplus Reactor Disposal on the 100-Area Sites

The geohydrology of the 100 Areas is not well defined. For that reason, a detailed ground-water model is not available for this region close to a river with fluctuating water levels that alternately cause bank storage, then drainage. Travel times to the river for the potential contaminants in the ground water would be short with respect to their half-lives. Modeling is based on a simple one-dimensional view of the problem, taking into consideration the mound, the protective barrier, the depth of soil between the

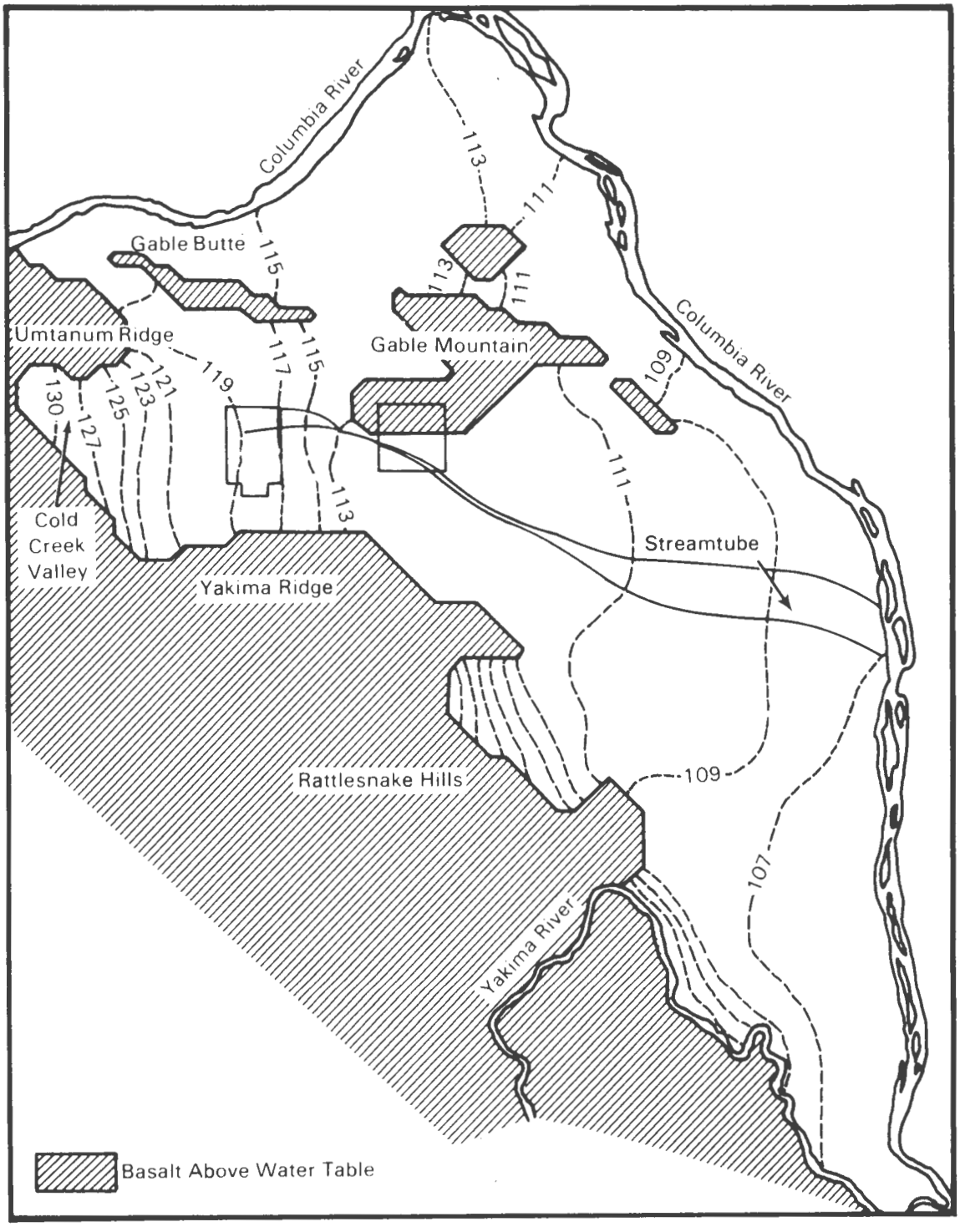

FIGURE C.1. Ground-Water Contours (meters above MSL) and Streamtube from the 200-West Area Burial Ground to the Columbia River, Assuming Steady-State Conditions, 0.5-Centimeter-Per-Year Annual Average Recharge

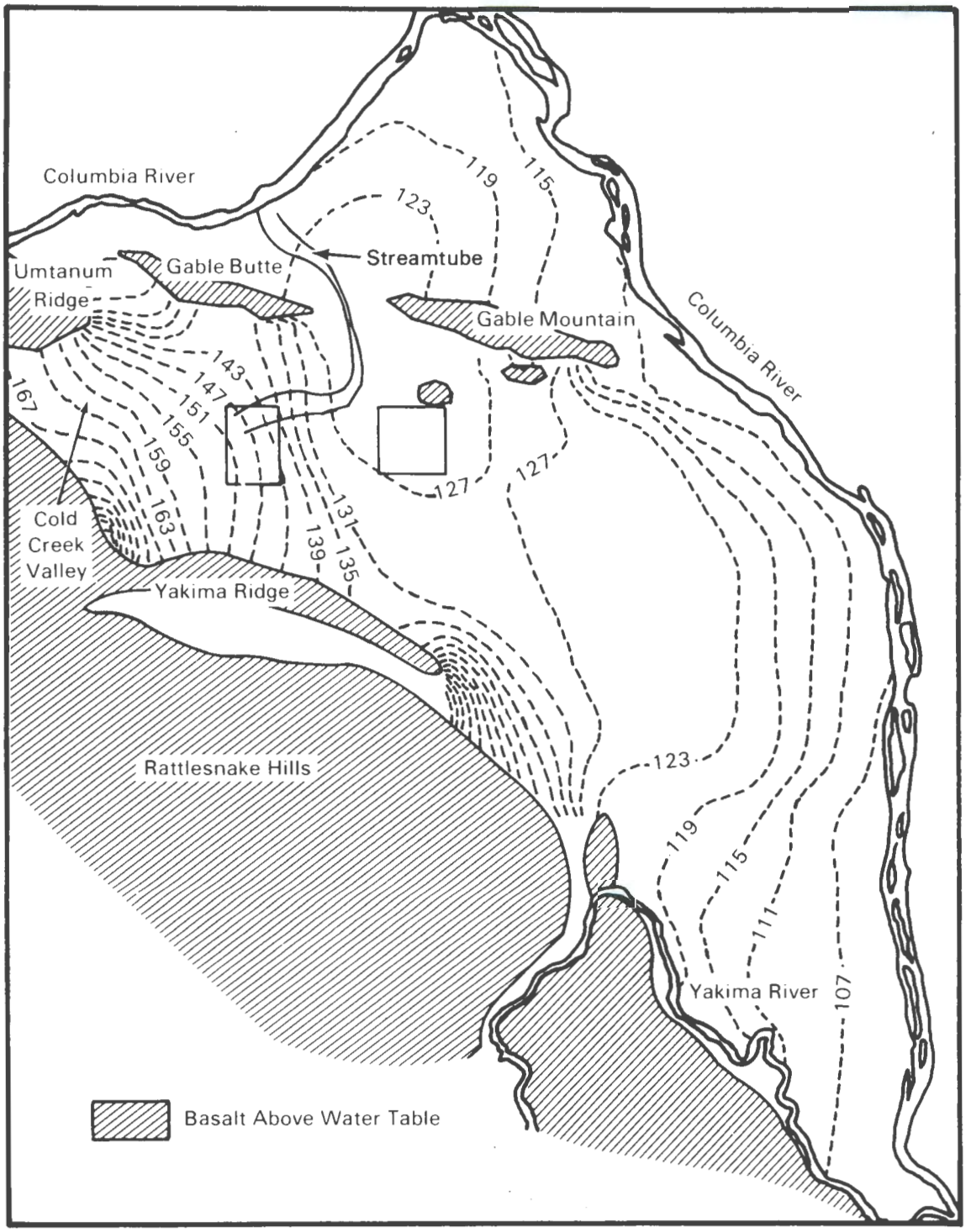

FIGURE C.2. Ground-Water Contours (meters above MSL) and Streamtube Showing Flow from the 200-West Area Burial Ground to the Columbia River with 5-Centimeter-Per-Year Annual Average Recharge Scenario

reactors and the water table, and an assumed conservative ground-water flow system. This is discussed in the following section.

C.3.3 Application of the Aquifer and Transport Model to In Situ Decommissioning Beneath the Mounds

The mounds placed over the reactors for the in situ decommissioning alternative would cover the fuel storage basins and no more than three small burial grounds at any reactor site (16 burial ground sites would be covered in all). The top of each mound would be covered with a protective barrier that would limit the infiltration through the buried wastes to no more than 0.1 centimeter per year. Because no local (100 Area) soils data were available for calculations of the travel time in the vadose zone, and to be conservative, soils data from a coarse sand taken from the Hanford 241 AP tank farm excavation were used. Table C.2 shows the approximate depth to ground water beneath the reactor foundation and the bottom of the fuel storage basins, and the travel time for a 0.1-centimeter-per-year infiltration to reach the ground water.

TABLE C.2. Depth to Ground Water Beneath the 100-Area Reactors

Reactor	Approx. Depth to Ground Water (m)	Estimated Travel Time to Ground Water (yr)[a]
105-B	15.2	730
105-C	18.3	880
105-KE	15.2	730
105-KW	15.2	730
105-D	18.3	880
105-DR	18.2	880
105-H	6.1	290
105-F	5.5	260

(a) Based on infiltration rate through barrier of 0.1 cm/yr.

The total flow of water infiltrating the barrier, contacting the waste, and causing a plume of contaminant in the ground water is pumped from a well when the full garden is irrigated in the full-garden scenario for the dose model (see Appendix G). The act of pumping causes a drawdown cone in the ground water, and it is assumed that the well intercepts the total contaminated plume, which is diluted by noncontaminated water drawn from outside the plume. For the scenario of the contaminants reaching the river, a simple flow system was assumed with a length of 200 meters from beneath the reactor to the Columbia River and a travel time of 1 year for all reactor sites for the contaminant to travel from the point of entry into the ground water to the river.

C.4 TRANSPORT ANALYSIS

A transport modeling approach was devised and employed to make maximum use of the aquifer information available and to reduce the number of parameter values subjectively assigned. The method, based on a stochastic formulation of transport (Simmons 1981, 1982), is incorporated in the transport code TRANSS (Simmons et al. 1986). The details of the formulation are contained in DOE 1987.

The following features of the TRANSS transport code are significant:

1. A probability-weighted summation of either the fluxes or concentration is calculated along the streamline, with a constant flow velocity determined from the travel time and length of the hydrologic streamline.
2. One-dimensional transport is represented along each streamline by an analytical solution of the convective dispersion equation (assuming constant flow velocity and a local scale dispersion coefficient).
3. Radioactive decay of the contaminant may be applied to contaminants in both the waste source and the ground-water system.
4. Retardation of the contaminant migration is based on a fixed distribution coefficient (K_d) for each nuclide.

5. The model contains a general empirical description of contaminant release, but also has built in the choice of three optional release models: 1) a constant fractional release rate, 2) a concentration-limited release based on chemical solubility, and 3) an adsorption-equilibrium release based on the K_d value for the nuclide.

The transport code used in the simulations accepts a distribution coefficient, K_d, for each radionuclide. The values of K_d used are shown in Table C.3 and are conservative representations of values germane to the Hanford Site. Specifically, K_d values for strontium, plutonium, and americium are conservative interpretations of values given by Delegard and Barney (1983). Values for tritium, carbon, chlorine, technetium, and uranium are taken to be zero. A K_d value of zero means that a nuclide migrates at the same rate as water. The K_d of cesium is taken as 26 milliliters per gram.

TABLE C.3. Distribution Coefficients[a] Used in Leach and Transport Models

Radionuclide	Distribution Coefficient, K_d (mL/g)	Source/Comments
^{3}H	0	Ames and Rai (1978)
^{14}C	0	General chemistry
^{36}Cl	0	Acts as anion
^{59}Ni	100	General chemistry
^{60}Co	100	Ames and Rai (1978)
^{63}Ni	100	General chemistry
^{90}Sr	0.64	Delegard and Barney (1983)
^{93}Zr	2,000	Rhodes (1957)
^{99}Tc	0	Acts as anion
^{137}Cs	26	Delegard and Barney (1983)
^{238}U	0	Chemistry - CO_3 complexed
^{239}Pu	71	Delegard and Barney (1983)
^{241}Am	76	Delegard and Barney (1983)

(a) As used here, K_d is defined as moles of solute adsorbed per gram of solid, divided by moles of solute left in solution per milliliter of solution.

Such a value is on the low end of the values for cesium reported by Delegard and Barney (1983) for various soil/waste solution combinations. Values of distribution coefficients applied to radionuclides in the leachates are based on the assumption that these wastes are equivalent to dilute, noncomplexed wastes.

Although conservative, the distribution coefficient model itself is not the most complete attenuation model. Tests run to determine K_d values do not in general consider:

- all competing ions
- the influence of various species of an element and of the implicit average K_d obtained
- the variety of soils contacted by solution.

C.5 APPLICATION OF THE TRANSPORT MODEL TO THE SURPLUS REACTOR BURIAL SITE

The conceptual transport model of the Hanford Site employed in this DEIS considers radionuclide transport as occurring in streamtubes originating at the contaminant source. These streamtubes are assumed to be vertical in the vadose zone and predominantly horizontal through the unconfined aquifer (see Figure C.3). Any lateral movement caused by soil layers above the water table would only add to the tortuosity of the path and travel time. The width of a streamtube in the unconfined aquifer is equal to the cross-sectional area of the associated source (waste site). Thus streamtubes arising from different sources will have different widths. No credit is being assumed for lateral hydrodynamic dispersion. Variations in travel times and path lengths along streamlines within the streamtube represent an aquifer-scale longitudinal dispersion.

Two points of ground-water release to the accessible environment were analyzed: 1) the contaminant flow into the Columbia River, and 2) a domestic well placed either 5 kilometers from the 200-Area burial ground for the removal alternatives, or between the reactor and the river for the in situ alternative, and used for drinking water and small-acreage irrigation. The

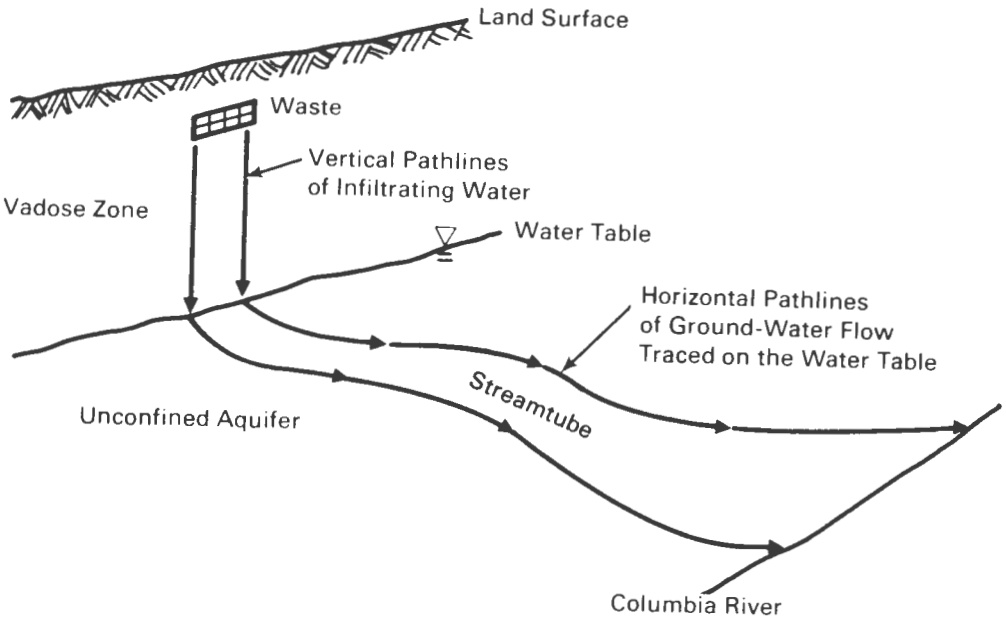

FIGURE C.3. Depiction of the Streamtube Approach to Transport in the Vadose Zone and the Unconfined Aquifer

well is assumed to pump water containing radionuclides that have been diluted in the top 5 meters of the aquifer. There may be more dilution in reality if a greater mixing depth occurs.

The output from the transport model from which environmental impacts are calculated is the concentration of radionuclides in the water pumped from the domestic well (in curies per liter), or the radionuclide flux (in curies per year) entering the Columbia River. These results are listed as a table of values that define a curve over the 10,000-year time frame of interest, or a shorter period if the inventory is depleted and the radionuclide leaves the flow system. These decay-corrected data are used in calculating dose from the well drinking water or, in the case of the contaminant reaching the river, they are used in calculating the exposure to downstream populations over the period of release.

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APPENDIX D

RELEASE RATES OF RADIONUCLIDES FROM REACTOR-BLOCK MATERIALS

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APPENDIX D

RELEASE RATES OF RADIONUCLIDES FROM REACTOR-BLOCK MATERIALS

To analyze the transport of radionuclides from the reactor blocks, it is necessary to know the rate of release of radionuclides from the graphite reactor block under storage conditions where the block material comes in contact with water, either from water infiltration or as a result of flooding, and under dry storage conditions. For this analysis, published literature and relevant reports were reviewed to identify release rates of radionuclides from a graphite matrix and corrosion rates that can be applied to activated radionuclides in the metal components of the reactor block. The review indicates that even after years of irradiation, graphite retains most of the mechanical properties that allow it to be used as a structural material for reactor cores; graphite is also nearly insoluble in water and not otherwise particularly reactive (Morgan 1985). Thus, irradiated graphite appears to have the characteristics of a solid, nonleachable, radioactive waste form.

D.1 RELEASE RATES OF CARBON-14 FROM GRAPHITE UNDER WET STORAGE CONDITIONS

Gray (1982) studied the reaction of unirradiated graphite powder with aerated deionized water at 200°, 250°, and 300°C. He concluded that the water acted as a catalyst and that the primary reaction was between the graphite and the oxygen from the air dissolved in the water. The rate of the $C + O_2 \rightarrow CO_2$ reaction at 250°C was 3×10^{-8} grams per square centimeter per day, with an activation energy of 12.8 kilocalories per mole. Extrapolating this rate to 22°C results in a rate of 2.2×10^{-12} grams per square centimeter per day.[a]

(a) The reaction is assumed to be a zero-order chemical reaction for which the reaction rate is equal to the rate constant k. Then $k = Ae^{-E/RT}$ where $A = 6.7 \times 10^{-3}$ g/cm^2 day, E = 12.8 kcal/mole, R = 1.9873 cal/mole deg, and T = the temperature in degrees Kelvin.

The release mechanism postulated by Gray (1982) for the reactor graphite is essentially one of oxidation of the carbon. The original experiments indicated approximately a 50% apportionment of the released carbon between the water and adjacent air (as carbon dioxide). For the dosimetric analysis, it has been assumed that one-half of the released carbon-14 is transported by ground water, and the remainder is transported directly out of the burial site into the atmosphere.

Gray's results are reported in terms of total surface area, whereas the reactions proceed only at active sites, which are only a small fraction of the total surface area (Laine et al. 1963). During oxidation, the active surface area increases more rapidly than does the total surface area. Irradiation decreases the total surface area (Spalaris 1954), but may increase the active surface area (and, thus, the oxidation rate) by as much as a factor of five to six (Kosiba and Dienes 1959). Spalaris (1956) measured total surface areas between 0.3 and 1 square meter per gram for small (1 centimeter in diameter) samples of five grades of Hanford reactor graphite; the total surface area of the full-sized bars may be somewhat lower because access through the pores in the graphite can be blocked. Nevertheless, assuming a total surface area of 1 square meter per gram and a reaction-rate enhancement factor of six to account for the increase in active surface area, and using Gray's extrapolated reaction rate, a leach rate of 1.3×10^{-7} centimeters per day is obtained for irradiated graphite saturated with deionized water at 22°C and exposed to air.

White et al. (1984) studied the leaching of carbon-14 from graphite that had been irradiated in the core of a Magnox reactor for approximately 13 years. After 100 days at 20° to 23°C in demineralized water, the leach rate slowed to 1.4×10^{-6} centimeters per day. The unit, centimeters per day, is from the ratio of volume to geometric surface area (V/S). For the 10.6-centimeter-square by 122-centimeter-long bars in the oldest Hanford production reactors, the V/S ratio is 2.55 centimeters; therefore, the leach

rate would be about 5.5×10^{-7} centimeters per day at 22°C. This result is in reasonable agreement with Gray's results, considering the multitude of differences between the tests.

White et al. (1984) found that the leach rate in simulated ground water at 25°C was initially the same as the rate in demineralized water at 20° to 23°C; however, after 100 days it was reduced by two orders of magnitude, whereas the rate in demineralized water was reduced by slightly less than a factor of 50. The leach rate measured at 100 days in the simulated ground water was 6×10^{-7} centimeters per day, corresponding to 2.4×10^{-7} per day for the reactor-sized bars.

Arnold and Libby (1946) also measured an enhanced oxidation rate for carbon-14 from graphite that had been irradiated in a test hole in one of the Hanford reactors. After being irradiated for only 15 months, the sample contained 0.38 ± 0.04 microcurie per gram of carbon-14. The ratio of carbon-14 to carbon-12 in the reaction products (CO and CO_2) produced at 750°C in O_2 was five times that in the solid; moreover, oxidation with chromic acid (CrO_3) yielded a product that was enriched 50 times in carbon-14. At 750°C, O_2 is nonselective; that is, it readily reacts with atoms in the basal plane. At lower temperatures, the reaction proceeds preferentially at edges of the planes. Thus, both the results reported by Arnold and Libby (1946) and those obtained by White et al. (1984) suggest that the initial rate of carbon-14 release should be about two orders of magnitude greater than the long-term corrosion rate of irradiated graphite.

The leach rate obtained by White et al. (1984) using simulated ground water lies midway between the rate they measured in demineralized water and the rate extrapolated from Gray's calculations using deionized water; therefore, it was used as the best estimate for release rate from the Hanford reactor graphite bars. Interpolating between the leach rates given by White et al. (1984; see White's Figure 6.5), it was determined that the leach rates in aerated water (R_s) can be fit rather well to the equation:

$$R_s = 6 \times 10^{-7} \left(1 + 100e^{-0.08t}\right) \text{ cm/day} \qquad \text{(D.1)}$$

Using the V/S ratio of 2.55 centimeters for the 10.6-centimeter-square bars in the first six Hanford reactors and the activation energy of 12.8 kilocalories per mole determined by Gray, the following equation was developed to describe the release rates from irradiated graphite in saturated ground water, as a function of time and temperature:

$$R_s(/\text{day}) = 565\ (1 + 100e^{-0.08t})\ e^{-6440/T} \qquad \text{(D.2)}$$

where t is the time in days after wetting of the graphite, and T is the ambient temperature in degrees Kelvin.

To keep the estimated release rates in perspective, if the 1,638 tonnes of graphite in one of the older reactors were to become saturated with aerated water, assuming an average carbon-14 activity of 5 microcuries per gram and a release rate of about 5.0×10^{-7} per day, the release rate from the reactor block would not exceed about 4 millicuries per day, or 1.5 curies per year. This rate, which probably represents the maximum release rate, is less than 0.005% of the annual worldwide cosmic carbon-14 production rate. Under the more normal conditions when saturation is incomplete, the release rate would be proportionally less.

The only available data on the release of radionuclides other than carbon-14 from irradiated graphite are those given by White et al. (1984). The incremental leach rates measured after 100 days in simulated ground water, corrected for the V/S ratio of the Hanford graphite, for tritium, cesium-134, cobalt-60, and barium-133, were 1.0×10^{-6}, 3.0×10^{-5}, 3.0×10^{-5}, and 3.0×10^{-4} per day, respectively. Maximum likely leach rates for iron-55 and europium-154 were calculated from their minimum detectable activities. These are estimated to be 1.0×10^{-5} and 8×10^{-5} per day, respectively. It was assumed that the leach rate of chlorine is similar to that of tritium; thus, a release rate of 1.0×10^{-6} per day was assumed.

To confirm the accuracy of this assumption, experiments on the leach rates of chlorine-36 were conducted in support of this DEIS (Gray and Morgan 1988). The data collected during these experiments were in good agreement

with the authors' previous estimates of chlorine-36 leach rates. Therefore, the authors concluded that the assumed release rate is valid.

D.2 RELEASE RATES OF CARBON-14 FROM GRAPHITE UNDER DRY STORAGE CONDITIONS

Complete saturation of the graphite with aerated water need not occur for the release of carbon-14 to be important; graphite normally contains moisture adsorbed from the atmosphere. At 25°C, in the absence of air, the amount of adsorbed water vapor is approximately a linear function of relative humidity (Rh) up to about 0.80 Rh. At 0.80 Rh, the amount adsorbed is statistically equivalent to about 25% of one monolayer of water (Nightingale et al. 1962). The adsorption rate, as a function of Rh, increases rapidly above about 0.80 Rh, reaching the equivalent of a full monolayer at about 0.94 Rh at 25°C. The adsorption-desorption isotherms exhibit some hysteresis, possibly indicating that part of the water vapor is being chemisorbed. It is quite probable that the rapid increase in amount adsorbed, as a function of Rh, above 0.80 Rh is a result of physical condensation in (and filling of) the small microcracks in the graphite structure. If this is indeed the case, then a linear relationship between coverage of active sites and Rh might underestimate the coverage (reaction rate) at low values of Rh. However, the U.S. Energy Research and Development Administration (1975) states that the average Rh at the Hanford Site ranges from 0.32 in July to 0.76 in January, and the Rh of entombed air may well be higher than outside air. Therefore, a linear relationship will probably suffice as a "best estimate," given the uncertainties in the remainder of the calculations. The best estimate of the release rate (R_d) of graphite in dry storage can, therefore, be expressed as:

$$R_d = R_s \times Rh/0.80, \text{ for } 0 < Rh \leq 0.80 \qquad (D.3)$$

where R_s is the release rate of graphite saturated with aerated water, and Rh is the relative humidity of the surrounding air.

D.3 OTHER SOURCES OF RADIONUCLIDES AND THEIR RELEASE RATES

Carbon-14 content and release rates from irradiated metals are unknown; carbon-14 could be incorporated by activation of nitrogen-14 impurities in the metal or from recoil-implantation. For activation products in metal components in the reactor block, release rates can be equated with corrosion rates. In ground water, corrosion rates of the aluminum alloys would probably be less than 0.1 mil (0.0001 inch) per year, but cast iron might corrode at a rate of about 5 mils per year. It is interesting to note that a rate of 0.1 mil per year is 7×10^{-7} centimeters per day; this is very comparable to the corrosion rate of irradiated graphite.

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APPENDIX E

METHODS FOR CALCULATING RADIATION DOSE

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APPENDIX E

METHODS FOR CALCULATING RADIATION DOSE[a]

The short-term radiological impacts associated with decommissioning operations and the long-term impacts from disposed radionuclides are presented in Chapter 5.0 and Appendix G in terms of calculated radiation doses to members of the general public. The doses are based on radionuclide inventories (Appendix A), on release rates (Chapter 5.0, Appendix C, and Appendix D), on transport conditions (Appendix C), and on radioactive decay. This appendix contains details of the assumptions, models, parameters, and data required for calculation of long-term environmental transport and human dose. The computer programs (codes) used and their relationships to internationally accepted models are also described in this appendix.

E.1 DEFINITIONS AND CONCEPTS

This section provides definitions of terms and brief descriptions of different types of long-term radiation doses, exposure pathways, and populations of exposed individuals.

Radiation doses to the general public as a consequence of decommissioning are possible only if radionuclides are released and reach accessible areas of the environment. Radionuclide release rates for each of the decommissioning alternatives were estimated. Ground-water (and subsequent river) release rates are summarized in Appendices C and D for long-term releases and in Chapter 5.0 for potential accidents. Atmospheric release of carbon-14 is also postulated for the period following the decommissioning operations (see Appendix G).

(a) In accordance with common practice, the term "dose," when applied to individuals and populations, is used for brevity in this report instead of the more precise term "dose equivalent" as defined by the International Commission on Radiation Units and Measurements.

Two general types of radionuclide release to the environment are of interest here: 1) short-term accidental releases; and 2) long-term releases that continue for relatively long periods of time, such as may occur from waste-disposal sites.

Many exposure pathways are possible (see Figure E.1). For example, in an acute release to the biosphere, a member of the public may be irradiated by drinking contaminated well or surface water, by eating fish or fresh vegetables contaminated by the water, or by being exposed to contamination (by irrigation, flooding, or atmospheric deposition) that may deposit on the ground and plants around the individual's home, resulting in a source of long-term exposure from a short-term release. For long-term releases, water ingestion is a continuing pathway (Figure E.1), and subsequent deposition on the ground and plants from irrigation may accumulate to provide a long-term source of radionuclides available to irradiate humans from ground contamination (external), resuspension (inhalation), or the consumption of contaminated food products (ingestion).

E.1.1 Doses During the Period Following Decommissioning

The doses calculated for members of the offsite public following decommissioning are functions of radionuclide inventories, radionuclide release rates, population distribution, and regional crop production. Scenarios resulting in chronic release to ground water also include the long-term possibility of radionuclides being brought to the surface, either through wells and irrigation or through deliberate excavations, resulting in the potential release of radionuclides to the atmosphere (resuspension). For the scenarios that release radionuclides to the atmosphere, the methods used for long-term analysis are the same as those for short-term analysis.

A different method is used for exposure scenarios for which a total population is small or cannot be determined. For individuals, many possible modes of exposure can be postulated that would result in minimal impact to the rest of society. Most of these "intruder" scenarios involve individuals intruding into the radioactive waste after decommissioning. The doses calculated are maximum annual doses to an individual.

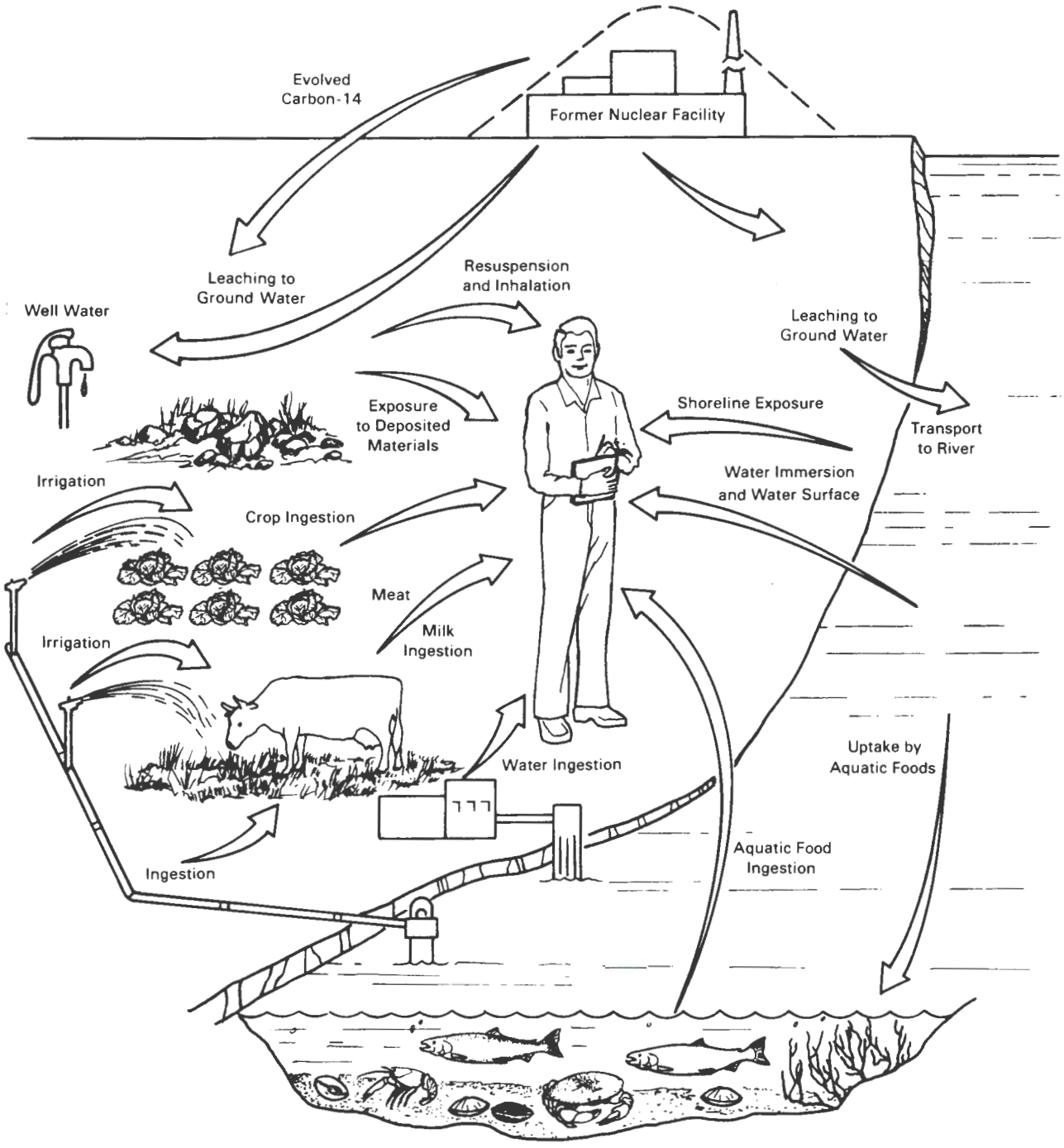


FIGURE E.1. Potential Environmental Exposure Pathways Following Decommissioning

The dominant transport mechanism for radionuclides in the soil is ground-water leaching and transport. Specific radionuclides interact with

Hanford soils, resulting in different rates of transport through the soil or ground water. Thus, site-specific modeling of the ground-water flow through the local aquifers must be done to determine times and concentrations of releases to the environment. Ground-water modeling is usually performed in two steps:

1. Ground-water flow models are used to determine the ground-water potentials, flow paths, and travel times.
2. Contaminant transport models are then applied to simulate mass transport and geochemical interactions.

