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PART I

INTRODUCTION

CHAPTER I

INTRODUCTION

By

J. S. Buckingham

WASTE MANAGEMENT TECHNICAL MANUAL

PART I INTRODUCTION

CHAPTER I INTRODUCTION

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PART I

CHAPTER I INTRODUCTION

A. PURPOSE, SCOPE AND ARRANGEMENT OF THE MANUAL

1. Purpose and Scope

The Waste Management Technical Manual has been prepared to provide a documented compendium of the technical bases and general physical features of Isochem Incorporated's Waste Management Program. The manual is intended to be used as a means of training and educating personnel unfamiliar with the Waste Management Program and as a reference handbook for use by personnel responsible for executing (carrying out) the Waste Management Program. The material in this manual was assembled by members of Isochem's Chemical Processing Division, Battelle Northwest Laboratory, and Hanford Engineering Services between September 1965 and March 1967.

2. Arrangement

The manual is divided into parts as follows:

Part I, Introduction, contains a summary of the overall Waste Management Program. It is written to provide the reader with a synoptic view and as an aid in understanding the subsequent parts.

Part II, Feed Material, contains detailed discussion of the types and sources of feed material used in the Waste Management Program, including a chapter on nuclear reactions and the formation of fission products.

Part III, Waste Fractionization Plant Processing, contains detailed discussions of the processes used in the Waste Fractionization Plant with supporting data and documentation of the technology employed.

Part IV, Waste Fractionization Plant Product and Waste Effluent Handling, contains detailed discussions of the methods of handling the product and waste material generated by the Waste Fractionization Plant.

Part V, Plant and Equipment, describes the layout of the Waste Management facilities, arrangement of equipment, and individual equipment pieces.

Part VI, Process Control, describes the instruments and analytical methods used for process control.

Part VII, Safety, describes process hazards and the methods used to safeguard against them.

Each part contains one or more chapters. A total of eighteen chapters is included in the seven parts. Pages are numbered to designate chapter number (i.e., Chapter I page numbers begin with 101, Chapter II with 201, etc.). Figures and Tables are numbered in series for each chapter. References to documents containing more detailed information are listed at the end of each chapter.

B. PURPOSE OF THE WASTE MANAGEMENT PROGRAM

The Atomic Energy Commission's nuclear reactors at Hanford are operated primarily to produce plutonium. Substantial quantities of other radioactive elements are also produced as a result of fission and other reactions in the reactors. Plutonium, uranium, selected fission products, and certain transuranium elements are isolated in Isochem Incorporated's Chemical Separations Plants for a variety of uses. Virtually everything else that leaves the chemical processing plants is considered to be a radioactive waste. Following is a brief description of these radioactive wastes and the ways these wastes have been handled in the past.

1. Description of Wastes and Past Handling Practices

1.1 Gaseous Waste

The chemical processing of irradiated fuel elements results in contaminated gaseous effluents which are discharged to the atmosphere after being treated to reduce contamination to acceptable levels. The principle sources of airborne radioactive contamination are the dusts and mists evolved during fuel dissolution, waste concentration, and jet transfer of process solutions. Some of the radioactive elements such as iodine-131 and krypton-85 exist as a gas. The past practice of handling gaseous effluents before they were discharged to the atmosphere was to remove the dusts and mists with filters which retained virtually all particles greater than one micron in diameter. Gaseous iodine-131 was removed through the use of silver reactors, acid absorption towers, and caustic scrubbers.

1.2 Solid Wastes

Solid materials which become contaminated with radioactive material are buried when their useful life is ended. If a significant amount of plutonium is present, the combustible waste is burned and the plutonium is recovered from the ash. In the past, large pieces of plant equipment which failed beyond repair were placed in special wooden or concrete boxes for burial. That equipment from the Purex Plant too large to box was stored in special railroad tunnels adjoining the Purex Plant.

1.3 Low Activity Level Liquid Wastes

Low activity level liquid wastes are those that do not create a hazard when discharged to the ground surface. These wastes are essentially free of radioactivity, but may become contaminated if a process leak were to occur. In general, the radionuclide concentrations are below their MPC_w (maximum permissible concentration in water). In the past, large volumes of low activity level wastes were discharged to natural surface depressions where they formed ponds or swamps. The water evaporated or seeped through the soil to the ground water below.

1.4 Intermediate Activity Level Liquid Wastes

Intermediate activity level liquid wastes such as process condensate, tank farm condensate, and process heat exchanger steam condensate, are those with radionuclide concentrations up to several times their MPC_w, and have a potential for contaminating the environment. The past practice was to discharge intermediate activity level liquid wastes to drainage fields called cribs built below the surface of the ground. The safety of this technique relies on the ion exchange properties of the soil and on the radionuclide decaying to innocuous levels before migrating to the edge of the Hanford reservation.

1.5 High Activity Level Liquid Wastes

High activity level liquid wastes are those solutions containing virtually all of the fission products and salts from chemical processing. Over the years of operation at Hanford, the high activity level liquid wastes were made alkaline and stored in underground tanks. In the storage tanks, solids settled to the bottom forming a sludge layer. Most of the fission products are contained in the sludge layer. The supernatant liquid over the sludge is composed mainly of solutions of sodium salts and contains the fission products cesium-137 and technetium-99. Those wastes which generate sufficient heat to self-boil are called "boiling wastes." Wastes which have a sufficiently low heat generation rate to allow the waste to be safely concentrated to a salt cake in underground tanks are called "solidifiable waste." Coating wastes are an example of solidifiable waste. Those high activity level wastes that do not generate enough heat to self-boil, but still generate too much heat to store as a salt cake are called "warm or simmering wastes."

2. Objectives of the Program

Through the years of experience in storing and disposing of radioactive wastes at Hanford, a high degree of safety has been provided at a reasonable cost. Studies have indicated that these practices could

have been continued almost indefinitely without jeopardizing environmental safety provided the stored liquid wastes and their sludges were periodically transferred to new tanks. A risk of contaminating the environment still existed, however, as the fission products were stored in a mobile form. Continuous surveillance was required to assure that the stored materials were in fact safely contained. In view of these considerations, the in-tank storage of radioactive liquids was considered to be a temporary practice and the Waste Management Program was established to implement improved methods of waste immobilization.

Research and development activities in support of the Waste Management program complemented Fission Product Recovery research and development activities. While the objectives of the two programs were different, the end results were nearly the same - the removal of long-lived fission products from the mobile waste streams. In one case, the isolated fission products were considered a waste requiring long-term storage and surveillance, and in the other case, the fission products were considered a concentrated source of radioisotopes for beneficial use.

The Waste Management Program as formulated by the Chemical Processing Division has four objectives:

1. Assure the safe confinement of the radioactive materials for centuries.

2. Minimize the long-term cost of the storage and surveillance operations.

3. Make selected fission products and other reactor-produced isotopes available for beneficial use.

4. Reduce to a minimum the amount of radioactive waste dispersed to the environs.

3. Outline of the Waste Management Program

3.1 Gaseous and solid wastes

The Waste Management Program will continue to handle solid and gaseous wastes the same way that they have been handled in the past. Development efforts are being directed toward methods for improved iodine removal from plant waste streams. Studies are being conducted to more fully understand the complex nature of iodine and to develop adsorbers of high performance and efficiency. The practice of burying solid wastes in trenches and tunnels will be continued.

3.2 Low Activity Level Liquid Waste

Low activity level liquid waste will continue to be discharged to ponds and swamps as has been done in the past. An operating limit of 5×10^{-5} microcuries of mixed fission products per cubic centimeter is the established limit for swamp disposal. Cooling towers have been considered as a way of reducing the volume of water discharged to the ground; however, the cost to benefit ratio was not favorable at the time this manual was written.

3.3 Intermediate Activity Level Liquid Waste

Intermediate activity level liquid wastes will continue to be discharged to the ground via cribs. The safety of this technique relies primarily on the ion exchange properties of the soil and on the fission product decay in transit to the Columbia River. In general, a well to the ground water is drilled adjacent to each crib. The appearance of the 30-year half-life cesium-137, the 28-year half-life strontium-90, or the 5-year half-life cobalt-60 in samples of ground water taken from beneath the crib in concentrations approaching one-tenth of the maximum permissible concentration (MPC_w) for drinking water is cause for abandonment. Hydrogen-3 (tritium) and ruthenium-106 are decayed and diluted to less than one-tenth MPC_w before they migrate to the Columbia River and are diluted to background when blended with the river.

Some intermediate activity level liquid wastes are disposed of by a technique which relies solely on the physical ability of the soil to retain the liquid. This is called disposal by specific retention. The volume of waste routed to a specific retention disposal site is limited to six percent of the soil column volume beneath the site. The waste types so disposed include organics, depleted uranium solutions, solutions with a somewhat higher than usual radioisotope concentration and those with poor or unknown ion exchange properties.

3.4 Stored High Activity Level Liquid Wastes That Can Be Solidified

Stored high activity level liquid wastes that generate heat at a sufficiently low rate are concentrated to a salt cake within an underground waste storage tank. Solidification is accomplished by using electrically powered In-Tank Solidification (ITS) units described in detail in Chapter VIII.

3.5 Stored High Activity Level Liquid Wastes That Cannot Be Solidified

Stored high activity level liquid wastes that generate enough heat from radioactive decay to self-boil are allowed to self-concentrate under controlled conditions. After about five years the short-lived fission products have decayed to the point where the waste storage tank is simmering rather than boiling. A sludge layer, composed of low solubility salts, forms in the bottom of the tank. This sludge layer contains a majority of the fission products, except for cesium which is in the supernatant liquid above the sludge.

The supernatant liquid is decanted from the sludge layer and pumped to the Waste Fractionization Plant (B Plant) where the cesium is removed by ion exchange techniques. The cesium-free supernatant liquid is then a waste that can be solidified in an ITS facility. The cesium is eluted from the ion exchanger, concentrated, and stored in tanks located in B-Plant. The stored cesium can also be made available for use in a fission products program.

The sludge layer is sluiced from the tank, acidified and transferred to the Waste Fractionization Plant where strontium is removed by precipitation and solvent extraction techniques. A rare earth fraction containing promethium-147 may also be recovered from the sludge by the same techniques. If the strontium is needed for a fission products program, it is purified further by solvent extraction.

3.6 Current High Activity Level Liquid Wastes

Current high activity level liquid wastes from the Purex Plant are processed immediately, or after only a few weeks of lag storage, in the Waste Fractionization Plant. Wastes generated by an processing that may be done in the Redox Plant will be sent to underground storage and considered as stored high activity level wastes.

In the Waste Fractionization Plant, Purex wastes are separated into a strontium fraction, a rare earth fraction, a cerium fraction, (or alternately a cerium-rare earth fraction) and a slat waste fraction. The salt waste fraction, containing cesium and short-lived fission products, is sent to underground waste storage for two to five years to allow the short-lived fission products to decay. The cesium is then removed by ion exchange as is done with high activity stored waste. The strontium fraction is stored for about a year to allow the 50.4-day half-life strontium-89 to decay. The "aged" strontium may then be purified further by solvent extraction for use in a fission products program. The cerium fraction may either be made available for use in a fission products program, or sent to underground storage for five to seven years, then solidified. The rare earth fraction may be purified further and stored in B-Plant for use in a fission products program, or sent to a non-boiling waste tank for eventual solidification.

A flow pattern for the Waste Management Program is shown schematically in Figure I-1.

Alternate flow schemes have been devised that remove the cesium from current waste at the same time that strontium and the rare earths are being removed. These alternate flow schemes are discussed in more detail in a later section.

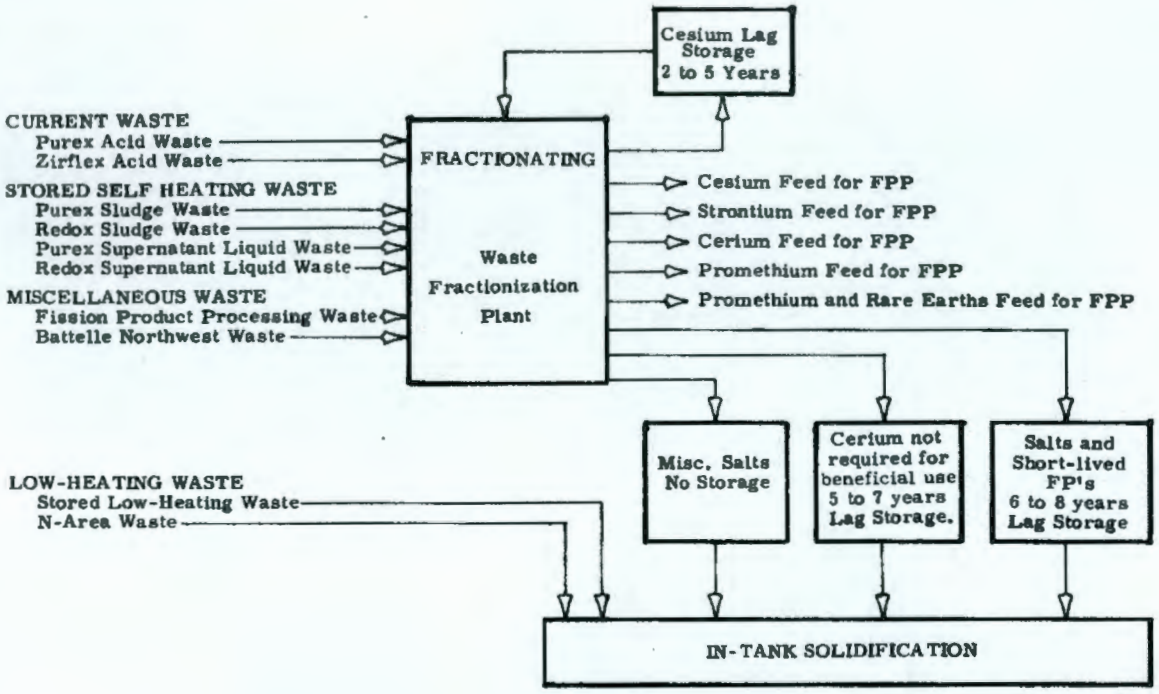

FIGURE I-1

Flow Pattern for Waste Management Program

C. FUNCTION OF THE WASTE FRACTIONIZATION PLANT

The function of the Waste Fractionization Plant is to remove the long-lived heat producing fission products, such as strontium-90 and cesium-137, from current and stored waste, and to recover strontium-90, cesium-137, promethium-147, and cerium-144 for beneficial use. Removal of the long-lived heat producing fission products from the wastes permits concentrating the wastes to a salt cake for long-term storage.

The wastes handled by the Waste Fractionization Plant are generally categorized by difference in physical and chemical properties into 1) current acid waste, 2) stored alkaline sludge wastes, and 3) stored alkaline supernatant liquid wastes. For convenience in descriving the various process streams, a system of letter designations has been developed. These designations are also used in flowsheets and flow diagrams. Table I-1 is a glossary of these terms.

TABLE I-1

GLOSSARY OF LETTER DESIGNATIONS

A. WASTE STREAMS WHICH MAY BE PROCESSED

PAW - Purex Acid Waste - Current high-level acid waste from the Purex plant solvent extraction process.

ZAW - Zirflex Acid Waste - Current high-level acid waste from processing zirconium clad fuel elements.

RAW - Redox Acid Waste - Current high-level acid waste from the Redox plant solvent extraction process

PAS - Purex Acid Sludge - Acid stream resulting from acid dissolution of water insoluble sludge solids sluiced from the Purex plant high level underground waste storage tanks (241-A and 241-AX Tank Farms.)

RAS - Redox Acid Sludge - Acid stream resulting from acid dissolution of water insoluble sludge solids sluiced from the Redox plant high level underground waste storage tanks. (241-S and 241-SX Tank Farms.)

PSN - Purex Supernatants - Alkaline supernatant liquid pumped from the Purex plant high-level waste storage tanks, (241-A and 241-AX Tank Farms.)

RSN - Redox Supernatants - Alkaline supernatant liquid pumped from the Redox plant high-level waste storage tanks, (241-S and 241-SX Tank Farms.)

PSS - Purex Sludge Supernatants - Alkaline liquid resulting from water leaching the sludge solids remaining after removing PSN from Purex plant high-level waste storage tanks.

RSS - Redox Sludge Supernatants - Alkaline liquid resulting from water leaching the sludge solids remaining after removing RSN from Redox plant high-level waste storage tanks.

B. SOLVENT EXTRACTION STREAMS

1AF - Aqueous feed to the 1A column.

1AX - Organic extractant to the bottom of the 1A column.

1AW - Aqueous raffinate from the 1A column; 1A column waste stream.

1AP - Organic raffinate from the 1A column containing extracted materials. 1A column product stream.

1SS - Aqueous scrub to the 1S column. Flows sequentially to the top of the 1A column.

1SP - Organic raffinate containing product material from top of the 1S column.

1BX - Aqueous strip to the top of the 1B column. Used to strip strontium from the organic phase.

1BP - Aqueous strontium product from the bottom of the 1B column.

1BW-1CF - Organic raffinate from the top of the 1B column. Contains the rare earth fraction.

1CX-1 Persulfate-acid oxidant for cerium-promethium separation.

1CX-2 Silver-acid catalyst for cerium-promethium separation. Added with 1CX-1 to the top of the 1C column.

1CS - Aqueous strip to top of 1C column. Used when cerium is not separated from promethium and other rare earths.

1CP-Pm - Aqueous raffinate from bottom of the 1C column containing promethium and rare earth product.

1CP-Ce - Organic raffinate from top of the 1C column containing cerium separated from the rare earth product.

1CP - Aqueous raffinate from the bottom of the 1C column containing unseparated cerium and rare earths.

1CW - Organic raffinate from top of the 1C column, stripped of cerium and rare earths. Organic waste stream.

Ce-Strip - Nitric acid solution added to batch contactor to strip cerium from the organic phase.

Ce-Prod. - Aqueous cerium nitrate fraction stripped from the organic phase in a batch contactor.

1OS - Aqueous scrub used to clean up the organic stream.

1OO - Washed organic stream.

1OW - Aqueous waste from the organic washing process.

Sr-1AF - Aqueous feed to 1A column during strontium purification cycle.

Sr-1AX - Organic extractant to 1A column during strontium purification cycle.

Sr-1SS - Aqueous scrub to 1S column during strontium purification cycle.

Sr-1AW - Aqueous raffinate from 1A column during strontium purification cycle. 1A column waste stream.

Sr-1BX - Aqueous strip to top of 1B column used to strip strontium from organic phase during strontium purification cycle.

Sr-1BP - Aqueous product raffinate from bottom of 1B column. Contains purified strontium product during strontium purification cycle.

Sr-1BW - Organic raffinate stripped of strontium from top of 1B column during strontium purification cycle. 1B column organic waste stream.

Sr-1OS - Aqueous scrub used to clean up organic stream during strontium purification cycle.

Sr-1OW - Aqueous waste from organic washing step during strontium purification cycle.

Sr-1OO - Washed organic during strontium purification cycle.

C. ION EXCHANGE STREAMS

CsXF - Alkaline supernatant feed to the cesium ion exchange column.

CsXW - Cesium ion exchange column waste effluents generated during column wash cycles.

CsXP - Cesium ion exchange column product effluent.

TcXF - Effluents from cesium ion exchange column during loading cycle. Feed material for projected technetium, rhodium, and palladium recovery processes.

1. Source and Composition of Feed Material

1.1 Current Waste

Current acid waste is the high activity acid waste generated by the Purex Plant. There are two types of current acid waste: Purex Acid Waste (PAW) is generated during the processing of aluminum-jacketed normal and enriched uranium fuel elements. Zirflex Acid Waste (ZAW) is generated by the Purex Plant during the processing of zirconium-jacketed fuel elements. Both PAW and ZAW are the bottoms of the Purex waste concentrator and have been treated with sugar to reduce the nitric acid concentration. PAW and ZAW do not include coating waste or solvent washes. PAW and ZAW do contain the entire spectrum of fission products produced by the Hanford reactors; however, only strontium-90, cesium-137, promethium-147, and cerium-144 are of primary interest in the Waste Management Program. The estimated composition of PAW and ZAW are shown in Table I-2.

1.2 Stored Sludge Waste

High activity alkaline waste solutions generated by the separations plants prior to the startup of the Waste Fractionization Plant were stored in underground steel-lined concrete tanks. These wastes contained solids and had a high inert salt content. In the storage tanks, these solids have settled to the bottom forming a sludge layer. A majority of the fission products, including strontium-90, promethium-147, and cerium-144, which constitute but a small fraction of the total salts present, are contained in the sludge layer. The composition of a typical Purex sludge waste is shown in Table I-2. Because the composition of various radioactive isotopes varies widely from tank to tank, the concentration of the radioisotopes is not included in the table. Sludge waste is identified as Purex Acid Sludge waste (PAS) and Redox Acid Sludge waste (RAS). Purex sludge wastes are stored in the A and AX Tank Farms. Redox sludge wastes are stored in the S and SX Tank Farms.

1.3 Stored Supernates

The supernatant liquid associated with the sludge layer in the underground waste storage tanks is called stored supernates and designated Purex Supernates (PSN) or Redox Supernates (RSN). A major portion of the cesium-137 associated with the alkaline wastes is found in the waste supernates. Other isotopes of interest found in the supernatant liquid are technetium-99, rhodium-103, and palladium. Technetium-99 has potential beneficial use and means of recovering it have been developed. Rhodium and palladium are precious metals used in industry. Ways of recovering rhodium and palladium are being developed.

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A third supernatant liquid waste, other than PSN and RSN, is generated by water leaching stored sludge after decanting the supernatant liquid. The designation for this waste is Purex or Redox Sludge Supernate (PSS or RSS). The compositions of PSN, RSN, and PSS are shown in Table I-2.

TABLE I-2
COMPOSITION OF WASTES

Purex Acid Waste (PAW)

H	0.5 M
Na	0.7
Fe	0.315
Al	0.08
Cr	0.032
Ni	0.016
Ca	0.0013
Sr	0.0013
RE + Am	0.0077
$SO_4^=$	0.24
NO_3^-	2.06
Sr-90	36.6 Ci/gal.
Cs-137	396
Pm-147	141
Ce-144	881

Zirflex Acid Waste (ZAW)

H	0.235 M
Na	0.35
Fe	0.39
Al	0.78
Cr	0.016
Ni	0.0078
Ca	0.0015
Sr	0.0013
Zr	0.005
RE + Am	0.0078
F^-	0.3
$SO_4^=$	0.119
NO_3^-	0.9
Sr-90	79 Ci/gal.
Cs-137	800
Pm-147	300
Ce-144	1900

Purex Sludge Waste (PAS)

H	0.1 M
Na	0.42
Fe	0.36
Al	0.55
Cr	0.021
Ni	0.012
Ca	0.031
Sr	0.0017
Mn	0.01
Mg	0.009
RE	0.0085
$SO_4^=$	0.026
NO_3^-	2.42

Purex Sludge Supernatant (PSS)

Na	5.4 M
Fe	--
Al	0.04
Cr	0.002
NO_3^-	4.2
NO_2^-	0.22
$SO_4^=$	0.25
$CO_3^=$	0.24

Purex Supernatant (PSN)

	A Farm
Na	4.57 M
NO_3^-	0.58
NO_2^-	2.25
$SO_4^=$	0.10
$CO_3^=$	0.77
Cs-137	13.1 Ci/gal.
RuRh-106	0.5
Tc-99	100 mg/gal.

Redox Supernatant (RSN)

	S Farm	SX Farm
Na	5.49 M	4.91 M
Al	0.34	0.84
NO_3^-	3.53	2.62
NO_2^-	--	0.36
$SO_4^=$	--	0.03
OH^-	1.59	0.93
Cs-137	0.33 Ci/gal.	2.0 Ci/gal.
RuRh-106	0.013	0.08
Tc-99	2.8 mg/gal.	16.8 mg/gal.

2. Basis of Design

The design of the Waste Management Fractionization Plant (B-Plant) is based on processing current Purex acid waste (PAW and ZAW), Purex aged supernate (PSN), Purex sludge waste (PAS), and Redox aged supernate (RSN). The equipment is sized to permit processing of the stored high level waste concurrently with fresh waste so as to work off the stored waste inventory within five to seven years.

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The alkaline supernate containing the cesium is processed by ion exchange using synthetic zeolites (aluminum silicates) as the ion exchange medium. Cesium is eluted from the ion exchange medium with a mixture of ammonium hydroxide and ammonium carbonate. At least 95 percent of the cesium is removed from the alkaline supernates by the ion exchange process.

Current acid waste and acidified sludge waste is fractionized in common equipment on a campaign basis using a solvent extraction process. Greater than 95 percent of the strontium-90 is removed from the waste. About 75 percent of the promethium-147 can be recovered from both current and stored waste, and made available for use in a fission products program. Approximately 75 percent of the cerium in current waste can be recovered and supplied to a fission product program on demand. Rates for processing current acid waste and stored sludge waste are based on campaign cycles allowing twice as much time for processing current waste as is allowed for sludge waste. The amount of waste processed is based on a plant operating efficiency of 72 percent.

3. Product material

The Waste Management Waste Fractionization Plant (B-Plant) has capabilities for recovering and purifying four major fission products: strontium-90, cesium-137, cerium-144, and promethium-147. Capabilities to recover seven additional products - technetium-99, rhodium, palladium, americium-241, plutonium-239, neptunium-237, and antimony-125 have been or are being developed. Each of the product materials is discussed below.

3.1 Strontium-90

Strontium-90 has a half-life of 28 years. It is a pure beta emitter; however, its daughter, yttrium-90, emits a 0.2 and a 1.7 Mev gamma. Together, strontium-90 and yttrium-90 produce 6.8 thermal watts of energy per kilocurie of strontium-90, which is 23.2 Btu/hr. per kilocurie. Because of its high heat generation and long half-life, strontium-90 must be removed from waste before the waste is concentrated to a salt cake. The strontium separated from the waste may be put to beneficial use as a heat source. Strontium-90 which cannot be put to beneficial use will eventually be contained in high-integrity containers for long-term storage. Because of its relatively long half-life, strontium-90 is found in stored sludge waste as well as current waste. The isotopic content of the strontium will vary from less than 25 weight percent strontium-90 for well-aged sludge to greater than 60 weight percent from the waste generated during the processing of high exposure reactor fuels. A major portion of any strontium used for beneficial purposes will have an isotopic content greater than 50 weight percent strontium-90.

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3.2 Cesium-137

Cesium-137 has a half-life of 30 years. The decay of cesium-137 produces both beta and gamma radiations. Cesium produces 4.8 thermal watts of energy per kilocurie during radioactive decay which amounts to 16.4 Btu/hr. Cesium-137 generates sufficient heat during decay that it must be removed from the salt wastes before they are concentrated to a salt cake. Cesium-137 has beneficial use as a heat source or as a radiation source. Cesium-137 which cannot be put to beneficial use will eventually be contained in high-integrity containers for long-term storage. The isotopic content of the cesium recovered from waste will range from 30 to 40 weight percent cesium-137, depending on the age of the material. The cesium will be recovered from stored supernatant liquid waste, and from a water leach of the stored sludge waste. Flowsheets exist for the recovery of cesium from current waste; however, economies favor the nitric storage of current waste and recovery of cesium from waste aged two to five years.

3.3 Cerium-144

The half-life of cerium-144 is a comparatively short 285 days. Cerium-144 produces moderately energetic beta and gamma radiation as it decays. However, cerium-144 in equilibrium with its daughter, preseodymium-144 produces extremely energetic beta and gamma radiation as it decays. The combination of cerium-praseodymium-144 produces 8.05 thermal watts or 27.5 Btu/hr per kilocurie of cerium-144 during decay. Because of its relatively short half-life, cerium-144 is present in considerable amounts only in current waste and in stored sludge waste aged less than five years. For any fission products program requirements, cerium will be recovered on demand from current waste. Separated cerium-144 not required for a fission products program will be returned to underground storage with the salt waste for five to ten-year aging before being concentrated to a salt cake. because of its short half-life, the isotopic content of the cerium-144 product changes quite rapidly; however, it is estimated that cerium with an isotopic content of 18 percent cerium-144 can be made available.

3.4 Promethium-147

Promethium-147 has a half-life of 2.62 years. It decays essentially by beta decay. The energy of the beta radiation is a very low 0.225 Mev. Promethium produces 0.36 watts or 1.2 Btu/hr per kilocurie. Promethium recovered from current waste contains the gamma-emitting promethium-148. Aging the promethium for two to two and one-half years allows the 42-day half-life promethium-148 to decay to innocuous levels. The low energy radiation from promethium requires only light shielding making promethium-147 a good candidate as a heat source for manned space efforts. Promethium recovered from the waste in the Waste

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Fractionization Plant is in a mixture of rare earths. The amount of promethium-147 in the rare-earth mixture will range from a fraction of 1 percent in the rare earths recovered from stored sludge waste to 3.5 percent in two-year-aged current waste. As other isotopes of promethium have short half-lives, it is possible to produce promethium-147 essentially 100 percent pure by a chromatographic ion exchange separation. The chromatographic separation of promethium is considered part of a fission product program and would not be done in the Waste Fractionization Plant.

3.5 Other Products

A number of other valuable products can be recovered during the processing of waste. Technology has been developed for the recovery of technetium-99 from stored supernatant liquid waste, and americium-241, neptunium-237, and plutonium-239 from current and stored sludge waste. Technology for the recovery of rhodium and palladium from stored supernatant liquid waste and antimony-125 from current waste is being developed for possible inclusion in the Waste Fractionization Plant or as part of a fission product program.

3.5.1 Technetium-99

Technetium-99 has a long half-life of 2.1×10^5 years and emits a weak beta radiation on decay. Technetium does not occur naturally; however, appreciable amounts are formed in nuclear fuels during irradiation. Technetium can be recovered from the same stored alkaline supernatant liquid waste from which cesium is recovered. The technetium product would be in the form of a technetium nitrate solution. Technetium has potential use as a corrosion inhibitor for steel. Technetium metal is also a superconductor of electricity at low temperatures.

3.5.2 Rhodium and Palladium

Rhodium and palladium are semi-rare metals having commercial use as industrial metals in the chemical and electrical industries. Rhodium and palladium originate from fission in nuclear fuels and are found in stored supernatant waste from which cesium is recovered. Rhodium and palladium are normally non-radioactive; however, radioactive rhodium-102 is also formed during irradiation of nuclear fuels. The amount of rhodium-102 present is not expected to constitute a radiation hazard.

3.5.3 Americium-241

Americium-241 has a half-life of 258 years. It is primarily an alpha emitter; however, several low energy gamma rays are also

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emitted. Americium-241 is formed in nuclear fuels during irradiation, and is also formed by the decay of plutonium-241. Americium is found in the current waste, and in the stored sludge waste. Americium generates 33 thermal watts or 113 Btu/hr per kilocurie when it decays. Americium can be used as a heat source for thermoelectric generators, or it can be used as target material for the production of transuranium elements.

3.5.4 Neptunium-237 and Plutonium-239

The Chemical Processing Division's chemical separation plants are designed to recover neptunium and plutonium from irradiated nuclear fuels; however, a small percentage of the neptunium and plutonium is lost in the waste streams from the separation plants. Plutonium and neptunium which was sent to the waste storage tanks has collected in the sludge layer, and can be recovered in the Waste Fractionization Plant during the processing of stored sludge waste. Neptunium and plutonium recovered in the Waste Fractionization Plant would be as nitrate solutions and could be returned to the Purex Plant for blending with Purex process streams.

3.5.5 Antimony-125

Antimony-125 has a half-life of 2.7 years. It emits a number of beta and gamma energies giving a total thermal heat output of around 3 watts per kilocurie. Antimony-125 has use as a source of X-rays, although at the present time there is no demand for the material. If a market should develop for antimony-125, technology for the recovery and purification of antimony from both current and stored waste can be developed. The isotopic purity of antimony-125 will range from 10 weight percent for well-aged sludge to 50 weight percent from current waste.

4. Waste Streams

As the primary purpose of the Waste Fractionization Plant is to prepare wastes generated by the chemical processing of nuclear fuels for permanent storage, the waste streams from the Waste Fractionization Plant can also be considered product streams. The waste generated during waste fractionization can be classified as 1) low activity waste discharged to swamps and cribs, 2) salt waste that can be solidified, and 3) salt waste that must be stored for an interim period before being solidified.

4.1 Low activity waste

The low activity wastes that can be discharged to swamps and cribs include cooling water, condensates, organic materials, etc. Any radioactivity associated with these materials are retained by the ion

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exchange capacity of the soil, or they migrate so slowly through the soil and ground water they will decay to innocuous levels by the time they reach the Columbia River or the edge of the Hanford reservation.

4.2 Solidifiable waste

Solidifiable wastes are alkaline salt wastes, primarily nitrate salts, from which a major portion of the heat-generating isotopes have been removed. The fission products remaining in the salt cake should have a heat generation rate of between 0.25 and 0.3 watts per cubic foot of salt cake. In general, solidifiable wastes generated by the Waste Fractionization Plant will come from processing stored supernatant liquid wastes for cesium removal, and stored sludge waste for strontium and rare earth removal.

4.3 Wastes requiring temporary storage

Much of the waste generated by the Waste Fractionization Plant during the processing of current wastes (PAW and ZAW) will require from three to seven years storage to allow the short-lived fission products to decay before the waste can be solidified to a salt cake. Wastes which will have to be stored temporarily include the following: Solids centrifuged from the Purex waste stream. Salt waste from the first solvent extraction column produced during the processing of current acid wastes. This salt waste, which contains cesium-137 and short-lived fission products, will be stored for three to five years to allow the short-lived fission products to decay. The cesium will be removed in the same way as when stored supernatant liquid wastes are processed. Cerium and rare earth fractions not required for beneficial use will be stored for seven to ten years for decay before being solidified to a salt cake.

D. OUTLINE OF THE WASTE MANAGEMENT PROCESS

The waste management process is designed to remove the long-lived heat producing isotopes, cesium-137 and strontium-90, from both current and stored wastes. The process is designed to make the selected isotopes cesium-137, strontium-90, cerium-144, and promethium-147, available for beneficial use. The long-lived heat producing isotopes not required for beneficial use are held in high integrity containers for long-term storage. Wastes from which the long-lived heat producing isotopes have been removed are solidified to a salt cake in steel-lined concrete tanks for permanent storage. The waste management program is composed of five interrelated processes: 1) the removal of stored wastes from underground storage, 2) an ion exchange

process to remove cesium from stored supernatant liquid wastes, 3) a precipitation process which separates desirable isotopes from associated iron and aluminum in stored sludge waste, 4) a solvent extraction process used to recover and purify desirable isotopes from both stored and current wastes, and 5) a salt solidification process. The basic principles and steps which make up these five processes are briefly explained in the following subsections. This section is intended only as an introduction to the waste management program; more complete and specific information on waste management processes is contained in other chapters.

1. Basic Principles

1.1 Precipitation Process

Stored sludge waste, which has been dissolved with nitric acid, is primarily a solution of sodium nitrate, ferric nitrate, and aluminum nitrate contaminated with small amounts of strontium and rare earths. The strontium and rare earths are concentrated and separated from the bulk of the sodium, iron, and aluminum by precipitating them as insoluble sulfates using lead as a carrier ion. The sulfate precipitates are metathesized to carbonate precipitates, then dissolved with a minimum of nitric acid. The resulting nitrate solution is adjusted as feed for solvent extraction processing. A ten-fold reduction in the volume of the solution containing the dissolved sludge is accomplished by the sulfate precipitation step. The supernatant liquid from which the insoluble sulfates have been removed is returned to underground storage where it is eventually solidified into a salt cake.

1.2 Ion Exchange Process

Ion exchange processes depend on a chemical exchange reaction between an ion in solution and an ion on the ion exchange medium. An ion exchange medium consists of a solid phase containing bound groups which carry an ionic charge in conjunction with free ions of opposite charge that can be displaced. The solid phase may be a porous inorganic material or a permeable organic resin. An ion exchange reaction may be expressed as a reversible reaction involving chemically equivalent quantities. For example, the recovery of cesium from stored waste supernates by cation exchange may be written:

$$Cs^+ (aq) + NH_4^+ X \rightleftarrows Cs^+ X + NH_4^+ (aq)$$

where X represents the ion exchange medium. Certain ion exchange media have greater affinity for one ion over another; for example, zeolite, an alumino-silicate, will adsorb approximately 40 times more cesium than sodium. Ion exchange processes for the recovery of cesium and technetium from stored supernatant waste solutions have been developed.

1.4 Solvent Extraction Process

The solvent extraction process used in the Waste Fractionization Plant employs Di-(2-ethylhexyl)phosphoric acid (D2EHPA) in a hydrocarbon diluent. The mechanism of the solvent is discussed in detail in Chapter IV. Briefly, D2EHPA acts similar to a liquid cation exchanger, in which a hydrogen ion in the solvent is displaced with the metallic ion being extracted. The system is extremely pH-sensitive requiring a buffering agent to maintain the proper pH value. The addition of the chelating agents suppresses the extraction of various ions at certain pH values. Also, depending on the pH, certain ions are more strongly extracted than others, loading the solvent and thereby suppressing the extraction of undesirable ions. By choosing the proper pH, solvent loading, chelating agent, and residence time (kinetics), conditions can be established for the separation and purification of the desired ions.

1.4 Simplified Flowsheets

Figure I-2 is a simplified flowsheet for the fractionization of current acid waste from the Purex Plant including feed preparation, strontium removal, cerium rare-earth separation, rare-earth sulfate removal, and the solvent treatment section. Figure I-3 is a simplified flowsheet for the fractionization of stored waste which includes cesium recovery by ion exchange, removal of sludge from the underground waste tanks, feed preparation, iron and aluminum removal, strontium removal, rare-earth recovery, and solvent treatment. Figure I-4 is a simplified flowsheet for the purification of aged strontium to prepare material for use in a fission product program. Figure I-5 is a simplified flowsheet of the waste handling facilities including the high level lag storage tanks, the low level waste concentrator and neutralizer, and the in-tank solidification facility.

The flowsheets show the letters usually used to identify the various process streams in the waste management plant. A glossary of waste management terms and process streams is included in Table I-1 The code designations follow accepted solvent extraction nomenclature as much as possible with minor modifications for clarity.

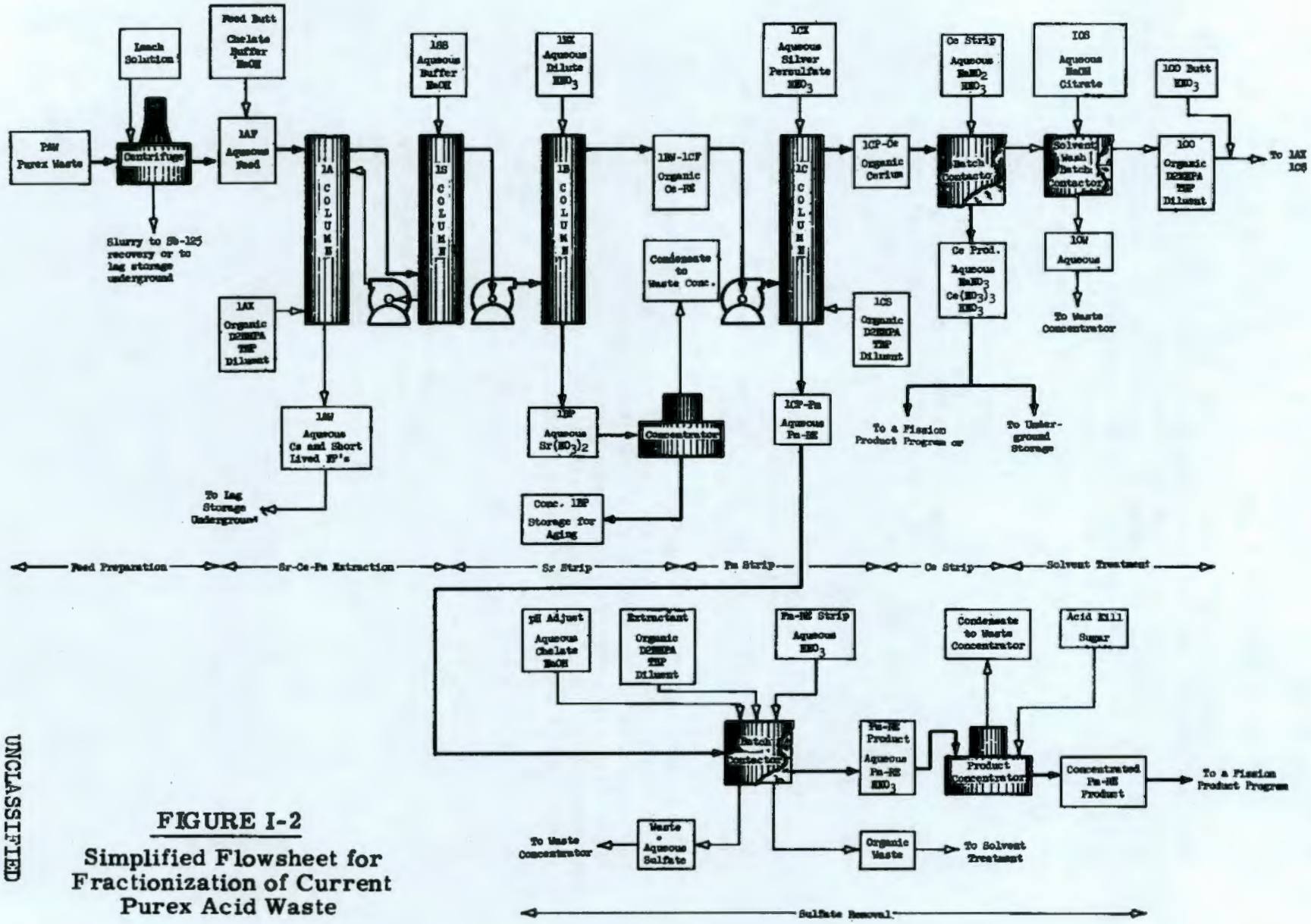

FIGURE I-2

Simplified Flowsheet for Fractionization of Current Purex Acid Waste

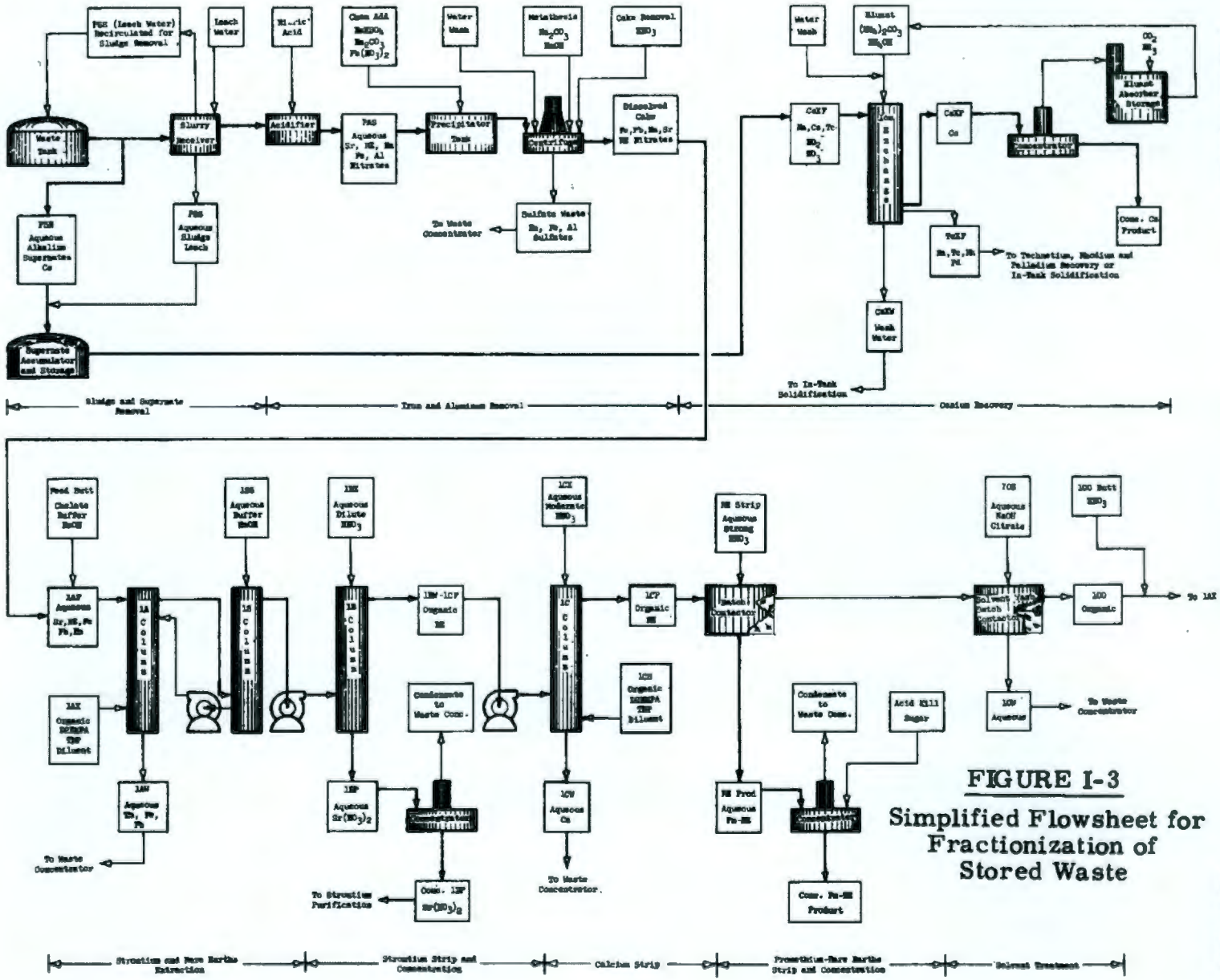

FIGURE I-3

Simplified Flowsheet for Fractionization of Stored Waste

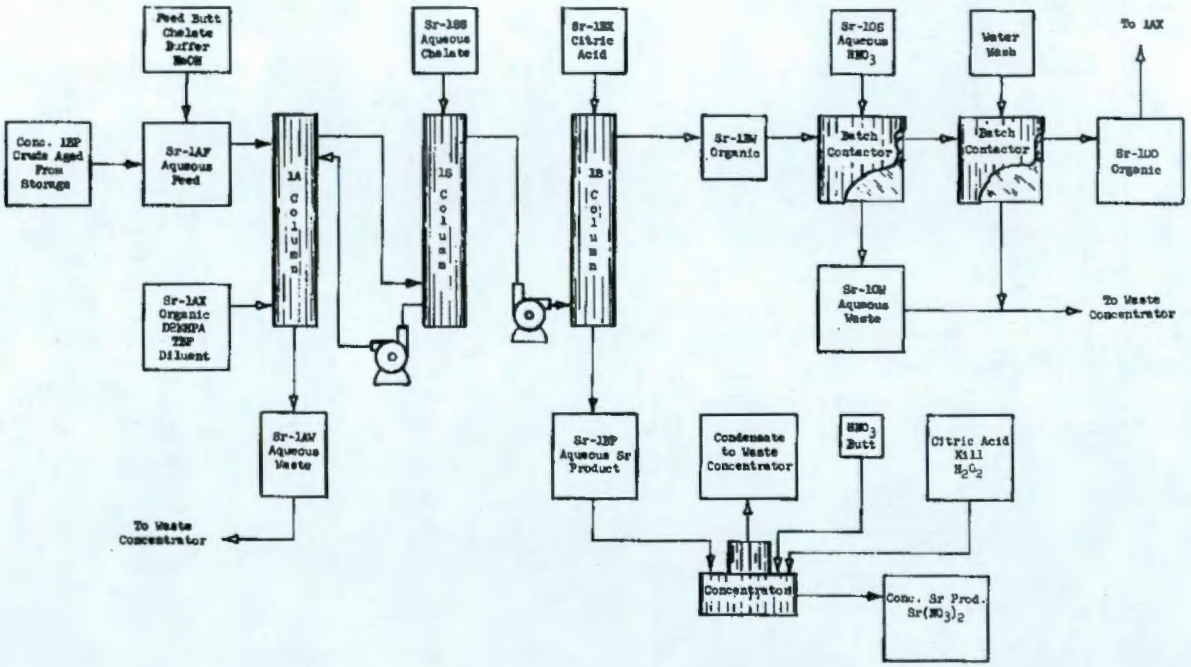

FIGURE I-4

Simplified Flowsheet for Strontium Purification

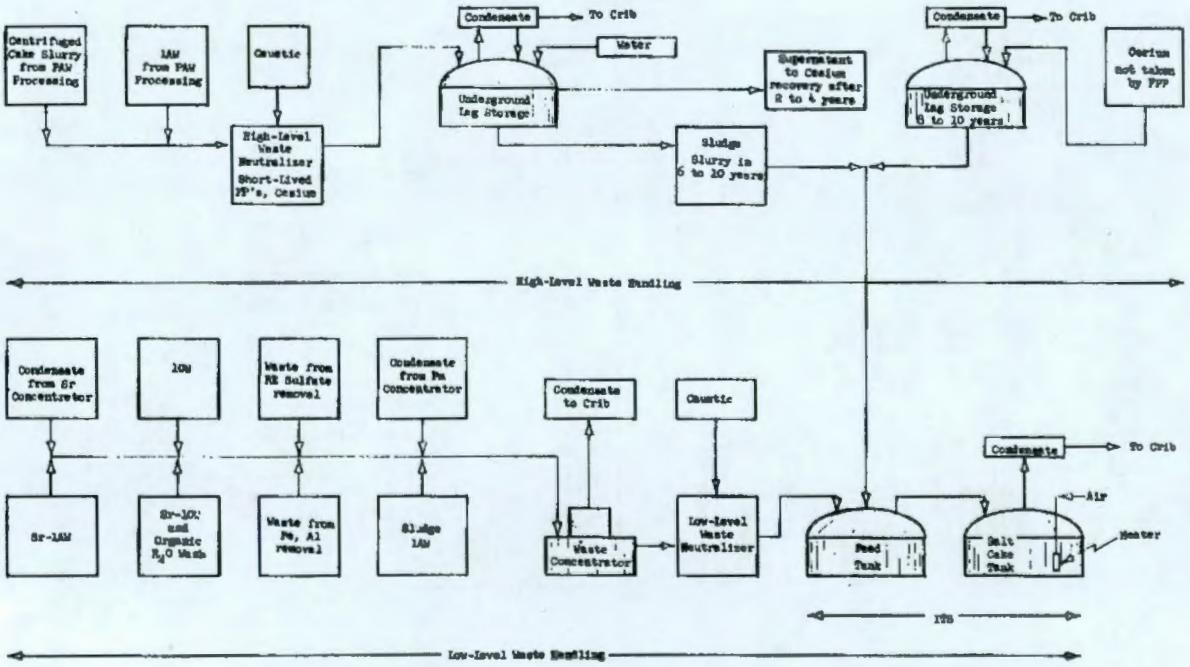

FIGURE I-5

Simplified Flowsheet for Fractionization Plant Waste

2. Removal of Wastes from Underground Storage Tanks

The purpose of the waste removal facility is to provide a way of removing high level wastes from underground storage tanks and subsequent transfer to the Waste Fractionization Plant. High activity level waste as generated by the chemical separation plants contained a high salt content and virtually all of the fission products present in irradiated nuclear fuel. The wastes were made alkaline and stored underground in steel-lined concrete tanks. Solids present in the waste settle to the bottom of the storage tank forming a sludge layer. The sludge layer, composed of low solubility salts, contains the majority of the fission products in the waste. The supernatant layer, composed primarily of a solution of sodium nitrate and sodium nitrite, contains cesium-137. The supernatant liquid is pumped from the underground storage tank with a deep-well turbine pump.