Depending on the level of detail required, computer codes for ground-water modeling can be implemented for one-, two-, or three-dimensional simulations. (Appendix C discusses ground-water transport modeling and limitations.) Ground-water models can be used to generate values for either radionuclide seepage to the Columbia River or contamination levels in well water.

A set of standardized data and assumptions has been established for use in performing radiation dose calculations for operational releases at Hanford (McCormack et al. 1984). The various computer programs used to assess radiation dose, as described below, use this consistent set of assumptions to calculate dose from sources both internal and external to the body. External sources include contaminated air, water, and surfaces. Internal sources result from ingestion or inhalation of radionuclides. For all sources, doses may be calculated for various commitment periods. In all cases, resultant doses are presented for the adult man as defined in Publication 23 of the International Commission on Radiological Protection (ICRP 1975). Dose as a function of age or sex is not considered.

E.1.2 Types of Dose Used for this DEIS

Radiation dose is proportional to the quantity of energy deposited per unit mass of irradiated tissue. Definitions of length of time of exposure and length of time following exposure determine the format of the dose reported. Three basic categories of public radiation doses can be calculated:

1. Committed dose from 1 year of external exposure plus extended internal dose accumulated as a result of a 1-year intake (ingestion plus inhalation); normally, a 50- or 70-year dose-commitment period is used. This is the dose currently used for public dose calculations and for occupational record-keeping by the NRC (1982). The committed dose is used as a measure of the potential longer-term impact of accidents and routine releases.

2. Accumulated dose from a lifetime (50 or 70 years) of external exposure plus internal exposure via ingestion and inhalation, including the effects of radionuclide accumulation or decay in the environment during the exposure period; this dose relates most closely to health effects from radiation exposure. The accumulated dose is used as a measure of the lifetime impact to an individual from any operation that results in chronic releases over a period of several years, or long-lasting, relatively constant, ground-water contamination.

3. Integrated population dose from very long-term population exposure (up to 10,000 years); this dose is calculated as a sum of lifetime-accumulated doses to populations over long periods. It gives a measure of the total impact of a very long, time-dependent release of radionuclides to the environment. The integrated population dose is used for long-term ground-water, surface-water, and atmospheric-release scenarios.

Each of these types of radiation dose is used in appropriate portions of Chapter 5.0 of this DEIS. A simplified table describing the type of dose used in each descriptive scenario is given as Table E.1.

E.1.3 External Dose

For calculating external dose factors, the penetrating power of the radiation emitted determines whether it contributes to whole-body dose. The beta and gamma radiation that can penetrate into tissue is considered to contribute to whole-body dose (and dose to internal organs). The dose

TABLE E.1. Types of Radiation Dose Used in the Various Scenarios of this DEIS

Scenario	Committed Dose	Accumulated Dose	Integrated Population Dose
Operational accidents	X		
100-Area flood	X	X	X
Intrusion (Appendix G):			
Drilling	X		
Habitation/farming	X		
Excavation/mining	X		
Ground-water transport (Appendix C):			
Drinking-water well	X	X	
Irrigation well	X	X	
To river	X	X	X
Long-term atmospheric releases of ^{14}C	X	X	X

factors for most external exposures are derived assuming that the contaminated medium is infinitely large compared to the range of the emitted radiations.

Concentrated sources of radiation, such as the surplus reactor blocks, are modeled using the shielding code ISOSHLD (Engel et al. 1966). ISOSHLD is a computer code that can be used to perform gamma-ray shielding calculations for isotope sources in a wide variety of source and shield configurations. Attenuation calculations are performed by point kernel integration; for most geometries, this is accomplished using Simpson's rule for numerical integration. Buildup factors are calculated by the code based on 1) the number of mean free paths of material between the source and detector points, 2) the effective atomic number of a particular shield region (the last region unless otherwise chosen), and 3) the point isotropic buildup data available as Taylor coefficients. This procedure allows calculation of geometry-specific dose factors.

E.1.4 Internal Dose

The dosimetry model recommended in ICRP Publication 26 (1977) and applied in ICRP Publication 30 (1979-1982) is used as the basis for radiation dose calculations in this DEIS. The models for uptake and retention of radionuclides in body organs are the most comprehensive available. The contribution to organ dose resulting from decay of radionuclides in other organs (crossfire) is accounted for. Rather than report the individual organ doses, the concept of an "effective whole-body dose" (the sum of the product of each organ dose times its appropriate weighting factor) is used. The effective whole-body dose is then used for comparison to a stochastic dose limit. The stochastic effective dose equivalent limit recommended for an individual in the general public, according to ICRP Publication 26 (1977), is 500 millirem per year. In addition, ICRP Publication 26 states that when prolonged exposures are expected, the annual dose limit should be 100 millirem per year. The weighting factors recommended by the ICRP are:

Gonads	0.25
Breast	0.15
Red bone marrow	0.12
Lung	0.12
Thyroid	0.03
Bone	0.03
Remainder	0.30

E.1.4.1 Critical Groups

The doses calculated for this DEIS are based on the metabolism of the "standard man" (ICRP 1975). This mathematical representation of an average male worker obviously does not fit every individual in the general public. Actual doses depend partly on age- and sex-specific relationships between annual intakes and dose (e.g., body size) and partly on age-specific factors (e.g., metabolism rates) influencing annual intake. Further complications arise from general lifestyle considerations. Hence, the average, standard-man parameters are the usual representation for these purposes.

The chemical form of the radionuclide can also play a role in variation of dose. Compounds of the same radionuclide found in the environment or in food may be metabolized differently. The resultant changes in dose values must be considered very carefully. For example, increased absorption of a radionuclide from the gastrointestinal tract into the blood will decrease the committed dose equivalent to the lower part of the tract, but will increase the doses in other tissues of the body. Other factors, such as particle size of airborne radionuclides, can also affect the value of dose calculated.

The use of standard-man parameters is appropriate for this DEIS because although dose factors can be expected to vary with age, sex, metabolism, chemical form, etc., the long-term differences will tend to average out and not be significant. It is also difficult, if not impossible, to quantify these differences and to be certain they are appropriately applied to population groups in the very distant future.

E.2 ENVIRONMENTAL PATHWAY AND DOSIMETRY MODELS

The doses caused by long-term and accidental releases of radioactivity from the surplus production reactor facilities were estimated using several calculational models. The models used are of the concentration factor type described in ICRP Publication 29 (1978). Models and parameters were selected to give a realistic but conservative appraisal for each specific application. Site-specific parameters were used wherever possible.

The fundamental relationship for calculating radiation doses to people from any radionuclide exposure pathway is given in Equation E.1 (Soldat et al. 1974):

$$R_{ipr} = C_{ip} \, U_p \, D_{ipr} \qquad \text{(E.1)}$$

where R_{ipr} = the annual radiation dose equivalent or committed radiation dose equivalent from radionuclide i via exposure pathway p to organ r, in mrem/yr

C_{ip} = concentration of radionuclide i in the media of exposure pathway p; for calculations involving airborne radionuclides, C_{ip} is replaced with the term χ_i = (chi$_i$), which represents the average airborne concentration of radionuclide i, in pCi/m^3, pCi/L, or pCi/kg

U_p = usage parameter (intake rate) associated with exposure pathway p, in m^3/yr, L/yr, or kg/yr

D_{ipr} = radiation dose equivalent factor or the committed dose equivalent factor for radionuclide i, exposure pathway p, and organ r to convert the concentration and usage parameters to the radiation dose equivalent or to the committed dose equivalent, in mrem/pCi.

An analysis of radiation doses from separate exposure pathways requires a determination of the radionuclide concentrations and exposure rate or intake rate associated with each exposure pathway. For external exposure, the concentration of radionuclides and the duration of exposure must be quantified (the right side of Equation E.1 must also be appropriately modified). For ingestion of farm products grown on a contaminated site, the radionuclide concentration in separate food products must be determined by accounting for root transfer from soil, dry deposition from air onto surfaces of vegetation, or animal consumption of contaminated forage or feed. The annual diet of the exposed individual, the length of the growing season, and the holdup time between harvest and consumption must also be determined.

E.2.1 Air-Submersion Dose

The contribution of gamma radiation to whole-body dose is estimated by calculating the body-surface dose and using energy-dependent factors to calculate organ doses from the surface dose. An occupancy factor may be used to account for the fraction of the year a person is exposed to the cloud. Also a shielding factor may be employed to correct for any shielding by buildings or structures between the recipient and the cloud.

E.2.2 Inhalation Dose

Air concentrations are used along with the ventilation rate and dose factors to estimate the dose through the inhalation of radionuclides dispersed in the air. The ventilation rate is the volume of air taken in by an individual per unit time. A value of 0.27 liter per second is used in this DEIS (ICRP 1975). The inhalation dose factor, given in units of millirem per year per picocurie per year intake, is dependent on the complex transport, retention, and elimination of radionuclides through the respiratory and gastrointestinal tracts. The model of the respiratory tract adopted by the task group on lung dynamics forms the general basis for the calculation of this dose factor (ICRP 1966, 1979).

E.2.3 Ground-Contamination Dose

Radionuclides from the air may settle on the ground, where they can accumulate during the time of the release. These can be a source of radiation for an individual or population groups. This dose is determined using 1) the air concentration, 2) a deposition "velocity" of the radionuclides traveling to the surface from the air, 3) an exponential expression that accounts for the accumulation and radioactive decay of the radionuclide on the ground over a certain time period, 4) a dose factor, and 5) an occupancy factor. The deposition "velocity," given in terms of meters per second, is highly dependent on surface roughness, wind speed, and particle size. Based on many experimental studies, values of 0.001 meter per second for particles and 0.01 meter per second for gases were selected for use in this report (Sehmel 1984). The dose factor for the dose from ground contamination is calculated by assuming that a receptor is 1 meter above a large, nearly uniform, slab of contamination. These dose factors have units of rem per hour per picocurie per square meter of surface.

E.2.4 Ingestion Dose

Food crops may become contaminated by radionuclides deposited directly on the plant surfaces from the air or from irrigation water, or by radionuclides taken up from soil previously contaminated via air or water. Many factors must be considered when calculating doses from ingestion of these

foods. These factors account for the movement of radionuclides from release to the receptor and form a complex sequence (Soldat 1971; Baker et al. 1977). Equations used to calculate such doses are given in two parts: the first part accounts for direct deposition onto leaves and translocation to the edible parts of the plant, and the second accounts for long-term accumulation in the soil and consequent root uptake. The concentration of radioactive material in vegetation resulting from direct deposition onto plant foliage and uptake of radionuclides previously deposited in the soil is determined by Equation E.2:

$$C_{iv} = \left[\frac{(d_i^a + d_i^I)\, r\, T_v\, (1 - \exp[-\lambda_{Ei}\, t_e])}{Y_v \lambda_{Ei}} + \frac{(d_i^a + d_i^I)\, f_t\, B_{iv}\, (1 - \exp[-\lambda_i\, t_b])}{p \lambda_i} + \frac{0.15 f_t\, C_{is}\, B_{iv}}{\rho} + \frac{f_w\, C_{it}\, B_{iv}}{\rho} \right] \exp(-\lambda_i\, t) \qquad \text{(E.2)}$$

where C_{iv} = concentration of radionuclide i in the edible portion of the vegetation, in pCi/kg

d_i^a = deposition rate or flux of radionuclide i, in pCi/m^2 day:

$d_i^a = 86{,}400\ \chi_i\ V_{di}$

where 86,400 = dimensional conversion factor, in sec/day

χ_i = average air concentration of radionuclide i, in pCi/m^3

V_{di} = deposition velocity of radionuclide i, in m/sec

d_i^I = deposition rate or flux of radionuclides applied with irrigation water, in pCi/m^2 day:

$d_i^I = C_{iw}\ I$

where C_{iw} = concentration of radionuclide i in the water used for irrigation, in pCi/L

I = irrigation rate; the amount of water sprinkled on a unit area of field in 1 day, L/m^2 day

r = fraction of initially deposited material retained on the vegetation (dimensionless)

T_v = factor for translocation of externally deposited radionuclides to the edible parts of the vegetation (dimensionless); for simplicity, this parameter is assumed to be independent of the radionuclide and is assigned values of 1 for leafy vegetables and fresh forage, and 0.1 for all other produce, including grain

λ_{Ei} = the effective removal constant for radionuclide i, in $days^{-1}$:

$$\lambda_{Ei} = \lambda_i + \lambda_w$$

where λ_i = radiological decay constant for radionuclide i, in $days^{-1}$

λ_w = weathering removal constant for vegetation, in $days^{-1}$, taken to be $(0.693/14)$ $days^{-1}$

t_e = time of above-ground vegetation exposure to contamination during growing season, in days

Y_v = vegetation yield, in kg wet weight/m^2

f_t = fraction of the roots in the plow layer of soil (dimensionless)

B_{iv} = concentration factor for uptake of radionuclide i from the soil in vegetation v, in pCi/kg wet weight, per pCi/kg dry soil

t_b = time for buildup of radionuclides in the soil, in days

p = soil "surface density," in kg dry soil/m^2; a value of 224 kg/m^2 is used assuming the contaminated ground is plowed to a depth of 15 cm (Napier et al. 1980)

0.15 = thickness of plow layer, in m

C_{is} = concentration of radionuclide i available for plant uptake from residual contamination in the soil plow layer (top 15 cm of soil), in pCi/m^2

f_w = fraction of the roots that penetrate the residual contamination (dimensionless)

C_{it} = concentration of radionuclide i available for plant uptake from subsurface contamination, in pCi/m^3

ρ = bulk density of subsurface soil, in kg/m^3

t_h = holdup time between harvest and food consumption, in days.

The first term inside the brackets of Equation E.2 relates to the concentration resulting from direct deposition of airborne and irrigation-borne material on foliage during the growing season. The second term relates to plant uptake from the soil of material previously deposited. The third and fourth terms account for uptake of radionuclides contained in the top 0.15 meter of soil and below this layer, respectively. Specific values used for the parameters in Equation E.2 are published in Napier et al. (1988).

The radionuclide concentration in animal products such as meat, milk, and eggs depends on the amount of contaminated forage or feed eaten by the animal. This concentration is described by Equation E.3:

$$C_{ia} = \left[S_{ia} \; C_{if} \, Q_f + C_{iaw} \, Q_{aw}\right] \qquad (E.3)$$

where C_{ia} = concentration of radionuclide i in the animal product, in pCi/kg or /L

S_{ia} = equilibrium transfer coefficient of radionuclide i from daily intake of the animal to the edible portion of the animal product, in pCi/L (milk) or pCi/kg, (meat or eggs), per pCi/day intake by animal

C_{if} = concentration of radionuclide i in feed or forage, in pCi/kg; calculated from Equation E.1

Q_f = animal consumption rate of contaminated feed or forage, in kg/day

C_{iaw} = concentration of radionuclide i in the water consumed by animals, in pCi/L; assumed to be the same as the irrigation water, C_{iw}, used in Equation E.2

Q_{aw} = consumption rate of contaminated water by the animal, in L/day.

Specific values of the parameters used in Equation E.3 are given in Napier et al. (1988).

The nuclides tritium and carbon-14 are treated as special cases in the calculations. The concentrations in the initial environmental media (air or water) are calculated on the basis of the specific activity of the nuclide in the naturally occurring stable element.

E.2.5 Models for Carbon-14 in the Environment

The behavior of the radionuclide carbon-14 in exposure pathways is handled in a special manner. The concentrations of carbon-14 in environmental media (soil, plants, and animal products) are assumed to have the same specific activity (curies of radionuclide per kilogram of soluble element) as the contaminating medium (air, water, or soil). The fractional content of carbon in a plant or animal product is then used to compute the concentration of carbon-14 in the food product under consideration. For airborne releases it is assumed that plants obtain all their carbon from airborne carbon dioxide and that animals obtain all their carbon through ingestion of plants.

The transfer of carbon-14 from water to plants is more difficult to model because plants acquire most of their carbon from the air. Currently available models (e.g., Killough 1977; Killough and Rohwer 1978; NCRP 1985) for carbon-14 uptake by plants deal exclusively with the atmospheric exposure pathway. Only one generally accepted model is available for calculating carbon-14 concentrations in vegetation from water, that of Baker et al. (1977) which uses specific-activity models relating the activity in the plants directly to the activity in irrigation water. This is extremely

conservative in that it assumes that plants receive all of their carbon from water. The authors of this model used it simply for completeness in an overall dosimetric system.

The Performance Assessment National Review Group (PANRG) was convened by the DOE Office of Civilian Radioactive Waste Management to review proposed performance assessment methods for the national geologic repository program. The PANRG (1985) report summarizes that although the EPA standards and NRC regulations do not specifically require the calculation of radiation dose or risk, the PANRG believes that such calculational capability should be performed for a time period beyond 10,000 years. Existing models, with some modifications, are believed to be usable for this purpose. The PANRG also made specific suggestions to improve the dosimetry modeling, including correction of an inappropriate model for carbon-14 environmental behavior (PANRG 1985). The inappropriate model referred to by the PANRG is that of Baker et al. (1977). An interim irrigation model is described here based on the ratio of grams of carbon-14 to grams of total carbon in soil and a correction for the amount of carbon plants obtain from soil.

As modeled by most groups (e.g., Killough and Rohwer 1978; Baker et al. 1977; NCRP 1985), the concentration of carbon-14 in crops from atmospheric contamination is calculated as:

$$C_{Cp} = Ca_C \, F_{Cp}/P_C \qquad \text{(E.4)}$$

where Ca_C = concentration of ^{14}C in air, in Ci/m^3

F_{Cp} = fraction of carbon in the plant (dimensionless)

P_C = concentration of carbon in air, in kg/m^3; a value of 1.7×10^{-4} kg/m^3 is used, based on a typical atmospheric CO_2 concentration of 350 ppm_v.

The concentration of carbon-14 in animal products is calculated as:

$$C_{Cm} = \frac{C_{Cp}\, Qf + Cw_C\, Qw}{F_{Cf}\, Qf + F_{Cw}\, Qw} \; F_{Cm} \qquad \text{(E.5)}$$

where C_{Cm} = concentration of ^{14}C in animal product p, in Ci/kg or Ci/L

C_{cp} = concentration of ^{14}C in crop used for animal feed, in Ci/kg

Cw_C = concentration of ^{14}C in animal drinking water, in Ci/L

F_{Cf} = fraction of carbon in animal feed (dimensionless)

F_{Cw} = fraction of carbon in animal drinking water (dimensionless)

F_{Cm} = fraction of carbon in animal product m (dimensionless)

Qf = the quantity of feed or fodder consumed by the animal, in kg/day

Qw = the quantity of water consumed by the animal in L/day

This expression can be simplified for airborne releases by noting that the water concentration (Cw_C) is zero, and that the carbon content in plants is much higher than in water ($F_{Cf} >> F_{Cw}$). The animal product concentration then becomes:

$$Cm = C_{Cp} \frac{F_{Cm}}{F_{Cf}} \qquad (E.6)$$

The concentration in animal products thus also requires knowledge of the concentration in plants. These models are used in this DEIS.

However, the results produced by the equivalent model for carbon-14 in plants from irrigation show that, for most reasonable scenarios of irrigation rates and plant biomass, the quantity of carbon-14 predicted to be in the vegetation is up to an order of magnitude greater than the quantity assumed to have been provided by the irrigation water (assuming that the carbon in the plant has the same specific activity as the carbon in irrigation water). This lack of mass conservatism results in an obviously incorrect answer.

The concentration of carbon-14 in vegetation from irrigation, as used in this DEIS, is based instead on an assumption of specific-activity equilibrium between the plants and the soil, with a correction to account for the fact

that plants obtain most of their carbon from the air via photosynthesis (Napier et al. 1986; Napier et al. 1988). The model is:

$$C_{Cp} = Cw_C \; I \; t \; \frac{0.1}{0.01 \; P \; \lambda s_C} \; [1 - \exp(\lambda s_C \; t)] \qquad (E.7)$$

where C_{Cp} = concentration of ^{14}C in plant type p, in Ci/kg
Cw_C = concentration of ^{14}C in irrigation water, in Ci/L
λs_C = effective removal rate constant for ^{14}C in soil, in yr^{-1}
0.1 = the assumed uptake of 10% of plant carbon from soil
0.01 = the average fraction of soil that is carbon
t = the time over which the irrigation occurs, in yr
P = the soil surface density, taken to be 224 kg/m^2
I = the irrigation rate, L/m^2 yr.

This model is anticipated to be conservative, but not to be as unreasonably conservative as the Baker et al. (1977) version.

The model described above is used only for calculating concentration in vegetation in proximity to the source of water--that is, vegetation irrigated with contaminated well water or Columbia River water. For carbon-14 released from the decommissioned Hanford reactors, this model is adequate for calculation of "local" impacts--those occurring in the immediate area and downstream, as presented for the other radionuclides in this analysis. However, carbon-14 released to the environment has been shown to enter into a global carbon cycle (Killough 1977; NCRP 1985).

A simplified schematic of the global carbon cycle described by Killough (1977) and the NCRP (1985) is given as Figure E.2. This figure shows that carbon released to the atmosphere or to surface waters enters the global cycle and equilibrates between the atmosphere, ocean, and plants and animals of the biosphere. The rate constants shown on the figure are from NCRP (1985).

Killough (1977) estimates that a release of 1 curie of carbon-14 in the year 2000 would result in a population dose integrated over all time of

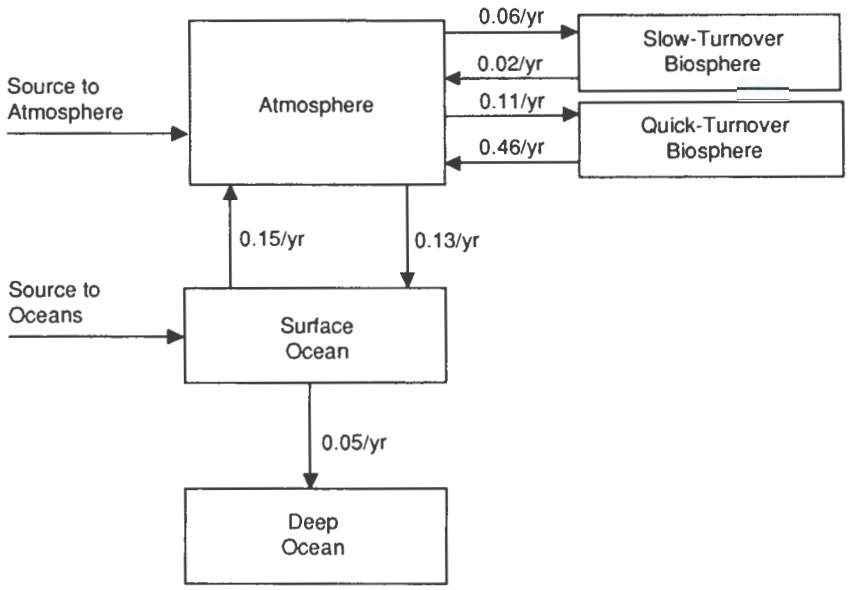


FIGURE E.2. Simplified Global Carbon Cycling Model (after NCRP 1985)

approximately 630 person-rem, for a world population stabilizing at about 12 billion people. Killough assumed that the release would be to the atmosphere. The model used by Killough was also used by the EPA in determining release limits from nuclear waste repositories to either air or water, although they specifically noted that the values were derived for atmospheric releases and that no reliable models existed for surface-water releases (Smith et al. 1985).

Using the simplified box model of Figure E.2, it can be shown that releases to the oceans (as releases to the Columbia River would quickly become) rapidly equilibrate with the atmosphere and biosphere. This is illustrated with the set of curves shown in Figure E.3. Concentrations in air and vegetation for releases to the ocean rapidly approach the values reached for direct releases to the atmosphere. These values are reached within 10 to 50 years following the release. The total area under the biosphere contents curve for ocean releases is about 75% that of the curve for atmospheric releases. Thus, integrated worldwide population doses estimated for atmospheric releases will be a conservative upper-bound on those expected for

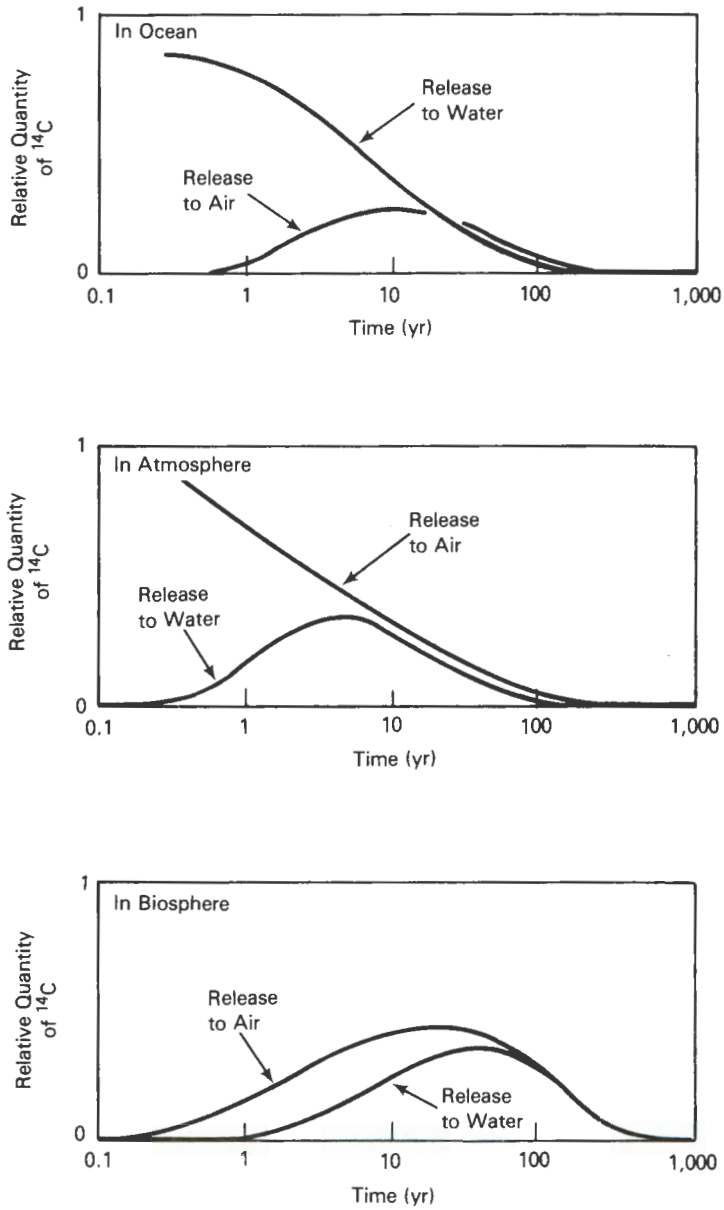


FIGURE E.3. Relative Quantities of Carbon-14 in the Ocean, the Atmosphere, and the Biosphere for Releases to the Atmosphere and Ocean

surface water releases by about 30%. Thus, for all practical purposes, they are the same, and the Killough values may be used to estimate long-term worldwide population doses.

E.3 STANDARD HANFORD CALCULATIONAL METHODS

A set of computer programs has been developed at Hanford to calculate the dose consequences from all significant exposure pathways illustrated in Figure E.1, using the models described in Section E.2.

The evaluation of potential radiation impacts is facilitated through the use of these computerized dose calculation programs. Each program accesses a common set of standardized libraries that contain Hanford-specific data. The Hanford Dose Overview Program staff maintain the programs and data libraries, documenting all revisions or updates (McCormack et al. 1984). An overall dose model quality assurance plan is in place and followed for all code developments, revisions, and use.

E.3.1 GENII

The Hanford Environmental Dosimetry Package, GENII (Napier et al. 1988), is the basic computer code used for estimating individual and population doses from releases of radionuclides to air, water, or soil. The package includes modules for calculating environmental transport and accumulation of radionuclides, external radiation dose factors, internal radiation dose factors, and individual and population exposures. The package can be used for routine or accidental releases, or for exposures to contaminated surface soil or subsoil.

The GENII software package is composed of several computer programs and data libraries. The computer programs fall into three categories: user interface (i.e., interactive menu-driven program to assist the user with scenario generation), internal and external dose factor generators, and the environmental dosimetry programs. APRENTICE is the user interface for the short-term environmental dosimetry programs, and EXTDF and INTDF generate internal and external dose-rate factors, respectively. Long-term environmental dosimetry is handled by DITTY (Napier et al. 1986). For maximum

flexibility, the short-term environmental dosimetry portion has been divided into three interrelated but separate programs (ENVIN, ENV, and DOSE) that handle input organization and checking, environmental exposure and dose calculations, respectively. Because the DITTY routine is extensively used in the long-term population dose calculations of this DEIS, it is described separately below.

E.3.2 DITTY

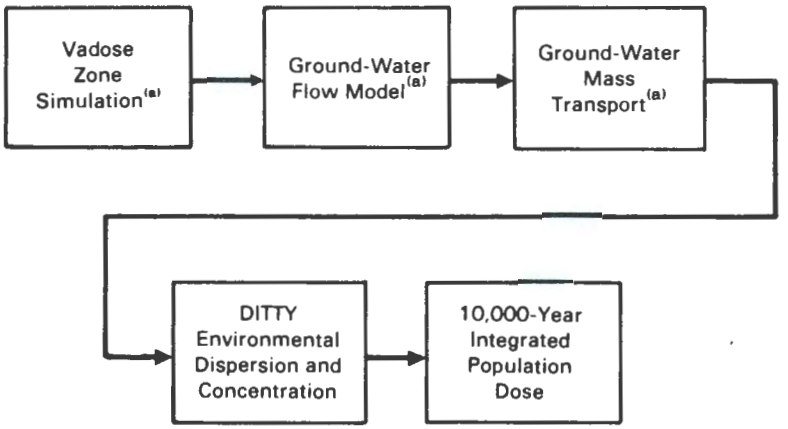
The DITTY program (Napier et al. 1986; Napier et al. 1988) estimates the time integral of collective dose over a period of up to 10,000 years for time-variant radionuclide releases to surface waters, wells, or the atmosphere. The program was initially developed to determine the collective dose resulting from ground-water pathways from high-level waste geologic repositories, but it considers other pathways as well. The relationship of DITTY to the hydrogeologic models described in Appendix D is shown in Figure E.4.

Source terms of DITTY may be defined for releases to the atmosphere or to ground water and to water wells or surface water via ground water. The actual release rates are specified in an input file as the curies released per year for selected years following the start time of the calculation.

The time frame for the calculation is any 10,000-year period. This period is broken into 143 periods of 70 years each. DITTY calculates the average release in each period from source-term data provided, and determines the total population dose to selected organs for the population present in each period. The radioactivity present during any period is the sum of material released during that period (uniformly released over 70 years) and residual material in the environment from releases in previous periods. The dose is calculated for all contributing pathways of exposure, including external exposure, inhalation, and ingestion of contaminated water and foods.

E.3.3 Exposure Parameters

The data used in performing dose calculations are extensive. Calculations require data describing transport through the atmosphere or river, transfer or accumulation in terrestrial or aquatic pathways, public exposure, and dosimetry. While most of these data are contained in computer files



[a] See Appendix C for Details.

FIGURE E.4. Computer Programs for Calculating 10,000-Year Integrated Population Doses from Releases to Ground Water

(libraries) automatically accessed by the programs during their operation, some data must also be added directly to the programs. Most of the libraries are used by more than one program, thus ensuring consistent use of the basic data for all calculations.

E.3.3.1 Population Distributions

The geographic distributions of population residing within an 80-kilometer radius of the Hanford Site areas used in the programs are based on 1980 Bureau of Census data (Sommer et al. 1981). The projected 1990 population within 80 kilometers of the Hanford Meteorology Station, located midway between the 200-East and 200-West Areas, has been used. This population distribution is given in Table E.2.

For long-term releases of radionuclides to the Columbia River, estimated downriver population totals are taken from the projections of Yandon and Landstrom (1980). These range from about 500,000 people in the year 2000 to nearly 5,000,000 people in 10,000 years. These projections are taken to be representative of the population potentially affected by the river between Hanford and the Pacific Ocean.

TABLE E.2. Projected Distribution of Population Within an 80-Kilometer Radius of the 200-Area Hanford Meteorology Station by Population Grid Sector, for the Year 1990 (Sommer et al. 1981)

Compass Direction	Number of People					
	0-16 km	16-32 km	32-48 km	48-64 km	64-80 km	Totals
N	0	202	1,320	907	2,298	4,727
NNE	0	108	790	6,448	17,482	24,828
NE	0	331	7,360	3,534	713	11,938
ENE	0	320	1,015	3,110	558	5,003
E	0	462	1,808	2,258	792	5,320
ESE	0	385	1,869	307	744	3,305
SE	0	8,664	62,866	65,306	4,094	140,930
SSE	0	2,561	16,873	3,483	6,243	29,160
S	0	1,962	1,909	251	2,114	6,236
SSW	0	1,160	6,757	787	157	8,861
SW	0	1,449	23,003	3,535	534	27,521
WSW	7	2,177	5,884	17,532	5,313	30,913
W	40	780	1,103	7,988	91,374	101,285
WNW	94	530	920	924	3,221	5,689
NW	0	652	430	499	1,467	3,048
NNW	0	89	536	1,013	5,268	7,106
TOTALS	141	22,032	134,443	117,882	142,372	416,870

E.3.3.2 Terrestrial and Aquatic Pathway Parameters

Following release and initial transport through the environment, radioactive materials may enter terrestrial or aquatic pathways that lead to public exposure. These potential pathways include consumption of foodstuffs, fish, and drinking water. Input parameters describing the movement of radionuclides within potential exposure pathways include irrigation rates, growing periods, holdup times, etc. These parameters are listed in Table E.3. Note that certain parameters are specific to maximally exposed individuals and others to average individuals.

TABLE E.3. Values of Parameters Affecting Ingestion Pathway Exposures

Food Product	Holdup (days)[a] Maximally Exposed Individual	Holdup (days)[a] Average Individual	Growing Period (days)	Yield (kg/m^2)	Irrigation Rate (L/m^2 mo)
Leafy vegetables	1	14	90	1.5	150
Other above-ground vegetables	1	14	60	0.7	160
Potatoes	10	14	90	4	180
Other root vegetables	1	14	90	5	150
Berries	1	14	60	2.7	150
Melons	1	14	90	0.8	150
Orchard fruit	10	14	90	1.7	0
Wheat	10	14	90	0.72	150
Other grains	1	14	90	1.4	150
Eggs	1	18	90	0.84	150
Milk	1	4	30	1.3	200
Beef	15	34	90	0.84	140
Pork	15	34	90	0.84	140
Poultry	1	34	90	0.84	140
Fish	1	1	--	--	--
Drinking water	1	1	--	--	--

(a) Holdup is the time between harvest and consumption.

E.3.3.3 Public Exposure Parameters

Offsite radiation dose is related to the extent of public exposure to or consumption of radionuclides of Hanford origin. Tables E.4 through E.6 provide the assumed food consumption values, exposure periods to air and ground contamination, and exposure periods for river recreation for maximally exposed and average individuals, respectively.

E.3.3.4 Atmospheric Dispersion

Radioactive material released to the atmosphere becomes diluted as the wind carries it away from the point of release. The degree of dilution and

TABLE E.4. Food Product Consumption Values for Maximally Exposed and Average Individuals (McCormack et al. 1984)

Food Product	Consumption (kg/yr) Maximally Exposed Individual	Consumption (kg/yr) Average Individual
Leafy vegetables	30	15
Other above-ground vegetables	30	15
Potatoes	110	100
Other root vegetables	72	17
Berries	30	6
Melons	40	8
Orchard fruit	265	50
Wheat	80	72
Other grains	8.3	7.5
Eggs	30	20
Milk (L/yr)	274[a]	230
Beef	40	40
Pork	40	30
Poultry	18	8.5
Fish	40	--[b]
Drinking water (L/yr)	730[a]	438

(a) 330 L/yr for infant.
(b) No individual value assigned; radiation doses are calculated based on an estimated total annual catch of 15,000 kg by the population within 80 km.

the resultant air concentrations are predicted through the use of the Gaussian plume model (NRC 1977) and onsite measurements of atmospheric conditions.

Meteorological data (wind speed, wind direction, and temperature at different elevations) for the 200 Areas are collected at the Hanford Meteorology Station, which has been in operation since 1945. Data for the 100 Areas

TABLE E.5. Exposure Periods to Air and Ground Contamination for Maximally Exposed and Average Individuals (McCormack et al. 1984)

Exposure Pathway	Exposure (hr/day) Maximally Exposed Individual	Average Individual
Ground contamination	12	8
Air submersion	24	24
Inhalation[a]	24	24

(a) Inhalation rates:
Adult--0.27 L/sec average; 0.33 L/sec acute.

TABLE E.6. River Recreational Exposure Periods for Maximally Exposed and Average Individuals (McCormack et al. 1984)

Recreational Activity	Exposure (hr/yr)[a] Maximally Exposed Individual	Average Individual
Shoreline	500	17
Boating	100	5
Swimming	100	10

(a) Assumes delay between release to river and exposure to water; 8-hr delay for maximally exposed individual, and 13-hr for average individual.

are a composite of wind-speed and -direction data collected in that area, and atmospheric-stability data (based on differential temperatures) collected at the station.

For chronic releases, the annual average atmospheric dispersion is calculated using the sector-averaged Gaussian model and joint-frequency distributions of wind speed, wind direction, and atmospheric stability. Values of the annual average air concentration per unit release rate ($\bar{\chi}/Q'$), in units of seconds per cubic meter (curies per cubic meter of concentration, per curie per second released), have been calculated from the extended record of atmospheric data at Hanford and are presented in Tables E.7 and E.8.

TABLE E.7. Annual Average Atmospheric Dispersion Parameters, $\bar{\chi}/Q'$ (sec/m), for Ground-Level Releases from the 200 Areas--Based on Historical Data[a]

Direction	Range (km) 0.8	2.4	4.0	5.6	7.2	12	24	40	56	72
N	6.41×10^{-6}	9.81×10^{-7}	4.51×10^{-7}	2.73×10^{-7}	1.99×10^{-7}	1.02×10^{-7}	4.50×10^{-8}	2.54×10^{-8}	1.78×10^{-8}	1.35×10^{-8}
NNE	5.02×10^{-6}	7.69×10^{-7}	3.54×10^{-7}	2.14×10^{-7}	1.56×10^{-7}	8.01×10^{-8}	3.54×10^{-8}	2.00×10^{-8}	1.40×10^{-8}	1.06×10^{-8}
NE	5.84×10^{-6}	8.93×10^{-7}	4.10×10^{-7}	2.48×10^{-7}	1.81×10^{-7}	9.27×10^{-8}	4.09×10^{-8}	2.32×10^{-8}	1.62×10^{-8}	1.23×10^{-8}
ENE	9.99×10^{-6}	1.53×10^{-6}	7.02×10^{-7}	4.25×10^{-7}	3.11×10^{-7}	1.60×10^{-7}	7.08×10^{-8}	4.02×10^{-8}	2.82×10^{-8}	2.14×10^{-8}
E	2.00×10^{-5}	3.05×10^{-6}	1.41×10^{-6}	8.52×10^{-7}	6.24×10^{-7}	3.21×10^{-7}	1.43×10^{-7}	8.10×10^{-8}	5.69×10^{-8}	4.31×10^{-8}
ESE	1.92×10^{-5}	2.93×10^{-6}	1.35×10^{-6}	8.18×10^{-7}	5.98×10^{-7}	3.07×10^{-7}	1.36×10^{-7}	7.71×10^{-8}	5.40×10^{-8}	4.10×10^{-8}
SE	1.71×10^{-5}	2.62×10^{-6}	1.20×10^{-6}	7.27×10^{-7}	5.30×10^{-7}	2.71×10^{-7}	1.19×10^{-7}	6.73×10^{-8}	4.71×10^{-8}	3.56×10^{-8}
SSE	8.78×10^{-6}	1.34×10^{-6}	6.15×10^{-7}	3.72×10^{-7}	2.70×10^{-7}	1.38×10^{-7}	6.02×10^{-8}	3.39×10^{-8}	2.36×10^{-8}	1.78×10^{-8}
S	6.78×10^{-6}	1.04×10^{-6}	4.72×10^{-7}	2.86×10^{-7}	2.06×10^{-7}	1.04×10^{-7}	4.49×10^{-8}	2.50×10^{-8}	1.73×10^{-8}	1.30×10^{-8}
SSW	3.76×10^{-6}	5.77×10^{-7}	2.61×10^{-7}	1.57×10^{-7}	1.13×10^{-7}	5.65×10^{-8}	2.39×10^{-8}	1.31×10^{-8}	9.02×10^{-9}	6.76×10^{-9}
SW	3.10×10^{-6}	4.76×10^{-7}	2.15×10^{-7}	1.30×10^{-7}	9.30×10^{-8}	4.67×10^{-8}	1.98×10^{-8}	1.09×10^{-8}	7.49×10^{-9}	5.61×10^{-9}
WSW	2.94×10^{-6}	4.51×10^{-7}	2.05×10^{-7}	1.24×10^{-7}	8.88×10^{-8}	4.47×10^{-8}	1.91×10^{-8}	1.05×10^{-8}	7.26×10^{-9}	5.45×10^{-9}
W	4.93×10^{-6}	6.75×10^{-7}	3.07×10^{-7}	1.86×10^{-7}	1.34×10^{-7}	6.79×10^{-8}	2.92×10^{-8}	1.63×10^{-8}	1.13×10^{-8}	8.48×10^{-9}
WNW	3.17×10^{-6}	4.86×10^{-7}	2.21×10^{-7}	1.34×10^{-7}	9.69×10^{-8}	4.92×10^{-8}	2.13×10^{-8}	1.19×10^{-8}	8.26×10^{-9}	6.23×10^{-9}
NW	5.01×10^{-6}	7.68×10^{-7}	3.51×10^{-7}	3.13×10^{-7}	1.55×10^{-7}	7.89×10^{-8}	3.45×10^{-8}	1.94×10^{-8}	1.35×10^{-8}	1.02×10^{-8}
NNW	5.03×10^{-6}	7.70×10^{-7}	3.53×10^{-7}	2.14×10^{-7}	1.56×10^{-7}	7.98×10^{-8}	3.51×10^{-8}	1.98×10^{-8}	1.39×10^{-8}	1.05×10^{-8}

(a) Data collected at the Hanford Meteorology Station from 1/76 through 1/84.

TABLE E.8. Annual Average Atmospheric Dispersion Parameters, $\overline{\chi}/Q'$ (sec/m), for Ground-Level Releases from the 100 Areas--Based on Historical Data[a]

Direction	Range (km) 0.8	2.4	4.0	5.6	7.2	12	24	40	56	72
N	4.85×10^{-6}	7.46×10^{-7}	3.36×10^{-7}	2.02×10^{-7}	1.44×10^{-7}	7.18×10^{-8}	3.01×10^{-8}	1.65×10^{-8}	1.13×10^{-8}	8.45×10^{-9}
NNE	4.55×10^{-6}	6.98×10^{-7}	3.16×10^{-7}	1.91×10^{-7}	1.36×10^{-7}	6.84×10^{-8}	2.90×10^{-8}	1.60×10^{-8}	1.10×10^{-8}	8.26×10^{-9}
NE	7.21×10^{-6}	1.11×10^{-6}	5.02×10^{-7}	3.02×10^{-7}	2.16×10^{-7}	1.08×10^{-7}	4.58×10^{-8}	2.52×10^{-8}	1.74×10^{-8}	1.30×10^{-8}
ENE	1.14×10^{-5}	1.75×10^{-6}	7.97×10^{-7}	4.80×10^{-7}	3.45×10^{-7}	1.74×10^{-7}	7.44×10^{-8}	4.13×10^{-8}	2.85×10^{-8}	2.14×10^{-8}
E	1.31×10^{-5}	2.02×10^{-6}	9.15×10^{-7}	5.51×10^{-7}	3.96×10^{-7}	1.99×10^{-7}	8.50×10^{-8}	4.71×10^{-8}	3.25×10^{-8}	2.44×10^{-8}
ESE	6.67×10^{-6}	1.02×10^{-6}	4.62×10^{-7}	2.78×10^{-7}	2.00×10^{-7}	1.00×10^{-7}	4.31×10^{-8}	2.39×10^{-8}	1.65×10^{-8}	1.24×10^{-8}
SE	4.73×10^{-6}	7.20×10^{-7}	3.25×10^{-7}	1.95×10^{-7}	1.40×10^{-7}	7.02×10^{-8}	3.00×10^{-8}	1.66×10^{-8}	1.15×10^{-8}	8.62×10^{-9}
SSE	3.44×10^{-6}	5.22×10^{-7}	2.34×10^{-7}	1.41×10^{-7}	1.01×10^{-7}	5.07×10^{-8}	2.16×10^{-8}	1.20×10^{-8}	8.26×10^{-9}	6.21×10^{-9}
S	3.71×10^{-6}	5.66×10^{-7}	2.55×10^{-7}	1.53×10^{-7}	1.10×10^{-7}	5.48×10^{-8}	2.32×10^{-8}	1.28×10^{-8}	8.80×10^{-9}	6.61×10^{-9}
SSW	1.92×10^{-6}	2.92×10^{-7}	1.32×10^{-7}	7.89×10^{-8}	5.65×10^{-8}	2.82×10^{-8}	1.20×10^{-8}	6.60×10^{-9}	4.55×10^{-9}	3.41×10^{-9}
SW	2.63×10^{-6}	4.01×10^{-7}	1.82×10^{-7}	1.09×10^{-7}	7.86×10^{-8}	3.95×10^{-8}	1.69×10^{-8}	9.38×10^{-9}	6.48×10^{-9}	4.88×10^{-9}
WSW	3.03×10^{-6}	4.64×10^{-7}	2.10×10^{-7}	1.27×10^{-7}	9.12×10^{-8}	4.59×10^{-8}	1.96×10^{-8}	1.09×10^{-8}	7.50×10^{-9}	5.65×10^{-9}
W	7.10×10^{-6}	1.09×10^{-6}	4.94×10^{-7}	2.98×10^{-7}	2.14×10^{-7}	1.07×10^{-7}	4.57×10^{-8}	2.53×10^{-8}	1.74×10^{-8}	1.31×10^{-8}
WNW	4.82×10^{-6}	7.44×10^{-7}	3.35×10^{-7}	2.01×10^{-7}	1.43×10^{-7}	7.11×10^{-8}	2.97×10^{-8}	1.62×10^{-8}	1.10×10^{-8}	8.25×10^{-9}
NW	4.89×10^{-6}	7.53×10^{-7}	3.40×10^{-7}	2.04×10^{-7}	1.46×10^{-7}	7.24×10^{-8}	3.04×10^{-8}	1.66×10^{-8}	1.14×10^{-8}	8.53×10^{-9}
NNW	3.46×10^{-6}	5.30×10^{-7}	2.39×10^{-7}	1.44×10^{-7}	1.03×10^{-7}	5.14×10^{-8}	2.17×10^{-8}	1.19×10^{-8}	8.19×10^{-9}	6.15×10^{-9}

(a) Data collected at the 100-N Area and the Hanford Meterology Station during 1982 and 1983.

For acute (short-term) releases, atmospheric dispersion was estimated under short-term meteorologic conditions using the sector-averaged model for evaluating impacts on the regional population and using the centerline model for impacts on the maximally exposed individual. Dispersion estimates for assessments of postulated acute releases are based on the extended record of atmospheric data collected at Hanford. Assessments of impacts from actual releases are based on actual atmospheric conditions during and following the release.

For predicting the consequences of a hypothetical release, it has been conservatively assumed that the release coincides with adverse atmospheric conditions. This is accomplished by calculating dispersion based on the 95th percentile atmospheric conditions derived from the recorded hourly measurements of wind speed, wind direction, and atmospheric stability. These are the conditions under which short-term (1-hour average) air concentrations are likely to be exceeded no more than 5% of the time. Doses for the maximally exposed individual are calculated using centerline values. Population doses are calculated using sector-averaged values. These are provided in Tables E.9 and E.10 for the 200 Areas, and Tables E.11 and E.12 for the 100 Areas.

E.3.4 Environmental Modeling Assessment

Modeling studies are relied on to describe the potential impacts from the subsequent transport of residual radionuclides during and following decommissioning, as well as the performance of complex systems like those that define radioactive-waste disposal. The major reason for conducting a modeling assessment is that real impacts on environmental media or humans resulting from long-term release and transport cannot be measured. In addition, the low concentrations of most materials that have been released to date provide site-specific parameter values for only a few radionuclide-pathway combinations.

Model uncertainty can best be determined by testing a model against measurements in the field under conditions similar to those the model was designed to simulate. Laboratory experiments are another potential source of

TABLE E.9. 95th Percentile[a] Centerline $\overline{\chi}/Q'$ (sec/m^3) Values for Acute Ground Level Releases from the 200 Areas[b]

Direction	Range (km) 0.8	2.4	4.0	5.6	7.2	12	24	40	56	72
N	9.63×10^{-4}	1.61×10^{-4}	7.95×10^{-5}	5.00×10^{-5}	3.90×10^{-5}	2.27×10^{-5}	1.27×10^{-5}	8.74×10^{-6}	7.15×10^{-6}	6.03×10^{-6}
NNE	9.88×10^{-4}	1.65×10^{-4}	8.12×10^{-5}	5.12×10^{-5}	3.99×10^{-5}	2.33×10^{-8}	1.30×10^{-5}	8.95×10^{-6}	7.30×10^{-6}	6.16×10^{-6}
NE	1.03×10^{-3}	1.71×10^{-4}	8.41×10^{-5}	5.32×10^{-5}	4.14×10^{-5}	2.41×10^{-5}	1.35×10^{-5}	9.29×10^{-6}	7.56×10^{-6}	6.39×10^{-6}
ENE	8.91×10^{-4}	1.50×10^{-4}	7.46×10^{-5}	4.66×10^{-5}	3.65×10^{-5}	2.13×10^{-5}	1.19×10^{-5}	8.16×10^{-6}	6.70×10^{-6}	5.64×10^{-6}
E	9.68×10^{-4}	1.62×10^{-4}	7.99×10^{-5}	5.02×10^{-5}	3.92×10^{-5}	2.29×10^{-5}	1.28×10^{-5}	8.79×10^{-6}	7.18×10^{-6}	6.06×10^{-6}
ESE	6.88×10^{-4}	1.16×10^{-4}	5.79×10^{-5}	3.60×10^{-5}	2.83×10^{-5}	1.65×10^{-5}	9.24×10^{-6}	6.32×10^{-6}	5.19×10^{-6}	4.37×10^{-6}
SE	4.70×10^{-4}	7.59×10^{-5}	3.71×10^{-5}	2.42×10^{-5}	1.84×10^{-5}	1.09×10^{-5}	6.01×10^{-6}	4.17×10^{-6}	3.37×10^{-6}	2.85×10^{-6}
SSE	8.70×10^{-4}	1.47×10^{-4}	7.32×10^{-5}	4.56×10^{-5}	3.58×10^{-5}	2.09×10^{-5}	1.17×10^{-5}	7.99×10^{-6}	6.57×10^{-6}	5.25×10^{-6}
S	9.33×10^{-4}	1.56×10^{-4}	7.75×10^{-5}	4.85×10^{-5}	3.80×10^{-5}	2.21×10^{-5}	1.24×10^{-5}	8.50×10^{-6}	6.96×10^{-6}	5.86×10^{-6}
SSW	7.06×10^{-4}	1.18×10^{-4}	5.82×10^{-5}	3.68×10^{-5}	2.86×10^{-5}	1.67×10^{-5}	9.33×10^{-6}	6.41×10^{-6}	5.24×10^{-6}	4.42×10^{-6}
SW	7.55×10^{-4}	1.26×10^{-4}	6.27×10^{-5}	3.94×10^{-5}	3.07×10^{-5}	1.80×10^{-5}	1.00×10^{-5}	6.89×10^{-6}	5.64×10^{-6}	4.75×10^{-6}
WSW	7.66×10^{-4}	1.28×10^{-4}	6.36×10^{-5}	4.00×10^{-5}	3.12×10^{-5}	1.82×10^{-5}	1.02×10^{-5}	6.99×10^{-6}	5.73×10^{-6}	4.82×10^{-6}
W	1.18×10^{-3}	1.93×10^{-4}	9.41×10^{-5}	6.01×10^{-5}	4.65×10^{-5}	2.71×10^{-5}	1.51×10^{-5}	1.05×10^{-5}	8.47×10^{-3}	7.18×10^{-6}
WNW	1.23×10^{-3}	2.01×10^{-4}	9.78×10^{-5}	6.28×10^{-5}	4.84×10^{-5}	2.82×10^{-5}	1.57×10^{-5}	1.09×10^{-5}	8.81×10^{-6}	7.48×10^{-6}
NW	1.22×10^{-3}	2.00×10^{-4}	9.73×10^{-5}	6.23×10^{-5}	4.81×10^{-5}	2.80×10^{-5}	1.56×10^{-5}	1.09×10^{-5}	8.76×10^{-6}	7.44×10^{-6}
NNW	1.04×10^{-3}	1.73×10^{-4}	8.50×10^{-5}	5.38×10^{-5}	4.18×10^{-5}	2.44×10^{-5}	1.36×10^{-5}	9.40×10^{-6}	7.65×10^{-6}	6.47×10^{-6}

(a) One-hr average value with 5% probability of being exceeded.
(b) Data collected at the Hanford Meteorology Station from 1/76 through 1/84.

TABLE E.10. 95th Percentile[a] Sector-Averaged $\overline{\chi}/Q'$ (sec/m^3) Values for Acute Ground-Level Releases from the 200 Areas[b]

Direction	Range (km) 0.8	2.4	4.0	5.6	7.2	12	24	40	56	72
N	2.41×10^{-4}	3.64×10^{-5}	1.66×10^{-5}	1.02×10^{-5}	7.45×10^{-6}	3.86×10^{-6}	1.72×10^{-6}	9.88×10^{-7}	6.91×10^{-7}	5.27×10^{-7}
NNE	2.42×10^{-4}	3.65×10^{-5}	1.67×10^{-5}	1.02×10^{-5}	7.47×10^{-6}	3.87×10^{-6}	1.72×10^{-6}	9.90×10^{-7}	6.93×10^{-7}	5.28×10^{-7}
NE	2.25×10^{-4}	3.40×10^{-5}	1.55×10^{-5}	9.57×10^{-6}	6.96×10^{-6}	3.61×10^{-6}	1.61×10^{-6}	9.24×10^{-7}	6.46×10^{-7}	4.92×10^{-7}
ENE	2.00×10^{-4}	3.02×10^{-5}	1.38×10^{-5}	8.54×10^{-6}	6.19×10^{-6}	3.22×10^{-6}	1.43×10^{-6}	8.22×10^{-7}	5.75×10^{-7}	4.38×10^{-7}
E	2.01×10^{-4}	3.03×10^{-5}	1.39×10^{-5}	8.58×10^{-6}	6.22×10^{-6}	3.23×10^{-6}	1.44×10^{-6}	8.26×10^{-7}	5.77×10^{-7}	4.40×10^{-7}
ESE	1.65×10^{-4}	2.50×10^{-5}	1.15×10^{-5}	7.11×10^{-6}	5.16×10^{-6}	2.69×10^{-6}	1.20×10^{-6}	6.84×10^{-7}	4.80×10^{-7}	3.65×10^{-7}
SE	1.37×10^{-4}	2.10×10^{-5}	9.83×10^{-6}	5.91×10^{-6}	4.39×10^{-6}	2.26×10^{-6}	1.02×10^{-6}	5.76×10^{-7}	4.10×10^{-7}	3.10×10^{-7}
SSE	2.08×10^{-4}	3.14×10^{-5}	1.43×10^{-5}	8.87×10^{-6}	6.44×10^{-6}	3.35×10^{-6}	1.49×10^{-6}	8.54×10^{-7}	5.98×10^{-7}	4.55×10^{-7}
S	2.45×10^{-4}	3.70×10^{-5}	1.69×10^{-5}	1.04×10^{-5}	7.57×10^{-6}	3.92×10^{-6}	1.75×10^{-6}	1.00×10^{-6}	7.02×10^{-7}	5.35×10^{-7}
SSW	1.93×10^{-4}	2.91×10^{-5}	1.33×10^{-5}	8.26×10^{-6}	5.98×10^{-6}	3.11×10^{-6}	1.38×10^{-6}	7.94×10^{-7}	5.55×10^{-7}	4.23×10^{-7}
SW	2.17×10^{-4}	3.28×10^{-5}	1.50×10^{-5}	9.26×10^{-6}	6.73×10^{-6}	3.49×10^{-6}	1.55×10^{-6}	8.93×10^{-7}	6.24×10^{-7}	4.76×10^{-7}
WSW	2.22×10^{-4}	3.35×10^{-5}	1.53×10^{-5}	9.44×10^{-6}	6.87×10^{-6}	3.56×10^{-6}	1.59×10^{-6}	9.11×10^{-7}	6.37×10^{-7}	4.86×10^{-7}
W	2.92×10^{-4}	4.42×10^{-5}	2.01×10^{-5}	1.23×10^{-5}	9.02×10^{-6}	4.65×10^{-6}	2.07×10^{-6}	1.19×10^{-6}	8.35×10^{-7}	6.37×10^{-7}
WNW	3.09×10^{-4}	4.69×10^{-5}	2.13×10^{-5}	1.30×10^{-5}	9.55×10^{-6}	4.92×10^{-6}	2.20×10^{-6}	1.26×10^{-6}	8.85×10^{-7}	6.74×10^{-7}
NW	2.98×10^{-4}	4.51×10^{-5}	2.06×10^{-5}	1.26×10^{-5}	9.20×10^{-6}	4.74×10^{-6}	2.12×10^{-6}	1.22×10^{-6}	8.52×10^{-7}	6.50×10^{-7}
NNW	2.76×10^{-4}	4.18×10^{-5}	1.90×10^{-5}	1.17×10^{-5}	8.53×10^{-6}	4.40×10^{-6}	1.96×10^{-6}	1.13×10^{-6}	7.90×10^{-7}	6.02×10^{-7}

(a) One-hr average value with 5% probability of being exceeded.
(b) Data collected at the Hanford Meteorology Station from 1982 and 1983.

TABLE E.11. 95th Percentile[a] Centerline $\overline{\chi}/Q'$ (sec/m^3) Values for Acute Ground-Level Releases from the 100 Areas[b]

Direction	Range (km) 0.8	2.4	4.0	5.6	7.2	12	24	40	56	72
N	1.79×10^{-3}	2.97×10^{-4}	1.46×10^{-4}	9.25×10^{-5}	7.19×10^{-5}	4.19×10^{-5}	2.34×10^{-5}	1.62×10^{-5}	1.31×10^{-5}	1.11×10^{-5}
NNE	1.81×10^{-3}	3.00×10^{-4}	1.48×10^{-4}	9.34×10^{-5}	7.26×10^{-5}	4.23×10^{-5}	2.36×10^{-5}	1.63×10^{-5}	1.33×10^{-5}	1.12×10^{-5}
NE	1.60×10^{-3}	2.64×10^{-4}	1.29×10^{-4}	8.22×10^{-5}	6.37×10^{-5}	3.71×10^{-5}	2.07×10^{-5}	1.43×10^{-5}	1.16×10^{-5}	9.84×10^{-6}
ENE	1.61×10^{-3}	2.64×10^{-4}	1.29×10^{-4}	8.23×10^{-5}	6.37×10^{-5}	3.72×10^{-5}	2.07×10^{-5}	1.44×10^{-5}	1.16×10^{-5}	9.85×10^{-6}
E	1.41×10^{-3}	2.30×10^{-4}	1.12×10^{-4}	7.20×10^{-5}	5.55×10^{-5}	3.24×10^{-5}	1.80×10^{-5}	1.25×10^{-5}	1.01×10^{-5}	8.58×10^{-6}
ESE	1.92×10^{-3}	3.18×10^{-4}	1.57×10^{-4}	9.91×10^{-5}	7.71×10^{-5}	4.50×10^{-5}	2.51×10^{-5}	1.73×10^{-5}	1.41×10^{-5}	1.19×10^{-5}
SE	1.98×10^{-3}	3.30×10^{-4}	1.63×10^{-4}	1.03×10^{-5}	8.01×10^{-5}	4.67×10^{-5}	2.61×10^{-5}	1.80×10^{-5}	1.47×10^{-5}	1.24×10^{-5}
SSE	1.75×10^{-3}	2.90×10^{-4}	1.42×10^{-4}	9.02×10^{-5}	7.01×10^{-5}	4.08×10^{-5}	2.28×10^{-5}	1.57×10^{-5}	1.28×10^{-5}	1.08×10^{-5}
S	1.67×10^{-3}	2.75×10^{-4}	1.35×10^{-4}	8.58×10^{-5}	6.65×10^{-5}	3.88×10^{-5}	2.16×10^{-5}	1.50×10^{-5}	1.21×10^{-5}	1.03×10^{-5}
SSW	1.51×10^{-3}	2.47×10^{-4}	1.20×10^{-4}	7.69×10^{-5}	5.95×10^{-5}	3.47×10^{-5}	1.93×10^{-5}	1.34×10^{-5}	1.08×10^{-5}	9.19×10^{-6}
SW	1.86×10^{-3}	3.09×10^{-4}	1.52×10^{-4}	9.63×10^{-5}	7.49×10^{-5}	4.37×10^{-5}	2.44×10^{-5}	1.68×10^{-5}	1.37×10^{-5}	1.16×10^{-5}
WSW	1.92×10^{-3}	3.20×10^{-4}	1.58×10^{-4}	9.94×10^{-5}	7.74×10^{-5}	4.51×10^{-5}	2.52×10^{-5}	1.74×10^{-5}	1.42×10^{-5}	1.20×10^{-5}
W	2.09×10^{-3}	3.48×10^{-4}	1.72×10^{-4}	1.08×10^{-5}	8.45×10^{-5}	4.93×10^{-5}	2.75×10^{-5}	1.89×10^{-5}	1.55×10^{-5}	1.31×10^{-5}
WNW	1.49×10^{-3}	2.43×10^{-4}	1.19×10^{-4}	7.58×10^{-5}	5.86×10^{-5}	3.42×10^{-5}	1.90×10^{-5}	1.32×10^{-5}	1.07×10^{-5}	9.06×10^{-6}
NW	1.81×10^{-3}	3.00×10^{-4}	1.47×10^{-4}	9.33×10^{-5}	7.26×10^{-5}	4.23×10^{-5}	2.36×10^{-5}	1.63×10^{-5}	1.33×10^{-5}	1.12×10^{-5}
NNW	1.76×10^{-3}	2.91×10^{-4}	1.43×10^{-4}	9.06×10^{-5}	7.04×10^{-5}	4.10×10^{-5}	2.29×10^{-5}	1.58×10^{-5}	1.29×10^{-5}	1.09×10^{-5}

(a) One-hr average value with 5% probability of being exceeded.
(b) Based on data collected at the Hanford Meteorology Station during 1982 and 1983.