The sludge layer is sluice-mined by a technique similar to that used in the Uranium Recovery Process. Water heated to between 80 and 90 degrees centigrade is impinged on the sludge layer at high pressure. The slurry is pumped from the underground storage tank to a slurry receiver. This operation is continued until a slurry equivalent to about 440 tons of uranium production has accumulated. In addition to acting as the liquid vehicle for carrying the sludge, the water used to slurry the sludge also leaches the soluble salts such as sodium nitrate, nitrite, and carbonate from the sludge along with the small amount of cesium that was occluded in the sludge. In the slurry receiver tank the sludge is allowed to settle, and the water leach decanted off and combined with the original supernatant liquid. The sludge is transferred from the slurry receiver to the acidification tank, dissolved with nitric acid, and transferred to B-Plant for fractionization. Figure I-6 is a diagram of the sludge removal facility.

3. Ion Exchange Processes

Ion exchange processes are used to remove cesium from stored alkaline supernatant liquid waste. Ion exchange processes can also be used to recover technetium, rhodium, and palladium from supernatants for beneficial use, and for the longer-term storage of strontium and cesium in high integrity containers. Each of the ion exchange processes will be discussed briefly here, and in more detail in later chapters.

3.1 Cesium Recovery from Supernatants

The processing of alkaline supernates and the alkaline sludge leach supernates to remove cesium is carried out in a fixed-bed ion exchange

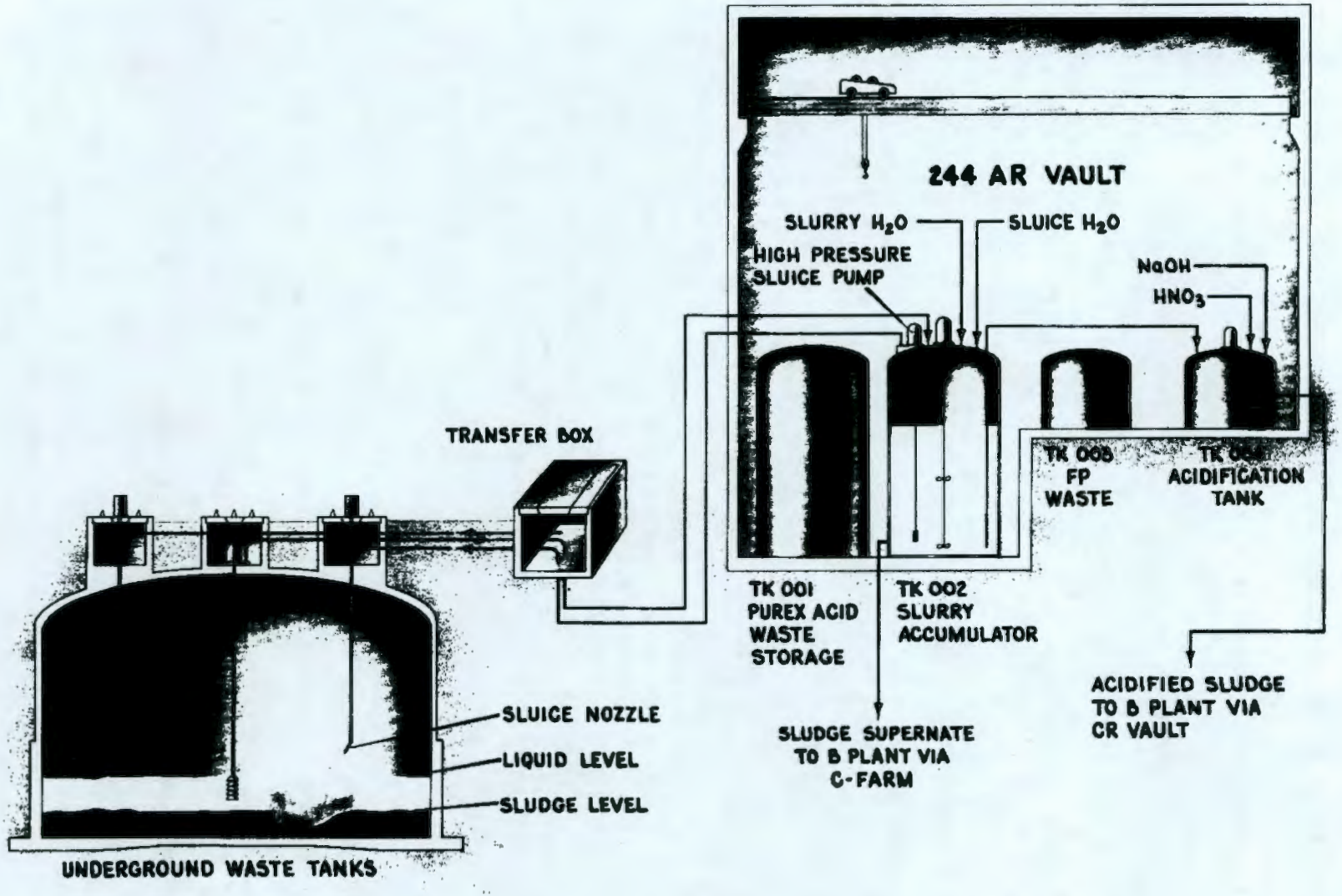

FIGURE I-6

Sludge Mining of Self-Boiling Wastes

unit filled with a zeolite. The zeolite used is a synthetic aluminosilicate ion exchange medium which preferentially adsorbs cesium from the high sodium supernatant solutions. After the column is loaded, the feed solution is displaced by a water wash, and sodium is selectively removed with a dilute ammonium carbonate-ammonium hydroxide wash. Cesium is eluted from the ion exchange medium with a strong solution of ammonium carbonate - ammonium hydroxide. The ammonium carbonate - ammonium hydroxide in the cesium product is recovered by distillation and re-used.

3.2 Technetium Recovery

An ion exchange process has been developed for the recovery of technetium from stored waste supernates. Technetium exists in the supernates as sodium pertechnetate which is analogous to sodium permanganate. The sodium pertechnetate is adsorbed on a strong base anion exchange medium, washed with dilute nitric acid to remove ruthenium, and eluted from the medium with strong nitric acid.

3.3 Strontium and Cesium Packaging

In the original design of the Waste Management Fractionization Plant, strontium and cesium removed from the wastes would be adsorbed on zeolite ion exchange medium in high integrity containers, dried, sealed, and stored for long-term surveillance. Technology and hardware for the packaging step were developed; however, the present plan calls for storing all of the strontium and cesium in liquid form in B-Plant, and the packaging equipment will not be used.

4. Precipitation Processes

The primary precipitation process used in the Waste Management Fractionization Plant is a sulfate precipitation based on a carrier precipitation technique. If an element in solution is not present in sufficient concentration to precipitate directly, it can be co-precipitated, or carried from solution by the formation of a precipitate of an element present in larger amounts. The most efficient carriers are those which have the same lattice type as the compound to be carried; that is, they form isomorphous crystals. In addition, the elements to be carried must form an insoluble compound with the precipitating anion. Carrying may also occur by adsorbing the trace element on the surface of the carrier, or by the trace element forming an insoluble double salt with the carrier. In the Waste Management Plant, strontium and the alkaline earths, and promethium and the rare earths are precipitated as insoluble sulfates using lead as the carrier ion. The sulfate precipitates are then metathesized to carbonate precipitates which are readily soluble in nitric acid.

Another precipitation process employs phosphotungstic acid which precipitates cesium when processing current Purex acid waste. Cesium salts of phosphotungstic acid are insoluble in an acidic system, and are removed by centrifugation. After washing, the precipitate is dissolved with caustic and the solution sent to the cesium ion exchange facility. The phosphotungstic acid process may be used as an alternate cesium separation process.

5. Solvent Extraction Processes

Solvent extraction processes are used in the Waste Fractionization Plant to remove strontium from both current and stored waste and to provide a purified strontium for beneficial use in a fission products program. Solvent extraction processes are also used to recover promethium from stored and current waste, to separate cerium from promethium, and to provide both cerium and promethium for beneficial use. The equipment used to mix the aqueous and organic phases in the solvent extraction processes are pulse columns and batch contactors. The flowsheets used for processing current waste and stored waste are briefly discussed below. A more complete discussion of flowsheets is given in Chapter IV.

5.1 Solvent Extraction of Current Acid Waste (PAW - ZAW)

In the solvent extraction process for current acid waste, the waste is clarified by centrifugation; the cesium, strontium, and rare earths are dissolved from the solids and combined with the clarified waste stream. Chelating agents are added to suppress the extraction of undesirable elements and the pH of the feed solution is adjusted with buffering agents and caustic or acid. Strontium and the rare earths are extracted into an organic phase of di-(2-ethylhexyl) phosphoric acid (D2EHPA), tributylphosphate (TBP), and hydrocarbon diluent. Cesium, short-lived fission products, and miscellaneous salts remain in the aqueous phase and are sent to underground storage for a period of two to three years, after which the cesium is recovered by ion exchange processing. The extracted strontium is separated from the rare earths by stripping the strontium in the IB column with dilute nitric acid. The strontium product is concentrated and stored in tanks in B-Plant for about one year to allow the short-lived strontium-89 to decay. Following the aging period, the strontium may be purified for beneficial use. See Section 5.3.

Cerium and the rare earths are stripped from the organic phase with strong nitric acid in the 1C column. The aqueous cerium and rare earth solution is neutralized and sent to underground waste storage for decay before being immobilized by in-tank solidification.

If cerium or promethium is needed for beneficial use, cerium is separated from the rare earths on a continuous basis in the 1C column by oxidizing inextractable Ce(III) to extractable Ce(IV) with persulfate catalyzed with silver. Trivalent ions are not extracted by D2EHPA from 2M nitric acid, while tetravalent ions are extractable. Cerium is stripped from the organic phase on a batch basis with nitric acid containing a reducing agent. The aqueous phase from the 1C column containing the promethium and rare earth fraction contaminated with sulfate is treated further by D2EHPA solvent extraction to remove sulfate impurity.

5.2 Solvent Extraction of Stored Sludge Waste

Strontium is removed from stored sludge waste using the same solvent extraction equipment as is used for processing current wastes. Promethium for beneficial use may be recovered from the sludge waste at the same time. Solvent extraction processes have also been developed to recover neptunium and plutonium from the sludge as well; however, present plans do not include facilities to recover these two elements.

Acidified sludge waste is treated by a precipitation process to remove a major part of the iron and aluminum present. Chelating agents are added to the product solution from the precipitation step to suppress the extraction of undesirable metal ions, and the pH of the solution is adjusted with buffer solution and sodium hydroxide. As with current waste, strontium and rare earths are extracted into an organic solution of D2EHPA, TBP, and hydrocarbon diluent in the 1A Column. The extracted strontium is stripped from the organic phase in the 1B Column with dilute nitric acid. The strontium product is concentrated and stored.

The rare earths are stripped from the organic phase in the 1C Column with strong nitric acid. The rare earth solution is neutralized with sodium hydroxide and sent to underground storage for eventual solidification in an ITS facility.

If the rare earths in stored sludge are needed for beneficial use, the 1C Column is used to strip calcium from the organic phase and the promethium and rare earths are stripped from the organic phase in a batch contactor. A nitric acid solution slightly more concentrated than that used to strip strontium in the 1B Column is used to strip calcium while strong nitric acid is used to strip the rare earths in the batch contactor. The organic solvent is washed using batch contactors, and the solvent is re-used.

5.3 Strontium Purification

On demand, crude aged strontium is campaign-purified in the solvent extraction equipment to provide a purified strontium product for bene-

ficial use. A chelating agent is added to the crude feed material to suppress the extraction of undesirable metal ions, and the solution pH is adjusted with buffering agent and caustic. Strontium is extracted into an organic phase of D2EHPA, TBP, and hydrocarbon diluent in the 1A Column. Strontium is stripped from the organic phase in the 1B Column with citric acid. Citric acid permits the preferential stripping of strontium, leaving calcium in the organic phase. The citric acid in the strontium product is destroyed by a combination of chemical oxidation using hydrogen peroxide and radiolysis, as the strontium is concentrated.

6. Salt Solidification

The purpose of the salt solidification facilities is to provide a means of concentrating suitable high activity level wastes to the point of solidification within the 750,000 gallon underground storage tanks. Salt solidification is accomplished by in-tank solidification (ITS) units and by an external pot concentrator (242-T Concentrator).

In the first in-tank solidification unit, which began operation in March 1965, electrically heated air is sparged directly into the waste solution through an annulus shroud tube. The annulus shroud tube acts as a heat transfer medium and a solution circulator as well as a means of introducing air into the solution. The tank effluent gases pass through a deentrainer, condenser, and a filter before being discharged to the atmosphere. The condensed water is routed to a crib. Additional wastes are added to the tank as the concentration progresses. When the terminal volume and concentration are reached, the tank contents will be allowed to cool and solidify. Figure I-7 is a sketch of the first in-tank solidification unit. The first ITS unit was originally installed in Tank 101-BY. It was moved to 102-BY in November, 1966, after the solution in 101-BY reached terminal concentration.

The second in-tank solidification unit achieves a high boil-off rate by immersing sheathed electrical heaters directly in the waste solution. An air lift circulator is still required to mix the tank contents, but the required air volume is much less. Because of the lower air volume, the off-gas equipment is smaller also. The second ITS unit is located in 112-BY. The third unit, if needed, will be located in the 200 West Area. A sketch of the second in-tank solidification unit is shown in Figure I-8.

The 242-T concentrator is a steam-heated pot concentrator located in the TX Tank Farm. Solidifiable waste is pumped to the evaporator from underground storage tank 118-TX. In the concentrator the waste is concentrated until there are about 10 volume percent solids in the concentrator bottoms. The concentrate is dumped to underground

storage tank 116-TX where a portion of the solids settle out. The supernatant liquid is pumped to 117-TX where additional cooling and settling is achieved. Supernatant liquid is decanted from 117-TX to 118-TX, blended with fresh feed from the tank farm, and recycled to the evaporator. As with the in-tank solidification units, concentration will continue until terminal volume and concentration is reached. The tanks will then be allowed to cool and solidify. Figure I-9 is a flowsketch of the 242-TX concentrator facility.

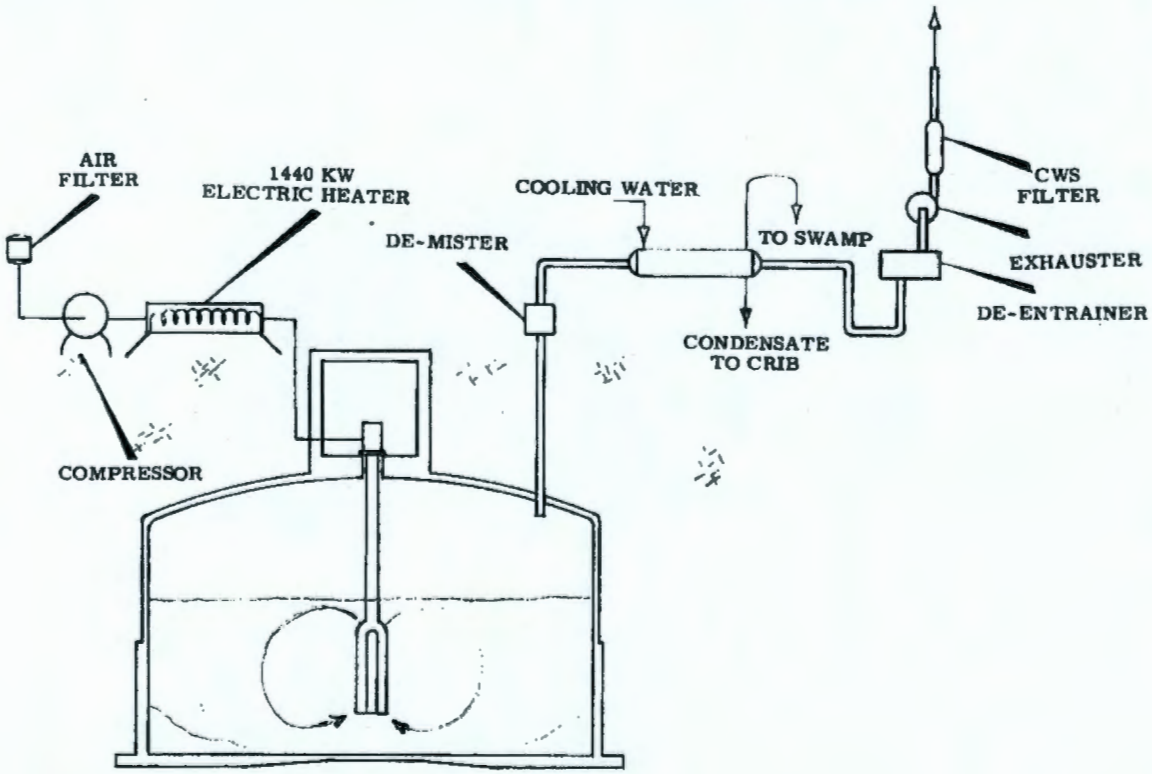

FIGURE I-7

First In-Tank Solidification Unit

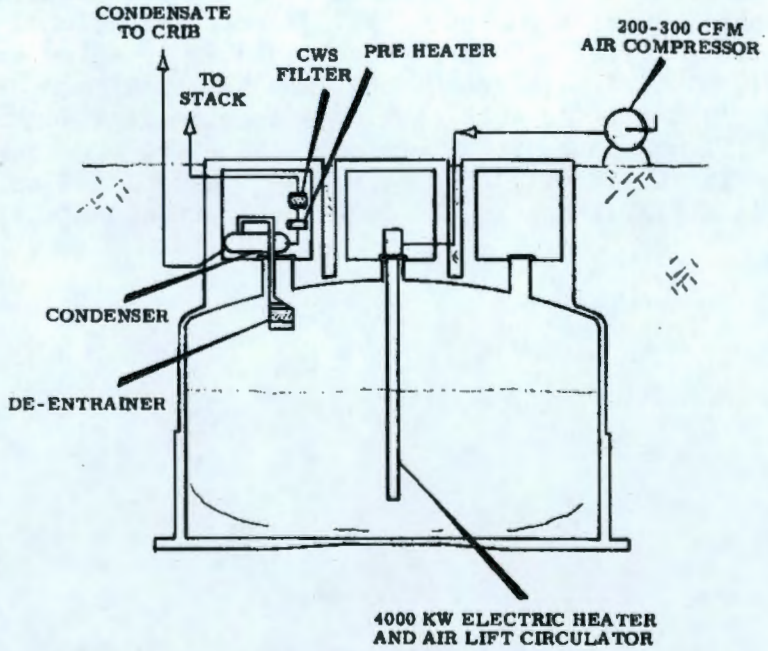

FIGURE I-8

Second In-Tank Solidification Unit

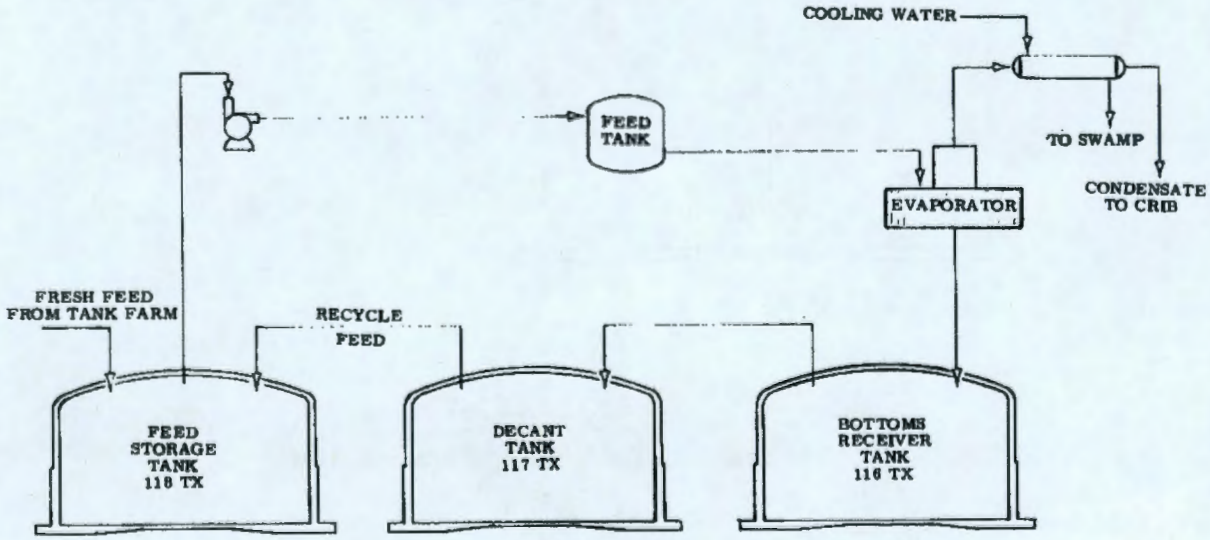

FIGURE I-9

242-T Concentrator

7. Packaging

At the time this chapter was written it was planned to store the strontium and cesium removed from wastes as nitrate solutions in tanks located in B-Plant. Eventually cesium and strontium which cannot be put to beneficial use will be "packaged" in high integrity containers for long-term storage. One approach, for which equipment has been developed but not installed, is to adsorb the cesium and strontium on synthetic alumino-silicate ion exchangers in stainless steel containers. After drying with heated air, the containers are closed and welded shut. The sealed canisters are stored under close surveillance in a water-cooled vault. Figure I-10 is a schematic flow diagram of this "packaging" process as it might be done in B-Plant.

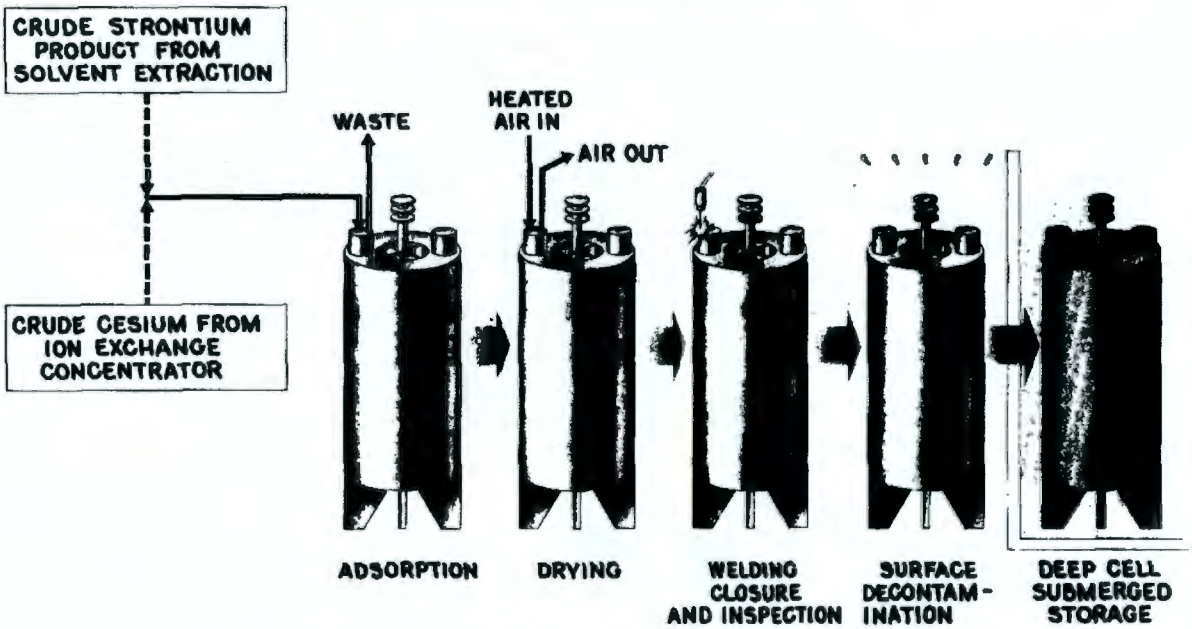

FIGURE I-10

Strontium and Cesium Packaging

8. Alternative Processes

Alternative flowsheets have been developed as back-up for the waste fractionization processes discussed above. The purpose of alternative fractionization technology is primarily to provide attractive alternative flowsheets in the event that mainline processes are proven uneconomical, or present exceptionally difficult operating problems.

Originally the CSREX process was planned for the solvent extraction fractionization of strontium and cesium in the Waste Management Program. However, due to severe radiolysis of the CSREX solvent, the D2EHPA process was shown to be more economical and more adaptable to a fission product recovery and purification program.

8.1 CSREX Process

In the CSREX Process (Figure I-11) cesium and strontium are co-extracted in the 1A Column along with the rare earth elements. The strontium and cesium are then stripped from the solvent in the 1B Column, and the rare earths removed in the solvent treatment equipment, or if desired, in a separate contactor for rare earth recovery.

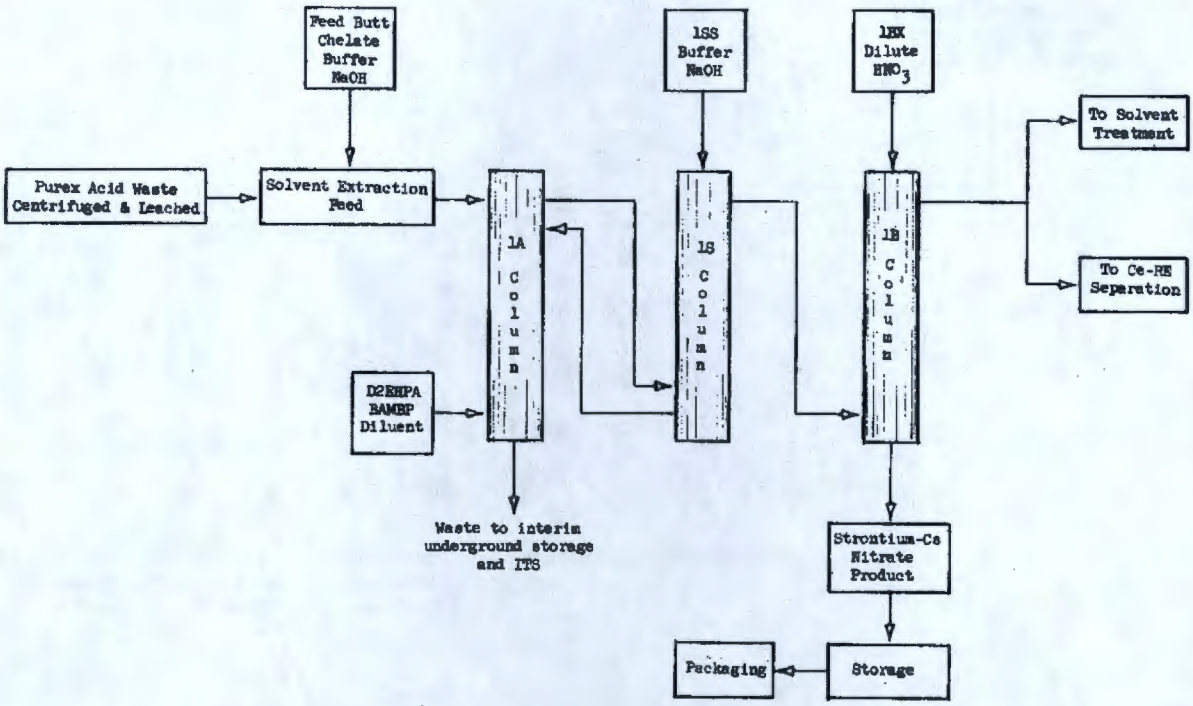

FIGURE I-11

CSREX Fractionization of Purex Acid Waste

8.2 Cesium Removal with Phosphotungstic Acid

In the event that it is desired to remove cesium from Purex Acid Waste at the same time that strontium and the rare earths are being recovered, a flowsheet has been developed to accomplish this. The cesium will be selectively precipitated as cesium phosphotungstate from the PAW with phosphotungstic acid prior to the solvent extraction processing for the recovery of strontium and rare earths. The cesium precipitate would be dissolved in sodium hydroxide and blended with stored alkaline supernates for ion exchange processing.

E. WASTE MANAGEMENT FACILITIES

1. General Layout of Waste Management Facilities

The waste management facilities consist of the Waste Fractionization Plant, (B-Plant), in-tank solidification (ITS) units, and a waste concentrator (242-T), 149 underground waste storage tanks, a facility for the removal and handling of stored waste (244-AR vault), a storage vault (244-CR), cribs, swamps, and associated facilities. All of the facilities are located in the vicinity of Isochem's Chemical Separations Plants. The Chemical Separations Plants are in the 200 Areas, 25 to 30 miles from the city of Richland on the Atomic Energy Commission's Hanford Reservation. A layout sketch showing location of the facilities on the Hanford Reservation and a detailed description of the facilities and equipment are shown and discussed in Chapter IX.

1.1 B-Area Layout

The layout of the B-Area (Waste Fractionization Plant) is shown in Figure I-12. The arrangement within the Waste Fractionization Plant is discussed in Section 1.2 below.

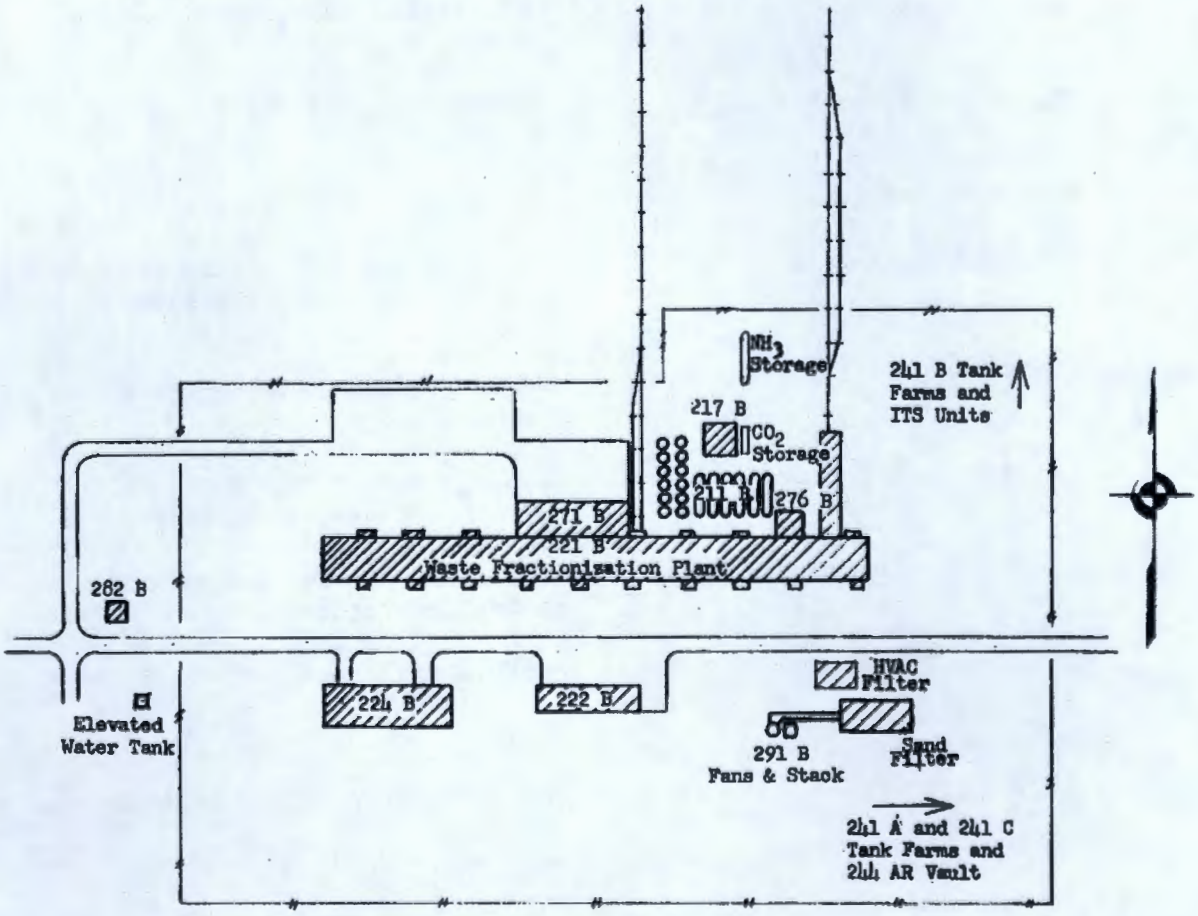

FIGURE I-12

Layout of Waste Fractionization Plant Area

The function of the various facilities in the vicinity of B-Plant are as follows:

Facility	Function
221-B Waste Fractionization Plant	Processing of waste to isolate selected fission and other products.
224-B Future Products Recovery	Not used as part of initial waste management program. May be used later for the recovery of products not included in the original design.
271-B Service Building	Contains offices and aqueous make-up facilities for the Waste Fractionization Plant.
222-B Office Building	Offices for support facilities, such as Financial.
291-B Fans, Stack, and Filters	Ventilation for the process building.
282-B Raw Water Well	Emergency raw water supply.
211-B Chemical Tank Farm	Storage area for liquid chemicals used in the Waste Fractionization Plant.
217-B Water Demineralizer	Demineralized process water supply.
276-B Organic Make-up and Storage	Storage and mek-up facility for organic solvent materials.
216-B-12 Process Condensate Crib	Crib for the disposal of condensates from process concentrators.
216-B-55 Steam Condensate Crib	Crib for disposal of condensates from heating coils in process tanks.
216-B-56 Organic Crib	Crib for disposal of organic solvents.

1.2 Waste Fractionization Plant (221-B) Layout

The Waste Fractionization Plant, Building 221-B, is a multi-storied, predominantly reinforced concrete structure, approximately 810 feet in length, called a "canyon" building. Figure I-13 is a cutaway sketch of the 221-B Building.

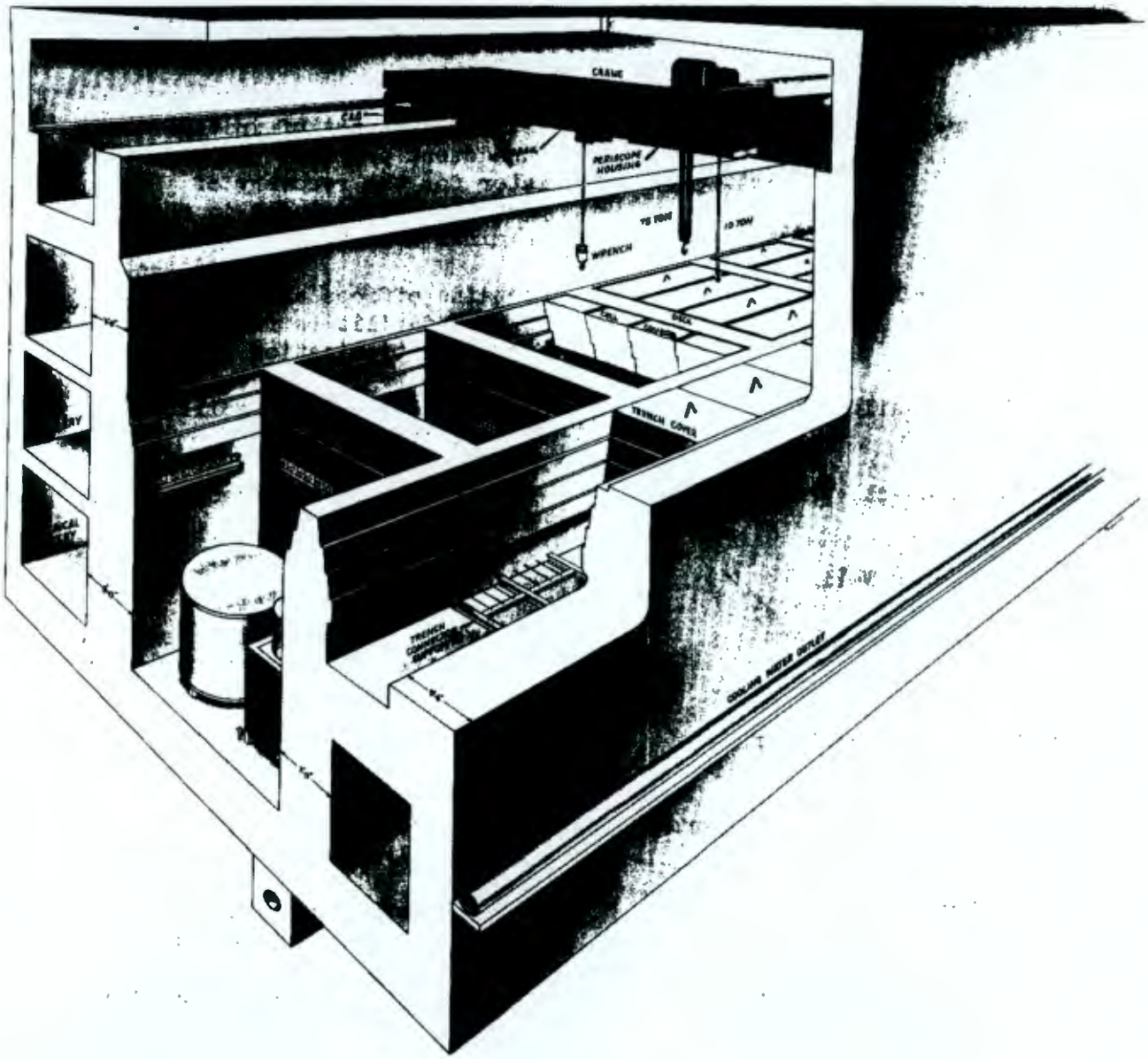

FIGURE I-13
221-B Canyon Building

The building has two major portions: The process portion which contains the "hot" equipment and the regulated work zones, and the service portion which houses personnel and equipment necessary for remote operation of the process portion.

The canyon cells house the various pieces of process equipment used to fractionize waste. The process equipment includes solvent extraction pulse columns, precipitation vessels, centrifuges, ion exchange columns, product and waste concentrators, and associated tanks, pumps, instrumentation, etc. The function assigned to each cell is shown in Figure I-14. The paths feeds from various sources take through the plant are also shown in Figure I-14.

The regulated work zones consist of areas where limited contact of personnel with radiation and radioactive contamination is allowed under carefully prescribed and monitored conditions. The following are regulated work zones: The Canyon, the Canyon Crane Gallery, Railroad Tunnel, and the SWP lobby at the east end of the operating gallery.

The service portion of the building includes the operating, pipe, and electrical galleries. Other service areas are located adjacent to the 221-B Building in the 271-B Building.

1.3 Layout of Underground Removal Facilities

Figure I-15 is a simplified layout drawing of the 241-A and 241-AX tank farms and the 244-AR process vault. A similar process vault may be constructed in the 200 West Area at the 241-SX tank farm if it is proven feasible to recover products from the Redox sludge.

Those tanks from which the sludge is removed are equipped with a minimum of two sluice pits for high-pressure sluicing nozzles, and a pump pit for a slurry pump. The material pumped from the tanks is segregated into supernates and sludge. The supernates are pumped to the 105-C tank in the 241-C tank farm. The sludge slurry is accumulated in Tank 002 in the 244-AR vault. A high head pump in Tank 002 returns slurry to the sluicing nozzles. When a suitable amount of sludge has accumulated in Tank 002, the circulation is stopped and the sludge is transferred to Tank 004 for acidification. Dissolved sludge is transferred to CR Vault 005 Tank and then to B-Plant. See Figure I-6.

1.4 Layout of Waste Disposal Facilities

Ultimate disposal of liquid radioactive wastes or potentially radioactive liquid waste will be in the ground via cribs or swamps, or as a salt cake in underground waste tanks located in 12 existing tank farms.