TABLE E.10. 95th Percentile[a] Sector-Averaged $\overline{\chi}/Q'$ (sec/m^3) Values for Acute Ground-Level Releases from the 200 Areas[b]

Direction	Range (km) 0.8	2.4	4.0	5.6	7.2	12	24	40	56	72
N	2.41×10^{-4}	3.64×10^{-5}	1.66×10^{-5}	1.02×10^{-5}	7.45×10^{-6}	3.86×10^{-6}	1.72×10^{-6}	9.88×10^{-7}	6.91×10^{-7}	5.27×10^{-7}
NNE	2.42×10^{-4}	3.65×10^{-5}	1.67×10^{-5}	1.02×10^{-5}	7.47×10^{-6}	3.87×10^{-6}	1.72×10^{-6}	9.90×10^{-7}	6.93×10^{-7}	5.28×10^{-7}
NE	2.25×10^{-4}	3.40×10^{-5}	1.55×10^{-5}	9.57×10^{-6}	6.96×10^{-6}	3.61×10^{-6}	1.61×10^{-6}	9.24×10^{-7}	6.46×10^{-7}	4.92×10^{-7}
ENE	2.00×10^{-4}	3.02×10^{-5}	1.38×10^{-5}	8.54×10^{-6}	6.19×10^{-6}	3.22×10^{-6}	1.43×10^{-6}	8.22×10^{-7}	5.75×10^{-7}	4.38×10^{-7}
E	2.01×10^{-4}	3.03×10^{-5}	1.39×10^{-5}	8.58×10^{-6}	6.22×10^{-6}	3.23×10^{-6}	1.44×10^{-6}	8.26×10^{-7}	5.77×10^{-7}	4.40×10^{-7}
ESE	1.65×10^{-4}	2.50×10^{-5}	1.15×10^{-5}	7.11×10^{-6}	5.16×10^{-6}	2.69×10^{-6}	1.20×10^{-6}	6.84×10^{-7}	4.80×10^{-7}	3.65×10^{-7}
SE	1.37×10^{-4}	2.10×10^{-5}	9.83×10^{-6}	5.91×10^{-6}	4.39×10^{-6}	2.26×10^{-6}	1.02×10^{-6}	5.76×10^{-7}	4.10×10^{-7}	3.10×10^{-7}
SSE	2.08×10^{-4}	3.14×10^{-5}	1.43×10^{-5}	8.87×10^{-6}	6.44×10^{-6}	3.35×10^{-6}	1.49×10^{-6}	8.54×10^{-7}	5.98×10^{-7}	4.55×10^{-7}
S	2.45×10^{-4}	3.70×10^{-5}	1.69×10^{-5}	1.04×10^{-5}	7.57×10^{-6}	3.92×10^{-6}	1.75×10^{-6}	1.00×10^{-6}	7.02×10^{-7}	5.35×10^{-7}
SSW	1.93×10^{-4}	2.91×10^{-5}	1.33×10^{-5}	8.26×10^{-6}	5.98×10^{-6}	3.11×10^{-6}	1.38×10^{-6}	7.94×10^{-7}	5.55×10^{-7}	4.23×10^{-7}
SW	2.17×10^{-4}	3.28×10^{-5}	1.50×10^{-5}	9.26×10^{-6}	6.73×10^{-6}	3.49×10^{-6}	1.55×10^{-6}	8.93×10^{-7}	6.24×10^{-7}	4.76×10^{-7}
WSW	2.22×10^{-4}	3.35×10^{-5}	1.53×10^{-5}	9.44×10^{-6}	6.87×10^{-6}	3.56×10^{-6}	1.59×10^{-6}	9.11×10^{-7}	6.37×10^{-7}	4.86×10^{-7}
W	2.92×10^{-4}	4.42×10^{-5}	2.01×10^{-5}	1.23×10^{-5}	9.02×10^{-6}	4.65×10^{-6}	2.07×10^{-6}	1.19×10^{-6}	8.35×10^{-7}	6.37×10^{-7}
WNW	3.09×10^{-4}	4.69×10^{-5}	2.13×10^{-5}	1.30×10^{-5}	9.55×10^{-6}	4.92×10^{-6}	2.20×10^{-6}	1.26×10^{-6}	8.85×10^{-7}	6.74×10^{-7}
NW	2.98×10^{-4}	4.51×10^{-5}	2.06×10^{-5}	1.26×10^{-5}	9.20×10^{-6}	4.74×10^{-6}	2.12×10^{-6}	1.22×10^{-6}	8.52×10^{-7}	6.50×10^{-7}
NNW	2.76×10^{-4}	4.18×10^{-5}	1.90×10^{-5}	1.17×10^{-5}	8.53×10^{-6}	4.40×10^{-6}	1.96×10^{-6}	1.13×10^{-6}	7.90×10^{-7}	6.02×10^{-7}

(a) One-hr average value with 5% probability of being exceeded.
(b) Data collected at the Hanford Meteorology Station from 1982 and 1983.

TABLE E.11. 95th Percentile[a] Centerline $\overline{\chi}/Q'$ (sec/m^3) Values for Acute Ground-Level Releases from the 100 Areas[b]

Direction	Range (km) 0.8	2.4	4.0	5.6	7.2	12	24	40	56	72
N	1.79×10^{-3}	2.97×10^{-4}	1.46×10^{-4}	9.25×10^{-5}	7.19×10^{-5}	4.19×10^{-5}	2.34×10^{-5}	1.62×10^{-5}	1.31×10^{-5}	1.11×10^{-5}
NNE	1.81×10^{-3}	3.00×10^{-4}	1.48×10^{-4}	9.34×10^{-5}	7.26×10^{-5}	4.23×10^{-5}	2.36×10^{-5}	1.63×10^{-5}	1.33×10^{-5}	1.12×10^{-5}
NE	1.60×10^{-3}	2.64×10^{-4}	1.29×10^{-4}	8.22×10^{-5}	6.37×10^{-5}	3.71×10^{-5}	2.07×10^{-5}	1.43×10^{-5}	1.16×10^{-5}	9.84×10^{-6}
ENE	1.61×10^{-3}	2.64×10^{-4}	1.29×10^{-4}	8.23×10^{-5}	6.37×10^{-5}	3.72×10^{-5}	2.07×10^{-5}	1.44×10^{-5}	1.16×10^{-5}	9.85×10^{-6}
E	1.41×10^{-3}	2.30×10^{-4}	1.12×10^{-4}	7.20×10^{-5}	5.55×10^{-5}	3.24×10^{-5}	1.80×10^{-5}	1.25×10^{-5}	1.01×10^{-5}	8.58×10^{-6}
ESE	1.92×10^{-3}	3.18×10^{-4}	1.57×10^{-4}	9.91×10^{-5}	7.71×10^{-5}	4.50×10^{-5}	2.51×10^{-5}	1.73×10^{-5}	1.41×10^{-5}	1.19×10^{-5}
SE	1.98×10^{-3}	3.30×10^{-4}	1.63×10^{-4}	1.03×10^{-5}	8.01×10^{-5}	4.67×10^{-5}	2.61×10^{-5}	1.80×10^{-5}	1.47×10^{-5}	1.24×10^{-5}
SSE	1.75×10^{-3}	2.90×10^{-4}	1.42×10^{-4}	9.02×10^{-5}	7.01×10^{-5}	4.08×10^{-5}	2.28×10^{-5}	1.57×10^{-5}	1.28×10^{-5}	1.08×10^{-5}
S	1.67×10^{-3}	2.75×10^{-4}	1.35×10^{-4}	8.58×10^{-5}	6.65×10^{-5}	3.88×10^{-5}	2.16×10^{-5}	1.50×10^{-5}	1.21×10^{-5}	1.03×10^{-5}
SSW	1.51×10^{-3}	2.47×10^{-4}	1.20×10^{-4}	7.69×10^{-5}	5.95×10^{-5}	3.47×10^{-5}	1.93×10^{-5}	1.34×10^{-5}	1.08×10^{-5}	9.19×10^{-6}
SW	1.86×10^{-3}	3.09×10^{-4}	1.52×10^{-4}	9.63×10^{-5}	7.49×10^{-5}	4.37×10^{-5}	2.44×10^{-5}	1.68×10^{-5}	1.37×10^{-5}	1.16×10^{-5}
WSW	1.92×10^{-3}	3.20×10^{-4}	1.58×10^{-4}	9.94×10^{-5}	7.74×10^{-5}	4.51×10^{-5}	2.52×10^{-5}	1.74×10^{-5}	1.42×10^{-5}	1.20×10^{-5}
W	2.09×10^{-3}	3.48×10^{-4}	1.72×10^{-4}	1.08×10^{-5}	8.45×10^{-5}	4.93×10^{-5}	2.75×10^{-5}	1.89×10^{-5}	1.55×10^{-5}	1.31×10^{-5}
WNW	1.49×10^{-3}	2.43×10^{-4}	1.19×10^{-4}	7.58×10^{-5}	5.86×10^{-5}	3.42×10^{-5}	1.90×10^{-5}	1.32×10^{-5}	1.07×10^{-5}	9.06×10^{-6}
NW	1.81×10^{-3}	3.00×10^{-4}	1.47×10^{-4}	9.33×10^{-5}	7.26×10^{-5}	4.23×10^{-5}	2.36×10^{-5}	1.63×10^{-5}	1.33×10^{-5}	1.12×10^{-5}
NNW	1.76×10^{-3}	2.91×10^{-4}	1.43×10^{-4}	9.06×10^{-5}	7.04×10^{-5}	4.10×10^{-5}	2.29×10^{-5}	1.58×10^{-5}	1.29×10^{-5}	1.09×10^{-5}

(a) One-hr average value with 5% probability of being exceeded.
(b) Based on data collected at the Hanford Meteorology Station during 1982 and 1983.

TABLE E.12. 95th Percentile[a] Centerline $\overline{\chi}/Q'$ (sec/m^3) Values for Acute Ground-Level Releases from the 100 Areas[b]

Direction	Range (km) 0.8	2.4	4.0	5.6	7.2	12	24	40	56	72
N	3.69×10^{-4}	5.66×10^{-5}	2.62×10^{-5}	1.57×10^{-5}	1.16×10^{-5}	5.98×10^{-6}	2.69×10^{-6}	1.53×10^{-6}	1.08×10^{-6}	8.21×10^{-7}
NNE	3.71×10^{-4}	5.68×10^{-5}	2.63×10^{-5}	1.58×10^{-5}	1.17×10^{-5}	6.01×10^{-6}	2.70×10^{-6}	1.54×10^{-6}	1.09×10^{-6}	8.25×10^{-7}
NE	3.51×10^{-4}	5.36×10^{-5}	2.46×10^{-5}	1.49×10^{-5}	1.10×10^{-5}	5.65×10^{-6}	2.53×10^{-6}	1.45×10^{-6}	1.02×10^{-6}	7.75×10^{-7}
ENE	3.51×10^{-4}	5.36×10^{-5}	2.47×10^{-5}	1.49×10^{-5}	1.10×10^{-5}	5.65×10^{-6}	2.53×10^{-6}	1.45×10^{-6}	1.02×10^{-6}	7.75×10^{-7}
E	3.33×10^{-4}	5.06×10^{-5}	2.31×10^{-5}	1.40×10^{-5}	1.03×10^{-5}	5.31×10^{-6}	2.38×10^{-6}	1.36×10^{-6}	9.57×10^{-7}	7.29×10^{-7}
ESE	3.81×10^{-4}	5.85×10^{-5}	2.72×10^{-5}	1.63×10^{-5}	1.21×10^{-5}	6.20×10^{-6}	2.78×10^{-6}	1.59×10^{-6}	1.12×10^{-6}	8.51×10^{-7}
SE	3.87×10^{-4}	5.95×10^{-5}	2.77×10^{-5}	1.66×10^{-5}	1.23×10^{-5}	6.32×10^{-6}	2.84×10^{-6}	1.62×10^{-6}	1.14×10^{-6}	8.67×10^{-7}
SSE	3.65×10^{-4}	5.59×10^{-5}	2.58×10^{-5}	1.55×10^{-5}	1.15×10^{-5}	5.91×10^{-6}	2.65×10^{-6}	1.51×10^{-6}	1.07×10^{-6}	8.11×10^{-7}
S	3.57×10^{-4}	5.46×10^{-5}	2.52×10^{-5}	1.52×10^{-5}	1.12×10^{-5}	5.76×10^{-6}	2.58×10^{-6}	1.48×10^{-6}	1.04×10^{-6}	7.91×10^{-7}
SSW	3.42×10^{-4}	5.20×10^{-5}	2.39×10^{-5}	1.45×10^{-5}	1.06×10^{-5}	5.47×10^{-6}	2.45×10^{-6}	1.41×10^{-6}	9.87×10^{-7}	7.51×10^{-7}
SW	3.76×10^{-4}	5.77×10^{-5}	2.67×10^{-5}	1.60×10^{-5}	1.19×10^{-5}	6.11×10^{-6}	2.74×10^{-6}	1.56×10^{-6}	1.10×10^{-6}	8.38×10^{-7}
WSW	3.82×10^{-4}	5.86×10^{-5}	2.72×10^{-5}	1.63×10^{-5}	1.21×10^{-5}	6.21×10^{-6}	2.79×10^{-6}	1.59×10^{-6}	1.12×10^{-6}	8.52×10^{-7}
W	3.97×10^{-4}	6.12×10^{-6}	2.85×10^{-5}	1.70×10^{-5}	1.26×10^{-5}	6.50×10^{-6}	2.92×10^{-6}	1.66×10^{-6}	1.18×10^{-6}	8.92×10^{-7}
WNW	3.40×10^{-4}	5.17×10^{-5}	2.37×10^{-5}	1.44×10^{-5}	1.06×10^{-5}	5.44×10^{-6}	2.43×10^{-6}	1.40×10^{-6}	9.81×10^{-7}	7.46×10^{-7}
NW	3.71×10^{-4}	5.68×10^{-5}	2.63×10^{-5}	1.58×10^{-5}	1.17×10^{-5}	6.01×10^{-6}	2.70×10^{-6}	1.54×10^{-6}	1.09×10^{-6}	8.25×10^{-7}
NNW	3.66×10^{-4}	5.60×10^{-5}	2.59×10^{-5}	1.56×10^{-5}	1.15×10^{-5}	5.92×10^{-6}	2.66×10^{-6}	1.52×10^{-6}	1.07×10^{-6}	8.13×10^{-7}

(a) One-hr average value with 5% probability of being exceeded.
(b) Based on data collected at the Hanford Meteorology Station during 1982 and 1983.

comparison data if care is taken in experimental design. This process of testing predicted values against measured values is often referred to as model validation (IAEA 1981). Models used in most long-term assessments cannot be validated because of the complexity of the system being modeled. Sometimes, parts of an overall model or submodel can be compared to limited data from another source. For example, calculations from pathway-analysis models are often compared with measurements of radioactive fallout in the environment (IAEA 1984). While such exercises are useful in increasing one's confidence in selecting and applying a model, they are often incomplete. In most practical applications, models are "verified" rather than "validated." This means that their predictions are compared with results generated by similar models. The verification of a model implies that it is operating properly and gives expected results in test problems.

During the past decade, many computer codes have been developed to predict the environmental transport and subsequent impacts of radionuclide releases. These codes use various mathematical models to simulate the behavior and fate of radionuclides in environmental media by using quantitative estimates of the relationships between environmental compartments. Most of the models in use are based on the mathematical formulas originally used in the HERMES computer code (Fletcher and Dotson 1971). These include models used by the EPA (Moore et al. 1979), IAEA (1982), NRC (1977), and the models used in this DEIS. A recent study by Hoffman et al. (1984) compared the predictions of six internationally recognized terrestrial food-chain models, four of which are based on HERMES-type equations, against United Nations summaries of empirical relationships between atmospheric deposition from fallout and concentrations of several radionuclides in food. Discrepancies among the model predictions varied between factors of 6 and 30. The authors concluded that the differences reflected model assumptions rather than uncertainties in model parameters.

E.3.4.1 Comparison of Intruder Scenario to NRC's 10 CFR 61 Scenarios

In support of 10 CFR 61, the NRC issued both draft and final environmental statements (NRC 1981, 1982). These statements describe the analysis of alternatives relating to waste forms, site design and operation,

institutional controls, and administrative requirements. They also describe the radiation exposure scenario analysis used to determine near-surface disposal limits. In their analysis, the NRC defined four human-intrusion scenarios. These scenarios are: 1) intruder-construction, 2) intruder-discovery, 3) intruder-agriculture, and 4) intruder-well. The disposal limits are based on a 500-millirem-per-year whole-body dose to the maximally exposed individual (the intruder). The first and third scenarios are used primarily in calculating the disposal limits. For the intruder-construction scenario, an individual is assumed to excavate a basement at an abandoned disposal site. The exposure to direct penetrating radiation during this scenario controls the disposal limits for many radionuclides. For the intruder-agriculture scenario, an individual is assumed to live in the house built during the intruder-construction scenario. This individual grows part of his/her diet in soil that is contaminated by waste exhumed during excavation of the basement. Ingestion of radionuclides in the garden crops and inhalation of resuspended soil control the disposal limits for the remainder of the radionuclides considered in the regulation. These scenarios are conceptually similar to those described in Appendix G of this DEIS.

E.3.4.2 Comparison of Long-Term Performance Assessment Codes

The DOE and the NRC both employ specific models and computer codes as part of their performance assessment of potential nuclear waste repositories. The codes provide documented and traceable means to evaluate certain aspects of the repository, and the results are typically incorporated in site-selection documents, safety analysis reports, EISs, and licensing requests.

While the DOE and the NRC employ different codes, their approaches are similar in that each consists of the same three components:

- description of environmental transport and distribution of contamination
- estimation of human exposure to contamination
- calculation of human radionuclide dosimetry.

The methods used for human exposure and human dosimetry are essentially the same for the NRC and the DOE. Only in portions of the environmental transport do the two methods differ significantly: the NRC method uses a code, PATH1, developed by Sandia National Laboratories (SNL), which allows consideration of widespread, low-level contamination in multiple zones (physical locations downstream from release points), while to date, the DOE method has considered only individual environmental zones (Dove 1983). The SNL/NRC approach requires additional outside hydrology/sediment transport modeling as a data source; however, the DOE also has many codes available, and if they were used in conjunction with the present DOE methodology, the DOE and SNL/NRC approaches would be essentially indistinguishable.

For both approaches, once the water and soil radionuclide concentrations are known, concentration ratios are used to determine the concentration in foods. The food concentrations are then used with input consumption rates to determine human intake of radionuclides, from which the doses are calculated. The present DOE approach is to stop at individual and population doses. The NRC approach goes one step further and applies a dose-to-risk conversion factor to obtain estimates of the risk of health effects for individuals.

E.3.4.3 Comparison of DITTY and EPA Long-Term Environmental Dosimetry Models

As part of its program to develop environmental standards for disposal of high-level radioactive wastes (40 CFR 191), the EPA estimated population health risks over a 10,000-year period after disposal in mined geologic repositories. The mathematical models used to calculate environmental dose commitments and health effects are reported by Smith et al. (1985) (EPA-520/5-85-026). The Smith et al. report also identifies the data used and gives the estimates used to prepare 40 CFR 191. The data used in the EPA calculations are designed to allow calculations for a representative generic waste-disposal site. For the comparison with the results of the DITTY model used in this DEIS, the important parameters used in the EPA model defining a basalt site are described, and the EPA model results are compared with those generated by the DITTY model.

The models and approach of the EPA differ significantly from those used in DITTY. Neither the EPA model nor DITTY can be described as being more "sophisticated" than the other (although DITTY is much more flexible), because both attempt to project into admittedly imprecise futures.

For purposes of the EPA rule making, Smith et al. (1985) evaluated the potential impacts of radionuclide releases to surface waters (rivers), oceans, land surface (through intrusions), and releases resulting from violent interactions (e.g., volcanos, meteorites).

The river releases have the highest impact per unit release and, therefore, control the EPA regulations. These releases are analyzed here in some detail. Five exposure pathways are used to define the surface-water release impacts: drinking water, fish ingestion, food-crop ingestion, inhalation of resuspended material, and external contamination. Each pathway has a basic equation used to estimate the dose per unit release (S/Q, person-rem per curie released):

Drinking water: $S/Q = I_w D_{nop} P_R/R$

Fish ingestion: $S/Q = CF_{np} P_{FF} I_f D_{nop}/R$

Food crop ingestion: $S/Q = RI_{np} D_{nop} CP_p f_p f_R$

Inhalation of resuspended material: $S/Q = RF\ PD_p I_B D_{nop} f_R$ (function of time)

External contamination: $S/Q = f_R PD_p D_{nop}$ SOF (function of time)

where I_w = the individual water ingestion rate, in L/yr

D_{nop} = the dose factor for nuclide n, organ o, and pathway p, in rem/Ci ingested or inhaled, or rem/yr per Ci/m^2 for surface contamination

P_R = the number of people drinking water

R = the river flow rate, in L/yr

CF_{np} = the bioaccumulation factor for nuclide n in pathway p

P_{FF} = the number of people eating freshwater fish

I_f = the fish consumption rate, in kg/yr

RI_{np} = the intake rate per unit deposition of nuclide n in food pathway p, as calculated using methods similar to those of AIRDOS-EPA, in Ci intake per Ci/m^2 deposited

CP_p = the number of people (per m^2) who can be fed per unit area of crops

f_p = the fraction of land used for food crop p (dimensionless)

f_R = the fraction of river flow used for irrigation (dimensionless)

RF = the resuspension factor, in m^{-1}

PD_p = the population density for pathway p, in persons/m^2

I_B = the individual breathing rate, in m^3/sec

SOF = the household shielding and occupancy factor (dimensionless).

The functions of time in the equations above define the buildup and decay of surface contamination and are incidental to the following analysis because similar methods are used by both the EPA model and DITTY.

For each pathway equation, one set of parameters can be defined as being site-specific; that is, that realistic values for Hanford may be specific rather than generic values. For drinking water, this is the ratio P_R/R, the ratio of the number of people drinking river water to the total river flow. The value the EPA uses is 3.3×10^{-7}. Using the projected average downriver population and a Columbia River flow rate of around 1×10^4 liters per year, a Hanford value of 2×10^{-8} can be derived. Thus the Hanford value for this pathway is 6% of that used by the EPA for its generic analysis because the Columbia River has a very large flow. Even then, the Hanford value is conservative because currently very few people relative to the EPA assumption actually consume water from the Columbia River downstream from Hanford.

The site-specific correction for the fish-consumption pathway can be incorporated in the ratio $P_{FF}I_f/R$, the ratio of the product of the number of people eating river-caught fish, times consumption, to the river flow rate. The EPA uses a world-average value of 3.3×10^{-7} person-kilograms per liter.

Columbia River sport fishing yields only about 15,000 kilograms per year of fish in the Hanford region (Price et al. 1984), for an average ingestion rate of only about 0.04 kilograms per person. Conservatively, assuming 10 times this average for the projected downriver population gives about 7×10^{-9} person-kilograms per liter, which is 2% of the EPA value.

The variables in the food-crop ingestion equation that can be modified for Hanford releases are $f_R CP_p$, the fraction of river flow used for irrigation, times the agricultural productivity. The EPA uses a value of 0.1 for f_R, which is appropriate for small western rivers, but is much too large for the Columbia River below Hanford. While much of the land area upstream and around Hanford is heavily irrigated with Columbia River water [using about 1.3% of the river flow (ERDA 1975)], only a small area below Hanford is suitable for or requires irrigation. Accounting for the potential for increased irrigation in the area upstream and around Hanford, for the EPA value for the fraction of land irrigated, and for the large river flow, an f_R value of only about 0.02 without major diversion projects was derived. The number of people who can be fed per unit area, CP_p, is estimated by the EPA at about 0.004 person per square meter. Approximating this either by averaging the parameters for yield and consumption, or by dividing the assumed irrigated area by the projected population, results in a value of 0.002 person per square meter. The ratio of the EPA value for the factor $f_R CP_p$ to the value used in this DEIS is thus 0.08.

For inhalation of resuspended material from irrigated soils, the parameters $f_R PD_p$ can be derived for Hanford-specific analyses. As described above, f_R is 0.1 for the EPA analysis and about 0.02 for the Hanford region. The EPA uses a value of 6.67×10^{-5} persons per square meter, based on world averages. If the projected population downstream from Hanford is assumed to live in a 30-kilometer-wide strip along the river, the population density is about 1×10^{-4} persons per square meter, which is somewhat higher than the EPA value. Combining these gives a ratio of Hanford values to EPA value of 0.3 for the factors $f_R PD_p$.

Doses from external exposure, like inhalation, depend on the area irrigated and the number of people exposed. The parameters $f_R PD_p$ apply here also. The ratio for the two external exposure scenarios is then 0.3.

The EPA background information document for 40 CFR 191 (EPA 1985) presents a table of the pathway contributions to the total calculated values of health effects per unit release. That table is reproduced here as Table E.13. The individual pathways are summed to obtain the total. If the individual pathways are modified using Hanford-specific parameters, the results are as given in Table E.14. The Hanford-specific results calculated using the DITTY model and the EPA health effects conversion methods are compared with the Hanford-specific values calculated using the EPA model. The results can be seen to correspond closely.

A few notable exceptions to the modeling agreement can be observed in Table E.14. The carbon-14 specific activity model used by the EPA is the Killough (1977) "global" model, which is incompatible with the more local models used for the other radionuclides. The carbon-14 model used in this DEIS is applicable to the immediate downriver area, and the local results can be seen to be about 10^{-3} of the total global results for atmospheric releases. Other differences in the tabulated results can be attributed to differences in parameters chosen for the analysis. The gastrointestinal tract-to-blood transfer factors used for the americium nuclides for the Hanford analysis are higher than those used generically by the EPA, as are the soil-to-plant transfer factors for neptunium. The soil-leaching parameters for radium, and its daughter lead-210, are lower for the Hanford analysis than the EPA used generically (i.e. the K_d is higher). The EPA used a much higher gastrointestinal tract-to-blood transfer factor for uranium than is recommended by the ICRP and used in this analysis. Otherwise, all results are within a factor of five or so, showing good agreement for such dissimilar models.

The last column of Table E.14 presents the EPA values for radionuclide releases to oceans. For the mobile radionuclides technetium-99 and iodine-129, the contribution from worldwide distribution of contamination in the ocean from the river releases is only a small increment to the total,

TABLE E.13. Fatal Cancers per Curie Released to a River, Estimated Using the EPA Model (Smith et al. 1985)

		Ingestion					Inhalation	External Dose	
Radionuclide	Total	Drinking Water	Freshwater Fish	Surface Crops	Milk	Resuspended Beef	Ground Material	Air Contamination	Submersion
^{14}C	5.83×10^{-2}	NA	NA	NA	NA	NA	NA	NA	NA
^{59}Ni	4.78×10^{-5}	4.91×10^{-6}	1.25×10^{-6}	3.94×10^{-5}	4.72×10^{-7}	1.83×10^{-8}	3.25×10^{-10}	3.17×10^{-10}	1.11×10^{-15}
^{90}Sr	2.26×10^{-2}	3.72×10^{-3}	1.04×10^{-4}	1.75×10^{-2}	1.19×10^{-3}	4.59×10^{-6}	4.05×10^{-9}	0.00×10^{0}	0.00×10^{0}
^{93}Zr	1.59×10^{-4}	1.66×10^{-5}	1.41×10^{-7}	1.28×10^{-4}	4.05×10^{-7}	5.23×10^{-6}	6.58×10^{-8}	1.45×10^{-7}	4.86×10^{-14}
^{99}Tc	3.68×10^{-4}	7.02×10^{-5}	7.70×10^{-6}	2.02×10^{-4}	8.38×10^{-5}	1.38×10^{-6}	4.67×10^{-11}	0.00×10^{0}	1.80×10^{-19}
^{126}Sn	1.25×10^{-2}	2.67×10^{-4}	2.04×10^{-3}	5.37×10^{-4}	2.42×10^{-5}	3.75×10^{-5}	6.47×10^{-8}	7.55×10^{-3}	1.14×10^{-10}
^{129}I	8.09×10^{-2}	3.15×10^{-3}	2.65×10^{-4}	6.75×10^{-2}	9.68×10^{-3}	1.31×10^{-4}	3.68×10^{-8}	5.41×10^{-6}	6.86×10^{-13}
^{135}Cs	7.76×10^{-3}	2.38×10^{-4}	7.89×10^{-4}	6.10×10^{-3}	5.71×10^{-4}	3.16×10^{-5}	5.38×10^{-9}	0.00×10^{0}	0.00×10^{0}
^{137}Cs	1.07×10^{-2}	1.62×10^{-3}	5.37×10^{-3}	2.53×10^{-3}	8.42×10^{-4}	4.65×10^{-5}	1.33×10^{-9}	3.19×10^{-4}	4.45×10^{-12}
^{151}Sm	9.78×10^{-6}	4.52×10^{-6}	2.88×10^{-7}	4.53×10^{-6}	6.13×10^{-9}	2.97×10^{-8}	2.14×10^{-9}	0.00×10^{0}	1.31×10^{-17}
^{210}Pb	1.25×10^{-1}	5.40×10^{-2}	1.38×10^{-2}	4.93×10^{-2}	9.26×10^{-4}	2.16×10^{-5}	3.45×10^{-7}	9.60×10^{-8}	6.13×10^{-15}
^{226}Ra	1.68×10^{-1}	6.41×10^{-2}	8.18×10^{-3}	7.78×10^{-2}	2.41×10^{-3}	6.03×10^{-5}	8.91×10^{-6}	1.00×10^{-2}	1.56×10^{-10}
^{238}U	2.08×10^{-2}	6.32×10^{-3}	1.61×10^{-4}	1.38×10^{-2}	2.96×10^{-4}	1.91×10^{-6}	4.09×10^{-6}	2.65×10^{-5}	1.88×10^{-12}
^{237}Np	8.66×10^{-2}	2.43×10^{-2}	3.10×10^{-2}	2.41×10^{-2}	1.83×10^{-5}	7.08×10^{-6}	3.40×10^{-6}	4.83×10^{-5}	1.55×10^{-12}
^{238}Pu	4.27×10^{-2}	2.43×10^{-2}	4.96×10^{-4}	1.75×10^{-2}	1.57×10^{-7}	6.10×10^{-8}	1.14×10^{-5}	1.74×10^{-9}	1.60×10^{-15}
^{239}Pu	5.20×10^{-2}	2.61×10^{-2}	5.33×10^{-4}	2.28×10^{-2}	1.85×10^{-7}	7.18×10^{-8}	3.14×10^{-4}	2.21×10^{-8}	4.26×10^{-14}
^{240}Pu	5.03×10^{-2}	2.60×10^{-2}	5.31×10^{-4}	2.16×10^{-2}	1.80×10^{-7}	6.99×10^{-8}	2.75×10^{-4}	3.97×10^{-8}	3.55×10^{-14}
^{241}Pu	2.18×10^{-3}	1.25×10^{-3}	2.55×10^{-5}	8.94×10^{-4}	8.10×10^{-9}	3.14×10^{-9}	8.73×10^{-8}	9.46×10^{-9}	1.68×10^{-15}
^{242}Pu	5.01×10^{-2}	2.48×10^{-2}	5.07×10^{-4}	2.23×10^{-2}	1.78×10^{-7}	6.90×10^{-8}	3.13×10^{-4}	3.95×10^{-8}	3.62×10^{-14}
^{241}Am	5.80×10^{-2}	2.70×10^{-2}	5.59×10^{-3}	2.16×10^{-2}	7.63×10^{-7}	1.29×10^{-7}	3.85×10^{-5}	6.22×10^{-6}	1.10×10^{-12}
^{243}Am	6.81×10^{-2}	2.69×10^{-2}	5.56×10^{-3}	2.40×10^{-2}	8.28×10^{-7}	1.41×10^{-7}	7.92×10^{-5}	7.08×10^{-4}	2.93×10^{-11}

NA = not specifically addressed by the EPA.

TABLE E.14. Comparison of DITTY and EPA Values for Number of Fatal Cancers per Curie Released

Nuclide	Standard EPA	Hanford-Specific EPA	Hanford-Specific DITTY	EPA Release to Ocean
^{241}Am	0.06	0.004	0.02	0.004
^{243}Am	0.07	0.004	0.02	0.01
^{14}C	0.06	NA[a]	0.00006[b]	NA[a]
^{135}Cs	0.008	0.0006	0.0003	0.00003
^{137}Cs	0.01	0.0006	0.001	0.000004
^{129}I	0.08	0.008	0.003	0.0001
^{237}Np	0.09	0.004	1.0	0.007
^{238}Pu	0.04	0.003	0.0009	0.0004
^{239}Pu	0.05	0.004	0.001	0.002
^{242}Pu	0.05	0.004	0.001	0.002
^{226}Ra	0.2	0.02	0.6	0.005
^{99}Tc	0.0004	0.00004	0.000009	0.000003
^{126}Sn	0.1	0.003	0.005	0.002
^{151}Sm	0.00001	0.0000007	0.000001	0.0000004
^{90}Sr	0.02	0.002	0.01	0.00008
^{238}U	0.02	0.002	0.0004	0.0002

(a) Not specifically addressed by the EPA.
(b) DITTY incorporates a revised ^{14}C model that more realistically reflects crop uptake of carbon from contaminated water in the local area.

even using the Hanford Site parameters. Therefore, to the degree of accuracy of the calculations, the integrated population doses along the Columbia River are a good approximation of the entire impact of releases from Hanford.

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APPENDIX F

RADIOLOGICALLY RELATED HEALTH EFFECTS

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APPENDIX F

RADIOLOGICALLY RELATED HEALTH EFFECTS

The radiation dose to humans from ingestion, inhalation, or external exposure to specified quantities of radionuclides can be calculated with reasonable confidence. The amounts of radioactive materials that may be released during or after decommissioning operations can be estimated; however, the fractions reaching humans via various environmental pathways are not as well defined. The relationship of dose to health effects is even less well defined. Therefore, estimates of health effects that may result from radiation exposure consequent to such activities can be derived only from a chain of estimates of varying uncertainty. The usual practice in making these estimates is to ensure that if an error is made, it is made in a way intended to overprotect the individual. As a result, if the chain of estimates is long, there may be considerable conservatism in the final value.

Because expected releases of radioactive materials are small and the radiation dose to any individual is small, the effects to be considered are long-delayed somatic and genetic effects. These will occur, if at all, in a very small fraction of the population exposed. Except as a consequence of an unusually severe accident involving larger doses, no possibility exists for an acute radiation effect. The effects that must be considered are 1) cancers that may result from whole-body exposures and from radioactive materials deposited in lung and bone, and 2) genetic effects that are reflected in future generations because of exposure of the germ cells.

Knowledge of these delayed effects of low doses of radiation is necessarily indirect, because these doses occur too infrequently to be observed against the much higher background incidence of similar effects from other causes. Thus, for example, it is not possible to attribute any specific number of human lung cancers to the radionuclides present in everyone's lungs from weapons-test fallout, because lung cancers are known to be caused by other materials present in much more hazardous concentrations and because lung cancers occurred before there were any manmade radionuclides. Even in

controlled studies with experimental animals, a low incidence of effect was found indistinguishable from the incidence of effect in unexposed animals, at exposure levels far higher than those predicted to result from or subsequent to decommissioning activities. Hence, the relationship between health effect and radiation dose can only be estimated. This estimate is based on observations made at very much higher exposure levels, where effects have been observed in humans, and on carefully conducted animal experiments. In this context, the National Council on Radiation Protection and Measurements (NCRP 1975) has said:

> "The NCRP wishes to caution governmental policy-making agencies of the unreasonableness of interpreting or assuming "upper limit" estimates of carcinogenic risks at low radiation levels derived by linear extrapolation from data obtained at high doses and dose rates, as actual risks, and of basing unduly restrictive policies on such interpretation or assumption."

The approach used in this DEIS was to compare estimated radiation doses from decommissioning activities with the more accurately known radiation doses from other sources, and to estimate health effects. The comparison of doses eliminates the uncertainty in estimating health effects (the dose-effect relationship) and provides a contrast to firmly established data on human exposure to naturally occurring radiation and radioactive materials. Some people prefer to judge the acceptability of a risk on knowledge that the risk is some certain fraction of an unquantifiable, but unavoidable, natural risk, rather than basing their judgments on an absolute estimate of future deaths that might be too high or too low by a large factor. In this DEIS, estimated radiation exposure from decommissioning activities is compared with naturally occurring radiation exposure, and estimates of cancer deaths and genetic effects are indicated.

F.1 LATE SOMATIC EFFECTS

Much recent literature has dealt with the prediction of late somatic effects of very low-level irradiation. This literature is not reviewed in detail here because it is readily available. Instead, the various dose-effect relationships and the current models for projecting risks are briefly

considered, and justification for the range of values employed in this DEIS and discussed in this appendix is provided.

Several publications include efforts to quantify risks of late somatic effects of irradiation. The most extensive of these are the reports by the National Academy of Sciences Advisory Committee on the Biological Effects of Ionizing Radiation (BEIR 1980)[a] and the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR 1977). (A more recent report, UNSCEAR 1982, does not focus on late somatic effects.) The most recent attempt to quantify risks of late somatic effects is the Health Effects Model for Nuclear Power Plant Accident Consequence Analysis (NRC 1985), provided to replace the health effects model used in the Nuclear Regulatory Commission's Reactor Safety Study (NRC 1975). In the discussion that follows, the BEIR (1980) and NRC (1985) reports are emphasized because they provide the most up-to-date information on radiation risks.

These various reports draw their conclusions from human effects data derived from medical, occupational, accidental, or wartime exposures to a variety of radiation sources (e.g., external x-irradiation, atomic-bomb gamma and neutron radiation, radium, radon, and radon decay products). Of course, these data on humans reflect the results of exposures to relatively large total doses of radiation at relatively high dose rates.

Many problems are encountered in attempting to use these data to estimate lifetime risks from low-level radiation exposure. These problems are briefly summarized in the following excerpt from BEIR (1980):

> "The quantitative estimation of the carcinogenic risk of low-dose, low-LET [linear energy transfer] radiation is subject to numerous uncertainties. The greatest of these concerns the shape of the dose-response curve. Others pertain to the length of the latent period, the RBE [relative biological effectiveness] for fast neutrons and alpha radiation relative to gamma and x radiation, the period during which the radiation risk is expressed, the model used in projecting risk beyond the period of observation, the effect of

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(a) Commonly referred to as BEIR III, the third in a series of reports by the National Academy of Sciences Advisory Committee on the Biological Effects of Ionizing Radiation, although not numbered as such by the academy.

> dose rate or dose fractionation, and the influence of differences in the natural incidence of specific forms of cancer. In addition, uncertainties are introduced by the characteristics of the human experience drawn on for the basic risk factors, e.g., the effect of age at irradiation, the influence of any disease for which the radiation was given therapeutically, and the influence of length of follow-up."

As noted, one of the largest sources of uncertainty involves the choice of the mathematical function used to express the dose-response relationship. An earlier study (BEIR 1972) used a linear function for this purpose, justifying its use in part by the desirability of conservatism for radiation-protection purposes. The BEIR (1980) report, however, deviates from this approach by providing an envelope of estimates based on linear, linear-quadratic, and quadratic functions. The BEIR (1980) report indicates that the linear-quadratic model, which results in lower risk estimates than the linear model at low doses and dose rates, is the most realistic. Experimental evidence summarized in a report of the NCRP (1980) suggests that effects (per unit dose) at dose rates of less than 5 rad per year would be reduced by a factor between 2 and 10 below estimates made per unit dose for rates greater than 5 rad per year. The BEIR (1980) linear-quadratic function, which is based on analyses of data on the Japanese atomic-bomb survivors, reduces risk estimates by a factor of 2.3 for leukemia and bone cancer, and by a factor of 2.5 for other types of cancer.

A second major source of uncertainty in estimating lifetime risks exists because no populations on which estimates of health effects are based have yet been followed to the end of their lifespans. For leukemia and bone cancer, rates appear to have returned to spontaneous levels 25 to 30 years after exposure. For other cancers, however, a model in which risks are assumed to persist over an exposed individual's lifetime seems more appropriate. The BEIR (1980) report estimates are based on the assumption that risks of leukemia and bone cancer persist 2 to 27 years following exposure, while risks of other effects persist for a lifetime after a minimal latent period of 10 years.

Two approaches were used in the BEIR (1980) report to extend risk estimates beyond the period represented by follow-up data. First, with the

absolute-risk projection model, it is assumed that the number of excess cases per unit of population per unit of time expressed as a function of radiation dose remains constant over a specified period. Second, with the relative-risk projection model, it is assumed that the ratio of the excess cancer risk to the spontaneous age-specific risk remains constant over the specified period. After early childhood, spontaneous cancer incidence and mortality rates generally increase with age, and, because of this, the relative-risk model yields larger numbers for the years beyond the follow-up period.

The calculations provided in the BEIR (1980) report require several assumptions that are not discussed here. In particular, sex and age at exposure are treated in a more rigorous fashion than by the earlier BEIR (1972) report or other groups that have attempted risk estimation.

The lifetime risk estimates for mortality from all forms of cancer based on the linear-quadratic model given in BEIR (1980) are summarized in Table F.1 for two exposure situations. BEIR (1980) also provides estimates for continuous exposure to 1 rad per year from ages 20 to 65, 35 to 65, and 50 to 65 (intended to represent occupational exposures), but these are not reproduced here. BEIR (1980) did not provide estimates for exposures lower than 1 rad per year because it was believed this involved too much uncertainty. Also, the BEIR (1980) report was primarily concerned with estimating overall cancer risks. No estimates of lifetime risks for specific cancer types (except leukemia and bone cancer) are provided, although evidence regarding many individual cancer types is extensively reviewed.

The recent NRC (1985) report does provide estimates for specific cancer types and also takes into account epidemiological data and analyses that have become available since 1980. The NRC (1985) report provides central estimates, as well as upper and lower bounds[a] for the number of deaths and

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(a) The terms "upper and lower bounds," are defined in NRC (1985) as follows: "The central estimates are intended to reflect the most realistic assessment of radiation risks . . . while the upper and lower bounds are intended to reflect alternative assumptions that are also reasonably consistent with available evidence" (NRC 1985, p. II-94).

TABLE F.1. Estimated Excess Mortality from All Forms of Cancer, Based on Linear Quadratic Dose-Response Model

	Absolute-Risk Projection Model	Relative-Risk Projection Model
Single exposure to 10 rads:		
Number of excess cases per million persons	766	2,255
% increase over normal risk	0.47	1.4
Continuous exposure to 1 rad/yr, lifetime:		
Number of excess cases per million persons	4,751	12,920
% increase over normal risk	2.8	7.7

Source: BEIR 1980, p. 209.

cases and for the years of life lost and years of life lived after the occurrence of cancer. Except for breast and thyroid cancer, the central estimates are based on a linear-quadratic function that reduces risks at low doses and dose rates by a factor of 3.3, slightly more than the linear-quadratic model suggested in the BEIR (1980) report. The lower-bound estimates are based on a reduction factor of 10, while the upper-bound estimates are based on a linear model.

Since the BEIR (1980) report was published, additional support for the assumption that risks persist for a lifetime and for the use of the relative-risk model has become available. The most recent data on the Japanese atomic-bomb survivors (Kato and Schull 1982), extending the follow-up from 30 to 34 years, indicates no tapering off of risks. In a parallel analysis of data from both Japanese atomic-bomb survivors and British ankylosing spondylitis patients, Darby (1984) investigated the fit of the relative- and absolute-risk models. These recent data and Darby's more rigorous statistical treatment provide added support for the use of the relative-risk model. However, risks

beyond the period for which follow-up data are available are still uncertain. Thus, the relative-risk model may overestimate lifetime cancer risks.

For the reasons noted above, the NRC (1985) report used the relative-risk model for central estimates and upper bounds for breast cancer, lung cancer, gastrointestinal cancers, and for "all other cancers" as a group. The absolute-risk model was used to estimate central and upper bounds for leukemia, bone cancer, skin cancer, and thyroid cancer, and to estimate the lower bounds for all cancer types. As in the BEIR (1980) report, risks for leukemia and bone cancer were assumed to persist from 2 to 27 years following exposure. Risks for other cancer types were assumed to have a 10-year minimal latent period, except for thyroid cancer, for which a 5-year minimal latent period was assumed.

In the NRC report (1985), the updated analyses of the Japanese data were taken into account in obtaining the numerical risk coefficients needed to calculate lifetime risks. For lung cancer, a larger relative coefficient was used for the upper bound than for the central estimate, a procedure intended to reflect the uncertainty in extrapolating to the United States population an estimate based on Japanese data. The NRC (1985) report did not treat sex and age at exposure in as detailed a manner as did the BEIR (1980) report. Age at exposure was considered only in estimates for thyroid effects and the upper-bound estimate for breast cancer; separate estimates were provided for cancers resulting from exposure received in utero.

The central estimates and upper and lower bounds for cancer mortality resulting from a per capita exposure of 1 rem, based on the NRC (1985) model, are summarized in Table F.2. These estimates are applicable to populations with age distributions and mortality rates similar to those of the United States. For comparison, this table also shows the BEIR (1980) report's estimates for such exposure, obtained by dividing the risks for a single 10-rem exposure by 10. Note that both the BEIR (1980) and NRC (1985) estimates are based on dose to the relevant organ or, in the case of all cancers together, on an appropriate average organ dose.

TABLE F.2. Comparison of Various Estimates of Cancer Deaths Per Million Person-Rem (i.e., effects in an average population of 1 million exposed to 1 rem per capita)

	BEIR (1980) Report[a]				NRC (1985) Model				
	Absolute-Risk Model		Relative-Risk Model						
Type of Cancer	Linear Model	Linear-Quadratic[b] Model	Linear Model	Linear-Quadratic[b] Model	Upper Bound	Central Estimate	Lower Bound[b]	UNSCEAR Report (1977)	ICRP-26
Leukemia	46[c]	22[c]	454[c]	203[c]	48	14	5	15 to 25	20
Nonleukemic:	120	54			519	174	24		
Lung					138	20	5	25 to 50	20
Bone	1.0[c]	0.5[c]			2	1	0.2	2 to 5	5
Thyroid					7	7	0.7	5 to 15	5
Cancers resulting from in utero exposure[d]	5.8	—	—	—	6	2.4	2.4	2 to 2.5	—
TOTAL	173	77	501[e]	226[e]	573	190	31	49 to 98	50

(a) The BEIR (1980) estimates are the average of sex-specific estimates.
(b) Calculated on the assumption that no individual dose will exceed 10 rem.
(c) The BEIR (1980) report gives a combined estimate for leukemia and bone cancer. This has been allocated to the two cancer types in proportion to the annual risk coefficients for the two types.
(d) These lifetime risks apply to the entire population and are about 1% of the risk to the in utero population only.
(e) Including leukemia and bone cancer death estimates based on absolute-risk model.

In addition to estimates of cancer mortality, the NRC (1985) report also provides estimates of cancer incidence, including nonfatal cancers. For all cancers other than leukemia and bone cancer, the total number of cancer cases is about 2.5 times the number of fatal cancers. This incidence-mortality ratio varies considerably by cancer site, from a factor of 1.1 for lung cancer to a factor of 10 for thyroid cancer.

Loewe and Mendelsohn (1981) and Kerr (1981) seriously challenged the dose estimates used in the studies of Japanese atomic-bomb survivors. Studies now in progress will determine new dose estimates, but this dose reassessment is not yet complete. Because the risk estimates obtained from the Japanese studies play a major role in determining risk estimates presented in the BEIR (1980), NRC (1985), and other reports, the reassessment could mean that these estimates will eventually need to be modified. Jablon (1984) has noted that the likely effect of the dose revision will be to increase estimates based on the earlier dosimetry by a factor of approximately two. One of the arguments in support of the quadratic model considered in the BEIR (1980) report has been based on differences in the dose-response curves between Hiroshima and Nagasaki. This argument has been weakened by the expected dosimetry revisions.

Lifetime risk estimates are provided in the 1977 UNSCEAR report and in the 1977 Recommendations of the International Commission of Radiological Protection (ICRP Publication 26). These estimates are also summarized in Table F.2. These two reports, however, have not given the details necessary to clearly indicate the assumptions underlying the estimates provided.

The recently published Radioepidemiological Tables (National Institutes of Health 1985) provide estimates of the probability that certain cancers observed could have resulted from some prior exposure to radiation. Although the tables do not provide lifetime risk estimates, they do provide models for estimating the risks of several cancer types resulting from a range of exposure situations. The model used in the Radioepidemiological Tables is very similar to that used for the NRC (1985) central estimates. In particular, the estimates for cancers other than breast and thyroid were based on a

linear-quadratic function that reduces risks estimated by the linear model at low doses and dose rates by a factor of 2.5, compared with the factor of 3.3 used in the NRC (1985) report. Furthermore, in both reports, risk estimates for cancers other than leukemia and bone cancer were based on the relative-risk model. The risk coefficients used in the two reports are comparable, although in the radioepidemiological tables, risks depend on age at exposure, in contrast to the NRC (1985) central estimates.

F.2 GENETIC EFFECTS

Genetic effects are generally assumed to result from alterations within genes, called mutations, or from rearrangements of genes within chromosomes. The production of mutations has no radiation-dose threshold, but repair of damage to genetic material can occur during exposure at low dose rates. This information is reviewed and discussed at length in the 1982 and earlier UNSCEAR reports and in the BEIR (1972, 1980) reports.

In the absence of quantitative data relating genetic effects in humans to radiation exposure, estimates of the genetic risk to humans have been based largely on data from animal studies. Two approaches commonly have been employed. In the "direct-method" approach, estimates of specific types of genetic damage, as measured in experimental animals, are applied, with suitable interspecies correction factors, directly to humans. Where animal data suitable for use in the "direct method" are unavailable, an "indirect-method" approach (or "doubling-dose method") has been employed. Using this method, researchers determine the amount of radiation required to double the spontaneous incidence of a genetic effect in a test species; they then assume that the same doubling dose is applicable to humans, and from estimates of the spontaneous occurrence of genetic diseases in humans, calculate the risk of genetic effect per unit dose of radiation. Both of these methods involve the uncertainties of extrapolation from animals to humans, plus considerable uncertainties about the normally occurring incidence of genetic diseases in humans.

Genetic disorders are commonly grouped into the following four types:

1. Autosomal dominant and X-linked disorders are those caused by the presence of a single defective gene. More than 1,000 such disorders are recognized. Examples of autosomal dominant disorders include polydactyly (extra fingers and toes), achondroplasia (short-limbed dwarfism), Huntington's chorea (progressive involuntary movements and mental deterioration), two types of muscular dystrophy, several kinds of anemia, and retinoblastoma (an eye cancer). Well-known X-linked disorders include hemophilia (failure of blood clotting), color blindness, and a severe form of muscular dystrophy. About 1% of all liveborn humans are appreciably handicapped by a disorder of this type. It is generally agreed that these disorders will double in frequency if the mutation rate is doubled.

2. Recessive disorders are those that require mutated genes on both members of a pair of homologous chromosomes. The potential for induction of such disorders by low-level, low-LET irradiation is generally considered negligible compared with other classes of genetic disorders, especially in early generations.

3. Chromosomal disorders are those characterized by changes in the number of chromosomes, or in the structural sequence within chromosomes. Such disorders are apt to result in early, spontaneous abortion, which is not considered here as a quantifiable effect. It is generally agreed that the increase in these disorders among liveborn humans as a result of low-level, low-LET irradiation will be relatively small compared with other types of disorders (see Table F.3).

4. Irregularly inherited (multifactorial) disorders have a more complex and poorly defined pattern of inheritance. These disorders include a wide variety of congenital malformations and constitutional and degenerative diseases. About 9% of liveborn humans are seriously handicapped by such disorders. Because the mechanisms of their inheritance are poorly understood and may in many cases be unaffected by mutations, estimates of radiation risk factors for these are more uncertain than for other types of disorders.

Table F.3 summarizes recent genetic-risk estimates developed by the BEIR and UNSCEAR committees. These estimates are for effects over all subsequent generations. They were derived by the "indirect method," but are, in several instances, supported by "direct" derivations.

TABLE F.3. Estimates of Genetic Effects of Radiation Over All Generations (effects per million liveborn in an average population exposed to 1 rem per capita per generation)

Effect	BEIR (1972)	BEIR (1980)	UNSCEAR (1977)	UNSCEAR (1982)
Dominant and X-linked	50 to 500	40 to 200	100	100
Chromosomal	NA	NA	40	4
Multifactorial	10 to 1,000	20 to 900	45	45
TOTAL	60 to 1,500	60 to 1,100	185	149

NA = not addressed.

It is important to note that the BEIR and UNSCEAR genetic risk estimates are expressed in terms of effects per million liveborn offspring of an average, uniformly irradiated population. For comparison with somatic risk estimates, the genetic risk must be expressed in terms of the irradiated population rather than in terms of the resulting offspring. The number of offspring produced in the United States per generation is about one-half the number of people in the total population. Thus, the 1982 UNSCEAR risk estimate of 150 effects per million offspring of an average population irradiated at a level of 1 rem is equivalent to about 75 effects per million person-rem delivered to the irradiated population. Similarly, the range for total genetic effects estimated by BEIR (1980) reduces to between 30 and 550 effects per million rem delivered to the irradiated population.

The most recent estimates, derived from the latest NRC health-effects model, produced a central estimate for genetic risk for all generations of 185 effects per million person-rem delivered to the irradiated population. This estimate is very similar to those provided in the earlier UNSCEAR reports and within the same range provided in the BEIR (1972, 1980) reports.

F.3 METHODS USED IN THIS DEIS

For this DEIS, a range encompassing commonly used cancer risk factors was employed, as indicated in Table F.4. The possibility of zero risk at very low exposure levels is not excluded by the available data. Values in the lower-to-middle range of risk estimates of Table F.4 may be more appropriate for comparison with the estimated risks of other energy technologies; values in the upper range may be more appropriate for radiation-protection considerations.

TABLE F.4. Health-Effects Risk Factors Employed in this DEIS

Type of Risk	Predicted Incidence per 10^6 person-rem
Fatal cancers from:	
Whole-body exposure	50 to 500
Lung exposure	10 to 100
Bone exposure	1 to 5
Thyroid exposure	1 to 15
Specific genetic effects to all generations from whole-body exposure	50 to 500
TOTAL	100 to 1,000

A range of 50 to 500 specific genetic effects to all generations per million person-rem was used. This is essentially the range recommended in the BEIR (1980) report, and it encompasses the central estimates of the 1977 and 1982 UNSCEAR reports, and of the NRC's (1985) improved radiological health-effects model. As for the somatic risk estimates, values in the lower range of these estimates may be more appropriate for comparative risk evaluations, while values in the upper range may be more appropriate for radiation protection considerations.

All estimates of health effects, as quoted elsewhere in this DEIS, employ the risk factors summarized in Table F.4. No special risks are considered to be associated with any specific radionuclide except as reflected

in the calculation of their dose equivalent (in rem) in the various tissues of concern. For simplicity, a linear, nonthreshold application of these risk factors was employed.

F.4 ALTERNATIVE VIEWPOINTS ON RECORD

Some other studies on record suggest values of the health effects risk factors both higher and lower than those recommended by BEIR (1980), UNSCEAR (1977, 1982), ICRP (1977), or NRC (1985). These studies are summarized below.

Gofman and Tamplin (1969, 1970) have proposed values of the health-effects risk factors that are approximately 5 to 10 times larger than those used here. BEIR (1972) provides a detailed review of these values and concludes them to be overestimates:

> "The reasons for [Gofman and Tamplin's] overestimates are: (i) an overestimation of the relative risk of solid tumor induction following irradiation of 0-9 year olds by a factor of 4-5, and by a factor of 10 for all other ages, and (ii) the unreasonable assumption of a life-long plateau region following in utero irradiation."

Mancuso et al. (1977) and Kneale et al. (1978) have reported finding dose-related excess cancer mortality among occupationally exposed workers at Hanford. Their risk estimates are much higher than estimates derived from studies of the Japanese atomic-bomb survivors and the populations exposed to radiation for medical reasons. Published criticisms of the Hanford study findings have suggested alternate explanations for the observed dose associations, including confounding of radiation exposure with exposures to other carcinogens, inadequate dosimetry, and poor statistical power (Gilbert and Marks 1979; Hutchison et al. 1979; Marks et al. 1978; BEIR 1980).

Irwin D. J. Bross has challenged the adequacy of low-dose risk estimates extrapolated from observed excess risks in populations exposed to radiation doses above 100 rad, claiming that new analyses of data from the Hanford study (Mancuso et al. 1977) and the tri-state leukemia survey (Bross et al. 1978) have shown that the risks of radiation-induced cancer from doses of around 1 rad are an order of magnitude greater than previously predicted (Bross 1977).

The Bross results are based on a novel statistical method. This method has been reviewed in BEIR (1980), which concludes that

> "The applications by Bross et al. have been clearly incorrect, and they provide no evidence that the risk of cancer from low-dose radiation is greater than indicated by conventional estimates."

Ernest J. Sternglass has charged that doses from radioactive fallout are responsible for increased infant mortality and decreased student academic achievement in the United States. Dr. Sternglass presented his position to the BEIR committee (BIER 1980). The group concluded that the alleged association did not fit the time course for radioisotope movement, nor was there clear evidence of a universally applicable change in infant mortality rates. Thus, the committee did not believe the allegations to be substantiated.

Evidence has also been propounded for risk estimators lower than those used in this DEIS. Frigerio and Stowe (1976) found an inverse relation between background radiation (including manmade radiation) and cancer mortality rates in all 50 states. Eckhoff et al. (1974) studied leukemia mortality rates for 5,000 geographic locations in the United States in relation to altitude; they reported a substantial increase in mortality up to 600 meters and a decrease at higher altitudes. Archer (1978) has attempted to analyze geomagnetic variation, as well as altitude variations, to account for a factor modifying cosmic radiation. This study indicated a positive correlation between cosmic ray flux and some cancers. The BEIR committee (1980) analyzed these studies, and concluded that

> "These types of studies, depending as they do on death-record data aggregated crudely by geographic region, do not constitute a sufficient basis for deciding whether one or another type of environmental factor, such as background radioactivity, is related to cancer rates. Thus, as a test of the effect on cancer risks of low-dose-rate lifetime exposure to radiation, this approach does not appear to be fruitful in the United States within the framework of variations in background-radiation exposure of populations large enough to provide data that would be statistically useful."

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APPENDIX G

ASSESSMENT OF LONG-TERM IMPACTS OF DECOMMISSIONING ALTERNATIVES

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APPENDIX G

ASSESSMENT OF LONG-TERM IMPACTS OF DECOMMISSIONING ALTERNATIVES

This appendix assesses the impacts of decommissioning on public health and safety during the postdisposal period, in support of Chapter 5.0 of this DEIS. This assessment identifies and evaluates plausible natural and human-induced events that could affect the disposal systems and result in the release of radionuclides. The approach used in this analysis is deterministic, and the calculated (predicted) environmental impacts should not be exceeded by those expected or those that would actually be experienced. Appendix E (dose calculation methods) and Appendix C (modeling of ground-water pathways) provide supporting information for the analyses presented here.

Key findings of the analyses reported in this appendix are as follows:

- The major pathway for transport of radionuclides and chemicals to the affected environment is ground water.
- For wastes disposed of near the surface on the Hanford Site, the consequences to the offsite population are negligible compared with consequences from naturally occurring radiation sources. This holds true for all scenarios for any of the decommissioning alternatives and also for the no action (continue present action) alternative.
- If only passive institutional controls exist for the disposal alternatives or no active institutional controls exist after 100 years for the no action alternative, the scenarios involving contact with or intrusion into waste indicate significant adverse consequences to those who ignore warnings and intrude into the wastes.
- Some events, such as catastrophic floods, would in themselves have such an overwhelming environmental impact as to obliterate or obscure any impact from waste they might release.

Assessment of Long-Term Impacts

No measurable releases of either radionuclides or toxic chemicals are expected from waste disposed of by either immediate or deferred one-piece removal, deferred dismantlement, or in situ decommissioning during planned operation of these disposal systems. However, for this DEIS, all reasonably postulated long-term events that might cause releases and possibly affect health and safety were examined. Therefore, this appendix describes post-disposal impacts, performance of decommissioning systems, and postulated natural and human-induced events over 10,000 years that could potentially disrupt such disposal systems. The events investigated for potential impact are listed below:

Resettlement/Farming/Gardening
- Residential/Home Garden
- Postdrilling/Excavation Habitation
- Contaminated Water-Supply Well

Drilling
- Water Well

Excavation
- Home Construction

Intentional/Casual Intruder
- Salvage or Archaeology
- Casual Intruder

Climate State
- Present
- Dryer
- Wetter

Glacial Flooding

Other Surface Flooding
- 100-Year Flood
- Standard Project Flood
- Probable Maximum Flood
- Dam Failure
- Rise in Sea Level

Wind Erosion
- Prevailing Winds
- Tornados

Seismic Activity

Of the list of possible events that might affect the waste, the following were judged to have sufficient probability or consequence to warrant analysis in the indicated sections:

Ground-Water Recharge and Transport	Section G.1
Drilling Intrusion	Section G.2
Excavation Intrusion	Section G.3
Other Intrusion Scenarios	Section G.4
Resettlement with Farming or Gardening	Section G.5
Postdrilling/Habitation	Section G.5.2
Glacial and Rise in Sea Level Flooding	Section G.6

The potential releases that would occur over time were postulated, and doses to individuals and population groups were calculated as appropriate according to the methods described in Appendix E.

The decommissioning alternatives and the no action alternative for which each exposure scenario is applicable are described in Chapter 3.0. Annual radiation dose commitments to individuals are provided for all scenarios evaluated. For scenarios potentially having an impact on more than a few individuals, population doses are given as well. Because the year in which some scenarios might occur cannot be predicted, impacts are given for 100, 400, 1,000, and 10,000 years after decommissioning for those cases for which these times could apply.

The long-term impacts of a number of waste forms have been analyzed in this appendix. These waste forms consist of 1) graphite reactor block, 2) reactor shields (thermal and biological), and 3) metal components (process tubes, control rods, ball 3X system).

G.1 WASTE MIGRATION THROUGH GROUND-WATER RECHARGE

Precipitation that percolates through the soil can cause radionuclides to move slowly from a waste site, through the vadose zone, into the ground water, and eventually to the biosphere via the Columbia River. The quantity of water available for downward transport depends on the climate and on the physical characteristics of any waste cover. The quantity of water available for horizontal transport depends on the climate and on the amount of land irrigated in the immediate vicinity. See Appendix C for a more detailed discussion of the ground-water pathway.

G.1.1 Climatic Considerations

Predictions of future climate are generally projected from data for past climatic states. The Pasco Basin was apparently cooler and wetter 13,000 to 10,000 years ago than it is today, and became warmer and drier about 8,000 years ago (Nickmann and Leopold 1985).

Because warm, interglacial climates like the present are typical of only about 10% of the climatic record for the past 1 million years (Bull, in Scott et al. 1979), the more probable climatic change will be cooling. However, the possibility of a "greenhouse effect" caused by carbon dioxide and other gases is also considered. For such a case, the climate could be both warmer and wetter. Because of the uncertainties in predicting what will happen over the next 10,000 years, climate is considered under three different states, with the larger expected change being toward a wetter state:

- current climate persisting
- climate becoming more arid
- climate becoming wetter, leading to additional recharge to the ground-water system (i.e., the amount of water trickling through the upper soil to the water table).

Persistence of current conditions and change to a more arid climate are discussed only briefly, because they are less likely to supply a mechanism for transporting waste than is a change that increases the amount of water available to the land surface.

A more arid climate is less likely to affect the disposal systems adversely than a wetter climate. A drier and windier climate could increase wind erosion over unprotected sites, but with the existing arid climate and low ground-water recharge rates, a change to more arid conditions would not be expected to disturb waste sites.

Estimates of ground-water recharge for the Pasco Basin and the Hanford Site under present conditions vary with location and soil characteristics. In the areas of principal interest for this DEIS, the 200-West Area and the 100 Areas, little ground-water recharge is expected from present levels of precipitation. Because of uncertainties in recharge, a range of 0.5 to 5 centimeters per year average annual recharge has been used in this DEIS to characterize climates ranging from the current one to a wetter one.

G.1.2 Water Recharge Rates

For analysis of migration, the scenarios considered are:

- no recharge[a]
- a ground-water recharge rate of 0.5 centimeter per year
- a ground-water rate recharge of 5 centimeters per year
- an infiltration rate through the protective barrier of 0.1 centimeter per year.

Water associated with the non-zero infiltration and recharge scenarios is postulated to cause portions of the radionuclide inventory in the waste to gradually dissolve, move downward to the water table, move horizontally, and eventually reach the Columbia River, except for the radioactivity that is intercepted by wells. These scenarios were used to provide a basis for estimating radiological impacts associated with non-zero recharge rates.