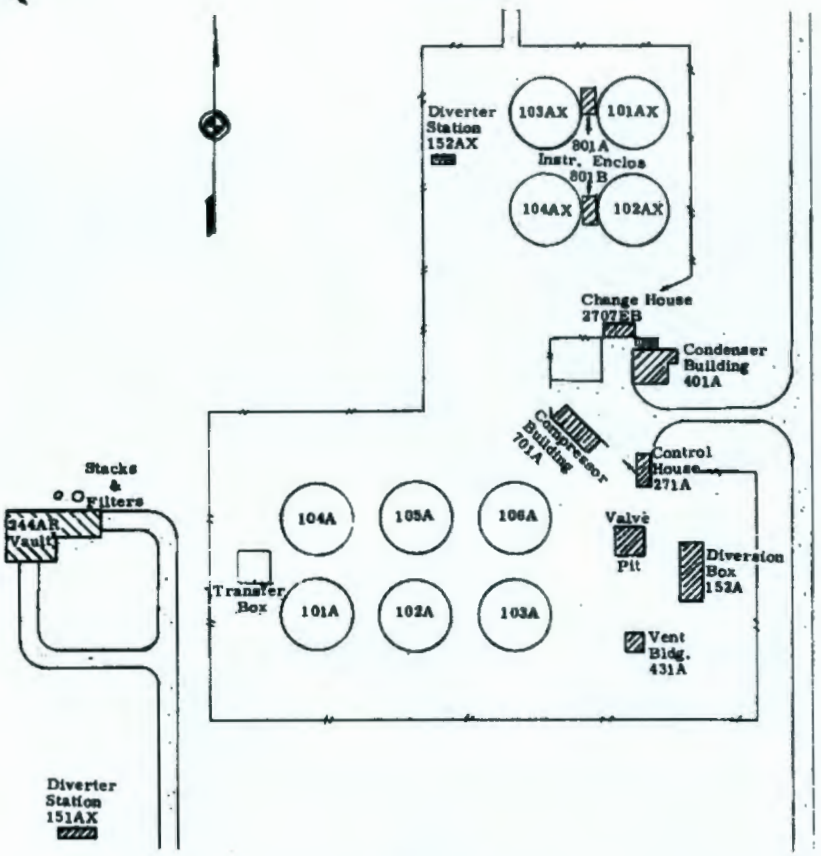

FIGURE I-15

Simplified Layout of Underground Storage Tanks and Removal Facility - 241A and 241AX Tank Farms

Reference Dwg. H-2-61916

1.4.1 Layout of Underground Waste Tank Farms

The underground waste tank farms are located within the 200 East and 200 West areas near the chemical separations plants. Each tank farm carries the number 241 followed by a letter or letters which designates the separations plant for which it was built to serve. For example, 241-A Tank Farm was built to service the Purex (A) Plant. Additional tankage built to service a plant or to replace an existing tank farm was designated with an X or a Y as 241-AX or 241-BY. The tank farms are interconnected by underground lines which makes it possible to transfer the contents of one tank farm to another. Each tank farm consists of 4 to 16 steel-lined concrete tanks. Table I-3 is a list of the tank farms showing the number and size of the tanks in each farm. The general type of waste that is stored in a particular farm is also shown in the table. Maps showing the location of the various tank farms are included in Chapter IX.

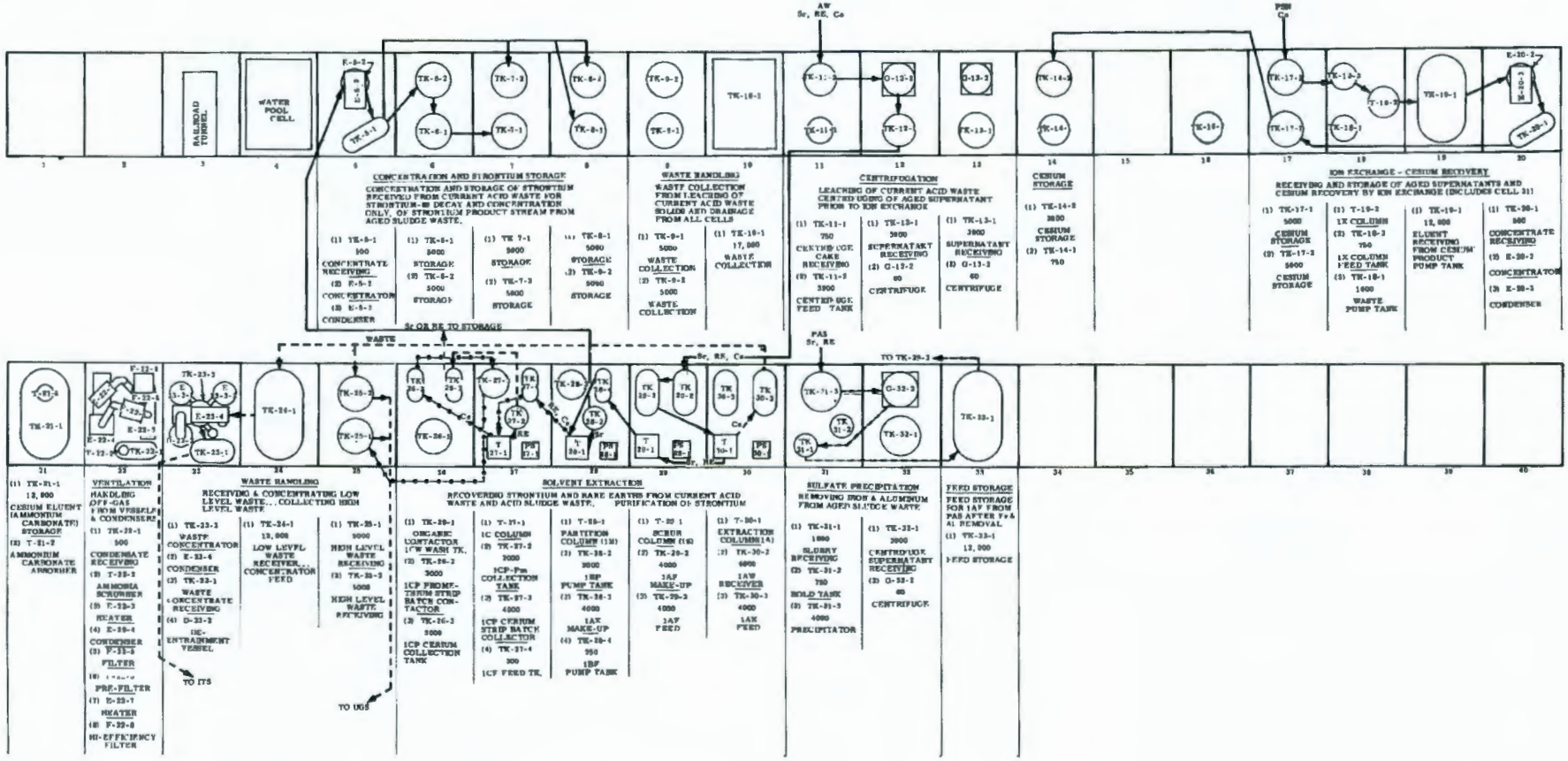

FIGURE I-14

B-Plant Cell Allocation and Fission Products Routes

TABLE I-3

UNDERGROUND WASTE TANK FARM INDEX

Tank Farm	No. of Tanks	Size Gal.	Type of Waste
241-A	6	1,000,000	Boiling high-level Purex waste to be fractionized
241-AX	4	1,000,000	Boiling high-level Purex waste to be fractionized
241-B	12	530,000	Non-boiling solidifiable wastes
	4	50,000	Non-boiling solidifiable wastes
241-BX	12	530,000	Non-boiling solidifiable wastes
	4	50,000	Non-boiling solidifiable wastes
241-BY	12	750,000	Non-boiling solidifiable wastes
241-C	12	530,000	Non-boiling solidifiable wastes
241-S	12	750,000	Non-boiling solidifiable wastes
241-SX	15	1,000,000	Boiling high-level Redox waste to be fractionized
241-T	12	530,000	Non-boiling solidifiable wastes
	4	50,000	Non-boiling solidifiable wastes
241-TX	18	750,000	Non-boiling solidifiable wastes
241-TY	6	750,000	Non-boiling solidifiable wastes
241-U	12	530,000	Non-boiling solidifiable wastes
	4	50,000	Non-boiling solidifiable wastes
Total	149		

1.4.2 In-Tank Solidification Facilities

The first in-tank solidification facility was installed in the 101-BY tank located in the 241-BY tank farm. In November, 1966, terminal concentration was reached in the 101-BY tank, and a portion of the tank contents was pumped to tank 105-BY for cooling and solidification. The In-Tank Solidification unit was moved to the adjacent 102-BY tank. Figure I-16 is a layout sketch of the facilities in the vicinity of the first In-Tank Solidification unit.

The second In-Tank Solidification unit will be installed in Tank 112-BY, and the third In-Tank Solidification unit, if needed, will be installed in a tank farm located in the 200 West Area.

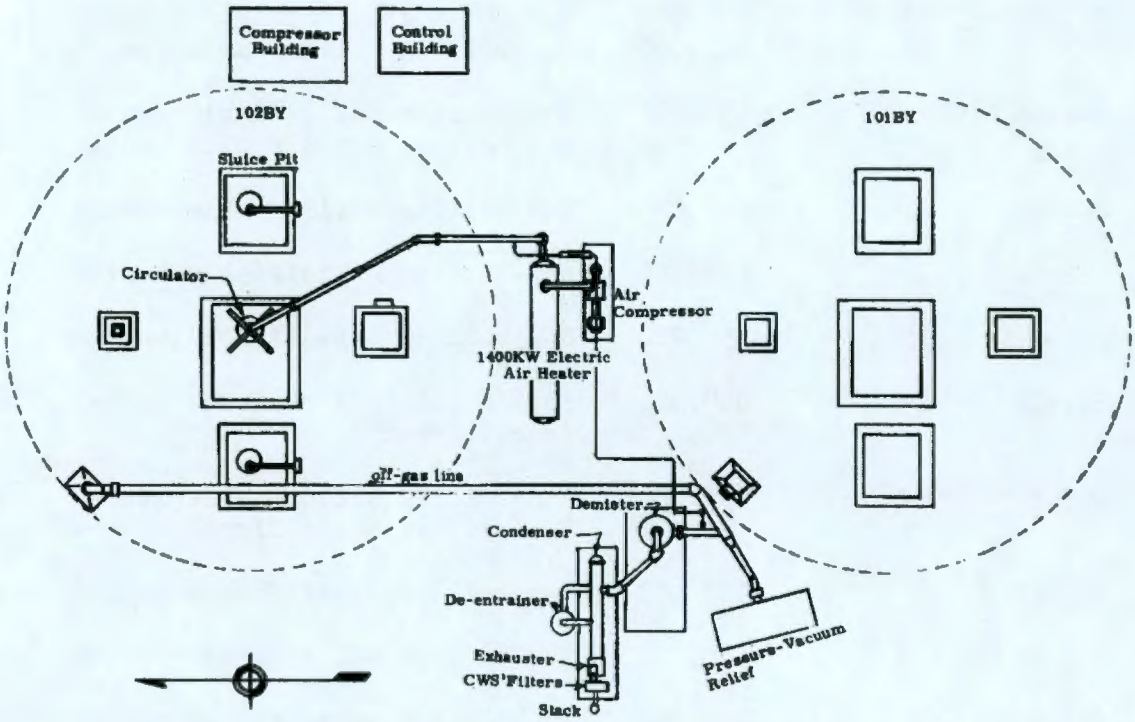

FIGURE I-16

Simplified Layout
First In-Tank Solidification Unit

Reference Dwg. H-2-32263

1.4.3 Cribs and Swamps

Natural depressions where low activity liquid wastes are disposed are called swamps, and the underground caverns or chambers where intermediate activity liquid wastes are disposed are called cribs. As low and intermediate activity level liquid wastes rely on the ion exchange capacity of the soil and the time it takes for the radionuclides reaching ground water to migrate to the river, cribs and swamps are discussed together. Swamps and cribs are designated by the building number 216, followed by the area letter of the plant they serve, and a site number. For example, 216-A-1 is crib number 1 located to serve the Purex (A) area.

The status of the cribs is designated as follows:

Active	Currently receiving or ready to receive radioactive wastes.
Inactive	Cribs not presently receiving radioactive wastes, but still possess enough capacity to be used again.
Abandoned	Cribs which have reached the capacity of radioactive wastes they can handle. This capacity is indicated by the appearance of cesium-137 or strontium-90 in samples of ground water taken from beneath the crib in concentrations approaching one-tenth of the maximum permissible concentration (MCP) for drinking water.
Specific Retention	Cribs used for specific retention depend solely on the physical ability of the soil to retain the liquid. The volume of waste routed to a specific retention site is limited to six percent of the soil column volume beneath the site.

Table I-4 lists the cribs and the status of the cribs for each plant area.

TABLE I-4

CRIB INDEX

Plant Area	Bldg. No.	Number of Active Cribs	Number of Inactive Cribs	Number of Abandoned Cribs	Number of Specific Retention Cribs
Purex	216-A	23	7	4	0
B-Plant	216-B	7	1	23*	25
Semiworks	216-C	5	4	1	0
200 North	216-N	0	3	4	0
Redox	216-S	8	8	6	0
T-Plant	216-T	6	3	13*	11
U-Plant	216-U	4	3	7	0
Z-Plant	216-Z	8	7	3	0

* The majority of these cribs reached their capacity between 1954 and 1957 during the ferrocyanide waste scavenging program.

2. Special Features of the Waste Management Facilities

The high levels of radiation associated with Waste Management process solutions, the nature of the process materials, and the nature of the process itself, have necessitated the installation of many special features in the Waste Management Process. Some of these features are discussed below.

2.1 Shielding

All service portions of the Waste Management facilities must be shielded from the processing areas to prevent personnel from receiving excessive amounts of radiation. In the Waste Fractionization Plant, radiation intensities are reduced by using concrete walls. In the waste removal facilities, a combination of earth and concrete is used to reduce radiation. Other outside facilities such as the underground storage tanks, diversion boxes, transfer stations, and pipe lines are also shielded with earth and concrete. In most places, shielding reduces radiation intensities to less than 0.1 mr/hr in non-regulated service areas.

2.2 Semi-continuous Operation

Portions of the Waste Management facilities are designed to operate on a continuous basis, while other portions are operated on a batch basis. For example, a current waste will be accumulated in a storage tank in 244-AR Vault and processed through the Waste Fractionization Plant on a campaign basis. A campaign will last from two to four weeks. The solvent extraction columns will operate on a continuous basis during the campaign. The batch contactors will be operated on a batch basis.

Other facilities which operate on a continuous basis are the in-tank solidification units. Other waste facilities which are operated on a batch basis are the ion exchange facilities and the sludge removal and acidification facilities.

The diversity and types of operations used in the Waste Management facilities require the use of a variety of automatic control instruments. Instrumentation is discussed in detail in Chapter XIII.

2.3 Materials of Construction

The process equipment used in the Waste Management facilities which handles all acidic process solutions are made of stainless steel. Type 404 or 304L are commonly used. Vessels in the service areas are constructed of either stainless steel or mild steel, depending upon the nature of the solutions which they handle.

The concrete surfaces of the canyon cells are painted with a protective coating to minimize absorption of radioactive solutions.

2.4 Remote Operation

Since the process equipment is located behind massive concrete or earth and concrete shielding, all tasks are performed by remote control. The remote operational controls are similar to those employed in the Purex Plant.

Processing operations for B Plant and 244-AR Vault are controlled from operating galleries. The In-Tank Solidification units are controlled from small buildings located in the tank farms. Some of the methods and devices employed for remote operation are briefly described below.

The transfer of process solutions and slurries in the Waste Management facilities is accomplished by using jets or pumps. The ion exchange medium is removed by means of a jet also. Flow rates of pumped streams are controlled from the operating galleries by recording-controlling instruments. Automatic instruments receive signals from transmitting rotameters indicating the flow rates which, in turn, actuate air-operated valves. Agitation of process solutions is accomplished by means of electrically driven agitators. The organic-aqueous interfaces in solvent extraction columns are controlled by recorder-controller instruments which are actuated by interface floats. Weight and specific gravity of solutions are determined from differential pressure instruments actuated by air-bubbling dip tubes in the vessels. Chemical additions to the process vessels are from the service areas through seal pots and pipe lines permanently cast into the concrete shielding. Ion exchange medium is added to the ion exchange column from the service area by means of a slurry line. Solutions in process vessels are sampled via special vacuum jets which draw the solutions into shielded sample boxes at the sample stations.

2.5 Remote Maintenance

Installation and removal of process equipment and remote maintenance in the Waste Fractionization Plant and the 244-AR Vault building process areas is accomplished with the aid of cranes. The crane in the Waste Fractionization Plant canyon is operated from a shielded control cab which travels behind the concrete shielding wall of the Crane Cab Gallery (See Figure I-13). Operations are observed from the cab through periscopes mounted on the crane bridge. The crane in the 224-AR Vault building is operated by remote control from the control room. Operations are observed by periscopes and television cameras.

Maintenance in the facilities located outside of the 224-AR Vault Building and the Waste Fractionization Plant such as tank farms and diversion boxes are performed by using portable boom cranes, mirrors, periscopes, television cameras, etc.

All equipment pieces are equipped with lifting bails to facilitate moving. All equipment, including electrical and pipe jumpers, are fastened in place with enlarged nuts which may be tightened or loosened by means of a crane-operated impact wrench.

2.6 Critical Mass Control

Plutonium concentration in Waste Management facilities streams should be sufficiently low that no criticality problems are anticipated. Adequate sampling will detect any unusually high concentration of plutonium occurring in process vessels.

2.7 Process Air Ventilation

The spread of radioactive particles throughout the Waste Fractionization Plant is controlled by proper direction of air flow. Process vessels are maintained at a lower static pressure than the canyon; while the canyon, in turn, is at a lower static pressure than the pipe and operating galleries. Thus, air flow is away from operating personnel toward the process vessels. Air is exhausted from the process cells through a series of ports into the air tunnel. From the air tunnel, the air is passed through two banks of high efficiency filters and exhausted to the atmosphere through the 291-B stack.

Separate vacuum systems are used for the two vessel vent systems. One vessel vent system is used extensively for those vessels which may give off ammonia fumes. The vessel vent systems provide a minimum of four stages of filtration for the off-gas.

Off-gas from the In-Tank Solidification units passes through high efficiency filters before being discharged to the atmosphere.

2.8 Vessel Cooling System

Cooling coils or jackets are provided on all storage vessels to remove heat generated by radioactive decay. Cooling water is supplied by the 200-E area raw water supply. An emergency cooling water supply from a well located adjacent to the B-Plant area supplies cooling water by means of Diesel-driven pumps in event the primary water supply fails.

2.9 Fire and Explosion Protection

The Waste Fractionization Plant employs a flammable organic hydrocarbon as a diluent for the D2EHPA extractant. The high flash point of the diluent makes it relatively safe from a fire viewpoint.

A number of protective features for the prevention or control of fire have also been incorporated into the plant. Among these are adequate process area ventilation which prevents accumulation of explosive mixtures.

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Process tanks containing sufficient radioactivity to produce hydrogen by radiolysis are continually purged with air to dilute the hydrogen to below the lower explosive limit.

Ammonium solutions are used in the process for recovery of cesium. A separate vessel vent system is provided for those vessels where ammonium solutions are anticipated. The ammonia in this system is removed by an absorber prior to being exhausted to the atmosphere.

3. Chemical Requirements

The estimated amount of chemicals required for processing wastes in the Waste Fractionization Plant is shown in Table I-5 for current waste, and Table I-6 for stored waste. The additional amounts of chemical required to isolate fission product fractions for beneficial use are also shown in the tables.

TABLE I-5

ESTIMATED CHEMICAL REQUIREMENTS FOR PROCESSING CURRENT ACID WASTE (PAW) IN THE WASTE FRACTIONIZATION PLANT

I. For Waste Management

Chemical	Amt/gal. PAW	
D2EHPA	0.0323	lbs.
HEDTA	0.718	lbs.
HNO_3	0.742	lbs.
NaOH	0.809	lbs.
Diluent	0.040	gal.
Tartaric Acid	0.372	lbs.
TBP	0.018	lbs.
Hydroxyacetic Acid	0.381	lbs.

II. To purify the rare earth fraction

Chemical	Amt/MCi Pm	
D2EHPA	180	lbs.
HNO_3	13,000	lbs.
Diluent	230	gal.
NaOH	4,400	lbs.
$NaNO_2$	100	lbs.
$Na_2S_2O_8$	2,700	lbs.
$AgNO_3$	190	lbs.
Sugar	650	lbs.
TBP	100	lbs.
HEDTA	1,100	lbs.

III. To purify the strontium fraction

Chemical	Amt/MCi Sr	
Acetic Acid	1,300	lbs.
Citric Acid	1,000	lbs.
D2EHPA	34	lbs.
DTPA	520	lbs.
H_2O_2	580	lbs.
HNO_3	300	lbs.
Diluent	42	gal.
NaOH	480	lbs.
TBP	18	lbs.

TABLE I-6

ESTIMATED CHEMICAL REQUIREMENTS FOR PROCESSING STORED WASTE IN THE WASTE FRACTIONIZATION PLANT

I. Cesium recovery by ion exchange

Material	Amt/gal. PSN	
Zeolite	0.0033	lbs.
NH_3	0.022	lbs.
CO_2	0.033	lbs.

II. For Waste Management

Chemical	Amt/gal. PAS	
D2EHPA	0.018	lbs.
HEDTA	0.448	lbs.
Hydroxyacetic acid	0.286	lbs.
Lead Nitrate	0.092	lbs.
HNO_3	0.349	lbs.
Oxalic Acid	0.032	lbs.
$NaHSO_4$	1.45	lbs.
Na_2CO_3	0.672	lbs.
NaOH	0.295	lbs.
TBP	0.010	lbs.
Diluent	0.023	gal.

III. To purify the rare earth fraction

HNO_3	0.237	lbs.
Sugar	0.061	lbs.

IV. To purify the strontium fraction

Acetic Acid	0.274	lbs.
Citric Acid	0.182	lbs.
DTPA	0.076	lbs.
D2EHPA	0.006	lbs.
H_2O_2	0.523	lbs.
HNO_3	0.029	lbs.
NaOH	0.088	lbs.
Diluent	0.008	gal.
TBP	0.003	lbs.

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PART II

FEED MATERIAL

CHAPTER II

NUCLEAR REACTIONS, TRANSURANIC ELEMENTS AND FISSION PRODUCTS

By

H. H. Van Tuyl

PACIFIC NORTHWEST LABORATORY

PART II: FEED MATERIAL

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A. INTRODUCTION

The separations plants are intimately associated with the production reactors. Nuclear fuel is transformed in the reactors to make plutonium and other elements heavier than uranium. Fission products are also formed in the fuel. The separations plants receive all of the irradiated fuel, recover any economically attractive components, and provide for safe disposal of other components of the spent fuel. Some understanding of what happens in the reactors will help in evaluating potential new by-products and in providing adequate waste disposal.

This chapter includes a rather elementary discussion of nuclear reactions and calculations, along with a discussion of some of their less familiar aspects. Most of the chapter does not presume much prior knowledge of radiochemistry or nuclear physics, but some parts are more detailed and specific than most introductory college level courses. Because of the inclusion of both levels of information, few readers will find use for all of the chapter, but most readers will find something of value or interest.

B. NEUTRON REACTIONS

1. Capture

A neutron traveling through any matter may be captured by a target nuclide to produce a new nuclide with a mass about one unit greater than the target. As a result of this process, mass is converted into energy in accordance with Einstein's famous equation, $E = mc^2$. Each mass unit corresponds to 931 MeV when convereted into energy. The total energy of a nuclide or neutron is thus the sum of the kinetic energy and the energy equivalent of the mass.

The total energy of the product nuclide is greater than the energy of the product nuclide in its lowest energy state (also called the ground state). The mass of the ground state of a product nuclide is usually between 0.994 and 1.003 units greater than the mass of the parent, while the mass of a free neutron is 1.008665 units. The mass difference is available to the product nuclide as excitation energy. The product nucleus in its highly excited state, is called a compound nucleus. The amount of energy released by neutron capture is the binding energy of a neutron in the product nuclide. This same amount of energy must be supplied to the product nuclide in its ground state in order to remove a neutron from it.

Excess energy in the compound nucleus must be lost promptly to form one or more nuclei in more stable states. Usually the transitions lead to the ground state within much less than a microsecond, but some excited states have much longer half lives, sometimes even greater than a year. Excited states of this type are called metastable states.

If the compound nucleus loses energy by emission of one or more gamma photons and no particles are emitted the reaction is called neutron capture and is referred to as a n,γ reaction. Other ways of losing energy are also possible as will be discussed later.

The production reactors at Hanford were built to take advantage of a particular neutron capture reaction. When U^{238} captures a neutron, the product after gamma emission is U^{239}. After two successive beta decays this is changed into Pu^{239}, which has been the primary product at Hanford since the reactors were built. The reactions leading to plutonium production are summarized below.

$$U^{238} \xrightarrow{n,\gamma} U^{239} \xrightarrow[23.5\ m]{\beta} Np^{239} \xrightarrow[2.35\ d]{\beta} Pu^{239}$$

Additional neutron capture reactions are currently being investigated for possible application at Hanford, and some have been used for by-product production already. A few of these reactions are listed below.

$$Np^{237} \xrightarrow{n,\gamma} Np^{238} \xrightarrow[2.10\ d]{\beta} Pu^{238}$$

$$Th^{232} \xrightarrow{n,\gamma} Th^{233} \xrightarrow[22.1\ m]{\beta} Pa^{233} \xrightarrow[27.4\ d]{\beta} U^{233}$$

$$Bi^{209} \xrightarrow{n,\gamma} Bi^{210} \xrightarrow[5.0\ d]{\beta} Po^{210}$$

$$Tm^{169} \xrightarrow{n,\gamma} Tm^{170}$$

These reactions are of no concern to Waste Management at present, but future production efforts may introduce wastes from the above or similar processes into the Waste Management system.

2. Fission

Thus far we have only considered gamma emission by the compound nucleus. Another very important manner of losing energy is by nuclear fission, in which the compound nucleus divides into two very highly excited nuclei of roughly equal size, called fission fragments. These fragments usually have excitation energy well in excess of the binding energy of a neutron, and can break up by neutron emission as well as by gamma emission. The number of neutrons produced from fission fragments depends on the fissioning nuclide and the neutron energy. On the

average each thermal fission results in the emission of 2.43 neutrons from U^{235} fission and 2.89 neutrons from Pu^{239} fissions. By some combination of neutron and gamma emission the fission products lose energy to reach a ground or metastable state. The first nuclides reached in their metastable or ground states are called primary fission products.

Primary fission products do not usually decay by neutron emission, but still contain too many neutrons to be stable (that is, the ground state of these nuclei usually contain more energy than does a nuclide of the same mass number but with one more proton and one less neutron). The unstable fission products decay by beta emission until the ground state of a stable nuclide is reached. The sequence of events in fission is summarized in the following reactions, in which parentheses are used to indicate compound or highly excited nuclei.

$$U^{235} + n \rightarrow (U^{236}) \rightarrow (Kr^{95}) + (Ba^{141})$$

$$(Kr^{95}) \rightarrow (Kr^{94}) + n$$

$$(Kr^{94}) \rightarrow Kr^{93} + n$$

$$Kr^{93} \xrightarrow{\beta} Rb^{93} \xrightarrow{\beta} Sr^{93} \xrightarrow{\beta} Y^{93} \xrightarrow{\beta} Zr^{93} \xrightarrow{\beta} Nb^{93}$$

$$(Ba^{141}) \rightarrow Ba^{140} + n$$

$$Ba^{140} \xrightarrow{\beta} La^{140} \xrightarrow{\beta} Ce^{140}$$

Over-all: $U^{235} + n \rightarrow Nb^{93} + Ce^{140} + 3n$

A rough estimate of the energy liberated in fission can be determined by adding up the masses of all of the stable products of the above reactions (i.e., Nb^{93}, Ce^{140} and three neutrons) and subtracting this from the sum of the parent mass plus one neutron mass. The difference, when converted to energy units, will represent the energy released in this particular fission reaction. The average energy released in fission of U^{235} is about 202 MeV, and is distributed as follows:

Recoil energy of fission products	166 MeV
Gammas from compound nucleus	7 MeV
Kinetic energy of neutrons	5 MeV
Neutrinos	11 MeV
Fission product decay energy	13 MeV

The neutrinos, which have no charge and essentially no mass, escape from a reactor without losing any energy, and thus carry away some fission energy. However, the extra neutrons produced in fission will be captured in the fuel or other reactor components with the release of about as much energy as is carried away by the neutrinos. The net effect is thus still about 200 MeV per fission.

Since the fission process liberates a large amount of energy, the neutrons produced in fission have a rather high average energy, about 2 MeV. The actual energies range from zero to over 15 MeV, and roughly follow the equation

$$n(E) = 0.770\sqrt{E}\, e^{-0.775\, E}$$

Neutrons with this energy distribution are called fission spectrum neutrons. Few have energies as great as 5 MeV or as small as 0.01 MeV.

3. Other Reactions

The compound nucleus formed by neutron capture can also break up by emission of neutrons, protons, or alpha particles provided the mass of the compound nucleus is greater than the mass of the products. Emission of a single neutron will be considered as a special case in the next section. If the energy of the incident neutron exceeds the binding energy of a neutron for the target nuclide, two neutrons may be emitted from the compound nucleus by a n,2n reaction. Some of the neutrons formed in fission have this much energy. Indeed, much of the valuable Np^{237} formed in Hanford reactors results from a n,2n reaction with U^{238}:

$$U^{238} \xrightarrow{n,2n} U^{237} \xrightarrow[6.75\ d]{\beta} Np^{237}$$

Even n,3n reactions have been observed with fission-produced neutrons:

$$Bi^{209} \xrightarrow{n,3n} Bi^{207}$$

The kinetic energy of the incident neutrons must be equal to the binding energy of two neutrons in the target nuclide for n,3n reactions to be possible. Since this energy is usually in excess of 12 MeV, few n,3n reactions are observed.

For some nuclides, particularly the lighter ones, the compound nucleus may break up by emission of charged particles. A neutron is held in a nucleus simply by its binding energy, while charge interactions are also effective in keeping charged particles in the nucleus. The charge effect is roughly proportional to the 2/3 power of Z, so that charged particle emission is common only among light elements. Low energy neutrons do not cause charged particle emission unless the binding energy of the charged

particle is appreciably lower than that of a neutron. Two typical charged particle emissions are as follows:

$$Li^6 \xrightarrow{n,\alpha} H^3$$

$$Cl^{35} \xrightarrow{n,p} S^{35}$$

4. Scattering

When a neutron interacts with a nuclide the effect on the neutron may be more important than the effect on the nuclide. A compound nucleus may break up by neutron emission, either leaving the nuclide in its initial state (as it was before neutron capture) or in an excited state which then emits one or more gamma photons to revert to its initial state. The neutron energy is reduced by the kinetic (recoil) energy transferred to the nuclide, and in the latter case is also reduced by the energy emitted as gamma photons. The former case is equivalent to an elastic or "billiard ball" type of collision. The maximum energy transfer in an elastic collision is limited by the laws of conservation of energy and momentum to $4AE_0/(A + 1)^2$ where A is the mass number of the target nuclide. For heavy targets the neutron is slowed down only very slightly, while for hydrogen atom collisions the neutron on the average loses half of its energy per collision.

A high energy neutron is slowed down largely by inelastic scattering (in which the target nuclide is left in an excited state), but as the neutron energy decreases, the probability of inelastic scattering decreases. When the neutron energy becomes less than the first excited state of the target, inelastic scattering is no longer possible. Neutrons are not reduced to thermal energies very efficiently by heavy atoms. Therefore, materials of low mass number are used to thermalize neutrons. This process is called moderation and the material is a moderator. Hanford production reactors use graphite (mass number of 12) as moderator because of its good structural properties and low neutron absorption cross section. Most power reactors use water as moderator to take advantage of the hydrogen content (mass number of 1). Some reactors such as PRTR use heavy water as moderator because of deuterium (mass number of 2) which has moderation qualities second only to hydrogen, and a vanishingly small neutron absorption cross section.

Neutrons do not continue to lose energy indefinitely, even though they may undergo a great many scatterings. When the neutron energy is less than 0.04 eV, the thermal agitation of the target nuclei may be great enough for the neutron to gain energy instead of losing energy by collision. The neutron energy is then determined by the kinetic energy distribution of the nuclei with which the neutrons collide. The energies depend on the moderator temperature and follow a Maxwellian distribution. At 20 C the most probable thermal neutron energy is

0.025 eV, which corresponds to a neutron velocity of 2200 meters per second. Neutrons which have been moderated to thermal energies are called thermal or slow neutrons.

During the moderation process the neutrons cannot be represented by either the fission spectrum or thermal distributions. In the intermediate range (about 0.2 eV to 1 MeV) the flux of neutrons at a given energy is inversely proportional to the energy. Neutrons in this range are called slowing-down neutrons, epithermal neutrons, or resonance neutrons. Neutrons with energies in excess of 1 MeV are usually called fast neutrons, although other arbitrary minimum energies for fast neutrons may also be used.

C. NEUTRON CROSS SECTIONS

1. General

The neutron cross section is a measure of the probability that a neutron will interact with a target nucleus. It is usually expressed in units of area, either square centimeters or barns. (A barn is 10^{-24} cm^2.) A convenient picture of the cross section may be obtained by considering it to be the area of the target nucleus as seen by the incident neutron. However, the neutron absorption cross section may be several orders of magnitude larger than the geometric area of the nucleus.

Ordinarily the cross section for a particular process is considered rather than the cross section for any interaction at all. The total cross section refers to all interactions, even elastic scattering. The absorption cross section includes all reactions except scattering. Waste Management is most concerned with cross sections for capture and for fission; and the absorption cross section is then the sum of capture and fission cross sections for the target. Capture cross sections which lead to radioactive products are also called activation cross sections.

The cross section is used in calculating the amount of product nuclide made in a nuclear reaction. Another quantity used in this calculation is the neutron flux, which is the number of neutrons passing through a sphere of unit cross sectional area per unit time. The flux is equal to the number of neutrons per unit volume times the velocity of the neutrons. The symbols Φ and nv may be used interchangeably to denote flux, usually in units of $cm^{-2}sec^{-1}$. The rate of a neutron reaction is proportional to the product of the cross section and the neutron flux. Thus, average cross sections for a given neutron distribution are determined with respect to neutron flux rather than number of neutrons.

2. Energy Dependence

At low energies (on the order of 1 eV) many cross sections vary inversely with the velocity of the neutron. This variation, known as

the "1/v law", is well illustrated by the n,α reaction with Boron-10, which obeys this law at least up to 10 keV.

Most nuclei exhibit absorption peaks superimposed on the 1/v variation between thermal energies and a few keV. The peak cross section may be several orders of magnitude higher than the 1/v component, and may be at sufficiently low energies to obscure the 1/v component completely in the thermal region. Peaks occur when the neutron energy is correct for formation of a compound nucleus at one of its permissible energy levels. This agreement of neutron energy with product energy level is called resonance. The height and spacing of resonances varies greatly, as shown in Figures II-1 through II-4.

The average thermal cross section for a nuclide is obtained by weighting the cross section in accordance with the Maxwellian distribution of neutron energies. As the moderator temperature increases the energy of thermal neutrons also increases. Since few cross sections are constant in the thermal region, the thermal cross section usually varies with temperature. For a 1/v absorber the thermal cross section is given as a function of temperature by

$$\sigma = \sigma_{2200}/K$$

where

$$K = \sqrt{\frac{4T}{\pi T_o}}$$

T_o is 293.6 K (20.44 C), T is the Maxwellian temperature, and σ_{2200} is the cross section for a velocity of 2200 meters per second. Deviation from the 1/v law in the thermal region may be evaluated in terms of the parameter g, defined by the equation

$$g = \frac{K\sigma}{\sigma_{2200}}$$

The reaction rate, $\sigma\Phi$, may also be expressed as $g\,\sigma_{2200}\,\Phi/K$.

A modified or conventional thermal flux, Φ/K, is usually used instead of the true flux, along with the conventional cross section $g\,\sigma_{2200}$. For most nuclides g is about unity, with little temperature variation; but if resonances are involved values of g may be either higher or lower than one.

Cross sections for some reactions (e.g. n,2n) are below a certain energy required by the conservation of energy. Cross sections for charged particle emission or fission may be very low below a certain energy. The limiting energy in either case is called the threshold until they reach a plateau which may contain resonance peaks.

In spite of the variation of cross sections with neutron energy, calculations are sometimes based solely on the 2200 meter per second cross sections and conventional flux. For thermal reactors such as the Hanford production reactors this gross simplification is not greatly in error for many nuclides, but for nuclides which have resonances in or near the thermal region, or which have a low thermal cross section and large resonances, the simplification may lead to errors of an order of magnitude or more.

3. Resonance Integral

In the epithermal region (between the thermal and fast regions) the cross section does not usually vary in a simple way because of resonances. The effective cross section in the epithermal region can be evaluated by integrating the product of cross section and neutron flux. The epithermal neutron flux varies inversely with energy. The integrated value (called the resonance integral, I) includes the effects of both 1/v and resonance contributions to the cross section. The upper limit of the integral is not critical since the 1/E neutron flux is very low in the MeV range. The lower limit of integration, called the cutoff energy, should be about where the upper end of the Maxwellian distribution equals the 1/E flux, or about 0.2 eV. The cutoff energy is proportional to neutron temperature.

The resonance integral can usually be separated into a 1/v component plus an excess resonance integral, which is the contribution from the resonances. A common way of doing this assumes that the 2200 meter per second cross section extends into the resonance region according to the 1/v law. An excess resonance integral can then be obtained from the resonance integral by subtracting a correction proportional to the thermal cross section and dependent on the cutoff energy used in obtaining the resonance integral. The excess resonance integral is only slightly dependent on temperature or cutoff energy unless resonances occur at less than 1 eV.

Westcott developed an expression for cross sections whereby the effect of both thermal and resonance neutrons may be included rather simply. The Westcott cross section is

$$\sigma_w = (g + rs)\,\sigma_{2200}$$

where

$$s = \frac{KI}{\sigma_{2200}} - 1.1762\,g$$

I is the resonance integral, and r is the "spectral index", a measure of the epithermal flux ratio. The excess resonance integral, I', is related to s by the equation

$$I' = s\sigma_{2200}/K$$

so that s varies with neutron temperature. The flux used with the Westcott cross section is close to the conventional flux for well-moderated reactors, but differs from it appreciably if the spectral index is high.

4. Resonance Flux Depression

In the case of an actual absorber the sample size is usually large enough so that its absorption modifies the 1/E neutron energy distribution appreciably. The neutron spectrum is depleted at the resonance energies and the resonance absorption integral is smaller than it would be if the spectrum were unmodified by absorption. The correct integral, or effective resonance integral, is then one in which the actual spectrum, depleted at the resonance energies, replaces the 1/E factor. The effect is seen most strontly with large resonance absorption peaks below 100 eV. In Hanford fuels the absorption cross section of U^{238} is greatly dependent on resonance flux depression, and the Pu^{240} cross section is affected toward the end of an irradiation as the Pu^{240} content increases. Some other cross sections are also affected, but to a lesser extent.

Because of the importance of resonance absorptions in U^{238} and the great effect of self shielding, several workers have derived empirical formulas to express the effective resonance integral. One such formula is as follows:

$$I' = 2.81 + 24.7\sqrt{S/M}$$

where S is the effective surface area, M is the mass of uranium, and S/M is between 0.07 and 0.53. The temperature dependence is given by

$$I'_T = I'_o\,[1 + 0.01(0.51 + 0.5\ S/M)(\sqrt{T} - \sqrt{T_o})]$$

where the subscripts T and o refer to the elevated temperature and to 293°K, respectively.

For closely packed lattices the shadowing of one rod by another is important, and can reduce the effective resonance integral substantially. This can be accounted for by means of a Dancoff correction, but it is not large for the Hanford production reactors.

5. Multigroup Representation

The treatment of cross sections described above is called a two-group treatment since one cross section is used for thermal and a second for resonance reactions. Accurate evaluation of nuclear reactions might require multigroup treatment to provide for deviations from the Maxwellian thermal distribution and the simple 1/E approximation to the flux in the resonance region. This refinement is unnecessary for most Waste Management purposes. However, multigroup tabulations may be used to obtain resonance integral data. The sum of values in a multigroup tabulation does not usually equal the resonance integral even if the correct energy range is covered. The tabulated value is usually the partial resonance integral divided by the natural logarithm of the ratio of high to low energy. The result is an average cross section per unit logarithmic energy change, and this value must be multiplied by the logarithmic energy change for the region being integrated in order to covert to a partial resonance integral. The sum of partial resonance integrals above the cut-off energy is then equal to the total resonance integral.

D. REACTOR DESCRIPTIONS

1. General Features

As previously mentioned, each fission gives rise to more than one additional neutron. If one neutron from each fission is used to create an additional fission, a self-sustaining nuclear reaction is obtained. A nuclear reaction is a device in which a nuclear chain reaction is sustained and controlled. Fission neutrons which are not used to cause additional fissions may be used to produce desirable products, or may be lost parasitically in reactor fuels, structural materials, or reactor shielding. Most reactors are controlled by neutron-absorbing rods which may be inserted into the reactor to increase the parasitic loss of neutrons, thus decreasing the number of neutrons available to cause fissions. Adjustment of the control rods will permit operation of the reactor at the desired power level.

The number of fissions caused directly by the neutrons from a single fission is defined as the multiplication factor, k. For steady-state operation, each fission must cause exactly one additional fission, so that k = 1.000000. If k is less than one, the reactor power level will decrease until either fissioning essentially ceases or changes in the reactor allow the multiplication factor to increase to unity. If k is greater than one, the reactor power level will increase until k is reduced to unity or less. Ordinarily the control rods in an operating reactor are set to obtain power close to the maximum allowable operating power. If the rods were totally removed from the reactor, some of the fuel might melt and part of the water in the

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reactor might be converted into steam. These changes would reduce the multiplication factor to less than one, and under no circumstances would a thermal reactor cause a bomb-like explosion.

Fission may be caused by either fast or slow neutrons, and reactors may be designed to operate with predominantly slow neutrons (as with Hanford production reactors and most power and research reactors) or with predominantly fast neutrons (as with the Fast Flux Test Facility). A reactor which operates with slow neutrons must contain a moderator to reduce the neutron energy, while a fast reactor is built without any moderator in the reactor core.

The Hanford production reactors are all thermal reactors with graphite moderator. They are operated primarily to produce plutonium by a neutron capture reaction with U^{238}. Most of the reactor fuel is natural uranium, which contains over 99 percent U^{238} and only 0.72 percent of the fissionable isotope U^{235}. Some uranium with a slightly higher U^{235} content is also used, but all of the currently used fuels contain well over 97 percent U^{238}.

The average thermal neutron flux in all Hanford production reactors is about 3×10^{13} neutrons/cm^2-sec, expressed as either a conventional or Westcott flux. The value is not constant throughout the reactor, however. The flux varies from front to back of the reactor in a cosine distribution, with a peak value about 1.4 times the average. Variation from side to side and from top to bottom is not great since reactor loadings can be varied to flatten the flux distribution in these directions. However, a few tubes near the outside of the reactor (fringe tubes) operate at lower power than the more centrally located tubes. For purposes of Waste Management the average reactor flux is usually all that needs to be considered.

The fission spectrum flux in a fuel element is roughly equal to the thermal flux at the same location. For each thermal neutron absorbed in the fuel (capture plus fission) slightly more than one fission spectrum neutron is generated. The number of fast neutrons crossing a given area of fuel per unit time will therefore be of the same order of magnitude as the number of thermal neutrons crossing the same area. At locations further removed from the fuel the fission spectrum flux is markedly lower than the thermal flux since the moderator converts fission spectrum neutrons into thermal neutrons.

2. Old Reactors

The six old reactors are designated as B, C, D, DR, F, and H. Only B and C are scheduled for continued operation at this time, with the others being held in standby condition or used for other purposes. The graphite core is 36 feet wide, 36 feet high, and 28 feet long. It

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is penetrated by 2004 process tubes, arranged on 8-3/8 inch centers in a square lattice. Most of the tubes are ribbed aluminum with 1.589" I.D., but C reactor has 1.632" aluminum and 1.681" smooth zirconium tubes. C reactor also has some tubes which are inserted into enlarged (or overbored) graphite channels. These overbore tubes are 2.147" I.D.

All of the fuel elements are tubes of uranium inside an aluminum can, with Al-Si bonding. Water flows both inside and outside of the fuel elements to obtain both internal and external cooling. Some of the fuel elements contain cross channels to permit mixing of the water between the inner and outer coolant streams. Some process tubes have been bowed by growth of the graphite moderator so that they can no longer take the normal 8" elements. Therefore, some 4" elements are also used. Most of the fuel is natural uranium with 0.72% U^{235}, but some elements contain enriched uranium with 0.947 w/o U^{235}. A summary of standard fuel elements for the old reactors and K reactor is given in Table II-1. The prefix designates the reactor type, the numeral shows the modification number, and the suffix designates the type of element (N for natural uranium, E for enriched uranium, and W for water mixing).

The old reactors have about 6.5 inches of graphite between tubes in the normal lattice, and 6.0 inches for the overbore lattice. The neutrons are very well thermalized, with a spectral index of 0.053 for normal uranium and 0.0660 for 0.947% enriched uranium. The higher spectral index for enriched uranium is caused largely by the greater depression of thermal flux in these elements. The reactors operate at total powers of between 1900 and 2300 megawatts, with an average neutron temperature of 580°K (307 C). Average power levels are 7.1 and 8.4 MW/T for natural and enriched uranium respectively, and the corresponding average goal exposures are 600 MWd/T and 850 MWd/T.