In the 200 Areas, the time required for the recharge water to travel downward to the water table depends on the amount of water available, the depth to ground water, and the soil types. By modeling the unsaturated flow through the layered soils, travel times to the water table were estimated for recharge rates of 0.5 centimeter per year and 5 centimeters per year (see Appendix C). If the rate of recharge is 0.5 centimeter per year, infiltrating water will take from 800 to 1,100 years to reach the water table. If the rate is 5 centimeters per year, the travel time is estimated to be between 100 and 150 years.

For the 100 Areas, water associated with the ground-water recharge is also postulated to move downward to the water table. Because the 100 Areas are so close to the Columbia River, the travel time for the water is on the order of days for any non-zero recharge rate.

(a) Where the recharge to ground water is zero, there is no driving force for nuclide movement, and radiological impacts from scenarios presented in this appendix would be zero. It should be noted that in 40 years of operation and monitoring, in the 100 and 200 Areas at Hanford no migration of any contaminated low-level burial waste that was caused by natural recharge has been observed. This is to be distinguished from the migration that has been observed resulting from artificial recharge associated with waste water discharge from Hanford operations.

The recharge rates discussed previously are to be distinguished from infiltration rates of water penetrating the waste barrier. Water penetrating the barrier is water that is available to dissolve the wastes and provide downward transport near the waste form.

An engineered barrier is used in all of the disposal alternatives and is designed to intercept, and thus minimize, water infiltration into wastes. The efficacy of this barrier is not well defined. Theoretical analyses have shown that under most circumstances, the barriers could be up to 100% effective at preventing moisture infiltration. However, the practical limits of detection (i.e., the limit to which it can be proved that the barrier is functioning) are at infiltration rates of about 0.1 centimeter per year (DOE 1987, Appendix M). Therefore, in the interest of conservatism, an infiltration rate of 0.1 centimeter per year was used in the analyses, and the calculations were performed assuming a uniform rate of water infiltration through the barrier of 0.1 centimeter per year. This should be considered to be an upper bound to the expected infiltration rates.

Over the long time period of interest (10,000 years) in the analysis, the efficacy of a liner/leachate collection system under the waste (200-Area disposal) is highly uncertain, and, therefore, no credit has been taken in the analyses for a liner/leachate collection system.

An engineered barrier similar to the one proposed for use over decommissioned reactors in this DEIS has been proposed and analyzed in another Hanford-related NEPA documentation (DOE 1987). In that analysis, four cases of barrier performance were analyzed: 1) no barrier (i.e., the no action alternative), 2) a 100% effective barrier that allowed no recharge at all, 3) a "functionally failed" barrier that allowed recharge of 0.1 centimeter per year, and 4) a "disruptively failed" barrier that resulted in enhanced recharge. For the analysis performed in this DEIS for the decommissioned reactors, the no-barrier case has been retained. Because the effective limits of detection on barrier performance are greater than zero, as described above, the concept of the completely effective barrier has been merged with that of the "functionally failed" barrier as the base case. Multiple analyses have shown that for the reactors, an enhanced recharge

"disruptively failed" barrier case is equivalent to the no-barrier case (because the results are controlled by the release rate from the graphite matrix rather than by the recharge rate). Therefore, separate analyses of the "disruptively failed" barrier case have been omitted, because they would be bounded by the no action result.

G.1.3 Dosimetric Analysis

People do not receive radiation doses as soon as the radionuclides begin to migrate through the soil. There is a delay while the nuclides are transported downward through the unsaturated zone and horizontally in the ground water before they finally arrive at a point where people can be exposed. The location of the point of exposure depends on future actions. A domestic water well may penetrate the contaminated plume, or the contaminated ground water may eventually reach the Columbia River. For this analysis, wells have been hypothetically placed at a distance of 5 kilometers downgradient from the 200 Areas, and between the reactors and the river in the 100 Areas. Radiation doses to individuals who drink water and irrigate from such wells were calculated. (The 5-kilometer distance is a calculational convenience. The calculated water concentrations of radionuclides change relatively little from the point of contaminant entry to downstream locations because lateral dispersion is neglected. The time of arrival, for the low-sorbed radionuclides of interest in this DEIS, is never more than about 20 years from the time of arrival in the ground water. The value at 5 kilometers is representative of distances 0 to 10 kilometers from the waste.)

Impacts from disposal in both the 100 Areas and the 200 Areas were evaluated for the downriver population. The total integrated population dose to all people living along the Columbia River for the next 10,000 years was also calculated. These doses are discussed in the following sections. Worldwide doses from releases of carbon-14 are discussed briefly in Chapter 5.0, using the global model described in Appendix E.

G.1.3.1 Drinking-Water Well

A measure of the level of contamination of ground water is the radiation dose caused by consumption of drinking water alone. Annual and lifetime doses to individuals drinking water from a well located 5 kilometers

downstream from the 200-Area disposal site for the immediate one-piece removal, deferred one-piece removal, and deferred dismantlement alternatives are given in Tables G.1 and G.2, respectively. These results are presented together in Tables G.1 and G.2 because the ultimate disposal configuration is essentially identical for each of these alternatives. Annual and lifetime drinking-water doses for the in situ decommissioning alternative are given in Tables G.3 and G.4, and for the no action alternative in Tables G.5 and G.6, respectively.

Whole-body doses, and the dose to the organ receiving the highest dose, are summarized in the tables, along with the time the dose occurs, the

TABLE G.1. Immediate One-Piece Removal, Deferred One-Piece Removal, and Deferred Dismantlement Alternatives--Individual Maximum Potential 1-Year Radiation Dose from the Drinking-Water Scenario

Waste Form	Whole-Body Dose (rem)	Highest Organ	Highest Organ Dose (rem)	Number of yr after Disposal	Dominant Nuclide
0.5-cm/yr Recharge, No Additional Dilution					
Reactor block	5.0×10^{-1}	GI Tract	5.9×10^{-1}	6,090	^{14}C
Thermal shield	4.7×10^{-5}	Thyroid	4.0×10^{-4}	6,020	^{99}Tc
Metal components (NR)	--	--	--	--	--
5-cm/yr Recharge, No Additional Dilution					
Reactor block	2.1×10^{-1}	GI Tract	2.4×10^{-1}	6,160	^{14}C
Thermal shield	2.0×10^{-5}	Thyroid	1.7×10^{-4}	5,880	^{99}Tc
Metal components (NR)	--	--	--	--	--
0.5-cm/yr Recharge, Full-Garden Dilution					
Reactor block	4.1×10^{-2}	GI Tract	4.9×10^{-2}	6,090	^{14}C
Thermal shield	3.9×10^{-6}	Thyroid	3.4×10^{-5}	6,020	^{99}Tc
Metal components (NR)	--	--	--	--	--
5-cm/yr Recharge, Full-Garden Dilution					
Reactor block	4.1×10^{-2}	GI Tract	4.7×10^{-2}	6,160	^{14}C
Thermal shield	3.9×10^{-6}	Thyroid	3.3×10^{-6}	5,880	^{99}Tc
Metal components (NR)	--	--	--	--	--

NR = no release.

TABLE G.2. Immediate One-Piece Removal, Deferred One-Piece Removal, Deferred Dismantlement Alternatives--Individual Maximum Potential 70-Year Radiation Dose from the Drinking-Water Scenario

Waste Form	Whole-Body Dose (rem)	Highest Organ	Highest Organ Dose (rem)	Number of yr after Disposal	Dominant Nuclide
0.5-cm/yr Recharge, No Additional Dilution					
Reactor block	3.5×10^{1}	GI Tract	4.1×10^{1}	6,090	^{14}C
Thermal shield	3.3×10^{-3}	Thyroid	2.8×10^{-2}	6,020	^{99}Tc
Metal components (NR)	--	--	--	--	--
5-cm/yr Recharge, No Additional Dilution					
Reactor block	1.5×10^{1}	GI Tract	1.7×10^{1}	6,160	^{14}C
Thermal shield	1.4×10^{-3}	Thyroid	1.2×10^{-2}	5,880	^{99}Tc
Metal components (NR)	--	--	--	--	--
0.5-cm/yr Recharge, Full-Garden Dilution					
Reactor block	2.9	GI Tract	3.4	6,090	^{14}C
Thermal shield	2.7×10^{-4}	Thyroid	2.4×10^{-3}	6,020	^{99}Tc
Metal components	--	--	--	--	--
5-cm/yr Recharge, Full-Garden Dilution					
Reactor block	2.9	GI Tract	3.3	6,160	^{14}C
Thermal shield	2.7×10^{-4}	Thyroid	2.3×10^{-3}	5,880	^{99}Tc
Metal components	--	--	--	--	--

NR = no release.

TABLE G.3. In Situ Decommissioning Alternative--Maximum Potential 1-Year Radiation Dose from the Drinking-Water Scenario

Maximum Waste Form[a]	Whole-Body Dose (rem)	Highest Organ	Highest Organ Dose (rem)	Number of yr after Disposal	Dominant Nuclide
Reactor block (B/C)	3.0×10^{-2}	GI Tract	3.4×10^{-2}	1,120	^{14}C
Thermal shield (B/C; D/DR)	9.1×10^{-7}	Thyroid	7.9×10^{-6}	1,050	^{99}Tc
Metal components (NR)	--	--	--	--	--

(a) Maximum refers to the 100-Areas site (out of 6) that would result in the highest doses for the particular waste form.
NR = no release.

TABLE G.4. In Situ Decommissioning Alternative--Maximum Potential 70-Year Radiation Dose from the Drinking-Water Scenario

Maximum Waste Form[a]	Whole-Body Dose (rem)	Highest Organ	Highest Organ Dose (rem)	Number of yr after Disposal	Dominant Nuclide
Reactor block (B/C)	2.1	GI Tract	2.4	1,120	^{14}C
Thermal shield (B/C; D/DR)	6.4×10^{-5}	Thyroid	5.5×10^{-4}	1,050	^{99}Tc
Metal components (NR)	--	--	--	--	--

(a) Maximum refers to the 100-Areas site (out of 6) that would result in the highest doses for the particular waste form.
NR = no release.

TABLE G.5. No Action Alternative--Maximum Potential 1-Year Radiation Dose from the Drinking-Water Scenario

Maximum Waste Form[a]	Whole-Body Dose (rem)	Highest Organ	Highest Organ Dose (rem)	Number of yr after Disposal	Dominant Nuclide
Reactor block (B/C)	1.1	Bone Surf.	1.3×10^{1}	140	^{241}Am
Thermal shield (B/C; D/DR)	7.4×10^{-2}	LLI	3.3×10^{-1}	140	^{60}Co
Metal components (B/C)	2.4×10^{-3}	LLI	1.4×10^{-2}	140	^{63}Ni

(a) Maximum refers to the 100-Areas site (out of 6) that would result in the highest doses for the particular waste form.
LLI = lower large intestine.

radionuclide that contributes most to the dose, and the fraction of the dose contributed by that radionuclide. Internal organs generally receive doses that exceed the whole-body dose.

The results reported in Tables G.1 through G.6 are given in terms of the dose rate to the whole body and highest organ at the time of highest dose in the next 10,000 years. The dose rate as a function of time depends on the release and transport rates of radionuclides from the wastes. Under the alternatives described in this DEIS, wastes would tend to be released slowly to

TABLE G.6. No Action Alternative--Maximum Potential 70-Year Radiation Dose from the Drinking-Water Scenario

Maximum Waste Form[a]	Whole-Body Dose (rem)	Highest Organ	Highest Organ Dose (rem)	Number of yr after Disposal	Dominant Nuclide
Reactor block (B/C)	7.7×10^{1}	Bone Surf.	8.9×10^{2}	140	^{241}Am
Thermal shield (B/C; D/DR)	5.2	LLI	2.3×10^{1}	140	^{60}Co
Metal components (B/C)	1.7×10^{-1}	LLI	9.5×10^{-1}	140	^{63}Ni

(a) Maximum refers to the 100-Areas site (out of 6) that would result in the highest doses for the particular waste form.
LLI = lower large intestine.

the environment. This slow release is illustrated in Figure G.1, which shows the calculated concentrations of radionuclides in water in a well 5 kilometers from a representative waste. The initial delay provided by the vadose-zone migration is evident in Figure G.1, as is the controlled, long-term nature of the potential release. For all of the decommissioning alternatives in the 200 Areas, no ground-water contamination is predicted within the first 5,000 years. Nonsorbed radionuclides, such as carbon-14 and chlorine-36, arrive at the well at the same time as would a water front moving from the waste. Nuclides whose transport is retarded, such as nickel-59, arrive much later, if at all, and in reduced concentration.

The pattern of the ground-water concentration of radionuclides is reflected in the potential radiation dose rate to individuals using water from the well. Figure G.2 shows dose rates to individuals drinking water from the well of Figure G.1. Doses to the whole body and to bone can be seen to replicate the curves of chlorine-36 and carbon-14. The dose to the gastrointestinal (GI) tract is the largest in this case, and it decreases as the carbon-14 decays and as the chlorine-36 release ends. Because both carbon-14 and chlorine-36 are nearly uniformly distributed throughout the tissues and organs of the body, the highest organ dose (to GI tract) is only slightly higher than that to the whole body.

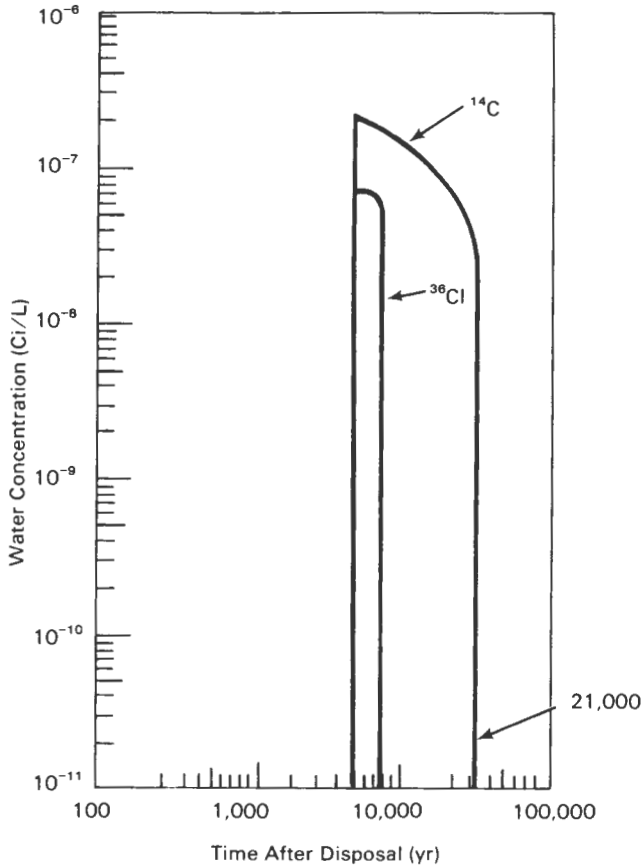

FIGURE G.1. Concentration of Selected Radionuclides in Ground Water at a Hypothetical Well 5 Kilometers from the Reactor Blocks in the 200-West Area--Immediate One-Piece Removal, Deferred One-Piece Removal, and Deferred Dismantlement Alternatives (0.5 cm/yr recharge)

Several key assumptions combine in this and the following scenario to result in reported doses that are relatively large. The conservative assumptions on total inventory of chlorine-36 and rapid release rate from the graphite block (which arise because of the paucity of data on these parameters) produce a relatively large calculated ground-water concentration. Assuming that the well is placed in the center of the streamtube issuing from the site results in the highest possible concentration to the future hypothetical maximally exposed individual. This latter assumption adds a degree of complexity to the analysis. For ground-water movement under the Hanford 200 Areas, relatively detailed calculations can be performed on the basis of current knowledge. Therefore, it is straightforward to predict the

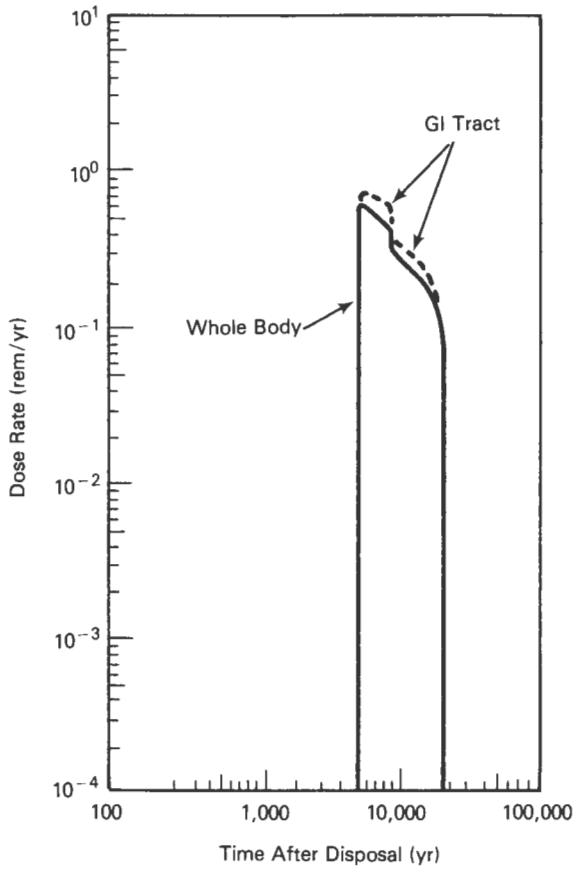

FIGURE G.2. Individual Dose Rates from Drinking Water from the Well 5 Kilometers Downgradient from the Reactor Blocks in the 200-West Area--Immediate One-Piece Removal, Deferred One-Piece Removal, and Deferred Dismantlement Alternatives

concentration of radionuclides in the ground water to which a drinking-water well in the 200 Areas would be exposed. However, for the Hanford 100 Areas, the closeness of the Columbia River adds a confounding factor that makes it impossible at present to predict the actual ground-water concentrations; therefore, the drinking-water calculations for the in situ and no action alternatives are based on the assumption that the released radionuclides are diluted in the flow required to support the full-garden scenario. As a result of the pumping-rate requirements of the full-garden scenario, the individual is essentially withdrawing 100% of the contaminated water from the well and using it for domestic purposes. This means that all of the contamination leached from the disposed reactors is being intercepted by one

individual or family. As a maximum, only one household could possibly be exposed to this level of contamination at one time.

To provide maximum information, but allow intercomparison of 100-Area and 200-Area disposal alternatives, Tables G.1 and G.2 incorporate dose results from both subscenarios. The first set of results are drinking-water doses resulting from the actual predicted concentrations in the streamtube issuing from the 200-West Area. The second set of results in these tables is for the drinking-water dose assuming the pumping requirements for the full-garden scenario dilutes the streamtube concentrations. This second set of results are more directly comparable with the results presented in Tables G.3 through G.6, for which the garden-scenario dilution is assumed. Note that the dose results are identical for the 0.5- and 5-centimeter-per-year recharge rates when using the garden-scenario dilution assumption, although the times are slightly different. The doses are identical because the release rates from the reactors are the same for the two climatic conditions (controlled by the 0.1-centimeter-per-year infiltration through the barrier), and 100% of the release is assumed to be intercepted by the well. Because the streamtube is only about as wide as the eight reactor cores, the probability of any particular well intercepting 100% of the release is considered to be remote.

The doses reported in Tables G.1 through G.6 are summaries of calculations that tracked dose rate versus time in a manner similar to that presented in Figure G.2. The peak dose reported is the highest dose in the 10,000-year period following decommissioning of the reactors. Both the whole-body dose, with contributing nuclide, and highest-organ dose are given. Detailed site-by-site results are presented in Tables G.7 and G.8.

In some instances, the doses are higher to the individual from the 0.5-centimeter-per-year recharge rate than from the 5-centimeter-per-year recharge rate. This higher dose seems contrary to what might be expected. However, the explanation for this apparent contradiction is related to shifting water tables. With a lower recharge rate, there is also decreased ground-water movement, resulting in less dilution of the wastes being transported (see Appendix C, Section C.3.1, for details). It should also be noted

TABLE G.7. In Situ Decommissioning Alternative--Maximum Potential 1-Year Radiation Dose from the Drinking-Water Scenario, by Reactor Site

Maximum Waste Form[a]	Whole-Body Dose (rem)	Highest Organ	Highest Organ Dose (rem)	Number of yr after Disposal	Dominant Nuclide
Site B/C					
Reactor block	3.0×10^{-2}	GI Tract	3.4×10^{-2}	1,120	^{14}C
Shield	9.1×10^{-7}	Thyroid	7.9×10^{-6}	1,050	^{99}Tc
Site D/DR					
Reactor block	2.4×10^{-2}	GI Tract	2.9×10^{-2}	1,260	^{14}C
Shield	9.1×10^{-7}	Thyroid	7.9×10^{-6}	1,050	^{99}Tc
Site F					
Reactor block	1.7×10^{-2}	GI Tract	2.0×10^{-2}	560	^{14}C
Shield	4.6×10^{-7}	Thyroid	3.9×10^{-6}	490	^{99}Tc
Site H					
Reactor block	1.2×10^{-2}	GI Tract	1.3×10^{-2}	630	^{14}C
Shield	4.6×10^{-7}	Thyroid	3.9×10^{-6}	560	^{99}Tc
Site KE					
Reactor block	2.3×10^{-2}	GI Tract	2.7×10^{-2}	1,120	^{14}C
Shield	6.9×10^{-7}	Thyroid	5.9×10^{-6}	1,050	^{99}Tc
Site KW					
Reactor block	2.3×10^{-2}	GI Tract	2.6×10^{-2}	1,120	^{14}C
Shield	6.9×10^{-7}	Thyroid	5.9×10^{-6}	1,050	^{99}Tc
All Sites					
Process tubes (NR)	--	--	--	--	--

(a) Maximum refers to the 100-Areas site (out of 6) that would result in the highest doses for the particular waste form.
NR = no release.

that in several instances, the ground-water flow changes direction. As a result, the hypothetical well at 5 kilometers for the 0.5-centimeter-per-year recharge case can be in a very different location from the well for the

TABLE G.8. In Situ Decommissioning Alternative--Maximum Potential 70-Year Radiation Dose from the Drinking-Water Scenario, by Reactor Site

Maximum Waste Form[a]	Whole-Body Dose (rem)	Highest Organ	Highest Organ Dose (rem)	Number of yr after Disposal	Dominant Nuclide
Site B/C					
Reactor block	2.1	GI Tract	2.4	1,120	^{14}C
Shield	6.4×10^{-5}	Thyroid	5.5 x 10-4	1,050	^{99}Tc
Site D/DR					
Reactor block	1.7	GI Tract	2.0	1,260	^{14}C
Shield	6.4×10^{-5}	Thyroid	5.5×10^{-4}	1,050	^{99}Tc
Site F					
Reactor block	1.2	GI Tract	1.4	560	^{14}C
Shield	3.2×10^{-5}	Thyroid	2.7×10^{-4}	490	^{99}Tc
Site H					
Reactor block	8.4×10^{-1}	GI Tract	9.1×10^{-1}	630	^{14}C
Shield	3.2×10^{-5}	Thyroid	2.7×10^{-4}	560	^{99}Tc
Site KE					
Reactor block	1.6	GI Tract	1.9	1,120	^{14}C
Shield	4.8×10^{-5}	Thyroid	4.1×10^{-4}	1,050	^{99}Tc
Site KW					
Reactor block	1.6	GI Tract	1.8	1,120	^{14}C
Shield	4.8×10^{-5}	Thyroid	4.1×10^{-4}	1,050	^{99}Tc
All Sites					
Process tubes (NR)	--	--	--	--	--

(a) Maximum refers to the 100-Areas site (out of 6) that would result in the highest doses for the particular waste form.
NR = no release.

5-centimeter-per-year recharge case for the same waste form.[a] Thus, it is important to recognize that the two cases are not directly comparable, because to bound the environmental impacts, the well was assumed to be located so as to intercept the plume.

G.1.3.2 Full-Garden Scenario for Well Water

Contaminated well water might be used for irrigation and livestock, as well as for human drinking water. Therefore, radiation doses were estimated for the same radionuclide concentrations in the well water for a scenario in which an individual grows a large percentage of his food using the well for irrigation, as might occur on a small, 2-hectare, family farm. In addition to radionuclides in the drinking water, the individual is exposed to those radionuclides deposited on the soil and accumulated in crops and animal products. Doses to individuals are given in Tables G.9 through G.14 for the various alternatives analyzed. As was done for the drinking-water scenario, site-by-site detail for the in situ decommissioning alternative is provided in Tables G.15 and G.16. The radiation doses the individual might receive from the full-garden scenario are greater than those that could be received from drinking water alone. For nuclides that are not readily taken up by plants, the dose from the full-garden scenario is generally less than 10 times that caused by drinking the water. For nuclides readily taken up by plants, such as chlorine-36, the increase in dose can be by as much as a factor of 50.

In general, the radiation dose rate to individuals under the full-garden scenario, as a function of time after reactor decommissioning, will follow the same pattern as the ground-water concentrations described for the drinking-water scenario in Section G.1.3.1. Radionuclides redistributed in the soil by irrigation make some additional contribution to the external dose, but over many years it is not as significant as the contribution from

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(a) In the 5-centimeter-per-year recharge case, contaminated ground-water moves to the north, west of Gable Mountain, and on to the Columbia River. In the 0.5-centimeter-per-year recharge case, contaminated water flows southeast from the 200 Areas and enters the river to the east and southeast. This scenario is illustrated in Appendix C.

TABLE G.9. Immediate One-Piece Removal, Deferred One-Piece Removal, and Deferred Dismantlement Alternatives--Individual Maximum Potential 1-Year Radiation Dose from the Full-Garden Scenario

Maximum Waste Form	Whole-Body Dose (rem)	Highest Organ	Highest Organ Dose (rem)	Number of yr after Disposal	Dominant Nuclide
0.5-cm/yr Recharge					
Reactor block	1.4	GI Tract	1.6	6,160	^{36}Cl
Thermal shield	2.7×10^{-4}	Thyroid	2.4×10^{-3}	6,020	^{99}Tc
Metal components (NR)	--	--	--	--	--
5-cm/yr Recharge					
Reactor block	1.3	GI Tract	1.6	6,160	^{36}Cl
Thermal shield	2.7×10^{-4}	Thyroid	2.3×10^{-3}	5,880	^{99}Tc
Metal components (NR)	--	--	--	--	--

NR = no release.

TABLE G.10. Immediate One-Piece Removal, Deferred One-Piece Removal, and Deferred Dismantlement Alternatives--Individual Maximum Potential 70-Year Radiation Dose from the Full-Garden Scenario

Maximum Waste Form	Whole-Body Dose (rem)	Highest Organ	Highest Organ Dose (rem)	Number of yr after Disposal	Dominant Nuclide
0.5-cm/yr Recharge					
Reactor block	9.5×10^{1}	GI Tract	1.1×10^{2}	6,160	^{36}Cl
Thermal shield	1.9×10^{-2}	Thyroid	1.7×10^{-1}	6,020	^{99}Tc
Metal components (NR)	--	--	--	--	--
5-cm/yr Recharge					
Reactor block	9.3×10^{1}	GI Tract	1.1×10^{2}	6,160	^{36}Cl
Thermal shield	1.9×10^{-2}	Thyroid	1.6×10^{-1}	5,880	^{99}Tc
Metal components (NR)	--	--	--	--	--

NR = no release.

TABLE G.11. In Situ Decommissioning Alternative--Maximum Potential 1-Year Radiation Dose from the Full-Garden Scenario

Maximum Waste Form[a]	Whole-Body Dose (rem)	Highest Organ	Highest Organ Dose (rem)	Number of yr after Disposal	Dominant Nuclide
Reactor block (B/C)	4.6×10^{-1}	GI Tract	5.3×10^{-1}	1,120	^{14}C, ^{36}Cl
Thermal shield (B/C, D/DR)	6.4×10^{-5}	Thyroid	5.4×10^{-4}	1,050	^{99}Tc
Metal components (NR)	--	--	--	--	--

(a) Maximum refers to the 100-Areas site (out of 6) that would result in the highest dose for the particular waste form.
NR = no release.

TABLE G.12. In Situ Decommissioning Alternative--Maximum Potential 70-Year Radiation Dose from the Full-Garden Scenario

Maximum Waste Form[a]	Whole-Body Dose (rem)	Highest Organ	Highest Organ Dose (rem)	Number of yr after Disposal	Dominant Nuclide
Reactor block (B/C)	3.2×10^{1}	GI Tract	3.7×10^{1}	1,120	^{14}C, ^{36}Cl
Thermal shield (B/C, D/DR)	4.5×10^{-3}	Thyroid	3.8×10^{-2}	1,050	^{99}Tc
Metal components (NR)	--	--	--	--	--

(a) Maximum refers to the 100-Areas site (out of 6) that would result in the highest dose for the particular waste form.
NR = no release.

the water directly. The caveats pertaining to the drinking-water pathway (Section G.1.3.1) apply also to the full-garden scenario.

In addition to the conservative assumptions previously described for the drinking-water scenario, further conservatisms appear in the calculation for the doses from the full-garden scenario. A very high soil-to-plant uptake factor has been assigned to chlorine-36, based on limited previous studies of chlorine in soils (Coughtrey et al. 1983). Also, the long-term model used in

TABLE G.13. No Action Alternative--Maximum Potential 1-Year Radiation Dose from the Full-Garden Scenario

Maximum Waste Form[a]	Whole-Body Dose (rem)	Highest Organ	Highest Organ Dose (rem)	Number of yr after Disposal	Dominant Nuclide
Reactor block (B/C)	3.3×10^{1}	Bone Surf.	3.4×10^{2}	140	^{90}Sr
Thermal shield (B/C)	2.3	LLI	5.3	140	^{60}Co
Metal components (B/C)	7.1×10^{-2}	LLI	3.6×10^{-1}	140	^{63}Ni

(a) Maximum refers to the 100-Areas site (out of 6) that would result in the highest dose for the particular waste form.
LLI = lower large intestine.

TABLE G.14. No Action Alternative--Maximum Potential 70-Year Radiation Dose from the Full-Garden Scenario

Maximum Waste Form[a]	Whole-Body Dose (rem)	Highest Organ	Highest Organ Dose (rem)	Number of yr after Disposal	Dominant Nuclide
Reactor block (B/C)	2.3×10^{3}	Bone Surf.	2.4×10^{4}	140	^{90}Sr
Thermal shield (B/C)	1.6×10^{2}	LLI	3.7×10^{2}	140	^{60}Co
Metal components (B/C)	5.0	LLI	2.5×10^{1}	140	^{63}Ni

(a) Maximum refers to the 100-Areas site (out of 6) that would result in the highest dose for the particular waste form.
LLI = lower large intestine.

this DEIS does not incorporate a removal-via-harvest term, which would be important for agricultural pathways for nuclides with such a high concentration ratio. Ignoring the removal by harvest results in conservatively high estimates of the dose.

G.1.3.3 Radionuclide Migration to the Columbia River

Radionuclides and other contaminants leached into the ground water would likely reach the Columbia River eventually. The rate at which nuclides enter

TABLE G.15. In Situ Decommissioning Alternative--Maximum Potential 1-Year Radiation Dose from the Full-Garden Scenario, by Reactor Site

Maximum Waste Form[a]	Whole-Body Dose (rem)	Highest Organ	Highest Organ Dose (rem)	Number of yr after Disposal	Dominant Nuclide
Site B/C					
Reactor block	4.6×10^{-1}	GI Tract	5.3×10^{-1}	1,120	^{36}Cl, ^{14}C
Shield	6.4×10^{-5}	Thyroid	5.4×10^{-4}	1,050	^{99}Tc
Site D/DR					
Reactor block	4.3×10^{-1}	GI Tract	5.0×10^{-1}	1,260	^{36}Cl, ^{14}C
Shield	6.4×10^{-5}	GI-LLI	5.4×10^{-4}	1,050	^{99}Tc
Site F					
Reactor block	2.7×10^{-1}	GI Tract	3.1×10^{-1}	560	^{36}Cl, ^{14}C
Shield	3.1×10^{-5}	Thyroid	2.7×10^{-4}	490	^{99}Tc
Site H					
Reactor block	1.7×10^{-1}	GI Tract	1.9×10^{-1}	630	^{36}Cl, ^{14}C
Shield	3.1×10^{-5}	Thyroid	2.7×10^{-4}	560	^{99}Tc
Site KE					
Reactor block	4.0×10^{-1}	GI Tract	4.6×10^{-1}	1,120	^{36}Cl
Shield	4.7×10^{-5}	Thyroid	4.1×10^{-4}	1,050	^{99}Tc
Site KW					
Reactor block	3.9×10^{-1}	GI Tract	4.4×10^{-1}	1,120	^{36}Cl, ^{14}C
Shield	4.7×10^{-5}	Thyroid	4.1×10^{-4}	1,050	^{99}Tc
All Sites					
Process tubes (NR)	--	--	--	--	--

NR = no release.
LLI = lower large intestine.

the river depends on the rate at which they enter the ground water, the rate of their radioactive decay, their chemical characteristics and mobilities in the soil, the flow of the aquifer, and the distance to the river. The highly mobile radionuclides (carbon-14, chlorine-36) could reach the Columbia River within a few hundred years after the initiation of waste leaching. The less

TABLE G.16. In Situ Decommissioning Alternative--Maximum Potential 70-Year Radiation Dose from the Full-Garden Scenario, by Reactor Site

Maximum Waste Form[a]	Whole-Body Dose (rem)	Highest Organ	Highest Organ Dose (rem)	Number of yr after Disposal	Dominant Nuclide
Site B/C					
Reactor block	3.2×10^{1}	GI Tract	3.7×10^{1}	1,120	^{36}Cl, ^{14}C
Shield	4.5×10^{-3}	Thyroid	3.8×10^{-2}	1,050	^{99}Tc
Site D/DR					
Reactor block	3.0×10^{1}	GI Tract	3.5×10^{1}	1,260	^{36}Cl
Shield	4.5×10^{-3}	Thyroid	3.8×10^{-2}	1,050	^{99}Tc
Site F					
Reactor block	1.9×10^{1}	GI Tract	2.2×10^{1}	560	^{36}Cl, ^{14}C
Shield	2.2×10^{-3}	Thyroid	1.9×10^{-2}	490	^{99}Tc
Site H					
Reactor block	1.2×10^{1}	GI Tract	1.3×10^{1}	630	^{14}C
Shield	2.2×10^{-3}	Thyroid	1.9×10^{-2}	560	^{99}Tc
Site KE					
Reactor block	2.8×10^{1}	GI Tract	3.2×10^{1}	1,120	^{36}Cl, ^{14}C
Shield	3.3×10^{-3}	Thyroid	2.9×10^{-2}	1,050	^{99}Tc
Site KW					
Reactor block	2.7×10^{1}	GI Tract	3.1×10^{1}	1,120	^{36}Cl, ^{14}C
Shield	3.3×10^{-3}	Thyroid	2.9×10^{-2}	1,050	^{99}Tc
All Sites					
Process tubes (NR)	--	--	--	--	--

NR = no release.

mobile nuclides (cesium-137, americium-241) may decay completely before ever reaching the water table.

The Columbia River is now used for drinking, irrigation, and recreation by many people living downstream from the Hanford Site. These uses are expected to increase in the future. Currently, however, only a small fraction of the river's flow below Hanford is used for irrigation or drinking.

(Water for the large irrigation projects in the area is primarily derived from the Columbia River upstream from Hanford.) McCormack et al. (1984) estimate that within 80 kilometers downstream from Hanford, only 2,000 people eat food grown with irrigation water taken from the Columbia River below Hanford; 70,000 people drink water from the river; and about 125,000 people swim or boat in the river. To conservatively account for all people living downstream along the Columbia River between Hanford and the river's mouth, the population of affected individuals was assumed to grow to nearly 5,000,000 over the next 10,000 years. For this many people to be affected, the amount of irrigated land in both Washington and Oregon must increase greatly concurrent with a large increase in overall population. The total number of people thus assumed to live along the Columbia River over the 10,000-year period is about 410 million. The total dose that a group this size would receive from naturally occurring background sources is nearly 8.6 billion person-rem. As a subset of this population, the 70,000 people currently using the Columbia for drinking water, if held constant over the next 10,000 years, would receive a natural background dose of about 210 million person-rem.

People living along the Columbia River downstream from where the radionuclides enter the river would be subject to time-dependent radiation doses. The gradual release of contaminants to the river would cause the dose rate to slowly increase to a peak, followed by a gradual decline. There could be more than one peak, separated in time, caused by different radionuclides. The total dose to all people living over the next 10,000 years depends mostly on the total activity (in curies) of each nuclide released; but the rate of release controls the dose rate to any one individual. This is analogous to the considerations described in Section G.1.3.1 for the ground-water well. The population dose is dominated by the arrival of the nonsorbed nuclides. The nuclides would reach the river in pulses, much like those shown in Figure G.1. The sorbed nuclides arrive later and at much lower rates than the early nonsorbed nuclides; thus they add only incrementally to the total dose. The maximum lifetime doses (70 years) to an average individual living downstream from Hanford along the Columbia River for each alternative are given in Tables G.17 through G.20.

TABLE G.17. Immediate One-Piece Removal, Deferred One-Piece Removal, and Deferred Dismantlement Alternatives--Public Doses from Contaminant Migration to the Columbia River, 0.5-Centimeter-per-Year Recharge

	Average Downriver Individual, Lifetime Dose, During Peak Release Period						10,000-Yr Integrated Population Dose	
					Dominant Nuclide			
Waste Form	Whole-Body Dose (rem)	Highest Organ	Highest Organ Dose (rem)	Number of yrs after Disposal	Whole Body	Highest Organ	Whole-Body Dose (person-rem)	Dominant Nuclide
Reactor block	1.1×10^{-5}	GI Tract	1.3×10^{-5}	8,470	^{36}Cl	^{36}Cl	1.9×10^{3}	^{36}Cl, ^{14}C
Thermal shield	1.5×10^{-9}	Thyroid	1.3×10^{-8}	6,230	^{99}Tc	^{99}Tc	2.8×10^{-2}	^{99}Tc
Metal components (NR)	--	--	--	--	--	--	--	--

NR = no release.

TABLE G.18. Immediate One-Piece Removal, Deferred One-Piece Removal, and Deferred Dismantlement Alternatives--Public Doses from Contaminant Migration to the Columbia River, 5-Centimeter-per-Year Recharge

	Average Downriver Individual, Lifetime Dose, During Peak Release Period						10,000-Yr Integrated Population Dose	
					Dominant Nuclide			
Waste Form	Whole-Body Dose (rem)	Highest Organ	Highest Organ Dose (rem)	Number of yrs after Disposal	Whole Body	Highest Organ	Whole-Body Dose (person-rem)	Dominant Nuclide
Reactor block	1.1×10^{-5}	GI Tract	1.3×10^{-5}	8,190	^{36}Cl	^{36}Cl	2.1×10^{3}	^{36}Cl, ^{14}C
Thermal shield	1.5×10^{-9}	Thyroid	1.3×10^{-8}	7,950	^{99}Tc	^{99}Tc	2.7×10^{-2}	^{99}Tc
Metal components (NR)	--	--	--	--	--	--	--	--

NR = no release.

TABLE G.19. In Situ Decommissioning Alternative-Public Doses from Contaminant Migration to the Columbia River, Independent of Recharge

Waste Form	Average Downriver Individual, Lifetime Dose, During Peak Release Period: Whole-Body Dose (rem)	Highest Organ	Highest Organ Dose (rem)	Number of yrs after Disposal	Dominant Nuclide: Whole Body	Dominant Nuclide: Highest Organ	10,000-Yr Integrated Population Dose: Whole-Body Dose (person-rem)	Dominant Nuclide
Reactor block	2.2×10^{-5}	GI Tract	2.5×10^{-5}	3,430	^{14}C	^{14}C	4.7×10^{3}	^{14}C
Thermal shield	1.5×10^{-9}	Thyroid	1.3×10^{-8}	1,120	^{99}Tc	^{99}Tc	2.1×10^{-2}	^{99}Tc
Metal components (NR)	--	--	--	--	--	--	--	--

NR = no release.

TABLE G.20. No Action Alternative--Public Doses from Contaminant Migration to the Columbia River, Independent of Recharge

Waste Form	Average Downriver Individual, Lifetime Dose, During Peak Release Period: Whole-Body Dose (rem)	Highest Organ	Highest Organ Dose (rem)	Number of yrs after Disposal	Dominant Nuclide: Whole Body	Dominant Nuclide: Highest Organ	10,000-Yr Integrated Population Dose: Whole-Body Dose (person-rem)	Dominant Nuclide
Reactor block	2.4×10^{-4}	Bone Surf.	2.4×10^{-3}	2,590	^{41}Ca	^{41}Ca	5.0×10^{4}	^{41}Ca
Thermal shield	6.7×10^{-5}	LLI	1.4×10^{-3}	140	^{60}Co	^{60}Co	6.0×10^{2}	^{41}Ca
Metal components	1.4×10^{-6}	LLI	6.7×10^{-6}	140	^{63}Ni	^{60}Co	1.2×10^{1}	^{93}Zr

LLI = lower large intestine.

The lifetime doses to average individuals from any of the decommissioning alternatives are very small; the largest is equivalent to the dose received in a few weeks from natural background radiation. The total 10,000-year integrated population doses are likewise small. Because the radionuclides reaching the river have long half-lives, with essentially no radioactive decay during transport, there is very little difference between the dose estimates for the two recharge rates assumed. For the 0.5-centimeter-per-year and 5-centimeter-per-year recharge rates, the total population doses are directly dependent only on the total quantity of each radionuclide ultimately released to the river, which is nearly the same in either case.

The individual doses reported in Tables G.17 through G.20 show relatively little difference, other than time of occurrence, for the 100-Area and 200-Area alternatives. This is because with the long half-lives of the dominant radionuclides, the only controlling factor is the release rate from the waste forms, which is the same for each alternative. The population doses show more variation between 100- and 200-Area decommissioning alternatives. The 200-Area alternative actually seems to result in a lower population dose than the 100-Area alternatives. Placement of the wastes in the 200 Areas results in a delay of the release of radionuclides to the river. Therefore, fewer curies total are released in the first 10,000 years, resulting in a decreased estimate of population dose for the 200-Area decommissioning alternatives. If the integration time were lengthened, the population doses would tend to converge.

The doses presented in this appendix incorporate a dilution factor for the radionuclides released from ground water into the Columbia River. This factor is based on the approximately 100-cubic-kilometer-per-year (120,000-cubic-foot-per-second) flow of water past Hanford. The additional dilution caused by influx of water from downstream tributaries is not taken into consideration. The flow of the Columbia River below the confluences of the Yakima, Snake, and Walla Walla rivers is about 215 cubic kilometers per year (260,000 cubic feet per second); below the Willamette River, the flow is about 242 cubic kilometers per year (290,000 cubic feet per second). This additional dilution would tend to lower the estimated doses.

G.1.3.4 Carbon-14 Evolution to the Atmosphere

The release mechanism postulated in Appendix D for the reactor graphite is essentially one of oxidation of the carbon. The original experiments (Gray 1982) indicated approximately a 50% split in the released carbon (as carbon dioxide) between the water and adjacent air. For the dosimetric analysis, it has been assumed that one-half of the released carbon-14 is transported by ground water, and the remainder is transported directly out of the burial site into the atmosphere. Assuming the release begins essentially immediately upon decommissioning, the combined release rate to the atmosphere from all eight reactors would total about 2 curies per year. The total dose from this release to the population within 80 kilometers over 10,000 years would be about 5.0×10^3 person-rem. The peak lifetime dose to any single individual would average about 4.2×10^{-5} rem to the whole body. This is equivalent to less than 1 day of natural background radiation.

The 80-kilometer population dose via the air pathway is coincidentally only slightly higher than that predicted via the ground-water pathway for all of the decommissioning alternatives. This indicates that, should the assumed apportionment between air and ground water for carbon-14 release be other than 50/50, the calculated doses to nearby persons would not change significantly.

G.1.3.5 Radiologically Related Health Effects

Estimated health effects based on the doses reported in this appendix are given in Table G.21. The projection of health effects, based on the range given in Appendix F, is not more than five health effects over the 10,000-year period in the entire downriver population for any of the decommissioning alternatives.

G.2 DRILLING

Drilling into a waste-disposal site involves penetration of the waste site from the land surface and actual removal of soil and waste material to the land surface. Drilling on the Hanford Site was considered in the assumed case of loss of active institutional control 100 years after cessation of

TABLE G.21. Estimated Incremental Radiation Dose to the Maximum Average Individual in the Downriver Population, as a Fraction of Natural Background, and the Total Number of Estimated Health Effects Resulting from Each Alternative

Alternative	Average Individual Dose (Fraction of Background)	Total Estimated Health Effects[a]
Immediate one-piece removal	5×10^{-7}	0.2 - 2
Deferred one-piece removal	5×10^{-7}	0.2 - 2
Deferred dismantlement	5×10^{-7}	0.2 - 2
In situ decommissioning	1×10^{-6}	0.5 - 5
No action	1×10^{-5}	5 - 50

(a) Based on a range of 100 to 1,000 health effects per 10^6 person-rem. Other factors are sometimes used that do not exclude zero as a possibility. See Appendix F for details.

decommissioning activities. Records, monuments, barriers, and markers may make drilling less likely, but they cannot preclude it (DOE 1987).

Sections G.2 through G.5 describe scenarios in which human activities result in direct contact with the waste form. A number of different waste forms and their associated annual doses are reported in this section. It is important to note that these doses are not additive. For example, a drill core was postulated to penetrate the thickest section of a thermal shield, this being a vertical side panel. Similarly, a drill shaft was postulated to penetrate the thickest section of the graphite core. It is geometrically impossible to drill through the thickest section of each waste type with the same drill core.

A shallow (100 meters or less) water well drilled for domestic water supply is a potential mechanism for moving buried waste directly to the earth's surface, one that gives little indication that the waste has been encountered. Any disposal alternative that leaves waste near the surface creates the potential for the waste to be struck during drilling for even relatively shallow wells.

In the drilling scenario modeled, a well 30 centimeters in diameter is assumed to be bored through waste of each form. Doses from larger or smaller drill holes were scaled in proportion to their cross-sectional areas. To

estimate the maximum radioactivity that might reasonably be transported to the surface, maximum contaminant concentrations were assumed.

Drilling through the waste form itself is assumed to take 1 hour. During this time, the driller breathes resuspended contaminated soil at a rate of 230 cubic centimeters per second, with a soil mass loading of 1×10^{-4} grams per cubic meters of air. For the calculation of external exposure, the exhumed waste was assumed to be spread over a 100-square-meter area.

The drillers were assumed to spend 40 hours working in the immediate vicinity of the exhumed waste. The maximum annual dose includes that from external radiation received during drilling, plus the longer-term dose that would result from inhalation of nuclides in resuspended contaminated drilling muds.

Whole-body radiation dose commitments to individual members of a drill crew as a result of drilling through the waste are presented in Table G.22 for the removal and dismantlement alternatives and for the various waste forms. The doses are dominated by the external exposure contribution, generally from cesium-137 at early times and niobium-94 in the longer time periods.

People living beyond the immediate vicinity of the contaminated area would be exposed to much lower concentrations of radionuclides because atmospheric dispersion and dilution of resuspended contaminants would greatly reduce the individual doses.

TABLE G.22. Potential Individual Whole-Body Dose Commitments Resulting from the Well-Drilling Scenario for the Removal and Dismantlement (200 Area) Alternatives (rem)

Number of yr after Disposal	Waste Form		
	Reactor Block	Thermal Shield	Metal Components
100	5×10^{-3}	2×10^{-3}	2×10^{-3}
400	2×10^{-3}	6×10^{-4}	2×10^{-3}
1,000	2×10^{-3}	6×10^{-4}	2×10^{-3}
10,000	2×10^{-3}	5×10^{-4}	1×10^{-3}

G.3 EXCAVATION INTRUSION

Several excavation events can be postulated that would represent major ground disturbance. These include such construction projects as highways, canals, or basements in buildings. In these cases, workers operating heavy machinery can be assumed to be working in a large hole in the ground and would be surrounded by contaminated soil. The size of the hole could range from relatively small (for a basement) to quite large (for a canal), but the direct exposure source and the concentration of radionuclides resuspended in the air would be about the same in either case. The workers in the hole would be exposed to direct radiation from radionuclides in the soil and to resuspended dust from the construction activity. Minor excavation or digging is considered similar to a drilling intrusion event (Section G.2) because of the amount of material removed and the similar processes of exposure.

An individual operating heavy equipment was assumed to work in a contaminated area for 80 hours. A mass loading of 1×10^{-2} grams per cubic meter of air was assumed. Density of the material was assumed to be 1.7 grams per cubic meter, and the waste was assumed to be uniformly mixed with soil.

Calculated whole-body radiation dose commitments to individual workers as a result of excavating the waste at various future times are presented in Table G.23 for the removal and dismantlement alternatives.

Excavation into the waste is not considered likely for the no action alternative. Intrusion into wastes under this alternative is considered in Section G.4.

People living beyond the immediate vicinity of the contaminated area would be exposed to much lower concentrations of radionuclides than the excavators would, because atmospheric dispersion and dilution of resuspended contaminants would reduce the doses.

TABLE G.23. Potential Individual Whole-Body Dose Commitments Resulting from the Excavation Scenario for the Immediate Dismantlement and Deferred Dismantlement Alternatives (rem)

Number of yr after Disposal	Waste Form		
	Reactor Block	Thermal Shield	Metal Components
100	5×10^{-1}	8×10^{-2}	2×10^{-1}
400	4×10^{-1}	3×10^{-2}	2×10^{-1}
1,000	3×10^{-1}	2×10^{-2}	2×10^{-1}
10,000	2×10^{-1}	2×10^{-2}	1×10^{-1}

G.4 OTHER INTRUSION SCENARIOS

In the preceding section, it was stated that excavation was not considered likely for the no action alternative. Because the reactors are under no cover if no action is taken, excavation of the site (e.g., for construction of a basement) is highly unlikely. However, someone (e.g., a salvager or archaeologist) may deliberately intrude into the waste. Intentional intrusion implies that the intruder knows of the potential hazard of the disposed waste but for some reason deliberately chooses to ignore the hazard. For example, the intruder could be seeking something of potential value in the disposed waste. An intentional intruder (e.g., a salvager or an archaeologist) was postulated to enter the reactor or its surroundings. Whether a mound or barrier is present (in situ decommissioning) or not (continue present action), the activities of the intruder would be similar, resulting in similar exposure times and resuspension factors. It was further assumed that the activities of a casual intruder involve exploring a previously excavated site, and that this casual intruder has no intention of removing material or further excavating the site, but only enters the excavation out of curiosity. It was assumed that a minimal amount of time is spent at the site. Table G.24 shows the exposure parameters used in these scenarios. Whole-body radiation dose commitments to the intentional and casual intruder are given in Tables G.25 and G.26.

TABLE G.24. Exposure Parameters for Intentional and Casual Intruder Scenarios

Waste Form	Applicable Scenarios	Exposure Time (hr)	Resuspension Soil Mass Loading (g/cm^3)
Block	Intentional intruder	2,000	1×10^{-2}
	Casual intruder	10	1×10^{-2}
Thermal shield	Intentional intruder	200	1×10^{-2}
	Casual intruder	10	1 x 10-2
Metal components	Intentional intruder	200	1×10^{-2}
	Casual intruder	10	1×10^{-2}

TABLE G.25. Potential Individual Whole-Body Dose Commitments Resulting from the Activities of an Intentional Intruder for the In Situ Decommissioning and No Action Alternatives (rem)

Number of yr after Disposal	Waste Form: Reactor Block	Thermal Shield	Metal Components
100	1×10^{1}	2×10^{-1}	6×10^{-1}
400	9	6×10^{-2}	5×10^{-1}
1,000	8	6×10^{-2}	5×10^{-1}
10,000	6	4×10^{-2}	4×10^{-1}

TABLE G.26. Potential Individual Whole-Body Dose Commitments Resulting from the Activities of a Casual Intruder for the In Situ Decommissioning and the No Action Alternatives (rem)

Number of yr after Disposal	Waste Form: Reactor Block	Thermal Shield	Metal Components
100	6×10^{-2}	1×10^{-2}	3×10^{-2}
400	5×10^{-2}	3×10^{-3}	3×10^{-2}
1,000	4×10^{-2}	3×10^{-3}	3×10^{-2}
10,000	3×10^{-2}	2×10^{-3}	2×10^{-2}

G.5 RESETTLEMENT WITH FARMING OR GARDENING

For purposes of analysis, it was hypothesized that the Hanford Site was abandoned, then reoccupied. Though not a likely event, this case was analyzed to provide an estimate of the potential long-term radiological impacts associated with such an eventuality. It is reasonable to assume that this type of resettlement would involve only a few individuals.

With resettlement could come small farm or garden activities that could provide contaminant exposure pathways to the individuals involved, as in the following scenarios:

1. A home and garden over a shallow waste site; exposure would come from consuming crops or garden produce and living over the waste site. The specific mechanisms involved would be direct radiation from the waste and roots growing into waste or contaminated soil and taking up radionuclides. This scenario is described in detail in Section G.5.1.
2. A home and garden at the site of former drilling activity; this drilling would have resulted in a higher level of radioactivity at the land surface where inhabitants carry out their activities. Direct exposure, resuspension, and ingestion of food products grown in contaminated soil are all primary exposure pathways to the inhabitants. This scenario is detailed in Section G.5.2.

G.5.1 Residential, with Home Garden

Without active institutional controls, and assuming that passive institutional controls, such as permanent markers and public records, are disregarded, waste-disposal areas could be used for residential purposes. People could build homes over buried waste sites and conduct routine activities there. They could grow food crops, for either domestic or animal consumption, over the waste site. The residents would consequently be exposed to both low levels of direct radiation from the buried material and to ingestion of radionuclides via crops grown on the site. The extent of crop contamination would be a function of the depth of waste burial, the integrity of

the waste form, the overall surface area used for gardening, and other factors that affect the fraction of plant roots that contact the waste.

Whole-body radiation dose commitments to resident individuals are given in Table G.27 for the various waste forms for the 200-Area decommissioning alternatives. People were assumed to live on the land and to grow 25% of their total food in gardens. The dominant exposure pathway is ingestion of contaminated food crops. The waste forms were assumed to be equivalent to soil, except for the metal components, which consist of activated metal. A linear corrosion release rate of 0.04% per year was superimposed on the decay, resulting in the slight increase in dose rate at long times.

TABLE G.27. Potential Individual Whole-Body Dose Commitments Resulting from the Residential (with Home Garden) Scenario for the Immediate One-Piece Removal and Deferred One-Piece Removal Alternatives (rem)

Number of yr after Disposal	Waste Form		
	Reactor Block	Thermal Shield	Metal Components
100	2×10^{1}	3×10^{-1}	3×10^{-3}
400	2×10^{1}	2×10^{-1}	2×10^{-3}
1,000	2×10^{1}	2×10^{-1}	3×10^{-3}
10,000	2×10^{1}	2×10^{-1}	8×10^{-3}

The effects of this scenario on populations depend directly on the number of people involved. For example, if a family of five were to reside over the waste site that was postulated for this scenario, each member would receive the dose shown in Table G.27.

G.5.2 Postdrilling/Habitation

The doses to persons contacting wastes that were presented in Sections G.2 (drilling), and G.3 (excavation) represent only part of the potential impact of intrusion into waste. Both drilling and excavation disturb the wastes physically and distribute them in the local environment. These wastes could be a source of radiation exposure to people living on or near the site of such disturbance long after the original redistribution. As in

the example of the residential scenario (Section G.5.1), people who live on or near the waste would be exposed to direct radiation from the soil, to inhalation of resuspended material, and to ingestion of garden-grown foods. Habitation after excavation is not considered likely because the waste removed would be in a recognizable form and hence not distributed in a garden.

Waste brought to the surface by the drilling scenario (Section G.2) was assumed to be spread uniformly throughout a 15-centimeter plow layer in a garden 2,500 square meters in area. Twenty-five percent of the individual's vegetable intake was assumed to come from this garden. Individuals were each assumed to spend 2,000 hours per year outside, where they are exposed to resuspended dust and to surface contamination.

Whole-body dose commitments to individuals living on the site of an intrusive event at various future times are presented in Table G.28 for the three alternatives involving disposal of wastes in the 200 Areas. The doses given in the table are for people inhabiting the site after it has been contaminated by the drilling scenario.

G.6 GLACIAL AND RISE-IN-SEA-LEVEL FLOODING

In a recent study, Craig and Hanson (1985) examined the potential for ice-age flooding affecting the Hanford Site as a result of climatic changes in the next 10,000 years. Their study was focused on evidence for ice-dammed

TABLE G.28. Potential Individual Whole-Body Dose Commitments Resulting from the Postdrilling Scenario for the Removal and Dismantlement Alternatives (rem)

Number of yr after Disposal	Waste Form		
	Reactor Block	Thermal Shield	Metal Components
100	2	7×10^{-2}	2×10^{-2}
400	2	4×10^{-2}	1×10^{-2}
1,000	2	4×10^{-2}	9×10^{-3}
10,000	2	4×10^{-2}	6×10^{-3}

lakes created during various past glacial stages, particularly on the catastrophic releases of impounded water from Lake Missoula, the largest of these lakes. There is considerable evidence of the effects of these floods in the Pasco Basin, where as much as 2,000 cubic kilometers of water flowed through in a period of a few weeks (Craig and Hanson 1985), compared to the river's present average annual flow of about 100 cubic kilometers per year. Studies conducted in support of the EIS for disposal of defense wastes at Hanford (DOE 1987) suggest that the advance and retreat of ice flows sufficient to result in catastrophic floods of this magnitude might recur 40,000 to 50,000 years from now.

The study by Craig and Hanson is based on a link between climatic variability and variations in the orbital parameters of the earth. The global volume of ice is related to orbital variability through various modeling techniques.

Based on current modeling techniques and current data, Craig and Hanson (1985) predict three major continental glaciations within the next 100,000 years. None of these, however, is within the next 10,000-year period. The first major continental glaciation is predicted to begin in about 15,000 years, and is not expected to be of sufficient magnitude and duration to significantly affect the Hanford Site by catastrophic flooding from a recurrence of glacial Lake Missoula. Glacial flooding is not, therefore, considered in this EIS as a release event for the decommissioning alternatives within the next 10,000 years.

Flooding by a rise in sea level is not likely to affect the Hanford Site. Rise and fall of worldwide sea level over the past 2 million years is well documented. These changes have generally occurred with the advances and retreats of the world's ice sheets and ice caps, and have a general time span of 100,000 years, with sea level changes of up to 100 meters (Scott et al. 1979). Present sea level has been essentially stable for the last 3,000 to 5,000 years, following its rise after the ebb of the Wisconsin glacial stage, about 17,000 years ago. The present time is generally considered to be interglacial; the most likely future change will be a sea-level lowering as ice builds up again on land. Andrews (1979) estimated that if the Antarctic

and Greenland ice sheets melted, worldwide sea level would rise approximately 75 meters. Such a rise would pose no threat from surface flooding to the Hanford Site in general, which is 125 meters or more above present sea level.

G.7 COLUMBIA RIVER FLOODING

Flooding of the 100 Areas by the Columbia River is discussed in Appendix B. Neither the 100-year nor the 500-year flood would have any great impact on continued present action or on in situ decommissioning. A failure of Grand Coulee Dam would, however, result in catastrophic flooding of downstream areas and would reach several of the reactors in the 100 Areas.

A 50% failure of Grand Coulee Dam would result in a flow of 227,000 cubic meters per second at Hanford. This flood would not reach the 200 Areas, but would reach several of the 100-Area surplus reactors. The elevation of the flood and flow velocity are given for each surplus reactor in Appendix B. The rise of flood waters and the flood velocity would not necessarily, in themselves, dislodge any reactor. However, it was postulated that the flood would cause erosion of the existing river bank and result in the undermining of a reactor (and barrier) such that the reactor block would topple or drop into a new river channel. Once the flood recedes, the reactor block would remain in the new river channel where its contents would be leached into the river at a maximum release rate. This release rate is equivalent to that assumed in Section G.1.3.3 for releases from the undisturbed reactors. Thus, the downstream population doses from one reactor would be approximately equivalent to one-eighth of those presented in Section G.1.3.3.

G.8 WIND EROSION

Both erosion and deposition of soils occur on the Hanford Site as a result of wind. On the sites considered for waste disposal, erosion of surface covering is slight. Even when the rate of wind erosion is temporarily high during windstorms, the amount of fine-grained material removed is limited by the formation of lag concentrates from coarser material. This "armoring effect" is quite stable and tends to prevent further wind erosion unless the surface is disturbed, after which another armored surface begins

to form. Wind action can also fill depressions and deposit material as effectively as it removes it. The riprap on the sides of the barriers envisioned for the decommissioning alternatives would exhibit this armoring effect and, thus, would mitigate the impact of wind erosion.

Denudation is the total of all processes, including continuous wind and water action, that reduce land surface relief. Rates of denudation are generally estimated from sediment samples from rivers in a given drainage basin. Tubbs (in Scott et al. 1979) cites evidence of a total denudation rate for a drainage basin tributary to the Columbia River in the Pasco Basin of about 0.25 centimeter every 100 years (0.0025 centimeter per year), and suggests that a small drainage basin tributary to the Columbia River in the Pasco Basin might have a denudation rate of about 0.5 centimeter per 100 years (0.005 centimeter per year).

There are no definitive estimates to separate the effects of wind erosion from the other processes resulting in denudation rates. Because the rates include the effects of stream erosion, and because erosion is not an effective process on the Hanford Site, 0.0025 centimeter per year is used for an estimated rate for wind erosion. Assuming this rate were to continue for 10,000 years, the land surface would be lowered by only 25 centimeters (without riprap armoring), and this would not expose any of the reactor decommissioning wastes.

The Hanford record of tornados occurring in this area indicates they are rare events. Those observed have been small, with little effect on soil surface. A tornado touched down near the east end of the Rattlesnake Hills on June 16, 1948 (Stone et al. 1983). Funnel clouds were also observed in 1961 to the south-southeast, and in 1970 to the south-southwest of Rattlesnake Mountain. So-called "dust devils" are frequently seen over plowed fields and burned-over areas in the region, but would not be significant in terms of wind erosion at the Hanford Site.

Because wind erosion occurs at such low rates and the wastes are so deeply buried, tornados are not considered likely to release radionuclides under any of the decommissioning alternatives. Even if the continue present action alternative were to be adopted and the reactors are left in place, and

if additional protective measures are not implemented, no release can reasonably be postulated. Wind erosion is not seen as a discriminator for choice among the surplus reactor decommissioning alternatives.

G.9 SEISMIC EVENTS

Seismic activity is not believed to be a probable means for directly releasing waste.

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APPENDIX H

WASTE DISPOSAL

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APPENDIX H

WASTE DISPOSAL

This appendix presents conceptual designs for disposal site barriers, liner/leachate collection systems, marker systems, and ground-water monitoring systems. These systems are included in each disposal alternative presented in Chapter 3.0, except that the liner/leachate collection system and leak-detection system are omitted from in situ decommissioning because of the impracticality of installing these systems under the reactor blocks. Information on the disposal-site cover and the liner/leachate collection system was prepared by Westinghouse Hanford Company, successor to Rockwell Hanford Operations. Information is also presented on the efficacy of the riprap armor, to be placed on the sides of the in situ mounds to control erosion and also to protect the mounds and reactors from flooding should a 50% failure of Grand Coulee Dam occur (Section H.5).

The design of the waste barrier presented in Section H.1 is based on the concept of the Hanford defense-waste (HDW) barrier (DOE 1987) and is intended to limit water recharge through the barrier to 0.1 centimeter per year. This barrier is not yet proven for the Hanford Site and will require at least 5 years of experimental work to demonstrate barrier performance (Adams and Wing 1986).

H.1 DISPOSAL-SITE BARRIER

The conceptual design of the disposal-site barrier is intended to limit or prevent downward infiltration of water through the barrier and into the waste form. The physical principle of the barrier's operation is equivalent to the principle of operation of the HDW barrier, which is presented in Appendix M of the HDW EIS (DOE 1987). The principle of operation is that of a capillary barrier in which a fine-textured soil, capable of acting as a capillary medium, is placed either above a void (actually large rocks in the HDW EIS case) or above an impermeable soil layer (in the case described here). In either case, water entering the system from above drains to the

bottom of the fine-textured soil (capillary medium), where it remains at the capillary barrier, supported by the pressure difference between the top and bottom of the capillary column, until it evaporates up through the fine-textured soil to the atmosphere or until it is taken up by the root systems of a surface plant cover and transpired to the atmosphere. If the water builds up and the water pressure in the fine-textured soil exceeds the pressure difference provided by the capillary system, then the water will pass downward through the soil into the rocks (in the HDW EIS case), or will be diverted to the side by the impermeable soil layer (in the case presented here). Should the impermeable soil layer fail, then larger rocks (pitrun gravel) below the impervious soil layer will still permit the capillary barrier to function.