3. K Reactors

The two K reactors, KE and KW, are similar to the old reactors but the size and spacing are different. The graphite core is 41 feet wide, 41 feet high, and 33-1/2 feet long. It is penetrated by 3220 tubes arranged on 7-1/2 inch centers in a square lattice. Most of the tubes are smooth zirconium with 1.724" I.D. but a few are ribbed aluminum, 1.686" I.D. The fuel elements are similar to the ones used in the old reactors. Standard dimensions are shown in Table II-1.

The K reactors have about 5.5 inches of graphite between tubes. The spectral index is 0.0625 with normal uranium and 0.0730 with 0.947% enriched uranium. The average neutron temperature is 650°K (377 C). The reactors are operated at 4400 MW. Average power levels are 8.2 and 9.7 MW/T for natural and enriched uranium respectively, and the corresponding average goal exposures are 640 and 900 MWd/T.

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4. N Reactor

The newest Hanford production is N reactor. It is also the only reactor designed for both power generation and production of weapons grade plutonium (i.e., plutonium with a low Pu^{240} content, at present about 6%). The graphite core is 33 feet wide, 33 feet high, and 39 feet long. It is penetrated by 1004 zirconium tubes with 2.71" I.D. N reactor has a rectangular instead of a square lattice, with a spacing of 8 inches horizontally and 9 inches vertically. The graphite lattice contains rather large gas channels to permit escape of steam with minimum damage if a process tube should rupture.

The fuel elements are of a completely different design, being tube-in-tube rather than a single tube. Typical fuel element dimensions are as follows:

	Inner Tube		Outer Tube	
	Cold	Operating	Cold	Operating
Clad O. D.	1.249	1.263	2.406	2.427
Core O. D.	1.166	1.180	2.354	2.357
Core I. D.	0.492	0.495	1.819	1.829
Clad I. D.	0.438	0.441	1.764	1.774

The fuel element length is 417.6 inches cold, and 420.4 inches operating. For a normal loading, N-Reactor uses mostly 0.947% enriched uranium with a little natural uranium and some 1.25% enriched uranium for power flattening. Goal exposures for making weapons grade plutonium are about 600, 820, and 1200 MWd/T for natural uranium and 0.947% and 1.25% enriched uranium respectively. Other loadings, for making products other than plutonium, use 2.1% enriched uranium. The 2.1% enriched uranium will be exposed to about 2100 MWd/T at a power level of 17.7 MW/T, and will not yield weapons grade plutonium. Some of the 0.947% and 1.25% enriched uranium will also be exposed to 2200 MWd/T instead of the weapons-grade limits.

N-Reactor has somewhat less than 5 inches of graphite between tubes, and a spectral index of 0.105 for 0.947% enriched uranium. The reactor operates at 4000 MW with an average neutron temperature of 700°K (433 C), a fuel temperature of 380 C and a graphite temperature of 525 C.

E. TRANSURANIC ELEMENTS

1. Decay Characteristics

Elements with atomic numbers greater than that of uranium (92) are known as the transuranic elements. All transuranic nuclides are radioactive, and none of them occur in nature. Nuclear data for selected transuranics are presented in Table II-2. Past production

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activities have been concentrated on Pu-239 because of its fission characteristics which make it suitable for application in nuclear weapons. Other transuranic nuclides have desirable characteristics as radioisotope heat sources. In particular, Pu-238, Cm-242 and Cm-244 are good because of high heat output per unit weight and relatively low amount of penetrating radiations (neutrons and high energy gamma rays). Other transuranic nuclides are valuable as precursors of other products.

Five types of radioactive decay are important among the transuranics of interest at Hanford: alpha, beta, or positron emission, electron capture, and spontaneous fission. Alpha emitting nuclides are usually most important since they usually have rather long half lives and yield few high-energy gammas. Alpha emissions occur when an alpha particle (two protons and two neutrons, or a He^4 nucleus) leaves a larger nucleus. This process liberates about 5 MeV per decay, mostly as kinetic energy of the alpha particle. The daughter nuclide (nucleus after alpha emission) is usually in either the ground state or a state of very low excitation.

The next three decay types, together with neutron-induced reactions, form the desired alpha emitters. In beta decay an electron (beta particle) leaves the nucleus and a neutron is changed into a proton within the nucleus. The mass number stays the same, but the atomic number increases by one. Positron emission is similar to beta emission, but the emitted particle has a positive charge (positron) instead of a negative charge. A proton is changed into a neutron within the nucleus, and the atomic number decreases by one. Electron capture has the same general effect as positron emission, but occurs when an electron enters the nucleus. All three of these decay types are often accompanied by gamma emission. Competition among these decay types determines whether a nuclide of higher or lower atomic number is formed.

Spontaneous fission is similar to neutron-induced fission with respect to fission products and neutron emission. The rate of neutron-induced fission is dependent on the neutron flux, while the rate of spontaneous fission is solely dependent on the number of atoms of fissioning nuclide which are present. Since spontaneous fission is accompanied by both neutron and gamma radiations, it is not desirable in a heat-source nuclide.

2. Methods of Formation

The sequence of reactions and decays which form transuranics up to mass number 244 are shown in Figure II-5. Important routes to Pu-238 and Cm-242 are shown by heavy lines. It is difficult to obtain either Cm-242 or Pu-238 of high purity. In the irradiation of Np-237 to produce Pu-238, some of the Pu-238 will capture neutrons to form Pu-239. This results in a lower heat output from the plutonium. The amount of Pu-239 formed is quite dependent on irradiation time, with short irradi[redacted]ielding less Pu-239. Irradiations are therefore kept as short

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as possible within economic limits. Formation of Pu-236 by n,2n [redacted] on Np-237 does not affect heat generation appreciably since little Pu-236 is formed, but Pu-236 is not desired because of gamma rays which come from some rather remote daughters of Pu-236. Formation of Pu-236 is controlled by properly locating the neptunium targets within the reactors.

Curium made by irradiation of americium will have an isotopic composition dependent on initial americium composition, irradiation conditions, and decay time after irradiation. Highest Cm-242 content will be obtained if the initial americium is high in Am-241 content, and the irradiation and decay times are both short to minimize loss of Cm-242 by radioactive decay.

Another route to Pu-238 is through Cm-242. Irradiation of Am-241 followed by decay of the product Cm-242 will yield plutonium of a rather high Pu-238 content. However, Pu-242 is also formed by irradiating Am-241 and will contaminate the Pu-238 product unless it is removed prior to the Cm-242 decay. If the curium fraction from americium irradiation is separated and then allowed to decay, almost pure Pu-238 will be obtained.

Some of the transuranic nuclides have very high resonance integrals compared to their thermal cross sections. Reaction rates for these nuclides are quite sensitive to the resonance neutron flux, and resonance flux depression may be important. This is particularly important with U-238 because of its high concentration in Hanford fuels. A smaller correction is necessary with some other nuclides such as Pu-240.

3. Composition in Hanford Fuels

Empirical equations for total plutonium production, content of Pu-240 and Pu-241, and neptunium production have been developed by several workers for specific application to certain Hanford reactors and loading conditions. One such set of equations for K-Reactor are presented below.

$$\text{grams total Pu} = a\,M \exp(-b\,M + c\,M^2)$$

where M is the exposure in MWD/T, and for natural uranium (K5N elements) $a = 1.04068$, $b = 2.30612\times10^{-4}$, $c = 3.2012\times10^{-8}$. For enriched uranium (K5E elements) $a = 0.84995$, $b = 1.43717\times10^{-4}$, $c = 1.2291\times10^{-8}$.

$$\text{Percent Pu-240} = M / (a + b\,M)$$

where for K5N elements $a = 83.816$ and $b = 0.0428$. For K5E elements, $a = 123.915$, and $b = 0.03133$.

$$\text{Percent Pu-241} = a\,M^b$$

where for K5N elements $a = 2.4246\times10^{-5}$ and $b = 1.64967$. For K5E elements, $a = 7.0654\times10^{-6}$ and $b = 1.70693$.

Similar constants representing slightly lower plutonium production apply for the old reactors.

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Neptunium production from virgin uranium (i.e. no initial U-236) is approximately 1.24 + 0.00385 (M - 400) for natural uranium; 1.74 + 0.0042 (M - 500) for K5E elements; and 1.68 + 0.00407 (M - 500) for O3E elements.

Calculated amounts of certain long-lived transuranics in Hanford fuels are shown in Table II-3. Values were obtained from the above equations and from program ISOGEN computer runs. The computer runs were designed primarily for calculating fission products, and cross section and reactor flux values were not critically evaluated for effects on transuranic elements. However, the values are useful to show approximate amounts and isotopic compositions, and effects of changes in irradiation conditions.

F. FISSION PRODUCTS

1. Fission Yields

The fission process is rarely symmetrical (yielding two fission products of equal size), but ordinarily yields two products differing in mass by 30 to 50 units. The number of atoms of fission products with a given mass number produced per 100 fissions is known as the fission yield, Y, for that mass number. A fission yield curve for U-235 thermal fissions is shown in Figure II-6. This curve is typical in its general features of any fission caused by thermal or fission spectrum neutrons. The "fine structure" at masses 100 and 134 is caused by high nuclear stability for certain nuclear configurations of fission products. A high yield for a favored nuclide causes a high yield for its complement in the other mass peak. The location of the "fine structure" peaks relative to the major peaks varies with mass number of the fissioning nuclide. Fission yield values for thermal fissions of U-235 and Pu-239 and fission spectrum neutron fissions of U-238 are listed in Table II-4.

Another important distribution is superimposed on the mass distribution in fission. This is the nuclear charge distribution, which determines which element of a particular mass is formed in fission. On the average, each fission product must undergo about three beta decays to reach a stable nuclide; and nuclear charge is distributed so that the number of beta decays by the heavy and light products are about equal. Charge distribution around the average value follows a probability distribution. A primary fission product removed even four or five charge units from the average charge value might have an appreciable fission yield. The yield of a nuclide as a primary fission product is called its independent yield, and the sum of all independent yields for a given mass number is the total or chain yield. Ordinarily only chain yields need to be considered, but "shielded" nuclides such as Cs-136 are not formed from the lower atomic number chain members since the chain is terminated by a stable nuclide before reaching the "shielded" nuclide.

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2. Decay Properties

The rate of radioactive decay, dN/dt, is proportional to the amount of nuclide present, N. The constant of proportionality, λ, is called the decay constant and has units of reciprocal time.

$$\frac{dN}{dt} = -\lambda N$$

The time required for a nuclide to be reduced to one half of its initial amount is called the half life, τ. The nuclide will be reduced to one-fourth of its initial amount in two half lives, to one-eighth in three half lives, etc. The half life is related to the decay constant by the equation

$$\lambda = \ln 2/\tau = 0.69315/\tau$$

Most radioactive fission products and nuclides made from the fission products by neutron capture reactions decay by beta emission, but a few decay by positron emission or electron capture. Unless otherwise noted, the following discussion of beta decay applies to all three decay types. These processes were described in general terms in the preceding section on transuranic elements.

In beta decay a fixed amount of energy is liberated by one nuclide in being transformed into another nuclide. However, some of the energy is carried away by a neutrino and is not absorbed even by massive shielding. The effective energy is only that of the beta particle itself. The beta energies vary from zero to the total amount of energy available from the decay. The average beta energy is approximately one-third of the maximum energy, but it varies from about 25 to 50 percent of the maximum energy. Figure II-7 shows the approximate variation of average to maximum beta energy ratio with beta energy and atomic number. Additional variation is caused by differences in nuclear transition types. However, this is beyond the scope of this manual.

Some gamma radiation accompanies most beta decays. All gamma photons are emitted with the same energy for any given transition, instead of a spectrum of energies as with beta particles. The maximum gamma energy for a particular transition is thus the same as the average gamma energy. However, a single beta decay may give rise to more than one gamma transition.

Not all gamma transitions result in a gamma photon being emitted from the decaying atom. Sometimes part or all of the gamma photons are absorbed by an extra-nuclear electron of the decaying atom in a process called internal conversion. The electron is emitted from the atom with a kinetic energy equal to the gamma energy less the binding energy of the electron. When an electron drops into the site vacated in the internal conversion process an x-ray is emitted. Thus the radiation observed from gamma transitions in a given nuclide may consist partly

of monoenergetic electrons and x-rays, and fewer gamma photons than might be expected. Internal conversion is very common for gammas of less than 0.2 MeV and usually negligible for gammas above 0.7 MeV.

Some of the decay properties of fission products with half lives of over three days are shown in Table II-5. Units used to express some of the properties are more fully explained in the next section.

3. Units of Measurement

3.1 Curies

The decay rate is most commonly expressed in units of curies. Originally the curie was the disintegration rate of the radon-222 in equilibrium with one gram of radium, but it has since been standardized as 3.700×10^{10} disintegrations per second, which is the same as 2.22×10^{12} disintegrations per minute. As defined, the unit is applicable to beta and alpha radiation, but must be modified somewhat for application to gamma radiation. Two usages of the term "gamma curie" are common at Hanford. The first is based on gamma photons per second regardless of energy, while the second is based on gamma photons of some particular energy per second. For example, Ce-144 is ordinarily in equilibrium with its short-lived daughter, Pr-144, and both decay by beta emission. Ce-144 emits a low energy gamma in about 20 percent of its disintegrations, and Pr-144 emits a 2.2 MeV gamma in 0.8 percent of its disintegrations. Thus, 1000 beta curies of Ce-144, 2000 beta curies of CrPr-144, 200 gamma curies of Ce-144, and 8 curies of 2.2 MeV gamma from CePr-144 are all expressions defining about the same amount of activity. Any of these units is quite acceptable provided it is adequately defined by the user.

3.2 Watts

The curie refers to the rate of disintegrations without regard to energy, while the watt refers to the energy liberated without regard to the disintegration rate. The watt is the logical unit to use if heating is being considered. Since one MeV is equal to 1.602×10^{-6} ergs, one curie of one MeV radiation emits 3.7×10^{10} MeV/sec or 5.93×10^{4} ergs per second, which is equivalent to 5.93 milliwatts. Conversion from curies to watts may be accomplished if the average energy dissipated per decay is known.

$$\text{Watts} = \text{curies} \times \text{energy in MeV} \times 5.93 \times 10^{-3}$$

Particles such as alphas and betas usually lose their energy in the source itself, while gamma radiation may lose its energy at some distance from the source. Therefore, heat generation is often expressed as beta watts (including other radiations absorbed inside the source) and gamma watts (including only radiation which is often, but not necessarily, lost outside the source). The amount of gamma radiation absorbed within the source is dependent on source size and shape.

For example, cesium-137 emits two betas. The weaker one has a maximum energy of 0.52 MeV, average energy of 0.19 MeV, and is emitted in 92 percent of the disintegrations. The stronger beta has a maximum energy of 1.18 MeV, average energy of about 0.42 MeV, and is emitted in only 8 percent of the disintegrations. The weaker beta is followed by a 0.66 MeV gamma (from Ba-137m) which is internally converted about ten percent of the time. The watts generated by 1000 curies of cesium-137 may then be calculated as follows:

watts from 0.52 MeV beta = $920 \times 0.19 \times 5.93 \times 10^{-3} = 1.04$

watts from 1.18 MeV beta = $80 \times 0.42 \times 5.93 \times 10^{-3} = 0.20$

watts from gamma photons = $828 \times 0.66 \times 5.93 \times 10^{-3} = 3.24$

watts from conversion electrons = $92 \times 0.62 \times 5.93 \times 10^{-3} = 0.34$

watts from x-rays = $92 \times 0.04 \times 5.93 \times 10^{-3} = 0.02$

This is 1.58 watts of electrons (beta plus conversion electrons), 3.24 watts of gamma, and only 0.02 watt of x-rays; or 1.60 watts of soft components, and 3.24 watts of gammas.

3.3 Grams

In considering large amounts of fission products in a rather pure state it is frequently helpful to express the quantity in units of grams. Usage at Hanford has usually been to give the total grams of that particular element produced in a reactor, whether the isotopes are active or inactive. The various possible sources of error in determining the weight of a fission product element are well exemplified in the case of cesium. Three isotopes are produced in fission product chains: stable cesium-133, 2×10^6 year; cesium-135, and 30 year Cs-137. During irradiation some of the cesium-133 captures neutrons to form cesium-134 which decays with a half-life of 2.3 years. The cross section of cesium-133 is low enough that the weight change by neutron capture and the decay of cesium-134 can usually be neglected. Cesium-136 is formed in very low yield in fissions since Xenon-136 is the stable end product of the 136 chain. However, a low percentage of the fissions result in cesium-136 as a primary fission product, thus giving an additional source of cesium. The 135 chain is the most complicated. Xenon-135, which is the parent of cesium-135, has a neutron capture cross section of 3.5×10^6 barns, so that at high neutron fluxes much of this nuclide reacts by neutron capture to give stable Xenon-136 rather than cesium-135 by beta decay. A brief summary of the various cesium isotopes produced in a reactor is as follows:

133 - amount formed in fission less amount removed by neutron capture.

134 - amount formed by neutron capture by cesium-133 less radioactive decay.

135 - amount of 135 chain formed in fission less amount of Xenon-135 which decayed by neutron capture rather than by beta decay.

136 - amount formed as primary fission fragment less radioactive decay.

137 - amount formed in fission less radioactive decay.

All of these various possibilities should be considered when calculating the total weight of any element formed in reactors. Methods of calculating the growth and decay of the various isotopes are given in a later section of this report.

Another term which is often used along with grams of fission products is the specific activity, usually expressed in curies per gram. The activity of a radioactive nuclide is given by the product of the decay constant and the number of atoms of the nuclide. If the half-life is in days, the specific activity A in curies per gram is given by

$$A = \frac{1.30 \times 10^8}{\text{atomic weight} \times \text{half-life}} .$$

This value of specific activity must be corrected for the weight of other nuclides of the same element before being used with the total weight of an element as described above.

3.4 Tons of Uranium Equivalent

This expression is convenient in relating fission product quantities to plant production, but the term is not exact unless irradiation conditions are defined in some detail. Short-lived nuclides depend almost exclusively on the specific reactor power (MW/T) and cooling time, while long-lived nuclides depend on the integrated power (MWD/T). Amounts of fission products per ton of uranium may be calculated by the methods outlined below.

G. GENERATION AND DECAY CALCULATIONS

1. Fundamentals

In a nuclear reactor some atoms of a nuclide may decay by radioactivity, while other atoms of the same nuclide may be destroyed by neutron reactions. The total rate of destruction is the sum of the rate of radioactive decay and the rate of neutron absorption. The destruction rate, dN/dt, is proportional to the number of atoms of that nuclide present, N, with the proportionality constant being the destruction constant, Λ.

$$\frac{dN}{dt} = -\Lambda N = -(\lambda + \sigma\Phi)N$$

Both the radioactive decay constant, λ, and the neutron absorption constant, $\sigma\Phi$ (the product of the cross section and flux), may be composed of two or more partial constants each of which yields a particular daughter nuclide. That portion of the total destruction constant which produces a particular daughter nuclide is known as the production constant, Λ^*, for that daughter from that parent. The production constant may be equal to the destruction constant if the parent has only one mode of decay, or it may be equal to a total or partial constant for either radioactive decay or neutron absorption. For example, plutonium-241 decays mostly by beta emission, but has a small alpha decay branch; and with neutrons it undergoes both fission and capture reactions. At a constant flux it has a single destruction constant, but four production constants, a different one for each mode of destruction.

Sometimes two or more decays or nuclear reactions in sequence lead from the parent to the daughter of interest. The rate equation then contains a term for production of the daughter from the parent as well as a term for destruction of the daughter:

$$\frac{dN_2}{dt} = \Lambda_1^* N_1 - \Lambda_2 N_2$$

This simply says that the rate of change of the daughter is equal to the rate of production from the parent less the rate of destruction of the daughter.

2. Bateman Equations

The rate equations are easy to work with, but must be integrated to obtain the amount of a nuclide present at a given time. The simple rate equation for a single nuclide may be easily integrated to obtain the following:

$$N_1 = N_1^o \exp(-\Lambda_1 t)$$

where N^o denotes the amount present initially. This equation gives the amount of parent remaining at time t. For the amount of the first daughter remaining at time t the equation is more complicated:

$$N_2 = N_1^o \frac{\Lambda_1^*}{\Lambda_2 - \Lambda_1} [\exp(-\Lambda_1 t) - \exp(-\Lambda_2 t)]$$

For the second daughter (third chain member) the equation becomes

$$N_3 = N_1^o \Lambda_1^* \Lambda_2^* \left[\frac{\exp(-\Lambda_1 t)}{(\Lambda_2 - \Lambda_1)(\Lambda_3 - \Lambda_1)} - \frac{\exp(-\Lambda_2 t)}{(\Lambda_2 - \Lambda_1)(\Lambda_3 - \Lambda_2)} + \frac{\exp(-\Lambda_3 t)}{(\Lambda_3 - \Lambda_1)(\Lambda_3 - \Lambda_2)} \right]$$

These equations, called the Bateman equations, express the fundamental relationships in radioactive decay or in neutron absorption at constant flux. A general form for these equations for the nth daughter, N_n, present at time t, can be conveniently considered as the product of two parts. The first part is the product of finite constants, and the second or saturation part, $S(\Lambda_i t)$, is a function of the product of total destruction constants and time. A form of the general expression is

$$N_n = N_1^o \left[\prod_{k=i}^{n-1} (\Lambda_k^* t) \right] S(\Lambda_i t)$$

where

$$S(\Lambda_i t) = \sum_{i=1}^{n} \frac{\exp(-\Lambda_i t)}{\prod_{\substack{j=1 \\ j \neq i}}^{n} (\Lambda_j t - \Lambda_i t)}.$$

The reactor flux to be used in evaluating the destruction constant must be derived for each desired combination of reactor type, integrated exposure (MWD/T), and exposure rate (MW/T). The ratio of integrated exposure to exposure rate defines the time in the reactor. The total number of fissions can be obtained from the integrated exposure since, at 200 MeV per fission, there are 2.70×10^{21} fissions per MWD. By trial and error the calculated number of fissions can be made equal to this derived value, and the flux required to achieve agreement is taken as the reactor flux. The number of thermal and resonance fissions may be obtained from Bateman equations for each of the fissioning nuclides, with the last chain member having a decay constant of zero and

a fission yield of one. The fissions from U-238 (due to fast neutrons) are, in Hanford production reactors, about 0.064 times the total number of fissions from thermal and resonance neutrons. These fissions must also be included in making the total number of fissions equivalent to the desired integrated exposure. As a crude approximation, the integrated conventional flux, Φt, is 1.9×10^{17} M/X where M is the integrated exposure in MWd/T and X is the percent of U-235 in the fuel.

3. Constant Fission Rate Method

Use of Bateman equations assumes the neutron flux to be constant throughout the irradiation, while another method assumes the fission rate (or specific reactor power) to be constant. Neither is exactly constant because of changes in fuel composition during irradiation and perturbations due to charge-discharge operations. However, each quantity is sufficiently constant for most fission product calculation purposes. With Bateman equations fission product generation is calculated separately for each fissioning nuclide and the results are summed. The constant fission rate method gives total fission product amounts upon evaluation of a rather simple expression in most cases. Calculation involving neutron capture reactions is possible by either method, but radioactive decay after irradiation must be handled by Bateman equations.

The number of fissions per unit time determines the heat generation rate in the reactor, or the reactor power level, P (usually expressed in MW/T). The rate of formation of a particular primary fission product is proportional to the product of power level and weighted average fission yield, $\bar{Y}$. Rate equations similar to those described above may be set up and integrated. The equation for the activity in curies of a primary fission product is as follows:

$$A = 8.45 \times 10^5 \, P \, \bar{Y} \, \lambda \left[\frac{1 - \exp(-\Lambda t)}{\Lambda} \right]$$

For the activity of the daughter of a primary fission product, the equation is:

$$A_2 = 8.45 \times 10^5 \, P \, \bar{Y} \, \Lambda_1 \lambda_2 \left[\frac{1}{\Lambda_1 \Lambda_2} - \frac{\exp(-\Lambda_1 t)}{\Lambda_1 (\Lambda_2 - \Lambda_1)} + \frac{\exp(-\Lambda_2 t)}{\Lambda_2 (\Lambda_2 - \Lambda_1)} \right]$$

The quantity in brackets is identical to the saturation part of the general Bateman equation except for the "t" terms in the denominator. It includes one nuclide more than the number of members of the fission product chain, with the destruction constant for this added member being zero. A general equation could be written similar to the generalized Bateman equation.

For stable nuclides the activity is necessarily zero, but the number of atoms is a significant quantity. The number of atoms of a primary

fission product is:

$$N = 2.70\text{x}10^{21}\ P\ t\ \bar{Y}\left[\frac{1 - \exp(-\Lambda t)}{\Lambda}\right]$$

Again a general equation similar to the Bateman equations could easily be written.

4. Average Fission Yield

The Bateman equations deal with a single fissioning nuclide at a time, and thus use only the fission yield values for that nuclide. The constant fission rate method deals with all fissions simultaneously and uses a fission yield based on a weighted average of fission yield values for all of the fissioning nuclides. For stable or long-lived fission product nuclides the weighting factor is simply the fraction of fissions from each of the fissioning nuclides:

$$\bar{Y} = 0.06Y_F + (0.94-f)Y_U + fY_{Pu}$$

where the subscripts U and Pu refer to uranium-235 and plutonium-239, respectively, F refers to fast fissions from uranium-238, and f is the fraction of total fissions from plutonium. The value of f may be determined from the Bateman equations used in determining reactor flux. Because of the small fraction of fissions from plutonium-241 it is usually not included in determining average fission yields.

The number of fissions per unit time decreases with time for uranium-235, but increases with time for plutonium-239. Therefore, the decay time in the reactor is different for the two parents. If the half-life of a primary fission product is less than the irradiation time, and the fission yields are different for uranium-235 and plutonium-239, an additional term in the weighted average yield should also be used:

$$\bar{Y} = 0.06Y_F + (0.94-f)Y_U + f\ Y_{Pu} + (f'-f)(1-e^{-0.1\Lambda t})(Y_{Pu}-Y_U)$$

where f' is the fraction of the final fission rate which is due to plutonium, and Λ is for the primary fission product. This places additional weight on plutonium fissions since they occur at an increased rate in the latter part of the irradiation, resulting in a reduced in-reactor decay time. This equation may be used for primary fission products regardless of their destruction constants since it reduces to the proper values for both large and small values of the destruction constant.

The correction for different in-reactor decay times is more complicated for fission products after the primary one. Ordinarily sufficient accuracy is obtained if the in-reactor decay correction is ignored for such subsequent fission products.

H. COMPUTER PROGRAMS

1. Nomenclature

Several computer programs have been developed for calculating fission product generation. The data described in the next section were obtained by program ISOGEN which is accurate and flexible, but requires rather careful programming. MELEAGER provides for more automatic control of changes in reactor flux and effective cross sections with time, but works with only a few nuclides at a time and is difficult to program for a large number of fission products. RIBD calculates production of a large number of fission products with relatively simple input but does not provide the flexibility of ISOGEN or MELEAGER in calculating transuranic formation, decay by electron capture, positron emission or alpha emission, or formation of nuclides by n,2n reactions. Another code, ALCHEMY, permits excellent accuracy, particularly when used in connection with good neutron diffusion codes, but requires excessive programming and computer time for application to fission product inventory calculations.

2. Tabulation of Results

Fission product data were calculated for several reactor conditions by program ISOGEN using Bateman equations, and based on one ton (2000 lbs) of uranium feed. The reactor operation was divided into three irradiation segments of approximately equal duration with constant power level for each irradiation. After the first and second irradiation steps a reactor shut-down was allowed for charge-discharge operations, so that the reactor was operating only about 85% of the time. Nuclides with a half-life of less than three days were not considered unless they are daughters of longer-lived nuclides.

Tables II-6 through II-14 show the activity as a function of decay time for the nuclides listed (not including any short-lived daughter activity). Beta watts in Tables II-15 to II-23 and gamma watts in Tables II-24 to II-32 do include contributions from both parent and short-lived daughter.

Long-lived nuclides such as strontium-90 and cesium-137 depend only on integrated exposure (MWd/T) and not on exposure rate (MW/T), while short-lived nuclides such as iodine-131 depend only on exposure rate. Long-loved nuclides such as cesium-134 which are formed from a fission product by neutron capture depend on about the square of the integrated exposure, while similar short-lived nuclides such as promethium-148M depend on the first power of the integrated exposure. Nuclides which have greatly different fission yields from uranium and plutonium do not vary in a simple manner with either integrated exposure or exposure rate. However, for most nuclides the above generalizations should permit reasonably accurate interpolation or extrapolation of the results.

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TABLE II-1
STANDARD FUEL ELEMENTS

	Fuel Element Specifications										
	Natural Uranium							0.947% Enriched Uranium			
	C2N	C5N	C6N	K4N	K5N	O3N	O5N	C3E	K4E	K5E	O3E
Canned Length	8.965	8.965	8.865	8.965	8.865	8.965	4.665	6.640	6.640	6.540	6.640
Core Length	8.378	8.378	8.325	8.378	8.325	8.378	4.078	6.053	6.053	6.000	6.053
Can O.D.	1.466	1.494	1.986	1.460	1.520	1.444	1.443	1.460	1.459	1.509	1.443
Core O.D.	1.370	1.406	1.883	1.370	1.431	1.356	1.356	1.370	1.370	1.419	1.356
Core I.D.	0.481	0.488	0.452	0.498	0.533	0.423	0.423	0.488	0.513	0.545	0.423
Can I.D.	0.375	0.375	0.334	0.385	0.420	0.310	0.310	0.375	0.400	0.432	0.310
Weight	7.37	7.78	14.87	7.29	7.86	7.43	3.60	5.29	5.21	5.49	5.36

Notes: Watermix elements C3W, K4W, and O3W have the same core and can dimensions as the corresponding E suffix elements, but an aluminum watermix section is added to one end.

Each type of element may also exist with spacers added to the outside in three or four radial locations. These are called bumper elements.

TABLE II-2

NUCLEAR DATA FOR SELECTED ACTINIDES

Symbol	Half Life	Decay Type	Neutron Cross Section: Product	Thermal	Resonance	Heat Generation, Watts: Per Kilocurie	Per Gram
U-234	2.485×10^5 y (2×10^{16} y	Alpha Fission)	U-235	97	650	28.8	1.77×10^{-4}
U-235	7.13×10^8 y (1.9×10^{17} y	Alpha Fission)	U-236 Fission	103 532	51.0 8.4	27.5	5.87×10^{-8}
U-236	2.39×10^7 y (2×10^{16} y	Alpha Fission)	U-237	8	400	27.2	1.72×10^{-8}
U-237	6.75 d	Beta	U-238 Fission	150 500	225 350	2.07	169
U-238	4.51×10^9 y (8×10^{15} y	Alpha Fission)	U-239	2.74	280	25.3	8.43×10^{-9}
U-239	23.5 m	Beta	U-240 Fission	22 15		2.90	
U-240	14.1 h	Beta				0.593	
Np-236m	22 h (43%	Beta EC)				0.830	
Np-236	>5000 y	Beta	Fission	2500			
Np-237	2.14×10^6 y	Alpha	Np-238	170 0.02	870	29.4	2.07×10^{-6}
Np-238	2.10 d	Beta	Np-239 Fission	1600 1600		4.98	1300
Np-239	2.35 d	Beta	Np-240m Np-240	35 25	210 150	2.67	620
Np-240m	7.3 m	Beta				6.16	
Np-240	60 m	Beta				8.59	
Pu-236	2.85 y (3.5×10^9 y	Alpha Fission)	Fission	170		34.6	18.4
Pu-238	89 y (4.9×10^{10} y	Alpha Fission)	Pu-239 Fission	489 17	3000 16	33.1	0.559
Pu-239	24360 y (5.5×10^{15} y	Alpha Fission)	Pu-240 Fission	657 1208	362 454	31.1	$1.9. \times 10^{-3}$
Pu-240	6760 y (1.22×10^{11} y	Alpha Fission)	Pu-241 Fission	318 0	8900 2.6	31.1	6.86×10^{-3}
Pu-241	13.0 y (0.004%	Beta Alpha)	Pu-242 Fission	527 1400	30 80	0.030	3.38×10^{-3}
Pu-242	3.79×10^5 y (7×10^{10} y	Alpha Fission)	Pu-243 Fission	18 0	1275 1.3	29.5	1.15×10^{-4}
Pu-243	4.98 h	Beta	Pu-244	170		1.20	
Pu-244	7.6×10^7 y (2.5×10^{10} y	Alpha Fission)	Pu-245	1.8		27.0	5.20×10^{-7}
Pu-245	10.1 h	Beta	Pu-246 Am-242m	260 70	 52		
Am-241	458 y	Alpha	Am-242 Fission	840 2.9	620 10	33.4	0.108
Am-242m	152 y (10%	Beta EC)	Am-243 Fission	1600 6400		1.30	0.0127
Am-242	16 h (19%	Beta EC)	Fission	3000		1.13	912
Am-243	7950 y	Alpha	Am-244m Am-244	100 2.6	1400 46	32.2	6.19×10^{-3}
Am-244m	25m (0.039%	Beta EC)				3.20	0.0987
Am-244	10 h	Beta	Fission	2300		0.652	837
Am-245	2.07 h	Beta					
Cm-242	163 d (7.2×10^6 y	Alpha Fission)	Cm-243	20		36.8	122
Cm-243	32 y (0.26%	Alpha EC)	Cm-244 Fission	250 630	200 350	36.5	1.68
Cm-244	18.1 y (1.4×10^7 y)	Alpha Fission	Cm-245	15	650	34.9	2.83
Cm-245	9320 y	Alpha	Cm-246	200		33.3	5.21×10^{-9}

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TABLE II-3
TRANSURANIC CONTENT OF SPENT FUELS

			Grams per Ton of Uranium											
MWd/T	MW/T	U^{235}, %	Pu^{238}	Pu^{239}	Pu^{240}	Pu^{241}	Pu^{242}	Np^{237}	Am^{241}	Am^{242m}	Am^{243}	Cm^{242}	Cm^{243}	Cm^{244}
640	8.17	Natural	0.041	542	37.3	2.70	0.066	1.99	0.056					
750	10	Natural	0.056	636	47.6	4.90	0.134	2.59	0.079	4.3 (-5)	2.5 (-6)	3.5 (-4)	2.4 (-7)	2.7 (-8)
900	10	Natural	0.083	711	62.5	7.53	0.251	3.16	0.159	9.1 (-5)	6.3 (-6)	6.7 (-4)	6.7 (-7)	8.3 (-8)
900	9.7	0.947	0.072	634	41.0	4.02	0.109	3.42	0.086					
1000	10	0.947	0.090	691	49.2	5.30	0.164	3.84	0.115	6.9 (-5)	4.4 (-6)	5.0 (-4)	4.4 (-7)	2.6 (-8)
1200	10	0.947	0.133	798	67.0	8.48	0.321	4.68	0.191	1.6 (-4)	1.2 (-5)	1.2 (-3)	1.2 (-6)	1.8 (-7)
2200	11	0.947	0.80	1336	216	33	2.40	12.3	0.87					
2200	11	1.25	0.57	1275	181	27.1	1.50	12.3	0.71					
2100	10.6	2.1	0.36	995	70.6	7.92	0.226	12.3	0.205	2.4 (-4)	1.5 (-5)	1.6 (-3)	1.5 (-6)	2.3 (-7)

Numbers in parentheses designates a power of 10. 4.3 (-5) = 4.3×10^{-5} or 0.000043

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TABLE II-4

CUMULATIVE FISSION YIELDS

Nuclide		Fission Yield, Percent U-235	Pu-239	U-238
Zn	72	1.6×10^{-5}	1.2×10^{-4}	1.0×10^{-4}
Ge	73	1.1×10^{-4}	3.0×10^{-4}	3.0×10^{-4}
Ge	74	3.5×10^{-4}	6.0×10^{-4}	6.0×10^{-4}
As	75	8.0×10^{-4}	0.0012	0.001
Ge	76	0.0020	0.003	0.002
As	77	0.0083	0.006	0.004
Se	78	0.020	0.013	0.008
Se	79	0.056	0.03	0.017
Se	80	0.11	0.06	0.035
Br	81	0.21	0.10	0.075
Se	82	0.35	0.18	0.13
Kr	83	0.496	0.29	0.22
Kr	84	0.953	0.47	0.38
Kr	85m	1.31	0.539	0.65
Kr	86	1.84	0.76	0.95
Rb	86	2.9×10^{-5}	2.3×10^{-5}	---
Rb	87	2.50	0.92	1.5
Sr	88	3.58	1.42	2.1
Sr	89	4.73	1.71	2.5
Sr	90	5.77	2.25	2.9
Y	91	5.97	2.61	3.3
Zr	92	6.03	3.14	3.9
Zr	93	6.51	3.97	4.5
Zr	94	6.55	4.48	4.9
Zr	95	6.55	5.03	5.2
Zr	96	6.41	5.17	5.5
Mo	97	6.33	5.65	5.8
Mo	98	5.93	5.89	6.1
Mo	99	6.25	6.10	6.3
Mo	100	6.58	7.10	6.4
Ru	101	5.00	5.91	6.5
Ru	102	4.10	5.99	6.4
Ru	103	2.90	5.67	6.2
Ru	104	1.80	5.93	5.7
Rh	105	0.90	3.90	4.7
Ru	106	0.38	4.57	2.3
Pd	107	0.17	3.10	1.1
Pd	108	0.07	2.2	0.53
Ag	109	0.03	1.4	0.26
Pd	110	0.02	0.56	0.13
Ag	111	0.016	0.23	0.07
Cd	112	0.013	0.12	0.06
Cd	113	0.012	0.08	0.05
Cd	114	0.011	0.055	0.045
Cd	115m	0.0007	0.0026	0.0025
Cd	115	0.0103	0.0384	0.0375
Cd	116	0.011	0.04	0.04
Sn	117	0.011	0.04	0.035
Sn	118	0.011	0.04	0.035
Sn	119	0.011	0.04	0.035

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TABLE II-4 (Continued)

Nuclide	Fission Yield, Percent		
	U-235	Pu-239	U-238
Sn 120	0.011	0.04	0.04
Sn 121	0.012	0.043	0.04
Sn 122	0.013	0.05	0.04
Sn 123m	0.0013	0.005	0.004
Sb 123	0.014	0.056	0.041
Sn 124	0.017	0.08	0.05
Sn 125	0.012	0.04	0.017
Sb 125	0.036	0.12	0.05
Sn 126	0.10	0.20	0.07
Sn 127	0.125	0.195	0.065
Sb 127	0.25	0.39	0.13
Te 128	0.5	0.85	0.26
Te 129m	0.36	0.54	0.19
I 129	1.0	1.5	0.53
Te 130	2.0	2.5	1.1
Te 131m	0.435	0.25	0.35
I 131	2.94	3.78	2.3
Te 132	4.22	5.26	4.7
Xe 133m	0.16	0.17	0.14
Xe 133	6.62	6.91	5.7
Xe 134	7.74	7.47	6.2
Xe 135	6.45	7.17	6.4
Xe 136	6.47	6.63	6.5
Cs 136	0.0068	0.084	0.00095
Cs 137	6.22	6.63	6.4
Ba 138	6.68	6.31	6.3
La 139	6.42	5.87	6.1
Ba 140	6.24	5.6	5.8
Ce 141	5.73	5.7	5.5
Ce 142	5.84	5.01	5.2
Ce 143	5.88	4.57	4.9
Ce 144	5.35	3.93	4.5
Nd 145	3.87	3.13	3.9
Nd 146	2.94	2.60	3.3
Pm 146	1.2×10^{-6}	1.0×10^{-6}	---
Nd 147	2.03	2.07	2.9
Nd 148	1.68	1.73	2.5
Pm 149	1.01	1.32	2.1
Nd 150	0.634	1.01	1.5
Pm 151	0.398	0.80	0.95
Sm 152	0.236	0.62	0.65
Sm 153	0.148	0.37	0.38
Sm 154	0.050	0.29	0.22
Eu 155	0.029	0.23	0.13
Eu 156	0.015	0.11	0.075
Gd 157	0.0078	0.065	0.035
Gd 158	0.0020	0.021	0.008
Gd 160	3.0×10^{-4}	0.008	0.004
Tb 161	7.6×10^{-5}	0.0039	0.0017

TABLE II-5

NUCLEAR DATA FOR SELECTED FISSION PRODUCTS

Nuclide	Half Life	Decay Energy, MeV Beta	Decay Energy, MeV Gamma	Cross Section, Barns Thermal	Cross Section, Barns Resonance	Remarks
Se 79	7.0×10^4 y	0.06	---	---	---	
Kr 85	10.4 y	0.25	0.005	7	26	
Rb 85	Stable	---	---	1.0	1.31	
Rb 86	18.7 d	0.649	0.095	---	---	
Sr 89	50.4 d	0.58	0.0002	0.4	---	
Sr 90	28 y	0.199	---	1	1.4	
Y 90	64.2 h	0.94	---	3.5	---	
Y 91	58 d	0.62	---	1.4	---	
Zr 93	9.5×10^5	0.014	---	1.1	28	4% to Nb-93m
Nb 93m	3.7 y	0.029	---	---	---	
Zr 95	65 d	0.119	0.724	13.9	109	2% to Zr-95m
Nb 95m	90 h	0.235	---	---	---	
Nb 95	35 d	0.046	0.757	7	---	
Tc 99	2.1×10^5 y	0.084	---	22	130	
Ru 103	39.6 d	0.113	0.505	---	---	Includes Rh-103m
Rh 103	Stable	---	---	171	1110	
Rh 105	36 h	0.18	0.016	21000	165000	
Ru 106	1.0 y	1.4	0.256	0.35	2.0	Includes Rh-106
Pd 107	7.0×10^6 y	0.01	---	10	36	
Pd 108	Stable	---	---	12.2	183	
Cd 108	Stable	---	---	10	---	
Ag 109	Stable	---	---	92	1390	3 b to Ag-110m
Cd 109	1.3 y	0.088	---	---	---	
Ag 110m	260 d	0.095	2.71	80	---	
Ag 111	7.5 d	0.37	0.023	---	---	
Cd 115m	43 d	0.60	0.018	---	---	
Cd 115	2.3 d	0.30	0.56	---	---	
In 115	5.0×10^{14} y	0.2	---	203	3380	
Sb 121	Stable	---	---	6.06	200	
Sn 123m	125 d	0.54	0.022	---	---	
Sb 123	Stable	---	---	3.345	160	
Sb 124	60 d	0.37	1.9	2000	---	
Sn 125	9.4 d	0.93	0.10	---	---	
Sb 125	2.7 y	0.115	0.393	1.56	---	21% to Te-125m
Te 125m	58 d	0.145	---	---	---	
Sn 126	1.0×10^5 y	0.02	---	0.3	---	14% to Sb-126
Sb 126	12.5 d	---	---	---	---	
Sb 127	3.9 d	0.4	0.45	---	---	
Te 127m	105 d	0.09	---	---	---	2% to I-127
Te 127	9.3 h	0.23	0.004	---	---	
I 127	Stable	---	---	6.4	140	
Te 129m	33 d	0.27	---	---	---	32% to I-129
Te 129	67 m	0.48	0.43	---	---	
I 129	1.6×10^7 y	0.08	---	28	24	
I 131	8.05 d	0.34	0.38	50	---	1% to Xe-131m
Xe 131m	12 d	0.159	0.005	---	---	
Te 132	78 h	0.061	0.23	---	---	
Xe 133	5.27 d	0.15	0.03	190	---	
Cs 133	Stable	---	---	30.6	490	
Cs 134	2.1 y	0.15	1.58	136	---	
Xe 135	2.0×10^6 y	0.058	---	8.7	58	
Cs 135	9.2 h	0.30	0.26	3.22×10^6	---	
Cs 136	13 d	0.11	2.49	---	---	
Cs 137	30 y	0.26	0.56	0.11	0.26	Includes Ba-137m
Ba 140	12.8 d	0.32	0.22	12	---	
La 140	40.2 h	0.51	2.39	3.1	---	
Ce 141	32.5 d	0.18	0.07	30	---	
Pr 143	13.7 d	0.315	---	89	154	
Ce 144	285 d	1.33	0.172	1.0	2.2	Includes Pr-144
Pm 146	2020 d	0.12	0.78	8400		35% to Sm-146
Nd 147	11.1 d	0.28	0.22	---	---	
Pm 147	2.62 y	0.0608	---	235	3110	110 b to Pm-148m
Sm 147	1.06×10^{11} y	2.18	---	90	1300	
Pm 148m	42 d	0.26	1.98	27000	32000	8% to Pm-148
Pm 148	5.4 d	0.71	0.64	2000	44000	
Sm 148	1.2×10^{13} y	2.14	---	9	46	
Sm 149	4.0×10^{14} y	1.84	---	90100	---	
Sm 150	Stable	---	---	100	215	
Sm 151	90 y	0.02	---	9720	---	
Eu 151	Stable	---	---	6851	4700	2200 b to Eu-152m
Sm 152	Stable	---	---	210	3057	
Eu 152m	9.3 h	0.55	0.23	---	---	25% to Sm-152
Eu 152	13 y	0.13	1.16	5000	---	73% Sm-152
Eu 153	Stable	---	---	280	1020	
Eu 154	16 y	0.23	1.26	1400		
Eu 155	1.81 y	0.10	0.023	13000	---	
Eu 156	15 d	0.42	1.3	---	---	

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TABLE II-6

FISSION PRODUCT ACTIVITY FROM NATURAL URANIUM

640 MWd/T, 8.17 MW/T

Activity, Curies per Ton of Uranium

Nuclide	Discharge	90 d	120 d	180 d	270 d	1 y
Kr 85	271.7	267.7	266.3	263.4	259.1	254.6
Rb 86	10.01	.3561	.1171	.0127	.0005	---
Sr 89	188900	54770	36260	15890	4607	1243
Sr 90	1945	1934	1930	1922	1910	1898
Y 91	222800	75990	53100	25920	8842	2832
Zr 95	238800	91460	66420	35030	13420	4858
Nb 95	136600	134200	108600	65190	27290	10260
Ru 103	164600	34070	20150	7050	1459	275.4
Ru 106	7775	6555	6192	5525	4658	3888
Ag 110m	.3968	.3122	.2882	.2456	.1932	.1499
Ag 111	3185	.7776	.0486	.0002	---	---
Cd 115m	47.76	11.19	6.902	2.624	.6149	.1324
Sn 123m	41.97	25.48	21.57	15.47	9.390	5.537
Sn 125	1116	1.460	.1603	.0019	---	---
Sb 125	206.6	204.0	199.8	191.5	179.8	168.1
Te 125m	25.21	42.84	41.96	40.22	37.76	35.30
Sb 127	18760	.0021	---	---	---	---
Te 127m	1080	660.9	542.2	364.8	201.4	107.4
Te 129m	20310	3067	1633	463.1	69.93	9.457
I 131	199200	87.95	6.643	.0377	---	---
Xe 131m	1807	31.13	5.685	.1805	.0010	---
Te 132	303500	.0014	---	---	---	---
Xe 133	451000	3.322	.0642	---	---	---
Cs 134	185.6	171.1	166.5	157.7	145.4	133.4
Cs 136	1207	9.949	2.009	.0820	.0007	---
Cs 137	2132	2120	2116	2108	2096	2083
Ba 140	396000	3027	596.4	23.14	.1769	.0010
Ce 141	303200	44470	23450	6524	956.9	125.5
Ce 144	61440	49360	45890	39660	31860	25270
Pr 143	358900	4238	929.0	44.63	.4697	.0038
Pm 146	.0015	.0014	.0014	.0014	.0013	.0013
Nd 147	136200	493.7	75.83	1.789	.0065	---
Pm 147	6125	7231	7080	6780	6352	5929
Pm 148m	805.6	182.4	111.2	41.30	9.352	1.942
Pm 148	4519	16.79	10.21	3.792	.8586	.1783
Sm 151	26.45	27.60	27.58	27.55	27.49	27.44
Eu 152	.0368	.0364	.0362	.0359	.0354	.0349
Eu 154	3.361	3.325	3.313	3.290	3.255	3.218
Eu 155	123.1	112.0	109.5	101.9	92.74	83.93
Eu 156	4414	68.97	17.24	1.078	.0168	.0002
Tb 160	.7426	.3160	.2376	.1344	.0572	.0232
Tb 161	45.86	.0054	.0003	---	---	---

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TABLE II-6 (Continued)

Activity, Curies per Ton of Uranium

Nuclide	1.5 y	2 y	3.5 y	5 y	7 y	10 y	20 y
Kr 85	246.3	238.2	215.5	195.0	170.7	139.7	71.76
Rb 86	---	---	---	---	---	---	---
Sr 89	100.9	8.183	.0044	---	---	---	---
Sr 90	1874	1851	1784	1719	1636	1519	1186
Y 91	319.4	36.01	.0516	.0001	---	---	---
Zr 95	692.9	98.83	.2867	.0008	---	---	---
Nb 95	1496	214.2	.6220	.0018	---	---	---
Ru 103	11.26	.4606	---	---	---	---	---
Ru 106	2749	1944	678.2	243.0	60.74	7.593	.0074
Ag 110m	.0921	.0566	.0131	.0030	.0004	---	---
Ag 111	---	---	---	---			
Cd 115m	.0070	.0004	---	---			
Sn 123m	2.011	.7306	.0305	.0017			
Sn 125	---	---	---	---			
Sb 125	147.9	130.1	88.50	60.22	36.03	16.68	1.280
Te 125m	31.06	27.32	18.59	12.65	7.566	3.503	0.2688
Sb 127	---	---	---	---			
Te 127m	32.13	9.623	.2586	.0069	.0001	---	---
Te 129m	.2041	.0044	---	---			
I 131	---	---	---	---			
Xe 131m	---	---	---	---			
Te 132	---	---	---	---			
Xe 133	---	---	---	---			
Cs 134	113.1	95.92	58.46	35.63	18.41	6.841	.2521
Cs 136	---	---	---	---			
Cs 137	2059	2036	1966	1899	1813	1692	1343
Ba 140	---	---	---	---			
Ce 141	2.553	.0519	---	---			
Ce 144	16210	10400	2743	723.5	122.4	8.520	.0012
Pr 143	---	---	---	---			
Pm 146	.0012	.0011	.0009	.0008	.0006	.0004	.0001
Nd 147	---	---	---	---			
Pm 147	5194	4550	3060	2058	1212	548.1	38.89
Pm 148m	.0953	.0047	---	---			
Pm 148	.0088	.0004	---	---			
Sm 151	27.33	27.23	26.91	26.61	26.20	25.60	23.70
Eu 152	.0340	.0331	.0306	.0282	.0254	.0216	.0127
Eu 154	3.149	3.082	2.888	2.706	2.482	2.179	1.413
Eu 155	69.30	57.22	32.22	18.14	8.433	2.673	.0581
Eu 156	---	---	---	---			
Tb 160	.0041	.0007	---	---			
Tb 161	---	---	---	---			

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TABLE II-7

FISSION PRODUCT ACTIVITY FROM NATURAL URANIUM

750 MWd/T, 10 MW/T

Activity, Curies Per Ton of Uranium

Nuclide	Discharge	90 d	120 d	180 d	270 d
Kr 85	312.7	308.1	306.4	303.1	298.2
Rb 86	13.65	.4856	.1597	.0173	.0006
Sr 89	222800	64630	42780	18750	5437
Sr 90	2239	2225	2221	2212	2198
Y 91	262000	89370	62440	30480	10400
Zr 95	279100	106900	77640	40940	15680
Nb 95	155100	156100	126600	76070	31870
Ru 103	191900	39700	23480	8216	1700
Ru 106	8516	7179	6782	6052	5102
Ag 110m	.4920	.3870	.3573	.3045	.2395
Ag 111	3498	.8541	.0534	.0002	---
Cd 115m	54.97	12.88	7.944	3.020	.7078
Sn 123m	47.59	28.89	24.46	17.54	10.65
Sn 125	1288	1.689	.1849	.0022	---
Sb 125	232.4	229.8	225.0	215.7	202.5
Te 125m	28.35	48.26	47.25	45.30	42.52
Sb 127	21820	.0025	---	---	---
Te 127m	1244	762.0	625.1	420.7	232.2
Te 129m	23810	3596	1915	543.0	82.0
I 131	233700	103.2	7.797	.0442	---
Xe 131m	2154	36.72	6.705	.2128	.0012
Te 132	354400	.0016	---	---	---
Xe 133	528800	3.895	.0753	---	---
Cs 134	258.2	238.0	231.7	219.5	202.3
Cs 136	1349	11.11	2.245	.0916	.0008
Cs 137	2439	2425	2420	2411	2397
Ba 140	470100	3594	708.0	27.48	.2101
Ce 141	357500	52440	27650	7692	1128
Ce 144	70850	56920	52920	45730	36740
Pr 143	427400	5039	1104	53.06	.5584
Pm 146	.0017	.0016	.0016	.0016	.0015
Nd 147	161400	584.9	89.85	2.120	.0077
Pm 147	6905	8236	8065	7723	7236
Pm 148m	1001	226.7	138.2	51.34	11.63
Pm 148	6272	20.88	12.69	4.713	1.067
Sm 151	27.40	28.73	28.71	28.68	28.62
Eu 152	.0404	.0398	.0397	.0393	.0388
Eu 154	4.565	4.517	4.501	4.469	4.421
Eu 155	121.8	110.8	107.4	100.8	91.74
Eu 156	5221	81.58	20.40	1.275	.0199
Tb 160	.9845	.4189	.3150	.1782	.0758
Tb 161	49.53	.0059	.0003	---	---

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TABLE II-7 (Continued)

Activity, Curies Per Ton of Uranium

Nuclide	1 y	2 y	5 y	10 y	20 y
Kr 85	293.0	274.1	224.4	160.8	82.60
Rb 86	---	---	---	---	---
Sr 89	1467	9.656	---	---	---
Sr 90	2184	2131	1978	1748	1365
Y 91	3331	42.35	.0001	---	---
Zr 95	5678	115.5	.0010	---	---
Nb 95	11990	250.3	.0021	---	---
Ru 103	320.9	.5368	---	---	---
Ru 106	4258	2129	266.1	8.316	.0081
Ag 110m	.1858	.0702	.0038	---	---
Ag 111	---	---	---	---	---
Cd 115m	.1524	.0004	---	---	---
Sn 123m	6.279	.8284	.0019	---	---
Sn 125	---	---	---	---	---
Sb 125	189.4	146.5	67.81	18.79	1.442
Te 125m	39.77	30.76	14.24	3.946	.3028
Sb 127	---	---	---	---	---
Te 127m	123.8	11.10	.0080	---	---
Te 129m	11.09	.0052	---	---	---
I 131	---	---	---	---	---
Xe 131m	---	---	---	---	---
Te 132	---	---	---	---	---
Xe 133	---	---	---	---	---
Cs 134	185.6	133.4	49.57	9.517	.3508
Cs 136	---	---	---	---	---
Cs 137	2383	2328	2173	1935	1536
Ba 140	.0012	---	---	---	---
Ce 141	147.9	.0612	---	---	---
Ce 144	29140	11990	834.3	9.825	.0014
Pr 143	.0045	---	---	---	---
Pm 146	.0015	.0013	.0009	.0005	.0001
Nd 147	---	---	---	---	---
Pm 147	6753	5183	2344	624.4	44.31
Pm 148m	2.414	.0058	---	---	---
Pm 148	.2216	.0005	---	---	---
Sm 151	28.57	28.35	27.70	26.65	24.68
Eu 152	.0383	.0363	.0309	.0237	.0139
Eu 154	4.372	4.186	3.676	2.960	1.919
Eu 155	83.02	56.61	17.94	2.645	.0574
Eu 156	.0002	---	---	---	---
Tb 160	.0307	.0010	---	---	---
Tb 161	---	---	---	---	---

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TABLE II-8

FISSION PRODUCT ACTIVITY FROM NATURAL URANIUM

900 MWd/T, 10 MW/T

Activity, Curies Per Ton of Uranium

Nuclide	Discharge	90 d	120 d	180 d	270 d
Kr 85	370.2	364.7	362.7	358.8	352.9
Rb 86	16.85	.5994	.1971	.0213	.0008
Sr 89	242100	70210	46470	20360	5906
Sr 90	2652	2636	2631	2620	2604
Y 91	287600	98100	68540	33460	11410
Zr 95	310200	118800	86280	45500	17430
Nb 95	192200	176800	142500	85100	35510
Ru 103	210600	43580	25780	9019	1866
Ru 106	10730	9047	8546	7626	6429
Ag 110m	.7705	.6061	.5595	.4768	.3751
Ag 111	3893	.9505	.0594	.0002	---
Cd 115m	61.79	14.48	8.930	3.395	.7957
Sn 123m	56.37	34.22	28.98	20.78	12.61
Sn 125	1345	1.764	.1931	.0023	---
Sb 125	285.0	279.7	273.9	262.6	246.5
Te 125m	39.90	58.74	57.52	55.15	51.76
Sb 127	21990	.0025	---	---	---
Te 127m	1451	877.0	719.4	484.1	267.3
Te 129m	25650	3874	2063	585.0	88.35
I 131	236500	104.4	7.884	.0045	---
Xe 131m	2230	37.42	6.831	.2168	.0012
Te 132	354500	.0016	---	---	---
Xe 133	529500	3.898	.0076	---	---
Cs 134	375.9	346.6	337.3	319.5	294.6
Cs 136	1556	12.82	2.589	.1056	.0009
Cs 137	2915	2898	2893	2882	2865
Ba 140	475600	3636	716.2	27.79	.2125
Ce 141	381300	55920	29490	8203	1203
Ce 144	82860	66570	61890	53480	42970
Pr 143	433100	5093	1116	53.63	.5644
Pm 146	.0020	.0019	.0019	.0018	.0018
Nd 147	163200	591.3	90.83	2.143	.0078
Pm 147	8439	9693	9490	9088	8514
Pm 148m	1264	286.2	174.4	64.80	14.67
Pm 148	7796	26.35	16.01	5.949	1.347
Sm 151	29.72	31.06	31.04	31.00	30.95
Eu 152	.0573	.0566	.0563	.0558	.0551
Eu 154	6.640	6.570	6.547	6.500	6.431
Eu 155	136.2	124.1	120.2	112.9	102.7
Eu 156	5967	93.24	23.31	1.457	.0228
Tb 160	1.445	.6146	.4623	.2615	.1113
Tb 161	56.55	.0067	.0003	---	---

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TABLE II-8 (Continued)

Activity, Curies Per Ton of Uranium

Nuclide	1 y	2 y	5 y	10 y	20 y
Kr 85	346.8	324.5	265.7	190.4	97.75
Rb 86	---	---	---	---	---
Sr 89	1593	10.49	---	---	---
Sr 90	2578	2524	2343	2071	1617
Y 91	3656	46.48	.0001	---	---
Zr 95	6311	128.4	.0011	---	---
Nb 95	13340	278.2	.0023	---	---
Ru 103	352.3	.5892	---	---	---
Ru 106	5366	2683	335.4	10.48	.0102
Ag 110m	.2910	.1099	.0059	---	---
Ag 111	---	---	---	---	---
Cd 115m	.1714	.0005	---	---	---
Sn 123m	7.438	.9814	.0023	---	---
Sn 125	---	---	---	---	---
Sb 125	230.5	178.3	82.55	22.87	1.755
Te 125m	48.40	37.44	17.34	4.803	.3686
Sb 127	---	---	---	---	---
Te 127m	142.5	12.77	.0092	---	---
Te 129m	11.95	.0094	---	---	---
I 131	---	---	---	---	---
Xe 131m	---	---	---	---	---
Te 132	---	---	---	---	---
Xe 133	---	---	---	---	---
Cs 134	270.3	194.3	72.17	13.86	.5107
Cs 136	---	---	---	---	---
Cs 137	2848	2783	2597	2313	1836
Ba 140	.0012	---	---	---	---
Ce 141	157.8	.0653	---	---	---
Ce 144	34080	14020	975.8	11.49	.0016
Pr 143	.0046	---	---	---	---
Pm 146	.0017	.0015	.0010	.0006	.0002
Nd 147	---	---	---	---	---
Pm 147	7947	6099	2758	734.7	52.14
Pm 148m	3.046	.0073	---	---	---
Pm 148	.2797	.0007	---	---	---
Sm 151	30.88	30.65	29.95	28.81	26.68
Eu 152	.0543	.0515	.0439	.0336	.0197
Eu 154	6.359	6.089	5.347	4.306	2.792
Eu 155	92.97	63.39	20.09	2.961	.0643
Eu 156	.0003	---	---	---	---
Tb 160	.0450	.0014	---	---	---
Tb 161	---	---	---	---	---

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TABLE II-9

FISSION PRODUCT ACTIVITY FROM 0.947% ENRICHED URANIUM

900 MWd/T, 9.7 MW/T

Activity, Curies Per Ton of Uranium

Nuclide	Discharge	90 d	120 d	180 d	270 d	1 y
Kr 85	384.0	378.3	376.2	372.1	366.0	359.7
Rb 86	13.78	.4903	.1612	.0174	.0006	---
Sr 89	245600	71240	47160	20660	5993	1617
Sr 90	2752	2735	2730	2719	2702	2685
Y 91	292000	99590	69580	33970	11590	3712
Zr 95	313800	120200	87280	46030	17630	6383
Nb 95	198400	179600	144500	86200	35940	13500
Ru 103	207700	42980	25420	8895	1841	347.4
Ru 106	10180	8586	8111	7238	6101	5092
Ag 110m	.5532	.4352	.4018	.3424	.2693	.2089
Ag 111	3525	.8607	.0538	.0002	---	---
Cd 115m	59.97	14.06	8.667	3.295	.7722	.1663
Sn 123m	55.47	33.68	28.51	20.44	12.41	7.319
Sn 125	1304	1.711	.1873	.0022	---	---
Sb 125	285.0	279.3	273.5	262.2	246.1	230.2
Te 125m	42.75	58.65	57.44	55.06	51.68	48.34
Sb 127	22060	.0025	---	---	---	---
Te 127m	1460	881.7	723.3	486.8	268.7	143.3
Te 129m	25390	3834	2042	579.0	87.43	11.82
I 131	237100	104.7	7.909	.0449	---	---
Xe 131m	2186	37.25	6.802	.2159	.0012	---
Te 132	358200	.0017	---	---	---	---
Xe 133	536800	3.954	.0764	---	---	---
Cs 134	293.6	270.7	263.4	249.5	230.0	211.1
Cs 136	1413	11.64	2.352	.0960	.0008	---
Cs 137	2993	2976	2971	2960	2943	2925
Ba 140	477100	3647	718.5	27.88	.2132	.0012
Ce 141	380600	55830	29440	8188	1201	157.2
Ce 144	85040	68320	63510	54890	44100	34980
Pr 143	434700	5122	1123	53.94	.5676	.0046
Pm 146	.0020	.0020	.0020	.0019	.0018	.0018
Nd 147	163600	593.0	91.09	2.149	.0078	---
Pm 147	8825	10060	9850	9432	8837	8248
Pm 148m	1173	266.5	162.4	60.34	13.66	2.837
Pm 148	6270	24.52	14.91	5.540	1.254	.2604
Sm 151	34.88	36.21	36.19	36.14	36.07	36.00
Eu 152	.0624	.0616	.0614	.0608	.0600	.0592
Eu 154	5.211	5.156	5.138	5.101	5.047	4.990
Eu 155	153.3	139.5	135.2	126.9	115.5	104.5
Eu 156	5317	83.08	20.77	1.298	.0203	.0002
Tb 160	1.041	.4430	.3332	.1885	.0802	.0325
Tb 161	49.75	.0059	.0003	---	---	---

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TABLE II-9 (Continued)

Activity, Curies Per Ton of Uranium

Nuclide	1.5 y	2 y	3.5 y	5 y	7 y	10 y	20 y
Kr 85	348.0	336.5	304.5	275.6	241.2	197.5	101.4
Rb 86	---	---	---	---			
Sr 89	131.2	10.64	.0057	---			
Sr 90	2652	2619	2524	2432	2314	2148	1677
Y 91	418.5	47.19	.0674	.0001			
Zr 95	910.5	129.9	.3768	.0011			
Nb 95	1966	281.4	.817?	.0024			
Ru 103	14.21	.5811	---	---			
Ru 106	3601	2546	900.2	318.3	79.57	9.946	.0097
Ag 110m	.1284	.0789	.0183	.0042	.0006	---	---
Ag 111	---	---	---	---			
Cd 115m	.0088	.0005	---	---			
Sn 123m	2.658	.9656	.0463	.0022			
Sn 125	---	---	---	---			
Sb 125	202.4	178.0	121.1	82.42	49.33	22.83	1.753
Te 125m	42.50	37.38	25.43	17.31	10.36	4.794	.3681
Sb 127	---	---	---	---			
Te 127m	42.87	12.84	.3450	.0093	.0001	---	---
Te 129m	.2551	.0055	---	---			
I 131	---	---	---	---			
Xe 131m	---	---	---	---			
Te 132	---	---	---	---			
Xe 133	---	---	---	---			
Cs 134	179.0	151.7	92.48	56.37	29.13	10.82	.3988
Cs 136	---	---	---	---			
Cs 137	2892	2858	2761	2667	2546	2376	1886
Ba 140	---	---	---	---			
Ce 141	3.204	.0652	---	---			
Ce 144	22430	14390	3796	1001	169.4	11.79	.0016
Pr 143	---	---	---	---			
Pm 146	.0017	.0016	.0013	.0011	.0008	.0006	.0002
Nd 147	---	---	---	---			
Pm 147	7226	6330	4257	2862	1683	762.5	54.11
Pm 148m	.1393	.0068	---	---			
Pm 148	.0128	.0006	---	---			
Sm 151	35.86	35.73	35.31	34.91	34.38	33.59	31.10
Eu 152	.0576	.0561	.0518	.0478	.0430	.0366	.0215
Eu 154	4.883	4.779	4.478	4.196	3.848	3.379	2.191
Eu 155	86.31	71.27	40.12	22.59	10.50	3.329	.0723
Eu 156	---	---	---	---			
Tb 160	.0057	.0010	---	---			
Tb 161	---	---	---	---			

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TABLE II-10

FISSION PRODUCT ACTIVITY FROM 0.947% ENRICHED URANIUM

1000 MWd/T, 10 MW/T

Activity, Curies Per Ton of Uranium

Nuclide	Discharge	90 d	120 d	180 d	270 d
Kr 85	427.2	420.7	418.4	413.9	407.1
Rb 86	16.50	.5870	.1931	.0209	.0007
Sr 89	266800	77380	51220	22440	6509
Sr 90	3061	3042	3036	3024	3005
Y 91	318200	108500	75830	37020	12630
Zr 95	342800	131300	95340	50280	19260
Nb 95	222700	197100	158400	94330	39290
Ru 103	224600	46480	27490	9618	1990
Ru 106	11560	9745	9206	8215	6925
Ag 110m	.7322	.5760	.5317	.4531	.3565
Ag 111	3931	.9598	.0600	.0002	---
Cd 115m	64.72	15.17	9.352	3.550	.8333
Sn 123m	61.29	37.21	31.51	22.59	13.71
Sn 125	1398	1.834	.2007	.0024	---
Sb 125	322.0	314.8	308.3	295.6	277.4
Te 125m	45.08	66.11	64.74	62.08	58.25
Sb 127	22950	.0026	---	---	---
Te 127m	1619	972.9	798.1	537.1	296.5
Te 129m	27480	4150	2210	626.8	94.65
I 131	249600	110.2	8.322	.0472	---
Xe 131m	2372	39.60	7.227	.2294	.0013
Te 132	370800	.0017	---	---	---
Xe 133	557200	4.104	.0794	---	---
Cs 134	385.8	355.7	346.2	328.0	302.3
Cs 136	1642	13.53	2.732	.1115	.0009
Cs 137	3329	3310	3304	3292	3273
Ba 140	503400	3849	758.2	29.42	.2249
Ce 141	410900	60270	31780	8840	1297
Ce 144	94070	75580	70260	60720	48780
Pr 143	460400	5409	1185	56.95	.5994
Pm 146	.0022	.0022	.0021	.0021	.0020
Nd 147	171300	620.9	95.37	2.250	.0082
Pm 147	9776	11040	10840	10350	9693
Pm 148m	1393	315.2	192.1	71.38	16.16
Pm 148	7557	29.01	17.64	6.553	1.484
Sm 151	36.07	37.44	37.42	37.37	37.30
Eu 152	.0713	.0703	.0700	.0694	.0685
Eu 154	6.620	6.550	6.526	6.480	6.411
Eu 155	162.0	147.4	142.8	134.1	122.0
Eu 156	5930	92.66	23.17	1.488	.0226
Tb 160	1.358	.5780	.4347	.2459	.1046
Tb 161	55.68	.0066	.0004	---	---

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TABLE II-10 (Continued)

Activity, Curies Per Ton of Uranium

Nuclide	1 y	2 y	5 y	10 y	20 y
Kr 85	400.1	374.0	306.5	219.6	112.8
Rb 86	---	---	---	---	---
Sr 89	1756	11.56	---	---	---
Sr 90	2986	2913	2705	2390	1866
Y 91	4045	51.42	.0001	---	---
Zr 95	6973	141.9	.0012	---	---
Nb 95	14750	307.5	.0026	---	---
Ru 103	375.7	.6284	---	---	---
Ru 106	5780	2890	361.2	11.29	.0110
Ag 110m	.2765	.1044	.0056	---	---
Ag 111	---	---	---	---	---
Cd 115m	.1795	.0005	---	---	---
Sn 123m	8.087	1.067	.0025	---	---
Sn 125	---	---	---	---	---
Sb 125	259.5	200.7	92.92	25.74	1.976
Te 125m	54.50	42.15	19.51	5.405	.4150
Sb 127	---	---	---	---	---
Te 127m	158.1	14.17	.0102	---	---
Te 129m	12.80	.0060	---	---	---
I 131	---	---	---	---	---
Xe 131m	---	---	---	---	---
Te 132	---	---	---	---	---
Xe 133	---	---	---	---	---
Cs 134	277.4	199.4	74.08	14.22	.5242
Cs 136	---	---	---	---	---
Cs 137	3253	3179	2966	2642	2097
Ba 140	.0013	---	---	---	---
Ce 141	170.0	.0704	---	---	---
Ce 144	38690	15920	1108	13.04	.0018
Pr 143	.0048	---	---	---	---
Pm 146	.0020	.0017	.0012	.0006	.0002
Nd 147	---	---	---	---	---
Pm 147	9046	6943	3140	836.4	59.35
Pm 148m	3.356	.0081	---	---	---
Pm 148	.3081	.0007	---	---	---
Sm 151	37.23	36.94	36.10	34.73	32.16
Eu 152	.0676	.0640	.0546	.0418	.0245
Eu 154	6.339	6.070	5.331	4.292	2.783
Eu 155	110.4	75.30	23.87	3.518	.0764
Eu 156	.0003	---	---	---	---
Tb 160	.0424	.0013	---	---	---
Tb 161	---	---	---	---	---

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TABLE II-11

FISSION PRODUCT ACTIVITY FROM 0.947% ENRICHED URANIUM

1200 MWd/T, 10 MW/T

Nuclide	Activity, Curies Per Ton of Uranium				
	Discharge	90 d	120 d	180 d	270 d
Kr 85	507.4	499.5	496.8	491.4	483.4
Rb 86	20.22	.7195	.2366	.0256	.0009
Sr 89	284700	82580	54660	23950	6946
Sr 90	3638	3616	3608	3594	3572
Y 91	343600	117200	81890	39980	13640
Zr 95	375600	143900	104500	55090	21100
Nb 95	268600	220200	175900	104100	43170
Ru 103	243100	50310	29760	10410	2154
Ru 106	14670	12360	11680	10420	8787
Ag 110m	1.160	.9123	.8422	.7177	.5646
Ag 111	4385	1.071	.0669	.0003	---
Cd 115m	71.99	16.87	10.40	3.955	.9270
Sn 123m	72.41	43.96	37.22	26.69	16.20
Sn 125	1461	1.917	.2098	.0025	---
Sb 125	396.3	385.2	377.2	361.6	339.4
Te 125m	73.98	80.89	79.21	75.94	71.27
Sb 127	23240	.0027	---	---	---
Te 127m	1868	1111	911.5	613.4	338.6
Te 129m	29160	4404	2345	665.0	100.4
I 131	252500	111.4	8.414	.0478	---
Xe 131m	2429	40.21	7.338	.2329	.0013
Te 132	372800	.0017	---		---
Xe 133	558600	4.114	.0796	---	---
Cs 134	562.2	518.3	504.5	477.9	440.5
Cs 136	1891	15.58	3.147	.1284	.0011
Cs 137	3997	3974	3966	3951	3929
Ba 140	506600	3873	763.0	29.61	.2264
Ce 141	430900	63200	33330	9271	1360
Ce 144	109800	88230	82020	70890	56950
Pr 143	462900	5432	1191	57.20	.6020
Pm 146	.0026	.0025	.0025	.0025	.0024
Nd 147	172700	625.8	96.12	2.268	.0082
Pm 147	11860	13010	12730	12190	11420
Pm 148m	1739	393.8	240.0	89.17	20.19
Pm 148	9307	36.24	22.04	8.186	1.854
Sm 151	39.11	40.51	40.48	40.43	40.35
Eu 152	.1011	.0998	.0993	.0985	.0972
Eu 154	9.700	9.597	9.563	9.495	9.394
Eu 155	182.3	165.9	160.8	151.0	137.4
Eu 156	6751	105.5	26.37	1.648	.0258
Tb 160	2.005	.8530	.6416	.3629	.1544
Tb 161	63.76	.0076	.0004	---	---

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TABLE II-11 (Continued)

Activity, Curies Per Ton of Uranium

Nuclide	1 y	2 y	5 y	10 y	20 y
Kr 85	475.1	444.4	363.9	260.7	133.9
Rb 86	---	---	---	---	---
Sr 89	1874	12.34	---	---	---
Sr 90	3549	3462	3214	2840	2217
Y 91	4368	55.53	.0001	---	---
Zr 95	7641	155.4	.0013	---	---
Nb 95	16180	336.9	.0028	---	---
Ru 103	406.6	.6801	---	---	---
Ru 106	7334	3667	458.2	14.32	.0140
Ag 110m	.4380	.1654	.0089	.0001	---
Ag 111	---	---	---	---	---
Cd 115m	.1996	.0006	---	---	---
Sn 123m	9.553	1.260	.0029	---	---
Sn 125	---	---	---	---	---
Sb 125	317.5	245.6	113.7	31.50	2.417
Te 125m	66.68	51.58	23.88	6.615	.5076
Sb 127	---	---	---	---	---
Te 127m	180.6	16.18	.0117	---	---
Te 129m	13.58	.0063	---	---	---
I 131	---	---	---	---	---
Xe 131m	---	---	---	---	---
Te 132	---	---	---	---	---
Xe 133	---	---	---	---	---
Cs 134	404.2	290.6	107.9	20.72	.7638
Cs 136	---	---	---	---	---
Cs 137	3905	3816	3561	3172	2518
Ba 140	.0013	---	---	---	---
Ce 141	178.3	.0738	---	---	---
Ce 144	45170	18580	1293	15.23	.0021
Pr 143	.0049	---	---	---	---
Pm 146	.0023	.0020	.0014	.0008	.0002
Nd 147	---	---	---	---	---
Pm 147	10660	8183	3700	985.7	69.95
Pm 148m	4.192	.0101	---	---	---
Pm 148	.3849	.0009	---	---	---
Sm 151	40.27	39.96	39.05	37.57	34.79
Eu 152	.0958	.0909	.0774	.0593	.0348
Eu 154	9.289	8.895	7.811	6.290	4.078
Eu 155	124.3	84.76	26.87	3.960	.0860
Eu 156	.0003	---	---	---	---
Tb 160	.0625	.0019	---	---	---
Tb 161	---	---	---	---	---

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TABLE II-12

FISSION PRODUCT ACTIVITY FROM 0.947% ENRICHED URANIUM

2200 MWd/T, 11MW/T

Activity, Curies Per Ton of Uranium

Nuclide	Discharge	90 d	120 d	180 d	270 d	1 y
Kr 85	869.3	856.2	851.3	842.1	828.5	812.8
Rb 86	41.31	1.470	.4834	.0523	.0019	.0001
Sr 89	320300	92910	61500	26950	7815	2109
Sr 90	6264	6226	6213	6188	6150	6111
Y 91	403200	137500	96090	46910	16000	5126
Zr 95	472800	181100	131500	69340	26560	9617
Nb 95	413000	289700	228300	133100	54700	20420
Ru 103	319600	66150	39120	13690	2833	534.7
Ru 106	35680	30080	28410	25350	21370	17840
Ag 110m	5.607	4.411	4.072	3.470	2.730	2.118
Ag 111	7429	1.814	.1133	.0004	---	---
Cd 115m	107.8	25.27	15.58	5.922	1.388	.2989
Sn 123m	130.4	79 14	67.01	48.04	29.17	17.20
Sn 125	1946	2.553	.2794	.0033	---	---
Sb 125	822.1	789.3	772.8	740.9	695.5	650.5
Te 125m	172.6	165.8	162.3	155.6	146.1	136.6
Sb 127	27290	.0031	---	---	---	---
Te 127m	2870	1678	1377	926.4	511.4	272.7
Te 129m	35690	5389	2870	813.8	122.9	16.62
I 131	289500	127.4	9.623	.0546	---	---
Xe 131m	2807	46.15	8.421	.2673	.0015	---
Te 132	423500	.0020	---	---	---	---
Xe 133	619100	4.560	.0882	---	---	---
Cs 134	2511	2315	2253	2134	1968	1805
Cs 136	3598	29.65	5.989	.2443	.0020	---
Cs 137	7349	7307	7293	7265	7224	7181
Ba 140	554700	4241	835.4	32.42	.2478	.0014
Ce 141	495200	72630	38310	10650	1563	204.9
Ce 144	176600	141800	131900	114000	91560	72620
Pr 143	498100	5840	1280	61.50	.6472	.0052
Pm 146	.0043	.0042	.0041	.0040	.0039	.0038
Nd 147	193400	700.9	107.7	2.540	.0092	---
Pm 147	20470	21290	20840	19960	18700	17450
Pm 148m	4110	930.7	567.3	210.7	47.72	9.907
Pm 148	22070	85.65	52.08	19.35	4.381	.9095
Sm 151	53.73	55.43	55.40	55.32	55.22	55.11
Eu 152	.2768	.2732	.2720	.2697	.2661	.2625
Eu 154	42.52	42.07	41.92	41.62	41.18	40.72
Eu 155	309.1	281.2	272.5	255.9	232.9	210.7
Eu 156	11780	184.1	46.02	2.877	.0449	.0006
Tb 160	9.898	4.211	3.167	1.792	.7623	.3086
Tb 161	118.0	.0140	.0007	---	---	---

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TABLE II-12 (Continued)

Activity, Curies Per Ton of Uranium

Nuclide	1.5 y	2 y	3.5 y	5 y	7 y	10 y	20 y
Kr 85	787.4	761.7	689.2	623.3	545.3	446.8	229.4
Rb 86	---	---	---	---			
Sr 89	171.1	13.88	.0074	---			
Sr 90	6035	5961	5744	5535	5267	4890	3818
Y 91	577.9	65.17	.0934	.0001			
Zr 95	1372	195.6	.5677	.0016			
Nb 95	2964	424.1	1.231	.0036			
Ru 103	21.87	.8943	.0001	---			
Ru 106	12610	8919	3153	1115	278.7	34.84	.0340
Ag 110m	1.301	.7998	.1856	.0431	.0061	.0003	---
Ag 111	---	---	---	---			
Cd 115m	.0157	.0008	---	---			
Sn 123m	6.247	2.269	.1088	.0052			
Sn 125	---	---	---	---			
Sb 125	572.1	503.2	342.4	232.9	139.4	64.53	4.953
Te 125m	120.1	105.7	71.90	48.91	29.27	13.55	1.040
Sb 127	---	---	---	---			
Te 127m	81.63	24.45	.6569	.0176	.0001	---	---
Te 129m	.3586	.0077	---	---			
I 131	---	---	---	---			
Xe 131m	---	---	---	---			
Te 132	---	---	---	---			
Xe 133	---	---	---	---			
Cs 134	1531	1298	791.0	482.1	249.2	92.56	3.411
Cs 136	---	---	---	---			
Cs 137	7098	7017	6778	6547	6251	5833	4629
Ba 140	---	---	---	---			
Ce 141	4.169	.0848	---	---			
Ce 144	46580	29870	7881	2079	351.8	24.48	.0034
Pr 143	---	---	---	---			
Pm 146	.0036	.0033	.0028	.0023	.0018	.0012	.0004
Nd 147	---	---	---	---			
Pm 147	15290	13390	9007	6057	3568	1613	1145
Pm 148m	.4864	.0239	---	---			
Pm 148	.0446	.0022	---	---			
Sm 151	54.90	54.69	54.06	53.44	52.62	51.42	47.61
Eu 152	.2556	.2488	.2297	.2121	.1906	.1624	.0953
Eu 154	39.84	38.99	36.54	34.24	31.40	27.57	17.88
Eu 155	174.0	143.7	80.90	45.55	21.18	6.713	.1458
Eu 156	---	---	---	---			
Tb 160	.0545	.0096	.0001	---			
Tb 161	---	---	---	---			

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TABLE II-13

FISSION PRODUCT ACTIVITY FROM 1.25% ENRICHED URANIUM

2200 MWd/T, 11 MW/T

Activity, Curies Per Ton of Uranium

Nuclide	Discharge	90 d	120 d	180 d	270 d	1 y
Kr 85	904.7	890.5	885.5	876.2	861.9	847.0
Rb 86	34.73	1.236	.4064	.0440	.0016	---
Sr 89	339100	98340	65100	28520	8272	2232
Sr 90	6523	6484	6470	6444	6405	6364
Y 81	422900	144300	100800	49210	16780	5377
Zr 95	481400	184400	133900	70610	27040	9397
Nb 95	419600	294800	232400	135500	55690	20790
Ru 103	300400	62160	36770	12860	2662	502.5
Ru 106	28120	23710	22390	19980	16850	14060
Ag 110m	3.185	2.505	2.313	1.971	1.550	1.203
Ag 111	5577	1.362	.0851	.0004	---	---
Cd 115m	95.08	22.28	13.74	5.223	1.224	.2637
Sn 123m	115.3	70.00	59.27	42.50	25.80	15.21
Sn 125	1711	2.245	.2457	.0029	---	---
Sb 125	742.5	712.4	697.5	668.7	627.8	587.1
Te 125m	148.5	149.6	146.5	140.4	131.8	123.3
Sb 127	25950	.0030	---	---	---	---
Te 127m	2770	1619	1328	893.6	493.3	263.1
Te 129 m	34340	5183	2761	783.0	118.2	15.99
I 131	280800	123.8	9.348	.0531	---	---
Xe 131m	2733	44.86	8.186	.2598	.0014	---
Te 132	412200	.0019	---	---	---	---
Xe 133	614000	4.522	.0874	---	---	---
Cs 134	2009	1852	1802	1707	1574	1444
Cs 136	2903	23.92	4.831	.1971	.0016	---
Cs 137	7320	7278	7264	7237	7196	7152
Ba 140	558330	4268	840.8	32.63	.2494	.0014
Ce 141	494800	72570	38270	10650	1561	204.8
Ce 144	179600	144300	134200	116000	93160	73890
Pr 143	507800	5953	1305	62.67	.6596	.0053
Pm 146	.0044	.0043	.0042	.0042	.0040	.0039
Nd 147	192500	697.5	107.1	2.528	.0092	---
Pm 147	21110	21890	21420	20510	19220	17940
Pm 148m	4024	911.2	555.3	206.3	46.71	9.699
Pm 148	18890	83.82	50.98	18.94	4.288	.8904
Sm 151	60.24	61.79	61.75	61.68	61.56	61.44
Eu 152	.3142	.3101 m	.3088	.3061	.3021	.2979
Eu 154	31.73	31.40	31.28	31.06	30.73	30.39
Eu 155	291.6	265.4	257.2	241.5	219.7	198.9
Eu 156	9153	143.0	35.75	2.234	.0349	.0004
Tb 160	6.119	2.603	1.958	1.108	.4713	.1908
Tb 161	84.50	.0100	.0005	---	---	---

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TABLE II-13 (Continued)

Activity, Curies Per Ton of Uranium

Nuclide	1.5 y	2 y	3.5 y	5 y	7 y	10 y	20 y
Kr 85	818.8	792.3	717.0	648.3	567.8	464.9	238.7
Rb 86	---	---	---				
Sr 89	181.1	14.69	.0078	---			
Sr 90	6285	6208	5982	5764	5485	5093	3976
Y 91	606.3	68.36	.0980	.0001			
Zr 95	1397	199.2	.5780	.0017			
Nb 95	3018	431.8	1.254	.0036			
Ru 103	20.55	.8404	.0001	---			
Ru 106	9943	7030	2486	878.8	219.7	27.46	.0268
Ag 110m	.7391	.4542	.1054	.0245	.0035	.0002	---
Ag 111	---	---	---	---			
Cd 115m	.0139	.0007	---	---			
Sn 123m	5.526	2.007	.0962	.0046	.0001	---	---
Sn 125	---	---	---	---			
Sb 125	516.4	454.2	309.0	210.3	125.8	58.25	4.470
Te 125m	108.4	95.38	64.89	44.16	26.42	12.23	.9387
Sb 127	---	---	---	---			
Te 127m	78.74	23.58	.6336	.0170	.0001	---	---
Te 129m	.3451	.0074	---	---			
I 131	---	---	---	---			
Xe 131m	---	---	---	---			
Te 132	---	---	---	---			
Xe 133	---	---	---	---			
Cs 134	1224	1038	632.7	385.7	199.3	74.04	2.729
Cs 136	---	---	---	---			
Cs 137	7070	6989	6751	6521	6227	5810	4611
Ba 140	---	---	---	---			
Ce 141	4.165	.0847	---	---			
Ce 144	47390	30400	8019	2115	357.9	24.91	.0035
Pr 143	---	---	---	---			
Pm 146	.0037	.0034	.0029	.0024	.0018	.0013	.0004
Nd 147	---	---	---	---			
Pm 147	15720	13770	9258	6226	3668	1658	117.7
Pm 148m	.4762	.0234	---	---			
Pm 148	.0437	.0021	---	---			
Sm 151	61.20	60.96	60.26	59.57	58.66	57.32	53.07
Eu 152	.2901	.2824	.2607	.2407	.2163	.1844	.1082
Eu 154	29.74	29.10	27.27	25.55	23.43	20.58	13.34
Eu 155	164.2	135.6	76.34	42.98	19.98	6.334	.1376
Eu 156	---	---	---	---			
Tb 160	.0337	.0059	---	---			
Tb 161	---	---	---	---			

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TABLE II-14

FISSION PRODUCT ACTIVITY FROM 2.1% ENRICHED URANIUM

2100 MWd/T, 10.6 MW/T

Activity, Curies Per Ton of Uranium

Nuclide	Discharge	90 d	120 d	180 d	270 d	1 y
Kr 85	900.0	886.1	880.8	871.7	857.6	842.6
Rb 86	21.48	.7641	.2513	.0272	.0001	---
Sr 89	347300	100700	66670	29210	8472	2286
Sr 90	6494	6454	6441	6415	6376	6335
Y 91	428700	146200	102200	49880	17020	5451
Zr 95	472400	180900	131400	69290	26540	9610
Nb 95	409300	288900	227900	132900	54640	20400
Ru 103	267100	55280	32690	11440	2367	446.8
Ru 106	18710	15780	14900	13300	11210	9357
Ag 110m	1.011	.795	.7339	.6254	.492	.3817
Ag 111	3188	.7784	.0486	.0002	---	---
Cd 115m	77.03	18.05	11.13	4.232	.9919	.2136
Sn 123m	93.96	57.04	48.3	34.63	21.02	12.4
Sn 125	1373	1.801	.1971	.0024	---	---
Sb 125	622.8	597	584.6	560.4	526.1	492
Te 125m	93.42	125.4	122.8	117.7	110.5	103.3
Sb 127	23460	.0027	---	---	---	---
Te 127m	2546	1486	1219	820.5	452.9	241.5
Te 129m	31510	4758	2534	718.6	108.5	14.67
I 131	260600	115.1	8.693	.0493	---	---
Xe 131m	2547	41.75	7.617	.2417	.0013	---
Te 132	384700	.0018	---	---	---	---
Xe 133	586600	4.32	.0835	---	---	---
Cs 134	1141	1052	1023	969.4	893.7	820
Cs 136	1882	15.5	3.132	.1278	.001	---
Cs 137	6946	6906	6893	6867	6828	6787
Ba 140	542400	4147	816.9	31.7	.2423	.0014
Ce 141	476000	69820	36820	10240	1502	197
Ce 144	175000	140600	130700	113000	90760	71990
Pr 143	500800	5869	1286	61.8	.6504	.0053
Pm 146	.0044	.0043	.0042	.0041	.0040	.0039
Nd 147	184400	668.4	102.7	2.422	.0088	---
Pm 147	21170	21850	21390	20480	19190	17910
Pm 148m	3408	771.7	470.4	174.7	39.57	8.215
Pm 148	12060	70.96	43.18	16.04	3.632	.7541
Sm 151	76.90	78.21	78.16	78.06	77.91	77.76
Eu 152	.3296	.3253	.3239	.321	.3168	.3125
Eu 154	16.53	16.36	16.3	16.18	16.01	15.83
Eu 155	287.1	261.3	253.2	237.8	216.4	195.8
Eu 156	5749	89.83	22.46	1.404	.0219	.0003
Tb 160	2.364	1.006	.7566	.428	.1821	.0737
Tb 161	42.05	.005	.0003	---	---	---

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TABLE II-14 (Continued)

Activity, Curies Per Ton of Uranium

Nuclide	1.5 y	2 y	3.5 y	5 y	7 y	10 y	20 y
Kr 85	815.0	788.5	713.3	645.3	564.9	462.6	237.5
Rb 86	---	---	---	---			
Sr 89	185.5	15.05	.008	--			
Sr 90	6257	6180	5955	5738	5461	5070	3958
Y 91	614.6	69.30	.0993	.0001			
Zr 95	1371	195.5	.5672	.0016			
Nb 95	2961	423.8	1.23	.0036			
Ru 103	18.27	.7473	.0001	---			
Ru 106	6616	4678	1654	584.8	146.2	18.27	.0178
Ag 110m	.2346	.1441	.0334	.0078	.0011	.0001	---
Ag 111	---	---	---	---			
Cd 115m	.0112	.0006	---	---			
Sn 123m	4.503	1.636	.0784	.0038	.0001	--	---
Sn 125	---	---	---	---			
Sb 125	432.7	380.6	259	176.2	105.4	48.81	3.746
Te 125m	90.87	79.93	54.39	37.00	22.13	10.25	.7867
Sb 127	---	---	---	---			
Te 127m	72.29	21.65	.5817	.0156	.0001	--	---
Te 129m	.3167	.0068	---	---			
I 131	---	---	---	---			
Xe 131m	---	---	---	---			
Te 132	---	---	---	--			
Xe 133	---	---	---	---			
Cs 134	695.2	589.5	359.3	219	113.2	42.04	1.550
Cs 136	---	---	---	---			
Cs 137	6709	6632	6406	6188	5909	5513	4376
Ba 140	---	---	---	---			
Ce 141	4.007	.0815	---	--			
Ce 144	46170	29610	7812	2061	348.7	24.27	.0034
Pr 143	---	---	---	---			
Pm 146	.0036	.0034	.0029	.0024	.0018	.0013	.0004
Nd 147	---	---	---	---			
Pm 147	15690	13740	9242	6215	3661	1655	117.5
Pm 148m	.4033	.0198	---	---			
Pm 148	.037	.0018	---	---			
Sm 151	77.46	77.16	76.27	75.4	74.25	72.55	67.17
Eu 152	.3042	.2962	.2735	.2524	.2269	.1934	.1135
Eu 154	15.49	15.16	14.21	13.31	12.21	10.72	6.951
Eu 155	161.7	133.5	75.16	42.32	19.67	6.237	.1355
Eu 156	---	---	---	---			
Tb 160	.013	.0023	---	---			
Tb 161	---	---	---	---			