The protective barrier conceptual design is shown in Figure H.1 for the in situ alternative. The barriers for the removal alternatives are similar in design. The capillary medium is the fine-textured soil layer, and the lower portion of the capillary barrier is provided either by the impermeable soil/bentonite clay layer or, in the case of failure of the impermeable layer, by the pitrun gravel. Also shown in Figure H.1 is a riprap berm placed on the sides of the mound for erosion-control purposes. The sides of the mound (and the riprap berm) are at a slope of 3 to 1, which is adequate for mound stability and is conservative in the use of material for mound construction. The riprap also functions to protect the mounds from the flooding that would be caused by a 50% failure of Grand Coulee Dam. This is discussed further in Section H.5.

H.2 LINER/LEACHATE COLLECTION SYSTEM

The liner/leachate collection system is shown in Figures H.2, H.3, and H.4 for the one-piece removal alternatives. The system is the same for the deferred dismantlement alternative, except for the dismantled condition of the waste form. With the liner/leachate collection system in place, leak detection would be accomplished by sensors at the bottom of the wells (Figures H.2 and H.4), and monitoring for the constituents of the leaking waste would be accomplished by pumping the leachate and analyzing it in the

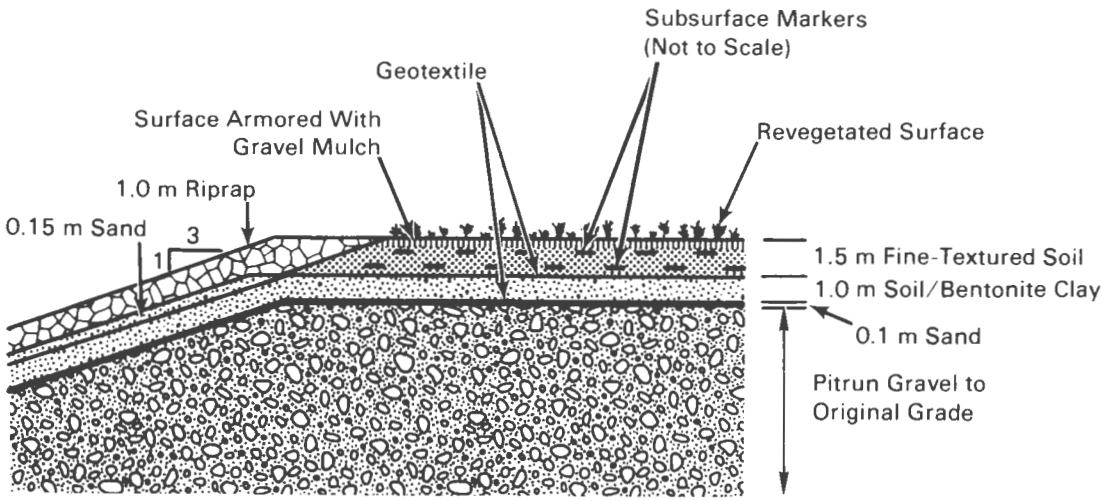

FIGURE H.1. Protective Barrier for the In Situ Decommissioning Alternative

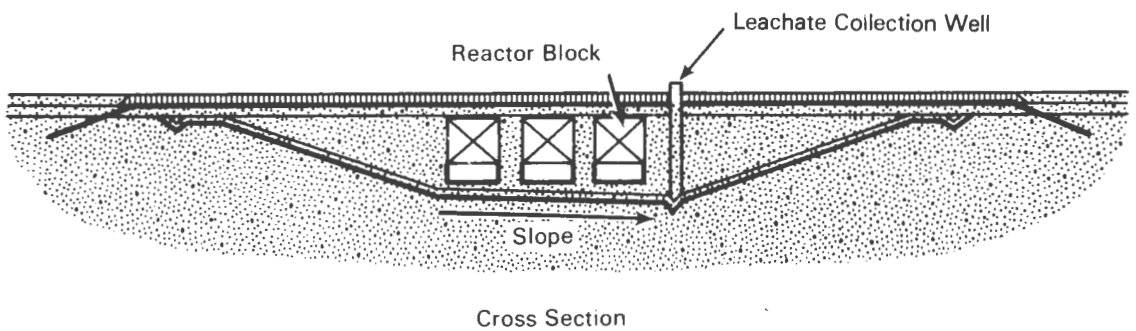

FIGURE H.2. Protective Barrier with Liner/Leachate Collection System for One-Piece Removal Alternatives (protective barrier construction similar to Figure H.1)

laboratory. Because the waste form will be solid and will not contain any liquids, the source of leachant would be rainfall passing through the barrier.

H.3 MARKER SYSTEM

Both surface and subsurface markers will be used at either the 100-Area disposal sites or the 200-Area disposal site to protect against inadvertent human intrusion. The surface markers are large, durable stones such as granite. They will be inscribed with warning symbols, messages, and

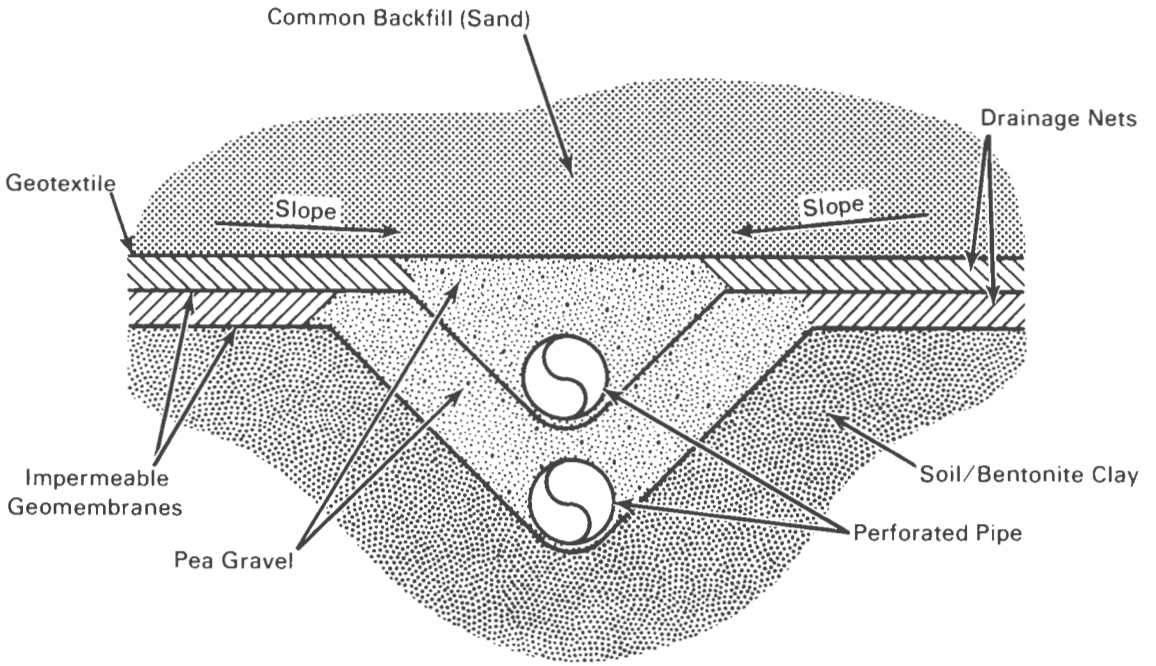

FIGURE H.3. Leachate Collection System

pictograms and will be set around the waste sites close enough for two to be seen on either side of the observer from any position on the periphery of the waste site. The subsurface markers are small stoneware disks placed within the barrier itself (see Figure H.1). The disks will contain the same (or abbreviated) markings as the surface markers and will be placed such that any excavation will uncover a number of markers.

H.4 GROUND-WATER MONITORING

In addition to the leak-detection and monitoring systems, ground-water monitoring wells will be placed around the waste-disposal sites. In the 100 Areas, 12 wells would be placed around each reactor on the perimeter of the approximately 160-meter square in situ mound. One well would be placed at the center of each side of the square, and two more would be located approximately 45 meters on either side of the central well. Quarterly water-level monitoring, batch sampling, and well-water analysis would be carried out. Laboratory analyses would be conducted specifically for lead and radioactivity. In the 200 Areas, monitoring wells would be located

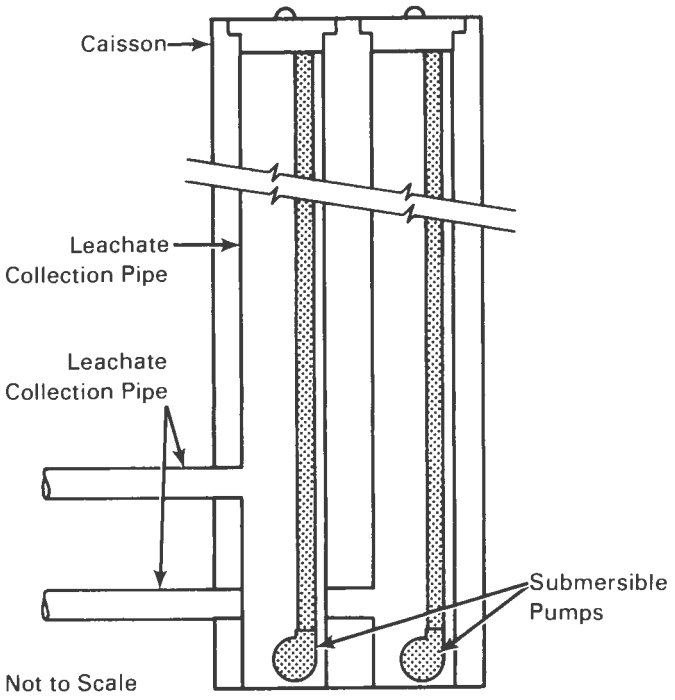

FIGURE H.4. Leachate Collecting and Removal System

around the perimeter of the single waste-disposal site, except that more wells would be located on the downgradient side of the waste-disposal site than on the upgradient side. The 100- and 200-Area wells have different locations because the ground-water hydrology gradients are better known in the 200 Areas than in the 100 Areas, due to the influence of the Columbia River on the 100-Area hydrology. The uncertainties in the location of the gradients in the 100 Areas dictate equal spacing of wells in that Area. The same quarterly monitoring activities would be carried out in the 200 Areas as in the 100 Areas.

H.5 FLOOD PROTECTION OF THE IN SITU MOUND

The 1-meter-thick riprap layer on the surface of the in situ mounds is for the purpose of controlling long-term erosion caused by wind, rainfall, and water runoff. With little further engineering design, the riprap would also be suitable for protection from flood erosion resulting from a catastrophic failure of Grand Coulee Dam. Flooding from the dam-regulated probable maximum flood (PMF) would not reach the ground-floor elevation of

any of the reactors (see Table B.2). (The dam-regulated flood is one in which the Columbia River dams remain in operation.) However, flooding from a 50% failure of Grand Coulee Dam could partially or completely inundate the in situ mounds and cause failure of unprotected mounds by severe, localized scour. A 50% failure of Grand Coulee Dam would also result in failure of the other downstream dams (Chief Joseph, Wells, Rocky Reach, Rock Island, Wanapum, and Priest Rapids).

H.5.1 Riprap Design

Design of the riprap cover for protection against catastrophic flooding is based on the water flow velocity and elevation (see Table B.2), and on the angle between the riprap layer and the horizontal. The American Society of Civil Engineers (1975) recommends the following empirical formula:

$$W = \frac{4.1 \times 10^{-5}\ G\ V^{6}}{(G - 1)^{3} \cos^{3} \phi} \qquad \text{(H.1)}$$

where W = the median rock weight, in pounds
G = the specific gravity of the rock
V = the flow velocity, in feet per second
ϕ = the angle between the riprap layer and the horizontal.

In this case, the slope of the mounds is 3H:1V, so ϕ equals 18.43°. The specific gravity of the rock is assumed to be 2.65, which is equivalent to a density of 165 pounds per cubic foot. The design velocity (peak flow) is taken as 4/3 times the average velocity (from Table B.2), as recommended by the California Department of Transportation (Caltrans 1970). For the flow velocity of 9.2 feet per second (2.8 meters per second), from Table B.2, the rock weight is 96 pounds, and the diameter of the rock (assumed spherical) is 12 inches.

Gradation in size of the rock in the riprap layer is required in order to resist being dislodged by the flowing water. This may be determined from criteria specified by the U.S. Army Corps of Engineers (1970):

$$D_{10} = 0.20\ D_{50}$$
$$D_{20} = 0.30\ D_{50}$$
$$D_{max} = 2.0\ D_{50} \qquad \text{(H.2)}$$

where D_{50} is the median rock diameter corresponding to the median rock weight W. The D_{10} and D_{20} sizes represent average rock diameters where 10% and 20% of the sizes in the gradation are finer. The Corps of Engineers (1970) recommends that the rock layer be as thick as the maximum rock size in the gradation. In this case, the maximum rock diameter is twice the diameter of the median, or 2 x 12 inches = 24 inches. Therefore, the riprap layer should be at least 24 inches thick, which is less than the 1-meter (39-inch) dimension shown in Figure H.1. Definitive engineering design at the time of construction of the mounds might reduce the thickness of the riprap layer, thus reducing material requirements while preserving protection against erosion and catastrophic flooding.

All riprap requires an underlying filter layer of smaller sized material that will prevent outward loss of soil through interstices in the riprap. For in situ decommissioning, the sand layer shown below the riprap layer in Figure H.1 can be engineered to provide the filter.

H.6 REFERENCES

Adams, M. R., and N. R. Wing. 1986. Protective Barrier and Warning Marker System Development Plan. RHO-RE-PL-35 P, Rockwell Hanford Operations, Richland, Washington.

American Society of Civil Engineers. 1975. Sedimentation Engineering. American Society of Civil Engineers, New York, New York.

Caltrans. 1970. Bank and Shore Protection in California Highway Practice. State of California Department of Transportation, Bank Protection Committee, Sacramento, California.

U.S. Army Corps of Engineers. 1970. Hydraulic Design of Flood Control Channels. EM 1110-2-1601, U.S. Army Corps of Engineers, Washington, D.C.

U.S. Department of Energy (DOE). 1987. Final Environmental Impact Statement, Disposal of Hanford Defense High-Level, Transuranic, and Tank Wastes, Hanford Site, Richland, Washington. DOE/EIS-0113 Vol. 1, 2, 3, and 4, U.S. Department of Energy, Washington, D.C.

APPENDIX I

ENDANGERED AND THREATENED SPECIES

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APPENDIX I

ENDANGERED AND THREATENED SPECIES

Section 7(c) of the Endangered Species Act requires federal agencies to request information on any plant or animal species either listed or proposed to be listed as an endangered or threatened species that might also be present in the area of a proposed federal action. The federal agency responsible for administration of the Endangered Species Act on the Hanford Site is the U.S. Fish and Wildlife Service (USFWS), Olympia, Washington. Attached is the USFWS response to a request for information on endangered and threatened species that might be impacted by the DOE's proposed action to decommission the eight surplus production rectors. The USFWS response is valid for 180 days. At the end of the 180-day period, the USFWS should be consulted again for any changes in the list.

United States Department of the Interior

FISH AND WILDLIFE SERVICE

Olympia Field Office
2625 Parkmont Lane SW, Bldg. B
Olympia, Washington 98502
206/753-9444 FTS 434-9444

September 10, 1987 Re: 1-3-87-SP-341

Emmett B. Moore
Deputy Project Manager
Battelle Pacific Northwest Laboratories
P. O. Box 999
Richland, Washington 99352

Dear Mr. Moore:

As requested by your letter, dated August 12, 1987 and received by us on August 19, I have attached a list of endangered and threatened species (Attachment A) that may be present in the area of the proposed Decommissioning of eight surplus production reactors at the Hanford Site in Benton, Franklin and Grant counties, Washington. The list fulfills the requirement of the Fish and Wildlife Service under Section 7(c) of the Endangered Species Act of 1973, as amended. The requirements for Department of Energy compliance under the Act are outlined in Attachment B.

Should the biological assessment determine that a listed species is likely to be affected (adversely or beneficially) by the project, the Department of Energy should request formal Section 7 consultation through this office. Even if the biological assessment shows a "no effect" situation, we would appreciate receiving a copy for our information.

I have also included a list of candidate species presently under review by this Service for consideration as endangered or threatened. Candidate species have no protection under the Endangered Species Act, and a determination of "may affect" for candidates does not require preparation of a biological assessment or consultation with the Fish and Wildlife Service. Candidate species are included simply as advance notice to Federal agencies of species which may be proposed and listed in the future. If early evaluation of your project indicates that it is likely to adversely impact a candidate species, the Department of Energy may wish to request technical assistance from this office.

Your interest in endangered species is appreciated. If you have additional questions regarding your responsibilities under the Act, please contact Jim Michaels of my staff at the above phone/address.

Sincerely,

Charles A. Dunn
Field Supervisor

Attachments

c: WDG (Nongame)
WNHP

LISTED AND PROPOSED ENDANGERED AND THREATENED SPECIES AND CANDIDATE SPECIES THAT MAY OCCUR WITHIN THE AREA OF THE PROPOSED DECOMMISSIONING OF EIGHT SURPLUS PRODUCTION REACTORS AT THE HANFORD SITE IN BENTON, FRANKLIN, AND GRANT COUNTIES, WASHINGTON

1-3-87-SP-341

LISTED

Bald eagle (*Haliaeetus leucocephalus*) - The Columbia River through the Hanford Reservation is a winter concentration area for bald eagles. They may occur in the area from about October 31 through March 31.

Peregrine falcon (*Falco peregrinus*) - peregrines may occur in the project area during the fall.

PROPOSED

None

CANDIDATE

The following candidate bird species nest on the site:

Swainson's hawk (*Buteo swainsoni*)
Ferruginous hawk (*Buteo regalis*)
Long-billed curlew (*Numenius americanus*)
Western sage grouse (*Centrocercus urophasianus phaios*) - resident

Two candidate invertebrate species occur in the Hanford Reach of the Columbia River:

Giant Columbia River limpet (*Fisherola nuttalli*)
Great Columbia River spire snail (*Lithoglyphus columbiana*)

The following candidate plant species have been identified on the reservation at the designated locations:

Columbia milk-vetch (*Astragalus columbianus*)
T13N R24E S9/11

Persistent sepal yellowcress (*Rorippa calycina columbiae*)
T13N R25E S2/6; T13N R26E S33/34;
T13N R27E S25; T14N R27E S7/29

Hoover's desert-parsley (*Lomatium tuberosum*)
T13N R25E S6

Attachment A

FEDERAL AGENCIES' RESPONSIBILITIES UNDER SECTIONS 7(a) AND 7(c) OF THE ENDANGERED SPECIES ACT

SECTION 7(a) - Consultation/Conference

Requires: 1. Federal agencies to utilize their authorities to carry out programs to conserve endangered and threatened species;

2. Consultation with FWS when a federal action may affect a listed endangered or threatened species to ensure that any action authorized, funded, or carried out by a federal agency is not likely to jeopardize the continued existence of listed species or result in the destruction or adverse modification of critical habitat. The process is initiated by the federal agency after they have determined if their action may affect (adversely or beneficially) a listed species; and

3. Conference with FWS when a federal action is likely to jeopardize the continued existence of a proposed species or result in destruction or a adverse modification of proposed critical habitat.

SECTION 7(c) - Biological Assessment for Construction Projects 1/

Requires federal agencies or their designees to prepare a Biological Assessment (BA) for construction projects only. The purpose of the BA is to identify any proposed and/or listed species which is/are likely to be affected by a construction project. The process is initiated by a federal agency in requesting a list of proposed and listed threatened and endangered species (list attached). The BA should be completed within 180 days after its initiation (or within such a time period as is mutually agreeable). If the BA is not initiated within 90 days of receipt of the species list, please verify the accuracy of the list with our Service. No irreversible commitment of resources is to be made during the BA process which would result in violation of the requirements under Section 7(a) of the Act. Planning, design, and administrative actions may be taken; however, no construction may begin.

To complete the BA, your agency or its designee should: (1) conduct an onsite inspection of the area to be affected by the proposal which may include a detailed survey of the area to determine if the species is present and whether suitable habitat exists for either expanding the existing population or potential reintroduction of the species; (2) review literature and scientific data to determine species distribution, habitat needs, and other biological requirements; (3) interview experts including those within FWS, National Marine Fisheries Service, state conservation departments, universities, and others who may have data not yet published in scientific literature; (4) review and analyze the effects of the proposal on the species in terms of individuals and populations, including consideration of cumulative effects of the proposal on the species and its habitat; (5) analyze alternative actions that may provide conservation measures; and (6) prepare a report documenting the results, including a discussion of study methods used, any problems encountered, and other relevant information. Upon completion, the report should be forwarded to our Endangered Species Project Leader, 2625 Parkmont Lane S.W., Olympia, Wa 98502.

1/ "Construction project" means any major federal action which significantly affects the quality of the human environment (requiring an EIS) designed primarily to result in the building or erection of man-made structures such as dams, buildings, roads, pipelines, channels, and the like. This includes federal actions such as permits, grants, licenses, or other forms of federal authorization or approval which may result in construction.

Attachment B

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APPENDIX J

NATIONAL HISTORIC PRESERVATION ACT REQUIREMENTS

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APPENDIX J

NATIONAL HISTORIC PRESERVATION ACT REQUIREMENTS

In accordance with 36 CFR 800, the DOE has completed a Section 106 evaluation of the potential eligibility of the 105-B Reactor as a National Historic Site, and has determined that the property is eligible using the criteria for evaluation in 36 CFR 60.4. The DOE has also solicited the views of the Washington State Historic Preservation Officer (WSHPO), who has rendered an opinion that the 105-B Reactor is eligible for inclusion in the National Register of Historic Places (36 CFR 60).

The Hanford 105-B Reactor is located in the 100-B/C Area on the Hanford Site, about 3.5 miles due east of Washington State Highway 240. Hanford Route 1 connects the 100-B/C Area with Highway 240 approximately 1 mile south of the Vernita Bridge over the Columbia River. The building and adjoining land lie within a 650-square-foot plot, with the center of the reactor process property designated by the following Universal Transverse Mercator coordinates: Zone 11, Easting 297,440, Northing 5,167,280, of the Coyote Rapids 1:62,500 scale Quadrangle, Benton County, Washington.

The facility and the graphite reactor pile were constructed in 1943 as a part of the Manhattan Project. The reactor was first operated in 1944 and shut down in 1968. The 105-B Reactor is now under the ownership of the DOE. Current access to the facility by the general public is restricted; however, interested parties can request an escorted tour of the facility.

The DOE assessed the effects of the proposed decommissioning action in accordance with 36 CFR 800.5 and determined that the proposed decommissioning action would have an adverse impact on the 105-B Reactor facility. The identified measures to mitigate or avoid the adverse impacts of the proposed action include two principal options. The first option is to select the no action alternative for the 105-B Reactor, maintain the facility in its current condition, and nominate it to the National Register of Historic Places. The second option is to provide extensive "recordation" in consultation with

the WSHPO, the Advisory Council on Historic Preservation (Council), and the National Park Service (NPS), and in accordance with the standards and guidelines of the Historic American Engineering Record (HAER).

The DOE is coordinating its responsibilities under the Section 106 review process by using this DEIS to fulfill the requirements for reports and documentation of the proposed major federal action, as required by 36 CFR 800. Further, the DOE has provided copies of the DEIS to the WSHPO, the Council, and the NPS for purposes of allowing comments under 36 CFR 800.4. This will afford these agencies the opportunity to provide comments on the eligibility of the 105-B Reactor for nomination to the National Register of Historic Places and on the proposed methods to mitigate the impacts of the proposed decommissioning action.

The DOE also hereby solicits from interested citizens and the general public comments on the impacts of the proposed decommissioning action on this eligible historic resource and on the proposed methods to mitigate these impacts.

Comments from the WSHPO, the Council, the NPS, the HAER, and interested citizens will be evaluated by the DOE before issuance of the final EIS. The evaluation and the recommended decommissioning alternative will be presented in the final EIS.

Included with Appendix J is correspondence between the DOE and the WSHPO, an official photograph of the 105-B Reactor (Figure J.1), and a U.S. Geological Survey quadrant map showing the location of the 105-B Reactor (Figure J.2).

RICHARD J. THOMPSON
Director

STATE OF WASHINGTON
DEPARTMENT OF COMMUNITY DEVELOPMENT
OFFICE OF ARCHAEOLOGY AND HISTORIC PRESERVATION
111 West Twenty-First Avenue, KL-11 • Olympia, Washington 98504-5411 • (206) 753-4011 • SCAN 234-4011

October 2, 1986

Mr. John R. Hunter
Department of Energy
P.O. Box 550
Richland, WA 99352

Log Ref: 826-F-DOE-07
RE: Hanford B Reactor

Dear Mr. Hunter:

Thank you for soliciting our opinion on the historical significance of the Hanford B Reactor near Richland. Based on information supplied by your office, we believe the structure is eligible for listing in the National Register of Historic Places.

The National Register is the nation's official list of properties significant to our cultural heritage. Although properties less than fifty years old are not generally eligible for listing, the B Reactor and Reactor Building have exceptionally strong associations with the history of the United States atomic energy program and the development of the atomic bomb at the end of World War II.

If a National Register nomination is prepared for the Reactor Building and B Reactor, mention should be made of the physical integrity of the structure and of other properties at the Hanford Site that may be associated with the same significant themes. If you have any questions about our opinion, please call me at (206) 586-2901.

Sincerely,

Leonard T. Garfield

Leonard T. Garfield
Architectural Historian

mr

FIGURE J.1. Photograph of the 105-B Reactor

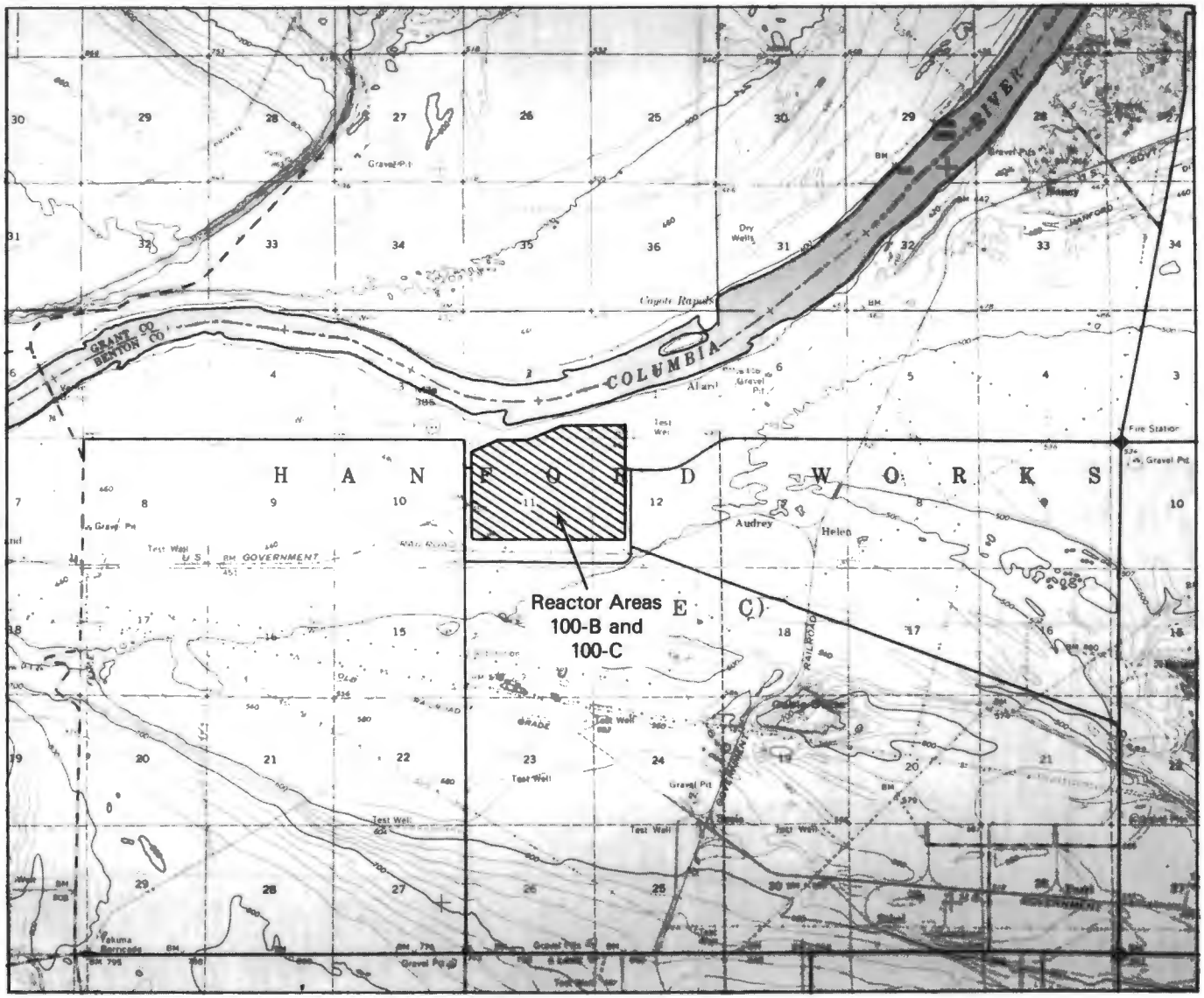

FIGURE J.2. U.S. Geological Survey Quadrant Map Showing the Hanford 105-B Reactor (B Reactor is in quadrant 11)

J.1 REFERENCES

U.S. Code of Federal Regulations, Title 36, Part 60 (36 CFR 60); "National Register of Historic Places." U.S. Department of the Interior.

U.S. Code of Federal Regulations, Title 36, Part 800 (36 CFR 800); "Protection of Historic and Cultural Properties." U.S. Department of the Interior.

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House Committee on Appropriations
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Bureau of Indian Affairs
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White Salmon, WA

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Washington State Department of
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Salem, OR 97310

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Benton City Council (6)
City Hall
Benton City, WA 99320

Benton County Commission (3)
Courthouse
Prosser, WA 99350

Benton County Planning Department (6)
7320 W. Quinault Avenue
Kennewick, WA 99306

Board of County Commissioners
Adams County
Ritzville, WA 99169

Franklin County Commission (3)
Courthouse
1016 N 4th
Pasco, WA 99301

Franklin County Planning Department (6)
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Pasco, WA 99301

Kennewick City Council (6)
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King County Commission
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Pasco Community Development Department
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Richland City Council (6)
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Richland Planning Department
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West Richland, WA 99352

Yakima County Planning Department
Courthouse
Yakima, WA 98901

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Albany Public Library
1390 Waverly Drive
Albany, OR 97321

Beaverton City Library
4550 SW Hall Boulevard
Beaverton, OR 97005

Cedar Mill Commercial Library
12505 NW Cornell Road
Portland, OR 97229

Central Washington University Library
Ellensburg, WA 98926

Corvallis Public Library
645 NW Monroe Avenue
Corvallis, OR 97330

DOE Office of Scientific and
  Technical Information
P.O. Box 62
Oak Ridge, TN 37831

DOE Public Reading Room
P.O. Box 800
Richland, WA 99352

DOE Public Reading Room
Forrestal Building
1000 Independence Avenue SW
Washington, DC 20585

Eastern Washington University
John F. Kennedy Memorial Library
Cheney, WA 99004

Eugene Public Library
100 W 13th Avenue
Eugene, OR 97401

Fort Vancouver Regional Library
1007 E Mill Plain Boulevard
Vancouver, WA 90663

Gonzaga University
Crosby Library
E 502 Boone
Spokane, WA 99258

King County Library System
300 8th Avenue N
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Longview Public Library
1600 Louisiana Street
Longview, WA 98632

Mid-Columbia Library
Kennewick Branch
405 S Dayton
Kennewick, WA 99336

Multnomah County Library
801 SW 10th Avenue
Portland, OR 97205

North Olympic Library Systems
2210 Peabody
Port Angeles, WA 98362

Oregon State Library
State Library Building
Sumner and Court Streets
Portland, OR 97229

Oregon State University
William Jasper Kerr Library
Corvallis, OR 97331

Pacific Lutheran University
Robert A. L. Mortvedt Library
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Tacoma, WA 98447

Pasco Public Library
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Portland State University
Branford Price Miller Library
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Portland, OR 97207

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Richland Public Library
Swift & Northgate
Richland, WA 99352

Salem Public Library
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Seattle Public Library
1000 4th Avenue
Seattle, WA 98122

Seattle University
A. A. Lemieux Library
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Spokane Public Library
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University of Oregon Library
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University of Portland
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University of Washington Libraries
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Walla Walla Public Library
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Washington State Library
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Washington State University
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