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TABLE II-15

FISSION PRODUCT BETA HEAT FROM NATURAL URANIUM

640 MWd/T, 8.17 MW/T

Beta Heat, Watts Per Ton of Uranium

Nuclide	Discharge	90 d	120 d	180 d	270 d	1 y
Kr 85	.4027	.3968	.3946	.3903	.3840	.3773
Rb 86	.0385	.0014	.0005	---	---	---
Sr 89	649.3	188.3	124.7	54.62	15.84	4.274
Sr 90	12.78	13.06	13.03	12.98	12.90	12.82
Y 91	818.8	279.3	195.1	95.26	32.49	10.41
Zr 95	174.8	68.22	48.81	25.75	9.860	3.571
Nb 95	37.24	36.60	29.63	17.78	7.440	2.799
Ru 103	110.2	22.83	13.50	4.724	.9776	.1846
Ru 106	64.53	54.40	51.38	45.85	38.66	32.26
Ag 110m	.0002	.0002	.0002	.0001	.0001	.0001
Ag 111	6.986	.0017	.0001	---	---	---
Cd 115m	.1699	.0398	.0246	.0093	.0022	.0005
Sn 123m	.1341	.0816	.0690	.0495	.0301	.0177
Sn 125	6.154	.0081	.0009	---	---	---
Sb 125	.1408	.1391	.1362	.1306	.1226	.1146
Te 125m	.0217	.0368	.0361	.0346	.0325	.0303
Sb 127	67.36	---	---	---	---	---
Te 127m	2.025	1.239	1.016	.6839	.3776	.2013
Te 129m	71.79	10.85	5.778	1.638	.1474	.0334
I 131	401.4	.1773	.0140	.0001	---	---
Xe 131m	1.703	.0293	.0054	.0002	---	---
Te 132	919.9	---	---	---	---	---
Xe 133	401.0	.0030	.0001	---	---	---
Cs 134	.1650	.1521	.1481	.1403	.1293	.1186
Cs 136	.7872	.0065	.0013	.0001	---	---
Cs 137	3.286	3.267	3.261	3.248	3.230	3.211
Ba 140	1937	16.27	3.205	.1244	.0009	---
Ce 141	323.5	47.45	25.03	6.961	1.021	.1339
Ce 144	495.5	388.6	361.3	312.2	250.8	199.0
Pr 143	670.2	7.914	1.735	.0833	.0009	---
Pm 146	---	---	---	---	---	---
Nd 147	226.1	.8194	.1259	.0030	---	---
Pm 147	2.208	2.606	2.552	2.444	2.289	2.137
Pm 148m	1.242	.2811	.1714	.0637	.0144	.0030
Pm 148	19.02	.0707	.0430	.0160	.0036	.0008
Sm 151	.0031	.0033	.0033	.0033	.0033	.0033
Eu 152	---	---	---	---	---	---
Eu 154	.0046	.0045	.0045	.0045	.0044	.0044
Eu 155	.0730	.0664	.0643	.0604	.0550	.0498
Eu 156	10.99	.1717	.0429	.0027	---	---
Tb 160	.0013	.0005	.0004	.0002	.0001	---
Tb 161	.0625	---	---	---	---	---

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TABLE II-15 (Continued)

Beta Heat, Watts Per Ton of Uranium

Nuclide	1.5 y	2 y	3.5 y	5 y	7 y	10 y	20 y
Kr 85	.3650	.3530	.3194	.2890	.2530	.2071	.1063
Rb 86	---	---	---	---			
Sr 89	.3468	.0281	---	---			
Sr 90	12.66	12.50	12.04	11.61	11.05	10.26	8.008
Y 91	1.174	.1323	.0002	---			
Zr 95	.5092	.0726	.0002	---			
Nb 95	.4078	.0584	.0002	---			
Ru 103	.0075	.0003	---	---			
Ru 106	22.81	16.13	5.703	2.016	.5041	.0630	.0001
Ag 110m	.0001	---	---	---	---	---	---
Ag 111	---	---	---	---			
Cd 115m	---	---	---	---			
Sn 123m	.0064	.0023	.0001	---			
Sn 125	---	---	---	---			
Sb 125	.1008	.0887	.0603	.0410	.0246	.0114	.0009
Te 125m	.0267	.0235	.0160	.0109	.0065	.0030	.0002
Sb 127	---	---	---	---			
Te 127m	.0602	.0180	.0005	---	---	---	---
Te 129m	.0007	---	---	---			
I 131	---	---	---	---			
Xe 131m	---	---	---	---			
Te 132	---	---	---	---			
Xe 133	---	---	---	---			
Cs 134	.1006	.0853	.0520	.0317	.0164	.0061	.0002
Cs 136	---	---	---	---			
Cs 137	3.174	3.137	3.030	2.927	2.795	2.608	2.070
Ba 140	---	---	---	---			
Ce 141	.0027	.0001	---	---			
Ce 144	127.6	84.84	21.59	5.695	.9637	.0671	---
Pr 143	---	---	---	---			
Pm 146	---	---	---	---	---	---	---
Nd 147	---	---	---	---			
Pm 147	1.872	1.640	1.103	.7416	.4369	.1975	.0140
Pm 148m	.0001	---	---	---			
Pm 148	---	---	---	---			
Sm 151	.0032	.0032	.0032	.0032	.0031	.0030	.0028
Eu 152	---	---	---	---	---	---	---
Eu 154	.0043	.0042	.0039	.0037	.0034	.0030	.0019
Eu 155	.0411	.0339	.0191	.0108	.0050	.0016	---
Eu 156	---	---	---	---			
Tb 160	---	---	---	---			
Tb 161	---	---	---	---			

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TABLE II-16

FISSION PRODUCT BETA HEAT FROM NATURAL URANIUM

750 MWd/T, 10 MW/T

Beta Heat, Watts Per Ton of Uranium

Nuclide	Discharge	90 d	120 d	180 d	270 d
Kr 85	.4634	.4566	.4541	.4492	.4419
Rb 86	.0525	.0019	.0006	.0001	---
Sr 89	766.2	222.2	147.1	64.45	18.69
Sr 90	14.71	15.02	15.00	14.94	14.83
Y 91	962.9	328.4	229.5	112.0	38.21
Zr 95	204.3	78.57	57.06	30.09	11.52
Nb 95	42.28	42.57	34.51	20.74	8.691
Ru 103	128.5	26.60	15.73	5.505	1.139
Ru 106	70.67	59.58	56.28	50.22	42.34
Ag 110m	.0003	.0002	.0002	.0002	.0001
Ag 111	7.673	.0019	.0001	---	---
Cd 115m	.1955	.0458	.0282	.0107	.0025
Sn 123m	.1523	.0925	.0783	.0561	.0341
Sn 125	7.099	.0093	.0010	---	---
Sb 125	.1584	.1566	.1534	.1470	.1380
Te 125m	.0024	.0041	.0040	.0039	.0036
Sb 127	78.35	---	---	---	---
Te 127m	2.333	1.428	1.172	.7885	.4351
Te 129m	84.19	12.72	6.775	1.921	.2901
I 131	471.1	.2080	.0157	.0001	---
Xe 131m	2.030	.0346	.0063	.0002	---
Te 132	1074	---	---	---	---
Xe 133	470.2	.0035	.0001	---	---
Cs 134	0.2296	.2117	.2060	.1951	.1799
Cs 136	0.8794	.0073	.0015	.0001	---
Cs 137	3.758	3.737	3.730	3.716	3.695
Ba 140	2304	19.32	3.806	.1477	.0011
Ce 141	381.4	55.95	29.51	8.207	1.204
Ce 144	575.1	448.1	416.5	360.1	289.2
Pr 143	798.0	9.409	2.062	.0991	.0010
Pm 146	---	---	---	---	---
Nd 147	267.9	.9708	.1491	.0035	---
Pm 147	2.488	2.968	2.907	2.783	2.608
Pm 148m	1.543	.3495	.2130	.0791	.0179
Pm 148	26.40	.0879	.0534	.0198	.0045
Sm 151	.0033	.0034	.0034	.0034	.0034
Eu 152	---	---	---	---	---
Eu 154	.0062	.0062	.0061	.0061	.0060
Eu 155	.0722	.0657	.0636	.0598	.0544
Eu 156	13.00	0.2031	.0508	.0032	---
Tb 160	.0016	.0007	.0005	.0003	.0001
Tb 161	.0675	---	---	---	---

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TABLE II-16 (Continued)

Beta Heat, Watts Per Ton of Uranium

Nuclide	1 y	2 y	5 y	10 y	20 y
Kr 85	.4343	.4063	.3326	.2384	.1224
Rb 86	---	---	---	---	---
Sr 89	5.043	.0332	---	---	---
Sr 90	14.75	14.39	13.36	11.80	9.216
Y 91	12.24	.1556	---	---	---
Zr 95	4.174	.0849	---	---	---
Nb 95	3.270	.0683	---	---	---
Ru 103	.2151	.0004	---	---	---
Ru 106	35.34	17.67	2.208	.0690	.0001
Ag 110m	.0001	---	---	---	---
Ag 111	---	---	---	---	---
Cd 115m	.0005	---	---	---	---
Sn 123m	.0201	.0027	---	---	---
Sn 125	---	---	---	---	---
Sb 125	.1291	.0998	.0463	.0128	.0010
Te 125m	.0034	.0026	.0012	.0003	---
Sb 127	---	---	---	---	---
Te 127m	.2322	.0208	---	---	---
Te 129m	.0392	---	---	---	---
I 131	---	---	---	---	---
Xe 131m	---	---	---	---	---
Te 132	---	---	---	---	---
Xe 133	---	---	---	---	---
Cs 134	.1650	.1186	.0441	.0085	.0003
Cs 136	---	---	---	---	---
Cs 137	3.673	3.589	3.348	2.983	2.368
Ba 140	---	---	---	---	---
Ce 141	.1579	.0001	---	---	---
Ce 144	229.4	94.37	6.569	.0773	---
Pr 143	---	---	---	---	---
Pm 146	---	---	---	---	---
Nd 147	---	---	---	---	---
Pm 147	2.434	1.868	.8447	.2250	.0160
Pm 148m	.0037	---	---	---	---
Pm 148	.0009	---	---	---	---
Sm 151	.0034	.0034	.0033	.0032	.0029
Eu 152	---	---	---	---	---
Eu 154	.0060	.0057	.0050	.0040	.0026
Eu 155	.0492	.0336	.0106	.0016	---
Eu 156	---	---	---	---	---
Tb 160	---	---	---	---	---
Tb 161	---	---	---	---	---

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TABLE II-17

FISSION PRODUCT BETA HEAT FROM NATURAL URANIUM

900 MWd/T, 10 MW/T

Beta Heat, Watts Per Ton of Uranium

Nuclide	Discharge	90 d	120 d	180 d	270 d
Kr 85	.5487	.5407	.5377	.5313	.5234
Rb 86	.0648	.0023	.0008	.0001	---
Sr 89	832.3	241.4	159.8	70.01	20.30
Sr 90	17.58	17.80	17.76	17.69	17.58
Y 91	1057	360.5	251.9	123.0	41.95
Zr 95	227.1	87.32	60.86	33.44	12.81
Nb 95	52.40	48.22	38.86	23.20	9.684
Ru 103	141.1	29.20	17.28	6.044	1.251
Ru 106	89.06	75.08	70.92	63.29	53.35
Ag 110m	.0004	.0003	.0003	.0003	.0002
Ag 111	8.539	.0021	.0001	---	---
Cd 115m	.2198	.0515	.0318	.0121	.0028
Sn 123m	.1805	.1096	.0928	.0665	.0404
Sn 125	7.413	.0097	.0011	---	---
Sb 125	.1943	.1907	.1867	.1790	.1680
Te 125m	.0034	.0050	.0049	.0047	.0044
Sb 127	79.25	---	---	---	---
Te 127m	2.721	1.644	1.349	.9076	.5010
Te 129m	90.71	13.71	7.299	2.070	.3126
I 131	476.7	.2104	.0159	.0001	---
Xe 131m	2.102	.0353	.0064	.0002	---
Te 132	1075	---	---	---	---
Xe 133	470.6	.0035	.0001	---	---
Cs 134	.3342	.3082	.2999	.2841	.2619
Cs 136	1.014	.0084	.0017	.0001	---
Cs 137	4.492	4.467	4.458	4.441	4.416
Ba 140	2335	19.55	3.850	.1494	.0011
Ce 141	406.8	59.67	31.47	8.753	1.284
Ce 144	669.7	524.2	487.2	421.1	338.3
Pr 143	808.7	9.510	2.084	.1001	.0011
Pm 146	---	---	---	---	---
Nd 147	270.8	.9814	.1508	.0036	---
Pm 147	3.041	3.493	3.420	3.275	3.069
Pm 148m	1.948	.4411	.2688	.0999	.0226
Pm 148	32.81	.1109	.0674	.0250	.0057
Sm 151	.0035	.0037	.0037	.0037	.0037
Eu 152	---	---	---	---	---
Eu 154	.0091	.0090	.0089	.0089	.0088
Eu 155	.0808	.0735	.0713	.0669	.0609
Eu 156	14.86	.2321	.0580	.0036	.0001
Tb 160	.0023	.0010	.0007	.0004	.0002
Tb 161	.0771	---	---	---	---

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TABLE II-17 (Continued)

Beta Heat, Watts Per Ton of Uranium

Nuclide	1 y	2 y	5 y	10 y	20 y
Kr 85	.5140	.4809	.3937	.2821	.1449
Rb 86	---	---	---	---	---
Sr 89	5.478	.0361	---	---	---
Sr 90	17.47	17.05	15.82	13.98	10.92
Y 91	13.44	.1708	---	---	---
Zr 95	4.638	.0943	---	---	---
Nb 95	3.638	.0759	---	---	---
Ru 103	.2360	.0004	---	---	---
Ru 106	44.53	22.26	2.783	0.0870	.0001
Ag 110m	.0002	.0001	---	---	---
Ag 111	---	---	---	---	---
Cd 115m	.0006	---	---	---	---
Sn 123m	.0238	.0031	---	---	---
Sn 125	---	---	---	---	---
Sb 125	.1571	.1216	.0563	.0156	.0012
Te 125m	.0042	.0032	.0015	.0004	---
Sb 127	---	---	---	---	---
Te 127m	.2671	.0239	---	---	---
Te 129m	.0423	---	---	---	---
I 131	---	---	---	---	---
Xe 131m	---	---	---	---	---
Te 132	---	---	---	---	---
Xe 133	---	---	---	---	---
Cs 134	.2403	.1727	.0642	.0123	.0005
Cs 136	---	---	---	---	---
Cs 137	4.390	4.289	4.002	3.565	2.830
Ba 140	---	---	---	---	---
Ce 141	.1684	.0001	---	---	---
Ce 144	268.3	183.6	7.682	.0905	---
Pr 143	---	---	---	---	---
Pm 146	---	---	---	---	---
Nd 147	---	---	---	---	---
Pm 147	2.864	2.198	.9940	.2648	.0188
Pm 148m	.0047	---	---	---	---
Pm 148	.0012	---	---	---	---
Sm 151	.0037	.0036	.0036	.0034	.0032
Eu 152	---	---	---	---	---
Eu 154	.0087	.0083	.0073	.0059	.0038
Eu 155	.0551	.0376	.0191	.0018	---
Eu 156	---	---	---	---	---
Tb 160	.0001	---	---	---	---
Tb 161	---	---	---	---	---

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TABLE II-18

FISSION PRODUCT BETA HEAT FROM 0.947% ENRICHED URANIUM

900 MWd/T, 9.7 MW/T

Beta Heat, Watts Per Ton of Uranium

Nuclide	Discharge	90 d	120 d	180 d	270 d	1 y
Kr 85	.5690	.5606	.5576	.5513	.5425	.5328
Rb 86	.0530	.0019	.0006	.0001	---	---
Sr 89	844.5	244.9	162.1	71.04	20.60	5.559
Sr 90	18.19	18.47	18.43	18.36	18.25	18.13
Y 91	1073	366.0	255.7	124.8	42.59	13.64
Zr 95	229.7	88.32	64.14	33.83	12.95	4.692
Nb 95	54.10	48.96	39.41	23.50	9.801	3.681
Ru 103	139.1	28.80	17.03	5.960	1.233	.2328
Ru 106	84.52	71.25	67.31	60.06	50.63	42.26
Ag 110m	.0003	.0002	.0002	.0002	.0002	.0001
Ag 111	7.732	.0019	.0001	---	---	---
Cd 115m	.2133	.0500	.0308	.0117	.0027	.0006
Sn 123m	.1776	.1078	.0913	.0654	.0397	.0234
Sn 125	7.191	.0094	.0010	---	---	---
Sb 125	.1943	.1904	.1864	.1787	.1678	.1569
Te 125m	.0367	.0504	.0494	.0473	.0444	.0415
Sb 127	79.49	---	---	---	---	---
Te 127m	2.737	1.652	1.356	.9125	.5038	.2686
Te 129m	89.77	13.56	7.224	2.049	.3093	.0418
I 131	477.8	.2110	.0159	.0001	---	---
Xe 131m	2.060	.0351	.0064	.0002	---	---
Te 132	1086	---	---	---	---	---
Xe 133	477.3	.0035	.0001	---	---	---
Cs 134	.2610	.2407	.2342	.2219	.2045	.1877
Cs 136	.9214	.0076	.0015	.0001	---	---
Cs 137	4.614	4.587	4.579	4.561	4.535	4.508
Ba 140	2338	19.61	3.862	.1499	.0011	---
Ce 141	406.1	59.56	31.41	8.737	1.282	.1681
Ce 144	682.9	537.8	500.0	432.1	347.1	275.3
Pr 143	811.7	9.564	2.096	.1007	.0011	---
Pm 146	---	---	---	---	---	---
Nd 147	271.6	.9843	.1512	.0036	---	---
Pm 147	3.181	3.626	3.550	3.399	3.185	2.972
Pm 148m	1.814	.4107	.2503	.0930	.0211	.0044
Pm 148	26.39	.1032	.0628	.0233	.0053	.0011
Sm 151	.0041	.0043	.0043	.0043	.0043	.0043
Eu 152	---	---	---	---	---	---
Eu 154	.0071	.0070	.0070	.0070	.0069	.0068
Eu 155	.0909	.0827	.0801	.0752	.0685	.0620
Eu 156	13.24	.2068	.0517	.0032	.0001	---
Tb 160	.0017	.0007	.0005	.0003	.0001	.0001
Tb 161	.0678	---	---	---	---	---

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TABLE II-18 (Continued)

Beta Heat, Watts Per Ton of Uranium

Nuclide	1.5 y	2 y	3.5 y	5 y	7 y	10 y	20 y
Kr 85	.5153	.4987	.4513	.4084	.3574	.2926	.1503
Rb 86	---	---	---	---			
Sr 89	.4510	.0366	---	---			
Sr 90	17.91	17.69	17.05	16.42	15.63	14.50	11.33
Y 91	1.538	.1734	.0003	---			
Zr 95	.6691	.0954	.0003	---			
Nb 95	.5360	.0767	.0002	---			
Ru 103	.0095	.0004	---	---			
Ru 106	29.88	21.13	7.471	2.641	.6603	.0825	.0001
Ag 110m	.0001	---	---	---	---	---	---
Ag 111	---	---	---	---			
Cd 115m	---	---	---	---			
Sn 123m	.0085	.0031	.0001	---			
Sn 125	---	---	---	---			
Sb 125	.1380	.1214	.0826	.0562	.0336	.0156	.0012
Te 125m	.0365	.0321	.0219	.0149	.0089	.0041	.0003
Sb 127	---	---	---	---			
Te 127m	.0804	.0241	.0006	---	---	---	---
Te 129m	.0009	---	---	---			
I 131	---	---	---	---			
Xe 131m	---	---	---	---			
Te 132	---	---	---	---			
Xe 133	---	---	---	---			
Cs 134	.1591	.1349	.0822	.0501	.0259	.0096	.0004
Cs 136	---	---	---	---			
Cs 137	4.456	4.405	4.255	4.110	3.925	3.662	2.906
Ba 140	---	---	---	---			
Ce 141	.0034	.0001	---	---			
Ce 144	176.6	113.3	29.88	7.884	1.333	.0928	---
Pr 143	---	---	---	---			
Pm 146	---	---	---	---	---	---	---
Nd 147	---	---	---	---			
Pm 147	2.604	2.282	1.534	1.032	.6078	.2748	.0195
Pm 148m	.0002	---	---	---			
Pm 148	.0001	---	---	---			
Sm 151	.0043	.0042	.0042	.0041	.0041	.0040	.0037
Eu 152	---	---	---	---	---	---	---
Eu 154	.0067	.0065	.0061	.0057	.0052	.0046	.0030
Eu 155	.0512	.0422	.0238	.0134	.0062	.0020	---
Eu 156	---	---	---	---	---	---	---
Tb 160	---	---	---	---			
Tb 161	---	---	---	---			

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TABLE II-19

FISSION PRODUCT BETA HEAT FROM 0.947% ENRICHED URANIUM

1000 MWd/T, 10 MW/T

Nuclide	Beta Heat, Watts Per Ton of Uranium				
	Discharge	90 d	120 d	180 d	270 d
Kr 85	.6338	.6233	.6203	.6133	.6033
Rb 86	.0635	.0023	.0007	.0001	---
Sr 89	917.3	266.1	176.1	77.16	22.38
Sr 90	20.30	20.55	20.50	20.42	20.30
Y 91	1169	398.8	278.7	136.0	46.40
Zr 95	251.0	96.49	70.07	36.96	14.15
Nb 95	60.72	53.76	43.20	25.72	10.71
Ru 103	150.4	31.14	18.42	6.445	1.334
Ru 106	95.93	80.87	76.40	68.17	57.47
Ag 110m	.0004	.0003	.0003	.0003	.0002
Ag 111	8.622	.0021	.0001	---	---
Cd 115m	.2302	.0540	.0333	.0126	.0030
Sn 123m	.1962	.1191	.1009	.0723	.0439
Sn 125	7.708	.0101	.0011	---	---
Sb 125	.2195	.2146	.2102	.2015	.1891
Te 125m	.0387	.0568	.0556	.0534	.0501
Sb 127	82.83	---	---	---	---
Te 127m	3.035	1.824	1.496	1.007	.5558
Te 129m	97.18	14.68	7.819	2.217	.3349
I 131	503.1	.2220	.0168	.0001	---
Xe 131m	2.235	.0373	.0068	.0002	---
Te 132	1124	---	---	---	---
Xe 133	495.4	.0036	.0001	---	---
Cs 134	.3431	.3163	.3079	.2916	.2688
Cs 136	1.070	.0088	.0018	.0001	---
Cs 137	5.131	5.102	5.092	5.073	5.044
Ba 140	2473	20.69	4.075	.1581	.0012
Ce 141	438.4	64.30	33.91	9.432	1.384
Ce 144	755.4	595.0	553.1	477.0	384.0
Pr 143	859.6	10.10	2.214	.1063	.0011
Pm 146	---	---	---	---	---
Nd 147	284.4	1.031	.1583	.0037	---
Pm 147	3.523	3.977	3.894	3.729	3.493
Pm 148m	2.146	.4859	.2961	.1100	.0249
Pm 148	31.80	.1221	.0742	.0276	.0062
Sm 151	.0043	.0044	.0044	.0044	.0044
Eu 152	.0001	.0001	.0001	.0001	.0001
Eu 154	.0090	.0089	.0089	.0088	.0087
Eu 155	.0960	.0874	.0847	.0795	.0723
Eu 156	14.76	.2307	.0577	.0036	.0001
Tb 160	.0022	.0009	.0007	.0004	.0002
Tb 161	.0759	---	---	---	---

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TABLE II-19 (Continued)

Beta Heat, Watts Per Ton of Uranium

Nuclide	1 y	2 y	5 y	10 y	20 y
Kr 85	.5928	.5552	.4542	.3255	.1671
Rb 86	---	---	---	---	---
Sr 89	6.038	.0398	---	---	---
Sr 90	20.16	19.68	18.26	16.14	12.60
Y 91	14.87	.1890	---	---	---
Zr 95	5.125	.1043	---	---	---
Nb 95	4.022	.0838	---	---	---
Ru 103	.2518	.0004	---	---	---
Ru 106	47.97	23.98	2.998	.0937	.0001
Ag 110m	.0002	.0001	---	---	---
Ag 111	---	---	---	---	---
Cd 115m	.0006	---	---	---	---
Sn 123m	.0259	.0034	---	---	---
Sn 125	---	---	---	---	---
Sb 125	.1769	.1368	.0633	.0176	.0013
Te 125m	.0468	.0362	.0168	.0046	.0004
Sb 127	---	---	---	---	---
Te 127m	.2963	.0266	---	---	---
Te 129m	.0453	---	---	---	---
I 131	---	---	---	---	---
Xe 131m	---	---	---	---	---
Te 132	---	---	---	---	---
Xe 133	---	---	---	---	---
Cs 134	.2467	.1773	.0659	.0126	.0005
Cs 136	---	---	---	---	---
Cs 137	5.014	4.899	4.571	4.073	3.232
Ba 140	---	---	---	---	---
Ce 141	.1814	.0001	---	---	---
Ce 144	304.6	125.3	8.720	.1027	---
Pr 143	---	---	---	---	---
Pm 146	---	---	---	---	---
Nd 147	---	---	---	---	---
Pm 147	3.260	2.502	1.132	.3014	.0214
Pm 148m	.0052	---	---	---	---
Pm 148	.0013	---	---	---	---
Sm 151	.0044	.0044	.0043	.0041	.0038
Eu 152	.0001	---	---	---	---
Eu 154	.0086	.0083	.0073	.0058	.0038
Eu 155	.0655	.0446	.0142	.0021	---
Eu 156	---	---	---	---	---
Tb 160	.0001	---	---	---	---
Tb 161	---	---	---	---	---

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TABLE II-20

FISSION PRODUCT BETA HEAT FROM 0.947% ENRICHED URANIUM

1200 MWd/T, 10 MW/T

Beta Heat, Watts Per Ton of Uranium

Nuclide	Discharge	90 d	120 d	180 d	270 d
Kr 85	.7522	.7406	.7365	.7278	.7166
Rb 86	.0778	.0028	.0009	.0001	---
Sr 89	978.9	283.9	187.9	82.34	23.88
Sr 90	24.30	24.42	24.37	24.27	24.12
Y 91	1263	430.7	300.9	146.9	50.11
Zr 95	275.1	105.8	76.78	40.49	15.50
Nb 95	73.23	60.03	47.96	28.37	11.77
Ru 103	162.8	33.71	19.94	6.976	1.444
Ru 106	121.7	102.6	96.93	86.50	72.92
Ag 110m	.0007	.0005	.0005	.0004	.0003
Ag 111	9.618	.0023	.0001	---	---
Cd 115m	.2560	.0600	.0370	.0140	.0033
Sn 123m	.2318	.1407	.1191	.0854	.0519
Sn 125	8.056	.0106	.0012	---	---
Sb 125	.2702	.2626	.2571	.2465	.2314
Te 125m	.0636	.0695	.0681	.0653	.0613
Sb 127	84.20	---	---	---	---
Te 127m	3.502	2.083	1.708	1.150	.6348
Te 129m	103.1	15.58	8.297	2.352	.3553
I 131	509.0	.2245	.0170	.0001	---
Xe 131m	2.289	.0379	.0069	.0002	---
Te 132	1130	---	---	---	---
Xe 133	496.7	.0037	.0001	---	---
Cs 134	.4999	.4609	.4486	.4249	.3917
Cs 136	1.233	.0102	.0021	.0001	---
Cs 137	6.159	6.125	6.113	6.090	6.055
Ba 140	2492	20.82	4.101	.1592	.0012
Ce 141	459.7	67.44	35.56	9.892	1.451
Ce 144	879.5	694.6	645.8	558.1	448.3
Pr 143	864.3	10.14	2.223	.1068	.0011
Pm 146	---	---	---	---	---
Nd 147	286.6	1.039	.1595	.0038	---
Pm 147	4.276	4.688	4.589	4.394	4.117
Pm 148m	2.681	.6070	.3699	.1374	.0311
Pm 148	39.17	.1525	.0928	.0344	.0078
Sm 151	.0046	.0048	.0048	.0048	.0048
Eu 152	.0001	.0001	.0001	.0001	.0001
Eu 154	.0132	.0131	.0130	.0130	.0128
Eu 155	.1082	.0983	.0953	.0895	.0814
Eu 156	16.81	.2626	.0656	.0041	.0001
Tb 160	.0032	.0014	.0010	.0006	.0002
Tb 161	.0869	---	---	---	---

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TABLE II-20 (Continued)

Beta Heat, Watts Per Ton of Uranium

Nuclide	1 y	2 y	5 y	10 y	20 y
Kr 85	.7041	.6585	.5397	.3864	.1984
Rb 86	---	---	---	---	---
Sr 89	6.444	.0424	---	---	---
Sr 90	23.97	23.38	21.71	19.18	14.98
Y 91	16.05	.2041	---	---	---
Zr 95	5.616	.1142	---	---	---
Nb 95	4.412	.0919	---	---	---
Ru 103	.2725	.0005	---	---	---
Ru 106	60.86	30.43	3.804	.1189	.0001
Ag 110m	.0002	.0001	---	---	---
Ag 111	---	---	---	---	---
Cd 115m	.0007	---	---	---	---
Sn 123m	.0306	.0040	---	---	---
Sn 125	---	---	---	---	---
Sb 125	.2164	.1674	.0775	.0215	.0016
Te 125m	.0573	.0443	.0205	.0057	.0004
Sb 127	---	---	---	---	---
Te 127m	.3384	.0303	---	---	---
Te 129m	.0480	---	---	---	---
I 131	---	---	---	---	---
Xe 131m	---	---	---	---	---
Te 132	---	---	---	---	---
Xe 133	---	---	---	---	---
Cs 134	.3594	.2584	.0960	.0184	.0007
Cs 136	---	---	---	---	---
Cs 137	6.019	5.881	5.487	4.889	3.880
Ba 140	---	---	---	---	---
Ce 141	.1903	.0001	---	---	---
Ce 144	355.6	146.3	10.18	.1198	---
Pr 143	---	---	---	---	---
Pm 146	---	---	---	---	---
Nd 147	---	---	---	---	---
Pm 147	3.843	2.949	1.334	.3553	.0252
Pm 148m	.0065	---	---	---	---
Pm 148	.0016	---	---	---	---
Sm 151	.0048	.0047	.0046	.0045	.0041
Eu 152	.0001	.0001	.0001	---	---
Eu 154	.0127	.0121	.0106	.0086	.0056
Eu 155	.0737	.0502	.0159	.0023	.0001
Eu 156	---	---	---	---	---
Tb 160	.0001	---	---	---	---
Tb 161	---	---	---	---	---

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TABLE II-21

FISSION PRODUCT BETA HEAT FROM 0.947% ENRICHED URANIUM

2200 MWd/T, 11 MW/T

Beta Heat, Watts Per Ton of Uranium

Nuclide	Discharge	90 d	120 d	180 d	270 d	1 y
Kr 85	1.289	1.268	1.261	1.248	1.227	1.206
Rb 86	.1589	.0057	.0019	.0002	---	---
Sr 89	1101	319.4	211.4	92.64	26.87	7.250
Sr 90	42.53	42.04	41.96	41.79	41.54	41.27
Y 91	1482	505.4	353.2	172.4	58.81	18.84
Zr 95	346.5	133.1	96.64	50.97	19.52	7.068
Nb 95	112.6	78.99	62.26	36.29	14.91	5.568
Ru 103	214.1	44.32	26.22	9.172	1.898	.3581
Ru 106	296.1	249.6	235.8	210.4	177.4	148.0
Ag 110m	.0032	.0025	.0023	.0020	.0015	.0012
Ag 111	16.29	.0040	.0002	---	---	---
Cd 115m	.3834	.0899	.0554	.0211	.0049	.0011
Sn 123m	.4173	.2533	.2145	.1538	.0934	.0550
Sn 125	10.73	.0141	.0015	---	---	---
Sb 125	.5604	.5380	.5268	.5051	.4741	.4434
Te 125m	.1483	.1425	.1395	.1337	.1256	.1174
Sb 127	99.71	---	---	---	---	---
Te 127m	5.381	3.146	2.580	1.736	.9587	.5112
Te 129m	126.3	19.06	10.15	2.879	.4348	.0588
I 131	583.4	.2568	.0194	.0001	---	---
Xe 131m	2.645	.0435	.0079	.0003	---	---
Te 132	1283	---	---	---	---	---
Xe 133	550.5	.0041	.0001	---	---	---
Cs 134	2.233	2.059	2.003	1.898	1.750	1.605
Cs 136	2.346	.0193	.0039	.0002	---	---
Cs 137	11.33	11.26	11.24	11.20	11.13	11.07
Ba 140	2934	22.79	4.491	.1743	.0013	---
Ce 141	528.3	77.50	40.87	11.37	1.667	.2186
Ce 144	1409	1116	1038	897.1	720.8	571.7
Pr 143	930.0	10.90	2.390	.1148	.0012	---
Pm 146	---	---	---	---	---	---
Nd 147	321.0	1.163	.1787	.0042	---	---
Pm 147	7.376	7.674	7.512	7.193	6.739	6.290
Pm 148m	6.335	1.434	.8743	.3248	.0735	.0153
Pm 148	92.89	.3605	.2192	.0814	.0184	.0038
Sm 151	.0064	.0066	.0066	.0066	.0065	.0065
Eu 152	.0002	.0002	.0002	.0002	.0002	.0002
Eu 154	.0580	.0574	.0572	.0567	.0561	.0555
Eu 155	.1832	.1667	.1616	.1517	.1380	.1249
Eu 156	29.33	.4583	.1146	.0072	.0001	---
Tb 160	.0158	.0067	.0051	.0029	.0012	.0005
Tb 161	.1609	---	---	---	---	---

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TABLE II-21 (Continued)

Beta Heat, Watts Per Ton of Uranium

Nuclide	1.5 y	2 y	3.5 y	5 y	7 y	10 y	20 y
Kr 85	1.167	1.128	1.021	.9241	0.8090	.6119	.3400
Rb 86	---	---	---	---			
Sr 89	.5882	.0477	---	---			
Sr 90	40.76	40.25	38.79	37.38	35.57	33.03	25.78
Y 91	2.124	.2395	.0003	---			
Zr 95	1.008	.1438	.0004	---			
Nb 95	.8081	.1156	.0003	---			
Ru 103	.0147	.0006	---	---			
Ru 106	104.7	74.02	26.17	9.252	2.313	.2891	.0003
Ag 110m	.0007	.0005	.0001	---	---	---	---
Ag 111	---	---	---	---			
Cd 115m	.0001	---	---	---			
Sn 123m	.0200	.0073	.0003	---			
Sn 125	---	---	---	---			
Sb 125	.3900	.3430	.2334	.1588	.0950	.0440	.0034
Te 125m	.1032	.0908	.0618	.0420	.0252	.0116	.0009
Sb 127	---	---	---	---			
Te 127m	.1530	.0458	.0012	---	---	---	---
Te 129m	.0012	---	---	---			
I 131	---	---	---	---			
Xe 131m	---	---	---	---			
Te 132	---	---	---	---			
Xe 133	---	---	---	---			
Cs 134	1.361	1.154	.7033	.4287	.2215	.0823	.0030
Cs 136	---	---	---	---			
Cs 137	10.94	10.81	10.45	10.09	9.635	8.989	7.135
Ba 140	---	---	---	---			
Ce 141	.0044	.0001	---	---			
Ce 144	366.7	235.2	62.04	16.37	2.769	.1927	---
Pr 143	---	---	---	---			
Pm 146	---	---	---	---	---	---	---
Nd 147	---	---	---	---			
Pm 147	5.510	4.827	3.246	2.183	1.286	.5815	.0413
Pm 148m	.0007	---	---	---			
Pm 148	.0002	---	---	---			
Sm 151	.0065	.0065	.0064	.0063	.0062	.0061	.0056
Eu 152	.0002	.0002	.0002	.0002	.0001	.0001	.0001
Eu 154	.0543	.0532	.0498	.0467	.0428	.0376	.0244
Eu 155	.1032	.0852	.0480	.0270	.0126	.0040	.0001
Eu 156	---	---	---	---			
Tb 160	.0001	---	---	---			
Tb 161	---	---	---	---			

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TABLE II-22

FISSION PRODUCT BETA HEAT FROM 1.25% ENRICHED URANIUM

2200 MWd/T, 11 MW/T

Beta Heat, Watts Per Ton of Uranium

Nuclide	Discharge	90 d	120 d	180 d	270 d	1 y
Kr 85	1.341	1.320	1.312	1.298	1.277	1.255
Rb 86	.1336	.0048	.0016	.0002	---	---
Sr 89	1166	338.1	223.8	98.06	28.44	7.674
Sr 90	44.10	43.79	43.69	43.52	43.26	42.98
Y 91	1554	530.2	370.4	180.8	61.69	19.76
Zr 95	352.9	135.6	98.41	51.90	19.88	7.198
Nb 95	114.4	80.40	63.38	36.95	15.19	5.670
Ru 103	201.2	41.65	24.64	8.619	1.784	.3467
Ru 106	233.4	196.7	185.9	165.8	139.8	116.7
Ag 110m	.0018	.0014	.0013	.0011	.0009	.0007
Ag 111	12.23	.0030	.0002	---	---	---
Cd 115m	.3382	.0793	.0489	.0186	.0044	.0009
Sn 123m	.3691	.2241	.1897	.1360	.0826	.0487
Sn 125	9.434	.0124	.0014	---	---	---
Sb 125	.5061	.4856	.4755	.4559	.4279	.4002
Te 125m	.1276	.1286	.1259	.1207	.1133	.1060
Sb 127	95.00	---	---	---	---	---
Te 127m	5.193	3.035	2.489	1.675	.9248	.4931
Te 129m	121.5	18.35	9.769	2.770	.4183	.0566
I 131	565.9	.2494	.0188	.0001	---	---
Xe 131m	2.575	.0423	.0077	.0002	---	---
Te 132	1249	---	---	---	---	---
Xe 133	545.9	.0040	.0001	---	---	---
Cs 134	1.786	1.647	1.603	1.518	1.399	1.284
Cs 136	1.893	.0156	.0032	.0001	---	---
Cs 137	11.28	11.22	11.20	11.15	11.09	11.02
Ba 140	2731	22.95	4.519	.1754	.0013	---
Ce 141	527.9	77.44	40.84	11.36	1.666	.2185
Ce 144	1429	1136	1056	912.9	733.4	581.7
Pr 143	948.1	11.11	2.436	.1170	.0012	---
Pm 146	---	---	---	---	---	---
Nd 147	319.4	1.158	.1778	.0042	---	---
Pm 147	7.609	7.888	7.721	7.393	6.927	6.465
Pm 148m	6.202	1.404	.8559	.3180	.0720	.0150
Pm 148	79.52	.3528	.2146	.0797	.0180	.0037
Sm 151	.0071	.0073	.0073	.0073	.0073	.0073
Eu 152	.0002	.0002	.0002	.0002	.0002	.0002
Eu 154	.0433	.0428	.0426	.0424	.0419	.0414
Eu 155	.1729	.1573	.1524	.1431	.1303	.1179
Eu 156	22.79	.3560	.0890	.0056	.0001	---
Tb 160	.0098	.0042	.0031	.0018	.0007	.0003
Tb 161	.1152	---	---	---	---	---

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TABLE II-22 (Continued)

Beta Heat, Watts Per Ton of Uranium

Nuclide	1.5 y	2 y	3.5 y	5 y	7 y	10 y	20 y
Kr 85	1.214	1.174	1.062	.9616	.8416	.6891	.3537
Rb 86	---	---	---	---			
Sr 89	.6226	.0505	---	---			
Sr 90	42.44	41.92	40.40	38.92	37.04	34.39	26.85
Y 91	2.228	.2512	.0004	---			
Zr 95	1.027	.1464	.0004	---			
Nb 95	.8229	.1177	.0003	---			
Ru 103	.0138	.0006	---	---			
Ru 106	82.51	58.34	20.63	7.293	1.823	.2279	.0002
Ag 110m	.0004	.0003	.0001	---	---	---	---
Ag 111	---	---	---	---			
Cd 115m	---	---	---	---			
Sn 123m	.0177	.0064	.0003	---	---	---	---
Sn 125	---	---	---	---			
Sb 125	.3520	.3096	.2107	.1433	.0858	.0397	.0030
Te 125m	.0932	.0820	.0558	.0380	.0227	.0105	.0008
Sb 127	---	---	---	---			
Te 127m	.1476	.0442	.0012	---	---	---	---
Te 129m	.0012	---	---	---			
I 131	---	---	---	---			
Xe 131m	---	---	---	---			
Te 132	---	---	---	---			
Xe 133	---	---	---	---			
Cs 134	1.089	.9231	.5626	.3429	.1772	.0658	.0024
Cs 136	---	---	---	---			
Cs 137	10.90	10.77	10.40	10.05	9.596	8.954	7.107
Ba 140	---	---	---	---			
Ce 141	.0044	.0001	---	---			
Ce 144	373.1	239.3	63.13	16.65	2.818	.1961	---
Pr 143	---	---	---	---			
Pm 146	---	---	---	---	---	---	---
Nd 147	---	---	---	---			
Pm 147	5.664	4.962	3.337	2.244	1.322	.5977	.0424
Pm 148m	.0007	---	---	---			
Pm 148	.0002	---	---	---			
Sm 151	.0073	.0072	.0071	.0071	.0070	.0068	.0063
Eu 152	.0002	.0002	.0002	.0002	.0002	.0001	.0001
Eu 154	.0405	.0397	.0372	.0348	.0320	.0280	.0182
Eu 155	.0973	.0804	.0452	.0255	.0118	.0038	.0001
Eu 156	---	---	---	---			
Tb 160	.0001	---	---	---			
Tb 161	---	---	---	---			

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TABLE II-23

FISSION PRODUCT BETA HEAT FROM 2.1% ENRICHED URANIUM

2100 MWd/T, 10.6 MW/T

Nuclide	Beta Heat, Watts Per Ton of Uranium					
	Discharge	90 d	120 d	180 d	270 d	1 y
Kr 85	1.334	1.313	1.306	1.291	1.270	1.248
Rb 86	.0826	.0029	.0010	.0001	---	---
Sr 89	1194	346.3	229.2	100.4	29.13	7.859
Sr 90	43.58	43.58	43.49	43.31	43.06	42.78
Y 91	1576	537.5	375.5	183.3	62.53	20.03
Zr 95	346.2	132.9	96.56	50.93	19.50	7.063
Nb 95	111.6	78.78	62.13	36.24	14.9	5.563
Ru 103	178.9	37.04	21.91	7.665	1.585	.2993
Ru 106	155.3	130.9	123.7	110.4	93.03	77.65
Ag 110m	.0006	.0004	.0004	.0004	.0003	.0002
Ag 111	6.993	.0017	.0001	---	---	---
Cd 115m	.274	.0642	.0396	.0150	.0035	.0008
Sn 123m	.3008	.1826	.1546	.1108	.0673	.0397
Sn 125	7.57	.0099	.0011	---	---	---
Sb 125	.4246	.407	.3985	.382	.3586	.3354
Te 125m	.0803	.1078	.1055	.1012	.0950	.0888
Sb 127	55.63	---	---	---	---	---
Te 127m	4.773	2.785	2.285	1.538	.849	.4527
Te 129m	111.4	16.84	8.966	2.542	.3839	.0518
I 131	525.2	.232	.0175	.0001	---	---
Xe 131m	2.4	.0393	.0072	.0002	---	---
Te 132	1165	---	---	---	---	---
Xe 133	521.6	.0038	.0001	---	---	---
Cs 134	1.014	.935	.9100	.862	.7946	.7291
Cs 136	1.227	.0101	.002	.0001	---	---
Cs 137	10.70	10.64	10.62	10.58	10.52	10.46
Ba 140	2670	22.28	4.39	.1704	.0013	---
Ce 141	507.9	74.50	39.29	10.93	1.603	.2102
Ce 144	1387	1107	1029	889.3	714.4	566.7
Pr 143	935.1	10.96	2.402	.1154	.0012	---
Pm 146	---	---	---	---	---	---
Nd 147	306.1	1.109	.1704	.004	---	---
Pm 147	7.628	7.875	7.708	7.380	6.915	6.454
Pm 148m	5.253	1.189	.7249	.2693	.061	.0127
Pm 148	50.75	.2986	.1817	.0675	.0153	.0032
Sm 151	.0091	.0093	.0093	.0092	.0092	.0092
Eu 152	.0002	.0002	.0102	.0002	.0002	.0002
Eu 154	.0225	.0223	.0222	.022	.0218	.0216
Eu 155	.1702	.1549	.1501	.1409	.1282	.1161
Eu 156	14.31	.2236	.0559	.0035	---	---
Tb 160	.0038	.0016	.0012	.0007	.0002	.0001
Tb 161	.0573	---	---	---	---	---

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TABLE II-23 (Continued)

Beta Heat, Watts Per Ton of Uranium

Nuclide	1.5 y	2 y	3.5 y	5 y	7 y	10 y	20 y
Kr 85	1.208	1.168	1.057	.9564	0.8368	.6857	.3520
Rb 86	---	---	---	---			
Sr 89	.6376	.0517	---	---			
Sr 90	42.25	41.74	40.21	38.74	36.87	34.24	26.73
Y 91	2.259	.2547	.0004	---			
Zr 95	1.0073	.1437	.0004	---			
Nb 95	.8075	.1155	.0003	---			
Ru 103	.0122	.0005	---	---			
Ru 106	54.91	38.82	13.73	4.853	1.213	.1517	.0001
Ag 110m	.0001	.0001	---	---	---	---	---
Ag 111	---	---	---	---			
Cd 115m	---	---	---	---			
Sn 123m	.0144	.0052	.0002	---	---	---	---
Sn 125	---	---	---	---			
Sb 125	.295	.2595	.1765	.1201	.0719	.0333	.0026
Te 125m	.0781	.0687	.0467	.0318	.0190	.0088	.0007
Sb 127	---	---	---	---			
Te 127m	.1355	.0406	.0011	---	---	---	---
Te 129m	.0011	---	---	---			
I 131	---	---	---	---			
Xe 131m	---	---	---	---			
Te 132	---	---	---	---			
Xe 133	---	---	---	---			
Cs 134	.6182	.5241	.3195	.1947	.1006	.0374	.0014
Cs 136	---	---	---	---			
Cs 137	10.34	10.22	9.873	9.537	9.106	8.496	6.744
Ba 140	---	---	---	---			
Ce 141	.0043	.0001	---	---			
Ce 144	363.4	233.1	61.49	16.23	2.746	.1911	---
Pr 143	---	---	---	---			
Pm 146	---	---	---	---	---	---	---
Nd 147	---	---	---	---			
Pm 147	5.654	4.953	3.331	2.240	1.320	.5966	.0423
Pm 148m	.0006	---	---	---			
Pm 148	.0002	---	---	---			
Sm 151	.0092	.0091	.009	.0089	.0088	.0086	.0080
Eu 152	.0002	.0002	.0002	.0002	.0002	.0001	.0001
Eu 154	.0211	.0207	.0194	.0182	.0166	.0146	.0095
Eu 155	.0958	.0791	.0446	.025	.0117	.0037	.0001
Eu 156	---	---	---	---			
Tb 160	---	---	---	---			
Tb 161	---	---	---	---			

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TABLE II-24

FISSION PRODUCT GAMMA HEAT FROM NATURAL URANIUM

640 MWd/T, 8.17 MW/T

Nuclide	Gamma Heat, Watts Per Ton of Uranium					
	Discharge	90 d	120 d	180 d	270 d	1 y
Kr 85	.0081	.0079	.0079	.0078	.0077	.0075
Rb 86	.0056	.0002	.0001	---	---	---
Sr 89	.2239	.0649	.0430	.0188	.0055	.0015
Sr 90	---	---	---	---	---	---
Y 91	---	---	---	---	---	---
Zr 95	1025	392.5	285.1	150.3	57.58	20.85
Nb 95	612.8	602.3	487.5	292.5	122.4	46.05
Ru 103	492.9	102.0	60.33	21.10	4.368	.8245
Ru 106	11.80	9.947	9.396	8.385	7.068	5.900
Ag 110m	.0064	.0050	.0046	.0039	.0031	.0024
Ag 111	.4343	.0001	---	---	---	---
Cd 115m	.0051	.0012	.0007	.0003	.0001	---
Sn 123m	.0055	.0033	.0028	.0020	.0012	.0007
Sn 125	.6617	.0009	.0001	---	---	---
Sb 125	.4813	.4753	.4654	.4462	.4188	.3917
Te 125m	---	---	---	---	---	---
Sb 127	50.44	---	---	---	---	---
Te 127m	.0252	.0154	.0126	.0085	.0047	.0025
Te 129m	35.19	5.323	2.834	.8038	.1214	.0164
I 131	448.6	.1981	.0150	.0001	---	---
Xe 131m	.0536	.0009	.0002	---	---	---
Te 132	4662	---	---	---	---	---
Xe 133	80.20	.0006	---	---	---	---
Cs 134	1.738	1.603	1.560	1.477	1.362	1.250
Cs 136	17.82	.1468	.0297	.0012	---	---
Cs 137	7.077	7.036	7.023	6.996	6.957	6.915
Ba 140	6075	53.30	10.50	.4074	.0031	---
Ce 141	125.8	18.45	9.732	2.707	.3970	.0521
Ce 144	62.95	50.32	46.78	41.43	32.48	25.76
Pr 143	---	---	---	---	---	---
Pm 146	---	---	---	---	---	---
Nd 147	177.7	.6438	.0989	.0023	---	---
Pm 147	---	---	---	---	---	---
Pm 148m	9.455	2.141	1.305	.4848	.1098	.0228
Pm 148	17.14	.0637	.0387	.0144	.0033	.0007
Sm 151	---	---	---	---	---	---
Eu 152	.0003	.0002	.0002	.0002	.0002	.0002
Eu 154	.0251	.0248	.0248	.0246	.0243	.0240
Eu 155	.0168	.0153	.0148	.0139	.0126	.0114
Eu 156	34.01	.5315	.1329	.0083	.0001	---
Tb 160	.0052	.0022	.0017	.0009	.0004	.0002
Tb 161	.0001	---	---	---	---	---

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TABLE II-24 (Continued)

Gamma Heat, Watts Per Ton of Uranium

Nuclide	1.5 y	2 y	3.5 y	5 y	7 y	10 y	20 y
Kr 85	.0073	.0071	.0064	.0058	.0051	.0041	.0021
Rb 86	---	---	---	---			
Sr 89	.0001	---	---	---			
Sr 90	---	---	---	---	---	---	---
Y 91	---	---	---	---			
Zr 95	2.974	.4241	.0012	---			
Nb 95	6.711	.9611	.0028	---			
Ru 103	.0337	.0014	---	---			
Ru 106	4.172	2.950	1.043	.3687	.0922	.0115	---
Ag 110m	.0015	.0009	.0002	---	---	---	---
Ag 111	---	---	---	---			
Cd 115m	---	---	---	---			
Sn 123m	.0003	.0001	---	---			
Sn 125	---	---	---	---			
Sb 125	.3445	.3030	.2062	.1403	.0840	.0389	.0030
Te 125m	---	---	---	---	---	---	---
Sb 127	---	---	---	---			
Te 127m	.0007	.0002	---	---	---	---	---
Te 129m	.0004	---	---	---			
I 131	---	---	---	---			
Xe 131m	---	---	---	---			
Te 132	---	---	---	---			
Xe 133	---	---	---	---			
Cs 134	1.060	.8984	.5476	.3337	.1725	.0641	.0024
Cs 136	---	---	---	---			
Cs 137	6.835	6.757	6.527	6.305	6.020	5.617	4.458
Ba 140	---	---	---	---			
Ce 141	.0011	---	---	---			
Ce 144	16.52	10.60	2.796	.7376	.1248	.0087	---
Pr 143	---	---	---	---			
Pm 146	---	---	---	---	---	---	---
Nd 147	---	---	---	---			
Pm 147	---	---	---	---	---	---	---
Pm 148m	.0011	.0001	---	---			
Pm 148	---	---	---	---			
Sm 151	---	---	---	---	---	---	---
Eu 152	.0002	.0002	.0002	.0002	.0002	.0001	.0001
Eu 154	.0235	.0230	.0216	.0202	.0185	.0163	.0106
Eu 155	.0094	.0078	.0044	.0025	.0012	.0004	---
Eu 156	---	---	---	---			
Tb 160	---	---	---	---			
Tb 161	---	---	---	---			

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TABLE II-25

FISSION PRODUCT GAMMA HEAT FROM NATURAL URANIUM

750 MWd/T, 10 MW/T

Gamma Heat, Watts Per Ton of Uranium

Nuclide	Discharge	90 d	120 d	180 d	270 d
Kr 85	.0092	.0091	.0091	.0090	.0088
Rb 86	.0077	.0003	.0001	---	---
Sr 89	.2642	.0766	.0507	.0222	.0064
Sr 90	---	---	---	---	---
Y 91	---	---	---	---	---
Zr 95	1198	458.8	333.2	175.7	67.30
Nb 95	695.9	700.5	568.0	341.3	143.0
Ru 103	57.54	119.0	70.44	24.59	5.090
Ru 106	12.92	10.89	10.29	9.184	7.742
Ag 110m	.0079	.0062	.0057	.0049	.0038
Ag 111	.4770	.0001	---	---	---
Cd 115m	.0059	.0014	.0008	.0003	.0001
Sn 123m	.0062	.0038	.0032	.0023	.0014
Sn 125	.7633	.0010	.0001	---	---
Sb 125	.5414	.5352	.5241	.5025	.4717
Te 125m	---	---	---	---	---
Sb 127	58.66	---	---	---	---
Te 127m	.0290	.0178	.0146	.0098	.0054
Te 129m	41.28	6.241	3.324	.9425	.1423
I 131	526.5	.2325	.0176	.0001	---
Xe 131m	0.0638	.0011	.0002	---	---
Te 132	5445	---	---	---	---
Xe 133	94.03	.0007	---	---	---
Cs 134	2.418	2.229	2.170	2.055	1.895
Cs 136	19.91	.1640	.0331	.0014	---
Cs 137	8.095	8.049	8.034	8.003	7.958
Ba 140	7229	63.27	12.46	.4837	.0037
Ce 141	148.3	21.76	11.47	3.192	.4681
Ce 144	72.69	58.04	53.95	46.62	37.46
Pr 143	---	---	---	---	---
Pm 146	---	---	---	---	---
Nd 147	210.5	.7628	.1172	.0028	---
Pm 147	---	---	---	---	---
Pm 148m	11.75	2.661	1.622	.6026	.1364
Pm 148	23.80	.0792	.0481	.0179	.0040
Sm 151	---	---	---	---	---
Eu 152	.0003	.0003	.0003	.0003	.0003
Eu 154	.0341	.0337	.0336	.0334	.0330
Eu 155	.0166	.0151	.0146	.0138	.0125
Eu 156	40.24	.6287	.1572	.0098	.0002
Tb 160	.0069	.0030	.0022	.0013	.0005
Tb 161	.0001	---	---	---	---

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TABLE II-25 (Continued)

Gamma Heat, Watts Per Ton of Uranium

Nuclide	1 y	2 y	5 y	10 y	20 y
Kr 85	.0087	.0081	.0066	.0047	.0024
Rb 86	---	---	---	---	---
Sr 89	.0017	---	---	---	---
Sr 90	---	---	---	---	---
Y 91	---	---	---	---	---
Zr 95	24.37	.4958	---	---	---
Nb 95	53.82	1.123	---	---	---
Ru 103	.9609	.0016	---	---	---
Ru 106	6.461	3.231	.4038	.0126	---
Ag 110m	.0030	.0011	.0001	---	---
Ag 111	---	---	---	---	---
Cd 115m	---	---	---	---	---
Sn 123m	.0008	.0001	---	---	---
Sn 125	---	---	---	---	---
Sb 125	.4411	.3412	.1580	.0438	.0034
Te 125m	---	---	---	---	---
Sb 127	---	---	---	---	---
Te 127m	.0029	.0003	---	---	---
Te 129m	.0192	---	---	---	---
I 131	---	---	---	---	---
Xe 131m	---	---	---	---	---
Te 132	---	---	---	---	---
Xe 133	---	---	---	---	---
Cs 134	1.739	1.250	.4643	.0891	.0033
Cs 136	---	---	---	---	---
Cs 137	7.910	7.729	7.212	6.425	5.099
Ba 140	---	---	---	---	---
Ce 141	.0614	---	---	---	---
Ce 144	29.72	12.23	.8507	.0100	---
Pr 143	---	---	---	---	---
Pm 146	---	---	---	---	---
Nd 147	---	---	---	---	---
Pm 147	---	---	---	---	---
Pm 148m	.0283	.0001	---	---	---
Pm 148	.0008	---	---	---	---
Sm 151	---	---	---	---	---
Eu 152	.0003	.0002	.0002	.0002	.0001
Eu 154	.0326	.0313	.0275	.0221	.0143
Eu 155	.0113	.0077	.0024	.0004	---
Eu 156	---	---	---	---	---
Tb 160	.0002	---	---	---	---
Tb 161	---	---	---	---	---

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TABLE II-26

FISSION PRODUCT GAMMA HEAT FROM NATURAL URANIUM

900 MWd/T, 10 MW/T

Gamma Heat, Watts Per Ton of Uranium

Nuclide	Discharge	90 d	120 d	180 d	270 d
Kr 85	.0110	.0108	.0107	.0106	.0104
Rb 86	.0095	.0003	.0001	---	---
Sr 89	.2870	.0832	.0551	.0241	.0070
Sr 90	---	---	---	---	---
Y 91	---	---	---	---	---
Zr 95	1331	509.9	370.3	195.3	74.79
Nb 95	862.3	793.5	639.5	381.9	159.4
Ru 103	630.6	130.5	77.19	27.01	5.588
Ru 106	16.29	13.73	12.97	11.57	9.756
Ag 110m	.0124	.0097	.0090	.0077	.0060
Ag 111	.5308	.0001	---	---	---
Cd 115m	.0066	.0015	.0010	.0004	.0001
Sn 123m	.0074	.0045	.0038	.0027	.0016
Sn 125	.7971	.0010	.0001	---	---
Sb 125	.6640	.6516	.6380	.6117	.5742
Te 125m	---	---	---	---	---
Sb 127	59.14	---	---	---	---
Te 127m	.0338	.0204	.0168	.0113	.0062
Te 129m	44.48	6.724	3.581	1.015	.1533
I 131	532.8	.2351	.0178	.0001	---
Xe 131m	.0661	.0011	.0002	---	---
Te 132	5447	---	---	---	---
Xe 133	94.11	.0007	---	---	---
Cs 134	3.521	3.246	3.159	2.992	2.759
Cs 136	22.96	.1892	.0382	.0016	---
Cs 137	9.675	9.621	9.602	9.566	9.512
Ba 140	7319	64.00	12.60	.4892	.0037
Ce 141	158.2	23.21	12.24	3.404	.4993
Ce 144	84.94	67.88	63.10	54.54	43.81
Pr 143	---	---	---	---	---
Pm 146	---	---	---	---	---
Nd 147	212.8	.7711	.1184	.0028	---
Pm 147	---	---	---	---	---
Pm 148m	14.83	3.359	2.047	.7606	.1722
Pm 148	29.58	.1000	.0608	.0226	.0051
Sm 151	---	---	---	---	---
Eu 152	.0004	.0004	.0004	.0004	.0004
Eu 154	.0496	.0491	.0489	.0486	.0480
Eu 155	.0186	.0169	.0164	.0154	.0140
Eu 156	45.98	.7185	.1796	.0112	.0002
Tb 160	.0102	.0043	.0033	.0018	.0008
Tb 161	.0001	---	---	---	---

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TABLE II-26 (Continued)

Gamma Heat, Watts Per Ton of Uranium

Nuclide	1 y	2 y	5 y	10 y	20 y
Kr 85	.0103	.0096	.0079	.0056	.0029
Rb 86	---	---	---	---	---
Sr 89	.0019	---	---	---	---
Sr 90	---	---	---	---	---
Y 91	---	---	---	---	---
Zr 95	27.08	.5509	---	---	---
Nb 95	59.87	1.248	---	---	---
Ru 103	1.055	.0018	---	---	---
Ru 106	8.143	4.071	.5089	.0159	---
Ag 110m	.0047	.0018	.0001	---	---
Ag 111	---	---	---	---	---
Cd 115m	---	---	---	---	---
Sn 123m	.0010	.0001	---	---	---
Sn 125	---	---	---	---	---
Sb 125	.5370	.4154	.1923	.0533	.0041
Te 125m	---	---	---	---	---
Sb 127	---	---	---	---	---
Te 127m	.0033	.0003	---	---	---
Te 129m	.0207	---	---	---	---
I 131	---	---	---	---	---
Xe 131m	---	---	---	---	---
Te 132	---	---	---	---	---
Xe 133	---	---	---	---	---
Cs 134	2.531	1.820	.6760	.1298	.0048
Cs 136	---	---	---	---	---
Cs 137	9.454	9.239	8.620	7.679	6.095
Ba 140	---	---	---	---	---
Ce 141	.0655	---	---	---	---
Ce 144	34.76	14.30	.9949	.0117	---
Pr 143	---	---	---	---	---
Pm 146	---	---	---	---	---
Nd 147	---	---	---	---	---
Pm 147	---	---	---	---	---
Pm 148m	.0358	.0001	---	---	---
Pm 148	.0011	---	---	---	---
Sm 151	---	---	---	---	---
Eu 152	.0004	.0004	.0003	.0002	.0001
Eu 154	.0475	.0455	.0399	.0322	.0208
Eu 155	.0127	.0086	.0027	.0004	---
Eu 156	---	---	---	---	---
Tb 160	.0003	---	---	---	---
Tb 161	---	---	---	---	---

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TABLE II-27

FISSION PRODUCT GAMMA HEAT FROM 0.947% ENRICHED URANIUM

900 MWd/T, 9.7 MW/T

Gamma Heat, Watts Per Ton of Uranium

Nuclide	Discharge	90 d	120 d	180 d	270 d	1 y
Kr 85	.0114	.0112	.0112	.0111	.0108	.0107
Rb 86	.0078	.0003	.0001	---	---	---
Sr 89	.2912	.0845	.0559	.0245	.0071	.0019
Sr 90	---	---	---	---	---	---
Y 90	---	---	---	---	---	---
Zr 95	1347	515.8	374.6	197.5	75.65	27.40
Nb 95	890.3	805.7	648.5	386.8	161.3	60.58
Ru 103	621.9	128.7	76.13	26.64	5.511	1.042
Ru 106	15.46	13.03	12.31	10.98	9.259	7.728
Ag 110m	.0089	.0070	.0065	.0055	.0043	.0034
Ag 111	.4807	.0001	---	---	---	---
Cd 115m	.0064	.0015	.0009	.0004	.0001	---
Sn 123m	.0072	.0044	.0037	.0027	.0016	.0010
Sn 125	.7732	.0010	.0001	---	---	---
Sb 125	.6639	.6506	.6370	.6107	.5733	.5362
Te 125m	---	---	---	---	---	---
Sb 127	59.32	---	---	---	---	---
Te 127m	.0340	.0206	.0169	.0114	.0063	.0033
Te 129m	44.01	6.655	3.544	1.005	.1518	.0205
I 131	534.1	.2358	.0178	.0001	---	---
Xe 131m	.0648	.0007	.0002	---	---	---
Te 132	5502	---	---	---	---	---
Xe 133	95.46	.0011	---	---	---	---
Cs 134	2.749	2.535	2.467	2.337	2.154	1.977
Cs 136	20.86	.1719	.0347	.0014	---	---
Cs 137	9.937	9.881	9.862	9.824	9.769	9.710
Ba 140	7339	64.21	12.65	.4909	.0037	---
Ce 141	157.9	23.16	12.22	3.398	.4984	.0654
Ce 144	87.05	69.66	64.76	55.96	42.97	35.66
Pr 143	---	---	---	---	---	---
Pm 146	---	---	---	---	---	---
Nd 147	213.4	.7734	.1188	.0028	---	---
Pm 147	---	---	---	---	---	---
Pm 14 m	13.81	3.128	1.906	.7082	.1604	.0330
Pm 148	23.79	.0930	.0566	.0210	.0048	.0010
Sm 151	---	---	---	---	---	---
Eu 152	.0004	.0004	.0004	.0004	.0004	.0004
Eu 154	.0389	.0385	.0384	.0381	.0377	.0373
Eu 155	.0209	.0190	.0184	.0173	.0158	.0142
Eu 156	40.98	.6402	.1601	.0100	.0002	---
Tb 160	.0073	.0031	.0024	.0013	.0006	.0002
Tb 161	.0001	---	---	---	---	---

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TABLE II-27 (Continued)

Gamma Heat, Watts Per Ton of Uranium

Nuclide	1.5 y	2 y	3.5 y	5 y	7 y	10 y	20 y
Kr 85	.0103	.0100	.0090	.0082	.0071	.0059	.0030
Rb 86	---	---	---	---			
Sr 89	.0002	---	---	---			
Sr 90	---	---	---	---	---	---	---
Y 91	---	---	---	---			
Zr 95	3.907	.5573	.0016	---			
Nb 95	8.821	1.263	.0037	---			
Ru 103	.0425	.0017	---	---			
Ru 106	5.464	3.864	1.366	.4830	.1207	.0151	---
Ag 110m	.0021	.0013	.0003	.0001	---	---	---
Ag 111	---	---	---	---			
Cd 115m	---	---	---	---			
Sn 123m	.0003	.0001	---	---			
Sn 125	---	---	---	---			
Sb 125	.4716	.4148	.2822	.1920	.1149	.0532	.0041
Te 125m	---	---	---	---	---	---	---
Sb 127	---	---	---	---			
Te 127m	.0010	.0003	---	---	---	---	---
Te 129m	.0004	---	---	---			
I 131	---	---	---	---			
Xe 131m	---	---	---	---			
Te 132	---	---	---	---			
Xe 133	---	---	---	---			
Cs 134	1.676	1.421	.8661	.5279	.2728	.1013	.0037
Cs 136	---	---	---	---			
Cs 137	9.598	9.488	9.165	8.853	8.453	7.887	6.260
Ba 140	---	---	---	---			
Ce 141	.0013	---	---	---			
Ce 144	22.88	14.67	3.870	1.021	.1727	.0120	---
Pr 143	---	---	---	---			
Pm 146	---	---	---	---	---	---	---
Nd 147	---	---	---	---			
Pm 147	---	---	---	---	---	---	---
Pm 148m	.0016	.0001	---	---			
Pm 148	---	---	---	---			
Sm 151	---	---	---	---	---	---	---
Eu 152	.0004	.0004	.0004	.0003	.0003	.0003	.0001
Eu 154	.0365	.0357	.0334	.0313	.0287	.0252	.0164
Eu 155	.0118	.0097	.0055	.0031	.0014	.0005	---
Eu 156	---	---	---	---			
Tb 160	---	---	---	---			
Tb 161	---	---	---	---			

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TABLE II-28

FISSION PRODUCT GAMMA HEAT FROM 0.947% ENRICHED URANIUM

1000 MWd/T, 10 MW/T

Gamma Heat, Watts Per Ton of Uranium

Nuclide	Discharge	90 d	120 d	180 d	270 d
Kr 85	.0127	.0125	.0124	.0123	.0121
Rb 86	.0093	.0003	.0001	---	---
Sr 89	.3163	.0917	.0607	.0266	.0077
Sr 90	---	---	---	---	---
Y 91	---	---	---	---	---
Zr 95	1471	563.4	409.2	215.8	82.65
Nb 95	999.2	884.6	710.9	423.3	176.3
Ru 103	672.5	139.4	82.32	29.36	5.959
Ru 106	17.54	14.79	13.97	12.47	10.51
Ag 110m	.0118	.0093	.0085	.0073	.0057
Ag 111	.5360	.0001	---	---	---
Cd 115m	.0069	.0016	.0010	.0004	.0001
Sn 123m	.0080	.0049	.0041	.0029	.0018
Sn 125	.8288	.0011	.0001	---	---
Sb 125	.7500	.7334	.7182	.6885	.6463
Te 125m	---	---	---	---	---
Sb 127	61.70	---	---	---	---
Te 127m	.0378	.0227	.0186	.0125	.0069
Te 129m	47.65	7.204	3.836	1.088	.1643
I 131	562.3	.2482	.0188	.0001	---
Xe 131m	.0703	.0012	.0002	---	---
Te 132	5696	---	---	---	---
Xe 133	99.09	.0007	---	---	---
Cs 134	3.614	3.332	3.243	3.072	2.832
Cs 136	24.23	.1997	.0403	.0016	---
Cs 137	11.05	10.99	10.97	10.93	10.86
Ba 140	7772	67.75	13.35	.5180	.0040
Ce 141	170.5	25.01	13.19	3.668	.5380
Ce 144	96.30	77.06	71.64	61.91	49.73
Pr 143	---	---	---	---	---
Pm 146	---	---	---	---	---
Nd 147	223.4	.8097	.1244	.0029	---
Pm 147	---	---	---	---	---
Pm 148m	16.34	3.700	2.255	.8378	.1897
Pm 148	28.67	.1101	.0669	.0249	.0056
Sm 151	---	---	---	---	---
Eu 152	.0005	.0005	.0005	.0005	.0005
Eu 154	.0494	.0489	.0487	.0484	.0479
Eu 155	.0221	.0201	.0195	.0183	.0166
Eu 156	45.70	.7141	.1785	.0112	.0002
Tb 160	.0096	.0041	.0031	.0017	.0007
Tb 161	.0001	---	---	---	---

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TABLE II-28 (Continued)

Gamma Heat, Watts Per Ton of Uranium

Nuclide	1 y	2 y	5 y	10 y	20 y
Kr 85	.0119	.0111	.0091	.0065	.0033
Rb 86	---	---	---	---	---
Sr 89	.0021	---	---	---	---
Sr 90	---	---	---	---	---
Y 91	---	---	---	---	---
Zr 95	29.93	.6088	---	---	---
Nb 95	66.19	1.380	---	---	---
Ru 103	1.127	.0019	---	---	---
Ru 106	8.771	4.386	.5482	.0171	---
Ag 110m	.0044	.0017	.0001	---	---
Ag 111	---	---	---	---	---
Cd 115m	---	---	---	---	---
Sn 123m	.0011	.0001	---	---	---
Sn 125	---	---	---	---	---
Sb 125	.6045	.4676	.2165	.0600	.0046
Te 125m	---	---	---	---	---
Sb 127	---	---	---	---	---
Te 127m	.0037	.0003	---	---	---
Te 129m	.0222	---	---	---	---
I 131	---	---	---	---	---
Xe 131m	---	---	---	---	---
Te 132	---	---	---	---	---
Xe 133	---	---	---	---	---
Cs 134	2.598	1.868	.6938	.1332	.0049
Cs 136	---	---	---	---	---
Cs 137	10.80	10.55	9.846	8.772	6.962
Ba 140	---	---	---	---	---
Ce 141	.0706	---	---	---	---
Ce 144	39.45	16.24	1.129	.0133	---
Pr 143	---	---	---	---	---
Pm 146	---	---	---	---	---
Nd 147	---	---	---	---	---
Pm 147	---	---	---	---	---
Pm 148m	.0394	.0001	---	---	---
Pm 148	.0012	---	---	---	---
Sm 151	---	---	---	---	---
Eu 152	.0005	.0004	.0004	.0003	.0002
Eu 154	.0464	.0453	.0398	.0321	.0208
Eu 155	.0151	.0103	.0033	.0005	---
Eu 156	---	---	---	---	---
Tb 160	.0003	---	---	---	---
Tb 161	---	---	---	---	---

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TABLE II-29

FISSION PRODUCT GAMMA HEAT FROM 0.947% ENRICHED URANIUM

1200 MWd/T, 10 MW/T

Gamma Heat, Watts Per Ton of Uranium

Nuclide	Discharge	90 d	120 d	180 d	270 d
Kr 85	.0150	.0148	.0147	.0146	.0143
Rb 86	.0114	.0004	.0001	---	---
Sr 89	.3376	.0979	.0648	.0284	.0082
Sr 90	---	---	---	---	---
Y 91	---	---	---	---	---
Zr 95	1612	617.4	448.3	236.4	90.56
Nb 95	1205	987.9	789.2	466.9	193.7
Ru 103	727.8	150.6	89.09	31.17	6.450
Ru 106	22.26	18.76	17.73	15.82	13.33
Ag 110m	.0186	.0147	.0135	.0115	.0091
Ag 111	.5979	.0001	---	---	---
Cd 115m	.0077	.0018	.0011	.0004	.0001
Sn 123m	.0094	.0057	.0049	.0035	.0021
Sn 125	.8663	.0011	.0001	---	---
Sb 125	.9233	.8974	.8787	.8424	.7908
Te 125m	---	---	---	---	---
Sb 127	62.50	---	---	---	---
Te 127m	.0436	.0259	.0213	.0143	.0079
Te 129m	50.56	7.643	4.070	1.154	.1743
I 131	568.9	.2509	.0190	.0001	---
Xe 131m	.0720	.0012	.0002	---	---
Te 132	5728	---	---	---	---
Xe 133	99.34	.0007	---	---	---
Cs 134	5.266	4.855	4.725	4.476	4.126
Cs 136	27.91	.2299	.0464	.0019	---
Cs 137	13.27	13.19	13.17	13.12	13.04
Ba 140	7836	68.18	13.44	.5213	.0040
Ce 141	178.8	26.23	13.83	3.847	.5643
Ce 144	112.4	89.96	83.63	72.28	58.06
Pr 143	---	---	---	---	---
Pm 146	---	---	---	---	---
Nd 147	225.2	.8161	.1254	.0030	---
Pm 147	---	---	---	---	---
Pm 148m	20.41	4.622	2.817	1.047	.2370
Pm 148	35.31	.1375	.0836	.0311	.0070
Sm 151	---	---	---	---	---
Eu 152	.0007	.0007	.0007	.0007	.0007
Eu 154	.0724	.0717	.0714	.0709	.0702
Eu 155	.0249	.0226	.0219	.0206	.0187
Eu 156	52.02	.8128	.2032	.0127	.0002
Tb 160	.0141	.0060	.0045	.0026	.0011
Tb 161	.0002	---	---	---	---

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TABLE II-29 (Continued)

Gamma Heat, Watts Per Ton of Uranium

Nuclide	1 y	2 y	5 y	10 y	20 y
Kr 85	.0141	.0132	.0108	.0077	.0040
Rb 86	---	---	---	---	---
Sr 89	.0022	---	---	---	---
Sr 90	---	---	---	---	---
Y 91	---	---	---	---	---
Zr 95	32.79	.6671	---	---	---
Nb 95	72.61	1.512	---	---	---
Ru 103	1.217	.0020	---	---	---
Ru 106	11.13	5.564	.6956	.0217	---
Ag 110m	.0070	.0027	.0001	---	---
Ag 111	---	---	---	---	---
Cd 115m	---	---	---	---	---
Sn 123m	.0012	.0002	---	---	---
Sn 125	---	---	---	---	---
Sb 125	.7396	.5721	.2649	.0734	.0056
Te 125m	---	---	---	---	---
Sb 127	---	---	---	---	---
Te 127m	.0042	.0004	---	---	---
Te 129m	.0236	---	---	---	---
I 131	---	---	---	---	---
Xe 131m	---	---	---	---	---
Te 132	---	---	---	---	---
Xe 133	---	---	---	---	---
Cs 134	3.786	2.721	1.011	.1941	.0072
Cs 136	---	---	---	---	---
Cs 137	12.96	12.67	11.82	10.53	8.357
Ba 140	---	---	---	---	---
Ce 141	.0740	---	---	---	---
Ce 144	46.06	18.94	1.318	.0155	---
Pr 143	---	---	---	---	---
Pm 146	---	---	---	---	---
Nd 147	---	---	---	---	---
Pm 147	---	---	---	---	---
Pm 148m	.0492	.0001	---	---	---
Pm 148	.0015	---	---	---	---
Sm 151	---	---	---	---	---
Eu 152	.0007	.0006	.0005	.0004	.0002
Eu 154	.0694	.0664	.0583	.0470	.0305
Eu 155	.0170	.0116	.0037	.0005	---
Eu 156	---	---	---	---	---
Tb 160	.0004	---	---	---	---
Tb 161	---	---	---	---	---

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TABLE II-30

FISSION PRODUCT GAMMA HEAT FROM 0.947% ENRICHED URANIUM

2200 MWd/T, 11 MW/T

Gamma Heat, Watts Per Ton of Uranium

Nuclide	Discharge	90 d	120 d	180 d	270 d	1 y
Kr 85	.0258	.0254	.0252	.0250	.0246	.0241
Rb 86	.0233	.0008	.0002	---	---	---
Sr 89	.3798	.1101	.0729	.0320	.0093	.0025
Sr 90	---	---	---	---	---	---
Y 91	---	---	---	---	---	---
Zr 95	2029	777.1	564.3	297.6	114.0	41.27
Nb 95	1853	1300	1025	597.2	245.4	91.63
Ru 103	957.1	198.0	117.1	40.99	8.481	1.603
Ru 106	54.14	45.64	43.11	38.47	32.43	27.07
Ag 110m	.0901	.0709	.0654	.0557	.0438	.0340
Ag 111	1.013	.0002	---	---	---	---
Cd 115m	.0115	.0027	.0017	.0006	.0001	---
Sn 123m	.0170	.0103	.0087	.0063	.0038	.0022
Sn 125	1.154	.0015	.0002	---	---	---
Sb 125	1.915	1.839	1.800	1.726	1.620	1.515
Te 125m	---	---	---	---	---	---
Sb 127	73.41	---	---	---	---	---
Te 127m	.0669	.0391	.0321	.0216	.0119	.0064
Te 129m	61.95	9.353	4.981	1.412	.2133	.0288
I 131	652.0	.2870	.0217	.0001	---	---
Xe 131m	.0832	.0014	.0002	---	---	---
Te 132	6502	---	---	---	---	---
Xe 133	110.1	.0008	---	---	---	---
Cs 134	23.52	21.68	21.10	19.99	18.43	16.91
Cs 136	53.11	.4376	.0884	.0036	---	---
Cs 137	24.39	24.26	24.21	24.12	23.98	23.84
Ba 140	8605	74.65	14.71	.5708	.0043	---
Ce 141	205.5	30.14	15.89	4.421	.6484	.0850
Ce 144	180.5	144.6	134.4	116.2	93.35	74.05
Pr 143	---	---	---	---	---	---
Pm 146	---	---	---	---	---	---
Nd 147	252.2	.9140	.1404	.0033	---	---
Pm 147	---	---	---	---	---	---
Pm 148m	48.24	10.92	6.658	2.473	.5600	.1163
Pm 148	83.73	.3249	.1976	.0734	.0166	.0034
Sm 151	---	---	---	---	---	---
Eu 152	.0019	.0019	.0019	.0019	.0018	.0018
Eu 154	.3176	.3142	.3131	.3109	.3076	.3041
Eu 155	.0421	.0383	.0372	.0349	.0318	.0287
Eu 156	90.80	1.419	.3547	.0222	.0003	---
Tb 160	.0698	.0297	.0223	.0126	.0054	.0022
Tb 161	.0003	---	---	---	---	---

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TABLE II-30 (Continued)

Gamma Heat, Watts Per Ton of Uranium

Nuclide	1.5 y	2 y	3.5 y	5 y	7 y	10 y	20 y
Kr 85	.0233	.0226	.0204	.0185	0.0162	.0132	.0068
Rb 86	---	---	---	---			
Sr 89	.0002	---	---	---			
Sr 90	---	---	---	---	---	---	---
Y 91	---	---	---	---			
Zr 95	5.887	.8396	.0024	---			
Nb 95	13.30	1.903	.0055	---			
Ru 103	.0655	.0027	---	---			
Ru 106	19.14	13.53	4.785	1.692	.4230	.0529	.0001
Ag 110m	.0209	.0128	.0030	.0007	.0001	---	---
Ag 111	---	---	---	---			
Cd 115m	---	---	---	---			
Sn 123m	.0008	.0003	---	---			
Sn 125	---	---	---	---			
Sb 125	1.333	1.172	.7976	.5427	.3247	.1503	.0115
Te 125m	---	---	---	---	---	---	---
Sb 127	---	---	---	---			
Te 127m	.0019	.0006	---	---	---	---	---
Te 129m	.0006	---	---	---			
I 131	---	---	---	---			
Xe 131m	---	---	---	---			
Te 132	---	---	---	---			
Xe 133	---	---	---	---			
Cs 134	14.34	12.15	7.408	4.515	2.333	0.8669	.0320
Cs 136	---	---	---	---			
Cs 137	23.56	23.29	22.50	21.73	20.75	19.36	15.37
Ba 140	---	---	---	---			
Ce 141	.0017	---	---	---			
Ce 144	47.49	30.46	8.035	2.119	.3586	.0249	---
Pr 143	---	---	---	---			
Pm 146	---	---	---	---	---	---	---
Nd 147	---	---	---	---			
Pm 147	---	---	---	---	---	---	---
Pm 148m	.0057	.0003	---	---			
Pm 148	.0002	---	---	---			
Sm 151	---	---	---	---	---	---	---
Eu 152	.0018	.0017	.0016	.0015	.0013	.0011	.0007
Eu 154	.2976	.2912	.2729	.2557	.2345	.2059	.1335
Eu 155	.0237	.0196	.0110	.0062	.0029	.0009	---
Eu 156	---	---	---	---			
Tb 160	.0004	.0001	---	---			
Tb 161	---	---	---	---			

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TABLE II-31

FISSION PRODUCT GAMMA HEAT FROM 1.25% ENRICHED URANIUM

2200 MWd/T, 11 MW/T

Gamma Heat, Watts Per Ton of Uranium

Nuclide	Discharge	90 d	120 d	180 d	270 d	1 y
Kr 85	.0268	.0264	.0262	.0260	.0255	.0251
Rb 86	.0196	.0007	.0002	---	---	---
Sr 89	.4020	.1166	.0772	.0338	.0098	.0026
Sr 90	---	---	---	---	---	---
Y 91	---	---	---	---	---	---
Zr 95	2066	791.3	574.6	303.0	116.1	43.03
Nb 95	1883	1323	1043	608.0	249.9	93.30
Ru 103	899.4	186.1	110.1	38.52	7.971	1.504
Ru 106	42.68	35.98	33.98	30.33	25.57	21.34
Ag 110m	.0512	.0402	.0372	.0317	.0249	.0193
Ag 111	.7604	.0002	---	---	---	---
Cd 115m	.0101	.0024	.0015	.0006	.0001	---
Sn 123m	.0150	.0091	.0077	.0055	.0034	.0020
Sn 125	1.014	.0013	.0001	---	---	---
Sb 125	1.730	1.660	1.625	1.558	1.462	1.368
Te 125m	---	---	---	---	---	---
Sb 127	69.81	---	---	---	---	---
Te 127m	.0646	.0378	.0310	.0208	.0115	.0061
Te 129m	59.59	9.000	4.793	1.359	.2052	.0278
I 131	632.4	.2788	.0211	.0001	---	---
Xe 131m	.0810	.0013	.0002	---	---	---
Te 132	6331	---	---	---	---	---
Xe 133	109.2	.0008	---	---	---	---
Cs 134	18.81	17.34	16.88	15.99	14.74	13.53
Cs 136	42.85	.3531	.0713	.0029	---	---
Cs 137	24.30	24.16	24.11	24.02	23.89	23.74
Ba 140	8656	75.14	14.80	.5744	.0044	---
Ce 141	205.3	30.11	15.88	4.417	.6479	.0850
Ce 144	183.6	147.2	136.8	118.2	94.98	75.34
Pr 143	---	---	---	---	---	---
Pm 146	---	---	---	---	---	---
Nd 147	251.0	.9096	.1397	.0033	---	---
Pm 147	---	---	---	---	---	---
Pm 148m	47.23	10.69	6.518	2.421	.5483	.1138
Pm 148	71.68	.3180	.1934	.0718	.0163	.0034
Sm 151	---	---	---	---	---	---
Eu 152	.0002	.0021	.0021	.0021	.0021	.0020
Eu 154	.2370	.2345	.2337	.2320	.2295	.2270
Eu 155	.0398	.0362	.0351	.0329	.0300	.0271
Eu 156	70.53	1.102	.2755	.0172	.0003	---
Tb 160	.0432	.0184	.0138	.0078	.0033	.0013
Tb 161	.0002	---	---	---	---	---

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TABLE II-31 (Continued)

Gamma Heat, Watts Per Ton of Uranium

Nuclide	1.5 y	2 y	3.5 y	5 y	7 y	10 y	20 y
Kr 85	.0243	.0235	.0212	.0192	.0168	.0138	.0072
Rb 86	---	---	---	---			
Sr 89	.0002	---	---	---			
Sr 90	---	---	---	---	---	---	---
Y 91	---	---	---	---			
Zr 95	5.994	.8550	.0025	---			
Nb 95	13.54	1.938	.0056	---			
Ru 103	.0615	.0025	---	---			
Ru 106	15.09	10.67	3.772	1.334	.3334	.0417	—
Ag 110m	.0119	.0073	.0017	.0004	.0001	—	—
Ag 111	---	---	---	---			
Cd 115m	---	---	---	---			
Sn 123m	.0007	.0003	---	---	---	—	---
Sn 125	---	---	---	---			
Sb 125	1.203	1.058	.7199	.4898	.2931	.1357	.0104
Te 125m	---	---	---	---	---	---	---
Sb 127	---	---	---	---			
Te 127m	.0018	.0006	---	---	---	—	—
Te 129m	.0006	---	---	---			
I 131	---	---	---	---			
Xe 131m	----	---	---	---			
Te 132	---	---	---	---			
Xe 133	---	---	---	---			
Cs 134	11.47	9.723	5.926	3.612	1.867	.6934	.0256
Cs 136	---	---	---	---			
Cs 137	23.47	23.20	22.41	21.65	20.67	19.29	15.31
Ba 140	---	---	---	---			
Ce 141	.0017	---	---	---			
Ce 144	48.32	30.99	8.176	2.157	.3649	.0254	---
Pr 143	---	---	---	---			
Pm 146	---	---	---	---	---	—	—
Nd 147	---	---	---	---			
Pm 147	---	---	---	---	---	---	—
Pm 148m	.0056	.0003	---	---			
Pm 148	.0002	---	---	---			
Sm 151	---	---	---	---	---	---	—
Eu 152	.0020	.0019	.0018	.0017	.0015	.0013	.0007
Eu 154	.2221	.2173	.2037	.1909	.1750	.1537	.0996
Eu 155	.0224	.0185	.0104	.0059	.0027	.0009	—
Eu 156	---	---	---	---			
Tb 160	.0002	---	---	---			
Tb 161	---	---	---	---			

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TABLE II-32

FISSION PRODUCT GAMMA HEAT FROM 2.1% ENRICHED URANIUM

2100 MWd/T, 10.6 MW/T

Gamma Heat, Watts Per Ton of Uranium

Nuclide	Discharge	90 d	120 d	180 d	270 d	1 y
Kr 85	.0267	.0262	.0261	.0258	.0254	.0250
Rb 86	.0120	.0004	.0001	---	---	---
Sr 89	.4117	.1194	.079	.0346	.01	.0027
Sr 90	---	---	---	---	---	---
Y 91	---	---	---	---	---	---
Zr 95	2027	776.5	563.9	297.4	113.9	41.24
Nb 95	1837	1296	1022	596.3	245.2	91.55
Ru 103	799.8	165.5	97.89	34.24	7.086	1.337
Ru 106	28.4	23.94	22.61	20.18	17.01	14.2
Ag 110m	.0162	.0128	.0118	.01	.0079	.0061
Ag 111	.4347	.0001	---	---	---	---
Cd 115m	.0082	.0019	.0012	.0005	.0001	---
Sn 123m	.0122	.0074	.0063	.0045	.0027	.0016
Sn 125	.8139	.0011	.0001	---	---	---
Sb 125	1.451	1.391	1.362	1.306	1.226	1.146
Te 125m	---	---	---	---	---	---
Sb 127	62.58	---	---	---	---	---
Te 127m	.0594	.0347	.0284	.0192	.0106	.0056
Te 129m	54.65	8.259	4.398	1.247	.1883	.0254
I 131	587	.2592	.0196	.0001	---	---
Xe 131m	.0755	.0012	.0002	---	---	---
Te 132	5907	---	---	---	---	---
Xe 133	104.3	.0008	---	---	---	---
Cs 134	10.68	9.849	9.585	9.080	8.370	7.68
Cs 136	27.77	.2288	.0462	.0019	---	---
Cs 137	23.06	22.93	22.88	22.8	22.67	22.53
Ba 140	8397	72.99	14.38	.5580	.0042	---
Ce 141	197.5	28.97	15.28	4.25	.6234	.0817
Ce 144	178.6	143.3	133.3	115.18	92.54	73.40
Pr 143	---	---	---	---	---	---
Pm 146	---	---	---	---	---	---
Nd 147	240.5	.8716	.1339	.0032	---	---
Pm 147	---	---	---	---	---	---
Pm 148m	40	9.057	5.521	2.051	.4644	.0964
Pm 148	45.74	.2692	.1638	.0609	.0138	.0029
Sm 151	---	---	---	---	---	---
Eu 152	.0023	.0022	.0022	.0022	.0022	.0021
Eu 154	.1235	.1222	.1217	.1209	.1196	.1182
Eu 155	.0392	.0356	.0345	.0324	.0295	.0267
Eu 156	44.30	.6922	.1731	.0108	.0002	---
Tb 160	.0167	.007	.0053	.003	.0013	.0005
Tb 161	.0001	---	---	---	---	---

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TABLE II-32 (Continued)

Gamma Heat, Watts Per Ton of Uranium

Nuclide	1.5 y	2 y	3.5 y	5 y	7 y	10 y	20 y
Kr 85	.0241	.0233	.0211	.0191	.0167	.0137	.0070
Rb 86	---	---	---	---			
Sr 89	.0002	---	---	---			
Sr 90	---	---	---	---	---	---	---
Y 91	---	---	---	---			
Zr 95	5.882	.8390	.0024	---			
Nb 95	13.29	1.901	.0055	---			
Ru 103	.0547	.0022	---	---			
Ru 106	10.04	7.099	2.51	.8874	.2219	.0277	---
Ag 110m	.0038	.0023	.0005	.0001	---	---	---
Ag 111	---	---	---	---			
Cd 115m	---	---	---	---			
Sn 123m	.0006	.0002	---	---	---	---	---
Sn 125	---	---	---	---			
Sb 125	1.008	.8867	.6033	.4105	.2456	.1137	.0087
Te 125m	---	---	---	---	---	---	---
Sb 127	---	---	---	---			
Te 127m	.0017	.0005	---	---	---	---	---
Te 129m	.0005	---	---	---			
I 131	---	---	---	---			
Xe 131m	---	---	---	---			
Te 132	---	---	---	---			
Xe 133	---	---	---	---			
Cs 134	6.512	5.521	3.365	2.051	1.060	.3938	.0145
Cs 136	---	---	---	---			
Cs 137	22.27	22.02	21.27	20.54	19.61	18.30	14.52
Ba 140	---	---	---	---			
Ce 141	.0017	---	---	---			
Ce 144	47.08	30.18	7.965	2.101	.3556	.0247	---
Pr 143	---	---	---	---			
Pm 146	---	---	---	---	---	---	---
Nd 147	---	---	---	---			
Pm 147	---	---	---	---	---	---	---
Pm 148m	.0047	.0002	---	---			
Pm 148	.0001	---	---	---			
Sm 151	---	---	---	---	---	---	---
Eu 152	.0021	.0020	.0019	.0017	.0016	.0013	.0008
Eu 154	.1157	.1132	.1061	.0994	.0912	.0801	.0519
Eu 155	.0220	.0182	.0102	.0058	.0027	.0009	---
Eu 156	---	---	---	---			
Tb 160	.0001	---	---	---			
Tb 161	---	---	---	---			

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TABLE II-33

COMPOSITION OF IRRADIATED NATURAL URANIUM

640 MWd/T, 8.17 MW/T

Weight, Grams Per Ton of Uranium

Element	Discharge	90 d	120 d	180 d	270 d	1 y
Ge	.0057	.0057	.0057	.0057	.0057	.0057
As	.0023	.0018	.0018	.0018	.0018	.0018
Se	1.172	1.172	1.172	1.172	1.172	1.172
Br	.4494	.4494	.4494	.4494	.4494	.4494
Kr	8.115	8.085	8.078	8.064	8.043	8.021
Rb	8.061	8.090	8.097	8.112	8.133	8.155
Sr	28.59	23.90	23.24	22.48	22.01	21.81
Y	13.66	12.33	12.04	11.64	11.34	11.21
Zr	82.51	81.56	81.33	81.00	80.75	80.68
Nb	3.490	3.423	2.770	1.662	.6955	.2616
Mo	56.34	62.47	64.31	66.90	68.89	69.73
Tc	16.75	17.65	17.65	17.65	17.65	17.65
Ru	42.16	37.72	37.18	36.57	36.14	35.88
Rh	4.639	8.591	9.025	9.435	9.609	9.646
Pd	6.570	7.058	7.165	7.363	7.620	7.849
Ag	.4802	.4598	.4598	.4598	.4598	.4598
Cd	.3475	.3642	.3640	.3639	.3638	.3638
In	.0447	.0483	.0485	.0487	.0487	.0488
Sn	.7464	.7323	.7319	.7311	.7304	.7300
Sb	.3845	.3142	.3106	.3036	.2932	.2827
Te	11.44	9.806	9.751	9.703	9.684	9.684
I	5.629	4.670	4.733	4.790	4.819	4.831
Xe	101.71	101.89	101.90	101.90	101.90	101.90
Cs	52.56	54.88	54.83	54.73	54.58	54.43
Ba	31.75	26.52	26.54	26.63	26.78	26.93
La	26.00	25.30	25.30	25.30	25.30	25.30
Ce	72.51	65.14	63.35	60.80	58.16	56.06
Pr	17.78	21.54	22.23	22.81	23.00	23.03
Nd	59.78	67.79	68.92	70.89	73.34	75.42
Pm	6.914	7.798	7.632	7.306	6.843	6.387
Sm	8.404	9.176	9.346	9.673	10.13	10.59
Eu	1.006	.9586	.9555	.9512	.9457	.9407
Gd	.2574	.3442	.3479	.3536	.3611	.3682
Tb	.0142	.0138	.0138	.0138	.0138	.0138
Dy	.0017	.0021	.0021	.0021	.0021	.0021
RE	192.67	198.06	198.10	198.10	198.10	198.10
Np	28.47	2.164	2.164	2.164	2.164	2.164
Am	.0087	.0446	.0564	.0800	.1149	.1513

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TABLE II-33 (Continued)

Weight, Grams Per Ton of Uranium

Element	1.5 y	2 y	3.5 y	5 y	7 y	10 y	20 y
Ge	.0057	.0057	.0057	.0057	.0057	.0057	.0057
As	.0018	.0018	.0018	.0018	.0018	.0018	.0018
Se	1.172	1.172	1.172	1.172	1.172	1.172	1.172
Br	.4494	.4494	.4494	.4494	.4495	.4495	.4495
Kr	7.979	7.939	7.827	7.726	7.606	7.453	7.116
Rb	8.196	8.236	8.348	8.450	8.570	8.723	9.059
Sr	21.61	21.44	20.96	20.51	19.92	19.10	16.75
Y	11.15	11.14	11.14	11.14	11.14	11.14	11.14
Zr	80.74	80.89	81.36	81.82	82.41	83.23	85.58
Nb	.0381	.0055	.0001	.0001	.0001	.0001	.0002
Mo	70.15	70.21	70.22	70.22	70.22	70.22	70.22
Tc	17.65	17.65	17.65	17.65	17.65	17.65	17.65
Ru	35.53	35.29	34.92	34.79	34.73	34.72	34.72
Rh	9.654	9.655	9.655	9.655	9.655	9.655	9.655
Pd	8.186	8.425	8.797	8.929	8.983	8.999	9.001
Ag	.4598	.4598	.4598	.4598	.4598	.4598	.4598
Cd	.3638	.3638	.3638	.3638	.3638	.3638	.3638
In	.0488	.0488	.0488	.0488	.0488	.0488	.0488
Sn	.7295	.7294	.7293	.7293	.7293	.7293	.7293
Sb	.2640	.2473	.2081	.1814	.1586	.1403	.1258
Te	9.694	9.709	9.747	9.774	9.793	9.815	9.830
I	4.839	4.841	4.842	4.842	4.842	4.842	4.842
Xe	101.90	101.90	101.90	101.90	101.90	101.90	101.90
Cs	54.14	53.86	53.03	52.24	51.24	49.84	45.82
Ba	27.22	27.51	28.34	29.12	30.12	31.53	35.55
La	25.30	25.30	25.30	25.30	25.30	25.30	25.30
Ce	53.21	51.38	48.97	48.34	48.15	48.11	48.11
Pr	23.04	23.04	23.04	23.04	23.03	23.03	23.03
Nd	78.26	80.09	82.50	83.13	83.32	83.36	83.36
Pm	5.595	4.902	3.296	2.216	1.306	5904	.0419
Sm	11.37	12.06	13.66	14.73	15.62	16.31	16.79
Eu	.9327	.9268	.9177	.9171	.9234	.9395	1.004
Gd	.3802	.3901	.4111	.4234	.4326	.4392	.4465
Tb	.0137	.0137	.0137	.0137	.0137	.0137	.0137
Dy	.0022	.0022	.0022	.0022	.0022	.0022	.0022
RE	198.10	198.10	198.10	198.10	198.10	198.10	198.10
Np	2.164	2.164	2.164	2.166	2.168	2.174	2.195
Am	.2197	.2863	.4754	.6495	.8602	1.135	1.180

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TABLE II-34

COMPOSITION OF IRRADIATED NATURAL URANIUM

750 MWd/T, 10 MW/T

Weight, Grams Per Ton of Uranium

Element	Discharge	90 d	120 d	180 d	270 d
Ge	.0065	.0065	.0065	.0065	.0065
As	.0027	.0021	.0021	.0021	.0021
Se	1.346	1.347	1.347	1.347	1.347
Br	.5166	.5166	.5166	.5166	.5166
Kr	9.332	9.299	9.291	9.274	9.250
Rb	9.277	9.311	9.319	9.336	9.360
Sr	33.09	27.56	26.78	25.98	25.34
Y	15.76	14.22	13.88	13.42	13.06
Zr	94.74	93.67	93.40	93.02	92.74
Nb	3.963	3.981	3.227	1.939	.8124
Mo	64.28	71.36	73.49	76.52	78.84
Tc	19.14	20.19	20.19	20.19	20.19
Ru	48.06	42.92	42.29	41.60	41.11
Rh	5.109	9.719	10.23	10.70	10.91
Pd	7.257	7.795	7.913	8.130	8.411
Ag	.5026	.4803	.4803	.4803	.4803
Cd	.3847	.4028	.4026	.4024	.4023
In	.0497	.0539	.0541	.0543	.0544
Sn	.8435	.8272	.8267	.8259	.8251
Sb	.4351	.3536	.3496	.3416	.3300
Te	13.10	11.19	11.13	11.08	11.05
I	6.453	5.331	5.399	5.465	5.499
Xe	117.2	117.4	117.4	117.4	117.4
Cs	59.16	61.88	61.82	61.70	61.53
Ba	36.57	30.36	30.38	30.49	30.66
La	29.81	28.98	28.97	28.97	28.97
Ce	83.34	74.80	72.72	69.77	66.71
Pr	20.22	24.59	25.40	26.08	26.31
Nd	68.19	77.59	78.90	81.17	84.00
Pm	7.818	8.883	8.695	8.322	7.795
Sm	9.580	10.48	10.67	11.04	11.57
Eu	1.153	1.099	1.096	1.092	1.086
Gd	.2897	.3907	.3946	.4003	.4078
Tb	.0153	.0148	.0148	.0148	.0148
Dy	.0018	.0023	.0023	.0023	.0023
RE	220.5	226.8	226.9	226.9	226.9
Np	35.29	2.588	2.588	2.588	2.588
Am	.0143	.0791	.1005	.1430	.2061
Cm*	.4798	.3482	.3067	.2377	.1622

*Curium values are in milligrams

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TABLE II-34 (Continued)

Weight, Grams Per Ton of Uranium

Element	1 y	2 y	5 y	10 y	20 y
Ge	.0065	.0065	.0065	.0065	.0065
As	.0021	.0021	.0021	.0021	.0021
Se	1.347	1.347	1.347	1.347	1.347
Br	.5166	.5166	.5166	.5166	.5166
Kr	9.224	9.131	8.885	8.570	8.183
Rb	9.385	9.479	9.725	10.04	10.43
Sr	25.10	24.68	23.60	21.98	19.28
Y	12.91	12.83	12.83	12.83	12.83
Zr	92.65	92.89	93.97	95.59	98.29
Nb	.3057	.0064	.0001	.0001	.0003
Mo	79.82	80.38	80.39	80.39	80.39
Tc	20.19	20.19	20.19	20.19	20.19
Ru	40.82	40.18	39.63	39.55	39.55
Rh	10.95	10.96	10.96	10.96	10.96
Pd	8.661	9.293	9.845	9.921	9.924
Ag	.4803	.4802	.4802	.4802	.4802
Cd	.4023	.4024	.4024	.4024	.4024
In	.0544	.0544	.0544	.0544	.0544
Sn	.8246	.8239	.8238	.8238	.8238
Sb	.3181	.2783	.2041	.1578	.1414
Te	11.05	11.18	11.15	11.20	11.21
I	5.513	5.524	5.525	5.525	5.525
Xe	117.4	117.4	117.4	117.4	117.4
Cs	61.35	60.69	58.83	56.07	51.47
Ba	30.84	31.50	33.36	36.12	40.72
La	28.97	28.97	28.97	28.97	28.97
Ce	64.29	58.90	55.39	55.13	55.13
Pr	26.35	26.35	26.35	26.35	26.35
Nd	86.39	91.78	95.28	95.54	95.55
Pm	7.275	5.584	2.525	.6726	.0477
Sm	12.09	13.77	16.80	18.61	19.16
Eu	1.081	1.068	1.058	1.081	1.147
Gd	.4150	.4370	.4709	.4878	.4970
Tb	.0148	.0148	.0148	.0148	.0148
Dy	.0023	.0023	.0023	.0023	.0023
RE	226.9	226.9	226.9	226.9	226.9
Np	2.588	2.588	2.588	2.588	2.588
Am	.2720	.5158	1.172	2.050	3.214
Cm*	.1083	.0232	.0006	.0003	.0003

*Curium values are in milligrams

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TABLE II-35

COMPOSITION OF IRRADIATED NATURAL URANIUM

900 MWd/T, 10 MW/T

Weight, Grams Per Ton of Uranium

Element	Discharge	90 d	120 d	180 d	270 d
Ge	.0078	.0078	.0078	.0078	.0078
As	.0031	.0025	.0025	.0025	.0025
Se	1.599	1.599	1.599	1.599	1.599
Br	.6128	.6128	.6128	.6128	.6128
Kr	11.06	11.03	11.02	11.00	10.97
Rb	11.00	11.04	11.05	11.07	11.09
Sr	38.46	32.44	31.59	30.61	30.00
Y	18.50	16.75	16.37	15.85	15.45
Zr	112.60	111.32	111.01	110.58	110.25
Nb	4.909	4.509	3.634	2.169	.9053
Mo	77.44	85.84	88.26	91.65	94.24
Tc	23.05	24.10	24.10	24.10	24.10
Ru	57.37	51.66	50.95	50.16	49.58
Rh	6.757	11.83	12.38	12.91	13.13
Pd	9.234	9.881	10.03	10.30	10.66
Ag	.6676	.6427	.6427	.6427	.6427
Cd	.4897	.5100	.5098	.5096	.5096
In	.0609	.0654	.0656	.0658	.0659
Sn	1.025	1.008	1.007	1.006	1.005
Sb	.5159	.4316	.4267	.4170	.4028
Te	15.38	13.41	13.34	13.28	13.26
I	7.507	6.423	6.497	6.570	6.608
Xe	140.19	140.44	140.44	140.44	140.44
Cs	71.30	73.97	73.90	73.76	73.56
Ba	42.52	36.28	36.31	36.44	36.65
La	35.42	34.58	34.57	34.57	34.57
Ce	98.51	88.61	86.25	82.88	79.33
Pr	24.59	29.59	30.46	31.19	31.43
Nd	82.75	92.94	94.47	97.12	100.42
Pm	9.497	10.46	10.23	9.793	9.173
Sm	11.72	12.74	12.97	13.41	14.03
Eu	1.424	1.360	1.356	1.351	1.345
Gd	.3897	.5051	.5095	.5160	.5245
Tb	.0198	.0192	.0192	.0192	.0192
Dy	.0024	.0030	.0030	.0030	.0030
RE	264.32	270.81	270.84	270.85	270.84
Np	34.58	3.165	3.165	3.165	3.165
Am	.0265	.1264	.1594	.2251	.3223
Cm*	1.066	.7663	.6746	.5230	.3570

*Curium values are in milligrams

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TABLE II-35 (Continued)

Weight, Grams Per Ton of Uranium

Element	1 y	2 y	5 y	10 y	20 y
Ge	.0078	.0078	.0078	.0078	.0078
As	.0025	.0025	.0025	.0025	.0025
Se	1.599	1.599	1.599	1.599	1.599
Br	.6128	.6128	.6129	.6129	.6129
Kr	10.94	10.83	10.54	10.16	9.709
Rb	11.12	11.24	11.53	11.90	12.36
Sr	29.74	29.24	27.96	26.04	22.84
Y	15.29	15.20	15.20	15.20	15.20
Zr	110.15	110.46	111.73	113.65	116.85
Nb	.3401	.0071	.0001	.0002	.0003
Mo	95.33	95.96	95.97	95.97	95.97
Tc	24.10	24.10	24.10	24.10	24.10
Ru	49.22	48.41	47.71	47.62	47.61
Rh	13.18	13.19	13.19	13.19	13.19
Pd	10.97	11.77	12.46	12.56	12.56
Ag	.6427	.6426	.6426	.6426	.6426
Cd	.5095	.5096	.5096	.5096	.5096
In	.0660	.0660	.0660	.0660	.0660
Sn	1.005	1.004	1.004	1.004	1.004
Sb	.3883	.3398	.2495	.1932	.1732
Te	13.27	13.30	13.39	13.44	13.46
I	6.623	6.637	6.638	6.638	6.638
Xe	140.44	140.44	140.44	140.44	140.44
Cs	73.34	72.53	70.29	66.99	61.49
Ba	36.86	37.67	39.91	43.21	48.71
La	34.57	34.57	34.57	34.57	34.57
Ce	76.50	70.19	66.09	65.79	65.78
Pr	31.47	31.47	31.47	31.47	31.47
Nd	103.22	109.52	113.62	113.92	113.93
Pm	8.561	6.571	2.971	.7914	.0562
Sm	14.64	16.62	20.19	22.33	22.98
Eu	1.339	1.323	1.311	1.333	1.401
Gd	.5326	.5577	.5968	.6174	.6302
Tb	.0192	.0192	.0192	.0192	.0192
Dy	.0030	.0030	.0030	.0030	.0030
RE	270.85	270.84	270.84	270.84	270.84
Np	3.165	3.165	3.171	3.191	3.253
Am	.4238	.8001	1.812	3.167	4.962
Cm*	.2384	.0512	.0014	.0008	.0007

*Curium values are in milligrams

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TABLE II-36

COMPOSITION OF IRRADIATED 0.947% ENRICHED URANIUM

900 MWd/T, 9.7 MW/T

Weight, Grams Per Ton of Uranium

Element	Discharge	90 d	120 d	180 d	270 d	1 y
Ge	.0079	.0079	.0079	.0079	.0079	.0079
As	.0031	.0026	.0025	.0025	.0025	.0025
Se	1.655	1.656	1.656	1.656	1.655	1.656
Br	.6353	.6353	.6353	.6353	.6353	.6353
Kr	11.47	11.43	11.42	11.40	11.37	11.34
Rb	11.42	11.46	11.47	11.49	11.52	11.55
Sr	39.71	33.60	32.74	31.75	31.13	30.86
Y	19.14	17.36	16.97	16.44	16.04	15.87
Zr	116.31	115.04	114.74	114.30	113.99	113.89
Nb	5.068	4.579	3.685	2.197	.9162	.3441
Mo	79.94	88.52	90.97	94.41	97.03	98.13
Tc	23.75	24.81	24.81	24.81	24.81	24.81
Ru	58.04	52.42	51.73	50.95	50.40	50.05
Rh	7.091	12.09	12.64	13.16	13.38	13.42
Pd	8.940	9.558	9.699	9.958	10.29	10.59
Ag	.6017	.5792	.5792	.5792	.5792	.5792
Cd	.4713	.4894	.4892	.4890	.4890	.4890
In	.0620	.0664	.0666	.0668	.0669	.0069
Sn	1.029	1.013	1.012	1.011	1.010	1.010
Sb	.5161	.4312	.4263	.4166	.4024	.3879
Te	15.69	13.72	13.65	13.59	13.56	13.57
I	7.652	6.556	6.630	6.702	6.740	6.756
Xe	142.43	142.64	142.64	142.64	142.64	142.64
Cs	74.79	77.52	77.45	77.31	77.10	76.88
Ba	43.58	37.32	37.35	37.48	37.69	37.91
La	36.45	35.60	35.60	35.60	35.60	35.60
Ce	101.12	91.10	88.71	85.27	81.63	78.73
Pr	25.55	30.50	31.37	32.10	32.34	32.38
Nd	85.52	95.88	97.45	100.16	103.56	106.43
Pm	9.896	10.85	10.62	10.16	9.520	8.885
Sm	11.89	12.93	13.17	13.62	14.26	14.89
Eu	1.392	1.334	1.330	1.325	1.318	1.312
Gd	.3676	.4726	.4772	.4843	.4936	.5027
Tb	.0184	.0180	.0180	.0179	.0179	.0179
Dy	.0022	.0027	.0027	.0027	.0027	.0028
RE	272.21	278.69	278.75	278.75	278.75	278.75
Np	30.01	3.420	3.420	3.420	3.420	3.420
Am	.0153	.0686	.0863	.1213	.1732	.2273

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TABLE II-36 (Continued)

Weight, Grams Per Ton of Uranium

Element	1.5 y	2 y	3.5 y	5 y	7.5 y	10 y	20 y
Ge	.0079	.0079	.0079	.0079	.0079	.0079	.0079
As	.0025	.0025	.0025	.0025	.0025	.0025	.0025
Se	1.656	1.656	1.656	1.656	1.656	1.656	1.656
Br	.6353	.6353	.6353	.6353	.6353	.6353	.6353
Kr	11.28	11.23	11.07	10.92	10.75	10.54	10.06
Rb	11.61	11.66	11.82	11.96	12.13	12.35	12.82
Sr	30.57	30.34	29.66	29.02	28.19	27.02	23.70
Y	15.79	15.78	15.78	15.78	15.78	15.78	15.78
Zr	114.00	114.21	114.87	115.52	116.35	117.52	120.84
Nb	.0501	.0072	.0001	.0001	.0001	.0002	.0003
Mo	98.69	98.77	98.78	98.78	98.78	98.78	98.78
Tc	24.81	24.81	24.81	24.81	24.81	24.81	24.81
Ru	49.60	49.29	48.80	48.63	48.55	48.53	48.53
Rh	13.43	13.43	13.44	13.44	13.44	13.44	13.44
Pd	11.04	11.35	11.84	12.01	12.08	12.10	12.10
Ag	.5791	.5791	.5791	.5791	.5791	.5791	.5791
Cd	.4890	.4890	.4890	.4890	.4890	.4890	.4890
In	.0669	.0669	.0669	.0669	.0669	.0669	.0669
Sn	1.009	1.009	1.009	1.009	1.009	1.009	1.009
Sb	.3623	.3395	.2859	.2493	.2181	.1931	.1732
Te	13.58	13.60	13.65	13.69	13.73	13.75	13.77
I	6.766	6.769	6.771	6.771	6.771	6.771	6.771
Xe	142.64	142.64	142.64	142.64	142.64	142.64	142.64
Cs	76.47	76.07	74.90	73.79	72.39	70.41	64.77
Ba	38.32	38.72	39.89	41.00	42.40	44.38	50.02
La	35.60	35.60	35.60	35.60	35.60	35.60	35.60
Ce	74.78	72.25	68.92	68.05	67.79	67.74	67.73
Pr	32.38	32.38	32.38	32.38	32.38	32.38	32.38
Nd	110.37	112.90	116.23	117.11	117.37	117.42	117.42
Pm	7.784	6.819	4.586	3.083	1.817	.8214	.0583
Sm	15.99	16.95	19.17	20.65	21.00	22.87	23.53
Eu	1.302	1.295	1.284	1.284	1.292	1.313	1.397
Gd	.5177	.5302	.5567	.5724	.5843	.5932	.6040
Tb	.0179	.0179	.0179	.0179	.0179	.0179	.0179
Dy	.0028	.0028	.0028	.0028	.0028	.0028	.0028
RE	278.75	278.75	278.75	278.75	278.75	278.75	278.75
Np	3.420	3.420	3.422	3.424	3.429	3.436	3.469
Am	.3291	.4283	.7095	.9684	1.282	1.691	2.648

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TABLE II-37

COMPOSITION OF IRRADIATED 0.947% ENRICHED URANIUM

1000 MWd/T, 10 MW/T

Element	Weight, Grams Per Ton of Uranium				
	Discharge	90 d	120 d	180 d	270 d
Ge	.0088	.0088	.0088	.0088	.0088
As	.0035	.0028	.0028	.0028	.0028
Se	1.848	1.849	1.849	1.849	1.849
Br	.7088	.7088	.7088	.7088	.7088
Kr	12.78	12.74	12.73	12.70	12.67
Rb	12.69	12.73	12.74	12.76	12.80
Sr	43.94	37.30	36.36	35.28	34.60
Y	21.23	19.27	18.84	18.26	17.83
Zr	129.32	127.92	127.59	127.11	126.76
Nb	5.688	5.027	4.040	2.405	1.002
Mo	89.07	98.63	101.32	105.09	107.96
Tc	25.59	26.69	26.69	26.69	26.69
Ru	64.27	58.17	57.42	56.56	55.94
Rh	7.973	13.39	13.98	14.54	14.78
Pd	10.08	10.76	10.92	11.22	11.60
Ag	.7201	.6950	.6950	.6949	.6949
Cd	.5367	.5572	.5570	.5568	.5567
In	.0678	.0724	.0726	.0728	.0729
Sn	1.153	1.135	1.134	1.133	1.132
Sb	.5720	.4827	.4772	.4662	.4501
Te	17.34	15.26	15.20	15.13	15.10
I	8.445	7.316	7.396	7.475	7.517
Xe	158.93	159.17	159.17	159.17	159.17
Cs	83.19	86.00	85.92	85.76	85.53
Ba	48.11	41.52	41.56	41.70	41.94
La	40.47	39.58	39.57	39.57	39.57
Ce	112.21	101.13	98.50	94.71	90.70
Pr	28.51	33.98	34.92	35.71	35.97
Nd	95.27	106.51	108.23	111.25	115.00
Pm	10.95	11.90	11.65	11.15	10.44
Sm	13.21	14.34	14.60	15.10	15.80
Eu	1.566	1.500	1.496	1.490	1.483
Gd	.4251	.5416	.5466	.5542	.5641
Tb	.0213	.0208	.0207	.0207	.0207
Dy	.0026	.0031	.0032	.0032	.0032
RE	302.64	309.51	309.54	309.56	309.55
Np	31.28	3.840	3.840	3.840	3.840
Am	.0214	.0917	.1149	.1611	.2296
Cm*	.7923	.5661	.4985	.3864	.2636

*Curium values are in milligrams

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TABLE II-37 (Continued)

Weight, Grams Per Ton of Uranium

Element	1 y	2 y	5 y	10 y	20 y
Ge	.0088	.0088	.0088	.0088	.0088
As	.0028	.0028	.0028	.0028	.0028
Se	1.849	1.849	1.849	1.849	1.849
Br	.7088	.7088	.7088	.7088	.7088
Kr	12.64	12.51	12.16	11.73	11.21
Rb	12.83	12.96	13.30	13.73	14.25
Sr	34.31	33.73	32.26	30.04	26.35
Y	17.64	17.54	17.54	17.54	17.54
Zr	126.66	127.01	128.48	130.70	134.39
Nb	.3760	.0079	.0001	.0002	.0004
Mo	109.16	109.85	109.87	109.87	109.87
Tc	26.69	26.69	26.68	26.68	26.68
Ru	55.55	54.68	53.93	53.83	53.83
Rh	14.83	14.84	14.84	14.84	14.84
Pd	11.94	12.80	13.55	13.65	13.65
Ag	.6949	.6949	.6948	.6948	.6948
Cd	.5567	.5568	.5568	.5568	.5568
In	.0729	.0729	.0729	.0729	.0729
Sn	1.132	1.131	1.131	1.131	1.131
Sb	.4338	.3792	.2776	.2142	.1917
Te	15.11	15.14	15.24	15.30	15.33
I	7.534	7.549	7.550	7.550	7.550
Xe	159.17	159.17	159.17	159.17	159.17
Cs	85.28	84.36	81.82	78.05	71.77
Ba	42.18	43.10	45.65	49.41	55.69
La	39.57	39.57	39.57	39.57	39.57
Ce	87.49	80.32	75.67	75.33	75.32
Pr	36.01	36.02	36.02	36.02	36.02
Nd	118.17	125.33	129.98	130.32	130.33
Pm	9.745	7.480	3.382	.9010	.0639
Sm	16.50	18.75	22.82	25.25	25.99
Eu	1.476	1.458	1.444	1.473	1.557
Gd	.5737	.6032	.6486	.6718	.6849
Tb	.0207	.0207	.0207	.0207	.0207
Dy	.0032	.0032	.0032	.0032	.0032
RE	309.56	309.56	309.56	309.56	309.56
Np	3.840	3.842	3.846	3.858	3.902
Am	.3011	.5659	1.278	2.232	3.495
Cm*	.1761	.0378	.0010	.0006	.0005

*Curium values are in milligrams

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TABLE II-38

COMPOSITION OF IRRADIATED 0.947% ENRICHED URANIUM

1200 MWd/T, 10 MW/T

Weight, Grams Per Ton of Uranium

Element	Discharge	90 d	120 d	180 d	270 d
Ge	.0107	.0107	.0107	.0107	.0107
As	.0040	.0034	.0034	.0034	.0034
Se	2.203	2.203	2.203	2.203	2.203
Br	.8439	.8439	.8439	.8439	.8439
Kr	15.21	15.16	15.15	15.12	15.08
Rb	15.09	15.14	15.16	15.18	15.22
Sr	51.12	44.02	43.01	41.85	41.11
Y	24.96	22.75	22.28	21.64	21.16
Zr	154.25	152.59	152.21	151.67	151.29
Nb	6.858	5.614	4.484	2.653	1.100
Mo	108.20	119.31	122.31	126.47	129.63
Tc	31.07	32.17	32.17	32.17	32.17
Ru	77.09	70.38	69.54	68.56	67.82
Rh	10.51	16.37	17.01	17.62	17.88
Pd	12.96	13.80	14.00	14.38	14.86
Ag	.9665	.9385	.9385	.9385	.9384
Cd	.6896	.7127	.7125	.7123	.7122
In	.0834	.0883	.0886	.0888	.0889
Sn	1.411	1.392	1.391	1.390	1.388
Sb	.6864	.5927	.5859	.5725	.5528
Te	20.52	18.39	18.30	18.23	18.20
I	9.954	8.860	8.947	9.032	9.079
Xe	190.99	191.25	191.25	191.25	191.25
Cs	100.49	103.25	103.16	102.96	102.67
Ba	56.41	49.83	49.89	50.07	50.36
La	48.33	47.43	47.42	47.42	47.42
Ce	132.73	120.14	117.19	112.86	108.20
Pr	35.03	41.07	42.05	42.88	43.16
Nd	116.03	128.24	130.25	133.76	138.14
Pm	13.23	14.03	13.73	13.14	12.31
Sm	16.27	17.57	17.87	18.46	19.29
Eu	1.949	1.871	1.867	1.860	1.852
Gd	.5743	.7070	.7126	.7212	.7326
Tb	.0278	.0272	.0272	.0272	.0271
Dy	.0036	.0042	.0042	.0042	.0043
RE	364.17	371.09	371.12	371.13	371.14
Np	32.05	4.680	4.680	4.680	4.680
Am	.0415	.1539	.1911	.2649	.3744
Cm*	1.857	1.317	1.159	.8987	.6134

*Curium values are in milligrams.

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TABLE II-38 (Continued)

Weight, Grams Per Ton of Uranium

Element	1 y	2 y	5 y	10 y	20 y
Ge	.0107	.0107	.0107	.0107	.0107
As	.0034	.0034	.0034	.0034	.0034
Se	2.203	2.203	2.203	2.203	2.203
Br	.8439	.8439	.8439	.8439	.8439
Kr	15.04	14.89	14.49	13.98	13.35
Rb	15.27	15.42	15.81	16.32	16.95
Sr	40.78	40.10	38.36	35.72	31.32
Y	20.96	20.85	20.85	20.85	20.85
Zr	151.18	151.62	153.36	156.00	160.39
Nb	.4125	.0086	.0001	.0002	.0005
Mo	130.95	131.71	131.73	131.73	131.73
Tc	32.17	32.17	32.17	32.16	32.16
Ru	67.33	66.23	65.28	65.15	65.15
Rh	17.93	17.94	17.94	17.94	17.94
Pd	15.29	16.38	17.33	17.46	17.47
Ag	.9384	.9383	.9393	.9383	.9383
Cd	.7122	.7123	.7123	.7123	.7123
In	.0890	.0890	.0890	.0890	.0890
Sn	1.388	1.387	1.387	1.387	1.386
Sb	.5328	.4659	.3416	.2640	.2365
Te	18.21	18.25	18.38	18.46	18.49
I	9.098	9.115	9.117	9.117	9.117
Xe	191.25	191.25	191.25	191.25	191.25
Cs	102.37	101.26	98.17	93.64	86.10
Ba	50.66	51.77	54.85	59.39	66.93
La	47.42	47.42	47.42	47.42	47.42
Ce	104.46	96.09	90.66	90.26	90.25
Pr	43.20	43.21	43.21	43.21	43.21
Nd	141.85	150.20	155.64	156.04	156.04
Pm	11.49	8.816	3.986	1.062	.0754
Sm	20.11	22.77	27.56	30.43	31.32
Eu	1.844	1.822	1.803	1.831	1.918
Gd	.7436	.7774	.8303	.8588	.8771
Tb	.0271	.0271	.0271	.0271	.0271
Dy	.0043	.0043	.0043	.0043	.0043
RE	371.14	371.14	371.14	371.14	371.14
Np	4.680	4.682	4.688	4.710	4.779
Am	.4887	.9123	2.052	3.576	5.595
Cm*	.4098	.0881	.0025	.0015	.0013

*Curium values are in milligrams

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TABLE II-39

COMPOSITION OF IRRADIATED 0.947% ENRICHED URANIUM

2200 MWd/T, 11 MW/T

Weight, Grams Per Ton of Uranium

Element	Discharge	90 d	120 d	180 d	270 d	1 y
Ge	.0206	.0206	.0206	.0206	.0206	.0206
As	.0071	.0065	.0065	.0065	.0065	.0065
Se	3.849	3.849	3.849	3.849	3.849	3.849
Br	1.464	1.464	1.464	1.464	1.464	1.464
Kr	26.41	26.33	26.31	26.26	26.19	26.12
Rb	26.13	26.21	26.23	26.28	26.34	26.42
Sr	82.33	74.25	73.08	71.72	70.80	70.32
Y	41.23	38.31	37.71	36.91	36.32	36.07
Zr	272.46	269.68	269.10	268.32	267.81	267.73
Nb	10.54	7.387	5.822	3.393	1.394	.5206
Mo	208.33	224.07	227.98	233.35	237.37	239.04
Tc	58.81	60.02	60.02	60.02	60.02	60.02
Ru	146.76	137.18	135.83	134.14	132.62	131.50
Rh	24.62	32.32	33.16	33.96	34.30	34.37
Pd	33.68	35.55	36.05	36.95	38.14	39.18
Ag	2.831	2.784	2.783	2.783	2.783	2.783
Cd	1.816	1.857	1.857	1.856	1.856	1.856
In	.1684	.1754	.1758	.1761	.1763	.1764
Sn	2.914	2.887	2.886	2.883	2.881	2.880
Sb	1.367	1.241	1.227	1.199	1.158	1.117
Te	37.03	34.53	34.43	34.35	34.32	34.34
I	18.03	16.87	16.99	17.10	17.16	17.19
Xe	352.34	352.75	352.75	352.75	352.75	352.75
Cs	187.06	189.78	189.57	189.16	188.56	187.93
Ba	98.34	91.47	91.63	92.03	92.63	93.26
La	87.24	86.25	86.25	86.24	86.24	86.24
Ce	228.89	210.93	206.63	200.05	192.69	186.70
Pr	69.17	76.61	77.75	78.70	79.02	79.07
Nd	221.21	237.86	241.06	246.70	253.74	259.69
Pm	22.77	22.98	22.48	21.51	20.14	18.80
Sm	33.83	35.93	36.44	37.41	38.77	40.11
Eu	4.718	4.581	4.572	4.559	4.541	4.525
Gd	1.643	1.876	1.886	1.902	1.923	1.944
Tb	.0763	.0748	.0747	.0746	.0745	.0744
Dy	.0110	.0126	.0126	.0128	.0129	.0129
RE	669.56	677.10	677.16	677.16	677.15	677.17
Np	44.27	12.34	12.34	12.34	12.34	12.34
Am	.2915	.7297	.8745	1.162	1.589	2.034

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TABLE II-39 (Continued)

Weight, Grams Per Ton of Uranium

Element	1.5 y	2 y	3.5 y	5 y	7.5 y	10 y	20 y
Ge	.0206	.0206	.0206	.0206	.0206	.0206	.0206
As	.0065	.0065	.0065	.0065	.0065	.0065	.0065
Se	3.849	3.849	3.849	3.849	3.849	3.849	3.849
Br	1.464	1.464	1.464	1.464	1.464	1.464	1.464
Kr	25.99	25.86	25.50	25.18	24.80	24.31	23.23
Rb	26.55	26.67	27.03	27.36	27.74	28.23	29.31
Sr	69.73	69.20	67.66	66.19	64.30	61.65	54.09
Y	35.96	35.94	35.94	35.94	35.94	35.94	35.94
Zr	268.06	268.55	270.07	271.55	273.43	276.09	283.65
Nb	.0756	.0109	.0002	.0002	.0003	.0004	.0008
Mo	239.88	240.00	240.02	240.02	240.02	240.02	240.02
Tc	60.02	60.02	60.02	60.02	60.02	60.02	60.02
Ru	129.93	128.84	127.13	126.52	126.28	126.20	126.20
Rh	34.38	34.38	34.38	34.38	34.38	34.38	34.38
Pd	40.73	41.83	43.54	44.14	44.39	44.46	44.47
Ag	2.783	2.783	2.783	2.783	2.783	2.783	2.783
Cd	1.857	1.857	1.857	1.857	1.857	1.857	1.857
In	.1764	.1764	.1764	.1764	.1764	.1764	.1764
Sn	2.878	2.878	2.878	2.878	2.878	2.878	2.877
Sb	1.044	.9796	.8281	.7248	.6365	.5658	.5096
Te	34.38	34.46	34.60	34.70	34.79	34.87	34.92
I	17.21	17.22	17.22	17.22	17.22	17.22	17.22
Xe	352.75	352.75	352.75	352.75	352.75	352.75	352.75
Cs	186.76	185.64	182.50	179.59	176.01	171.08	157.18
Ba	94.43	95.55	98.69	101.59	105.17	110.11	124.02
La	86.24	86.24	86.24	86.24	86.24	86.24	86.24
Ce	178.51	173.26	166.35	164.53	163.98	163.88	163.87
Pr	79.07	79.07	79.07	79.07	79.07	79.07	79.07
Nd	267.88	273.13	280.04	281.86	282.41	282.51	282.52
Pm	16.47	14.43	9.703	6.524	3.844	1.738	.1233
Sm	42.43	44.47	49.17	52.32	54.97	57.03	58.51
Eu	4.498	4.477	4.434	4.414	4.406	4.414	4.487
Gd	1.978	2.008	2.074	2.118	2.157	2.194	2.266
Tb	.0744	.0744	.0744	.0744	.0744	.0744	.0744
Dy	.0129	.0129	.0129	.0129	.0129	.0129	.0129
RE	677.16	677.17	677.17	677.16	677.16	677.16	677.17
Np	12.34	12.34	12.35	12.37	12.39	12.46	12.73
Am	2.869	3.682	5.993	8.118	10.69	14.06	21.92

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TABLE II-40

COMPOSITION OF IRRADIATED 1.25% ENRICHED URANIUM

2200 MWd/T, 11 MW/T

Weight, Grams Per Ton of Uranium

Element	Discharge	90 d	120 d	180 d	270 d	1 y
Ge	.0199	.0199	.0199	.0199	.0199	.0199
As	.0070	.0063	.0063	.0063	.0063	.0063
Se	3.968	3.968	3.968	3.968	3.968	3.968
Br	1.516	1.516	1.516	1.516	1.516	1.516
Kr	27.36	27.28	27.25	27.21	27.14	27.06
Rb	27.22	27.31	27.33	27.38	27.45	27.52
Sr	85.91	77.36	76.13	74.68	73.71	73.21
Y	42.95	39.95	39.34	38.51	37.89	37.64
Zr	278.52	276.02	275.49	274.77	274.30	274.23
Nb	10.71	7.518	5.926	3.454	1.420	.5300
Mo	208.72	224.76	228.73	234.20	238.30	240.00
Tc	59.02	60.22	60.22	60.22	60.22	60.22
Ru	139.67	130.92	129.74	128.28	127.03	126.14
Rh	23.91	31.16	31.96	32.70	33.02	33.09
Pd	27.68	29.18	29.57	30.28	31.21	32.04
Ag	2.012	1.977	1.977	1.976	1.976	1.976
Cd	1.452	1.482	1.482	1.481	1.481	1.481
In	.1568	.1629	.1632	.1635	.1637	.1637
Sn	2.676	2.652	2.651	2.649	2.647	2.646
Sb	1.238	1.119	1.106	1.081	1.044	1.007
Te	36.30	33.87	33.77	33.69	33.66	33.68
I	17.60	16.46	16.57	16.68	16.74	16.77
Xe	346.55	346.85	346.85	346.85	346.85	346.85
Cs	190.30	193.08	192.88	192.48	191.91	191.31
Ba	98.60	91.63	91.78	92.16	92.74	93.34
La	87.73	86.73	86.73	86.73	86.73	86.73
Ce	230.92	212.83	208.49	201.80	194.32	188.22
Pr	69.41	76.70	77.83	78.78	79.10	79.15
Nd	222.91	239.91	243.18	248.92	256.08	262.14
Pm	23.42	23.62	23.11	22.11	20.71	19.32
Sm	32.46	34.58	35.10	36.10	37.49	38.87
Eu	4.124	4.020	4.012	4.001	3.986	3.972
Gd	1.320	1.504	1.513	1.528	1.547	1.566
Tb	.0577	.0567	.0566	.0566	.0565	.0565
Dy	.0081	.0091	.0092	.0092	.0093	.0093
RE	672.36	679.96	680.03	680.03	680.03	680.03
Np	40.96	12.34	12.34	12.34	12.34	12.34
Am	.2333	.5926	.7113	.9396	1.297	1.662

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TABLE II-40 (Continued)

Weight, Grams Per Ton of Uranium

Element	1.5 y	2 y	3.5 y	5 y	7 y	10 y	20 y
Ge	.0199	.0199	.0199	.0199	.0199	.0199	.0199
As	.0063	.0063	.0063	.0063	.0063	.0063	.0063
Se	3.968	3.968	3.968	3.968	3.968	3.968	3.968
Br	1.516	1.516	1.516	1.516	1.516	1.516	1.516
Kr	26.93	26.79	26.42	26.08	25.68	25.17	24.06
Rb	27.66	27.79	28.16	28.50	28.90	29.41	30.52
Sr	72.59	72.04	70.45	68.91	66.95	64.18	56.31
Y	37.52	37.50	37.50	37.50	37.50	37.50	37.50
Zr	274.58	275.09	276.68	278.22	280.18	282.95	290.82
Nb	.0770	.0111	.0002	.0002	.0003	.0004	.0008
Mo	240.85	240.97	241.00	241.00	241.00	241.00	241.00
Tc	60.22	60.22	60.22	60.22	60.22	60.22	60.22
Ru	124.90	124.04	122.69	122.21	122.02	121.96	121.95
Rh	33.10	33.10	33.10	33.10	33.10	33.10	33.10
Pd	33.26	34.12	35.47	35.95	36.14	36.20	36.21
Ag	1.976	1.976	1.976	1.976	1.976	1.976	1.976
Cd	1.481	1.481	1.482	1.482	1.482	1.482	1.482
In	.1637	.1637	.1637	.1637	.1637	.1637	.1637
Sn	2.645	2.644	2.644	2.644	2.644	2.644	2.644
Sb	.9412	.8829	.7461	.6529	.5732	.5094	.4586
Te	33.73	33.78	33.91	34.00	34.09	34.15	34.20
I	16.79	16.80	16.80	16.80	16.80	16.80	16.80
Xe	346.85	346.85	346.85	346.85	346.85	346.85	346.85
Cs	190.19	189.10	186.05	183.21	179.68	174.79	160.96
Ba	94.46	95.54	98.59	101.43	104.96	109.85	123.68
La	86.73	86.73	86.73	86.73	86.73	86.73	86.73
Ce	179.88	174.54	167.51	165.66	165.10	165.00	164.99
Pr	79.15	79.15	79.15	79.15	79.15	79.15	79.15
Nd	270.47	275.81	282.84	284.70	285.25	285.36	285.36
Pm	16.93	14.83	9.973	6.706	3.951	1.786	.1268
Sm	41.26	43.35	48.18	51.42	54.14	56.25	57.76
Eu	3.949	3.931	3.898	3.887	3.888	3.909	4.015
Gd	1.598	1.625	1.684	1.722	1.754	1.785	1.840
Tb	.0565	.0565	.0565	.0565	.0565	.0565	.0565
Dy	.0093	.0093	.0093	.0093	.0093	.0093	.0093
RE	680.03	680.03	680.03	680.04	680.03	680.03	680.03
Np	12.34	12.34	12.35	12.36	12.40	12.43	12.65
Am	2.348	3.015	4.909	6.652	8.763	11.52	17.97

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TABLE II-41

COMPOSITION OF IRRADIATED 2.1% ENRICHED URANIUM

2100 MWd/T, 10.6 MW/T

Weight, Grams Per Ton of Uranium

Element	Discharge	90 d	120 d	180 d	270 d	1 y
Ge	.0182	.0182	.0182	.0182	.0182	.0182
As	.0065	.0058	.0058	.0058	.0058	.0058
Se	3.907	3.908	3.908	3.908	3.908	3.908
Br	1.501	1.501	1.501	1.501	1.501	1.501
Kr	27.09	27.01	26.98	26.94	26.87	26.79
Rb	27.11	27.19	27.22	27.26	27.33	27.41
Sr	85.83	77.08	75.82	74.35	73.36	72.86
Y	42.81	39.86	39.25	38.42	37.80	37.55
Zr	271.92	269.83	269.37	268.73	268.31	268.27
Nb	10.45	7.367	5.809	3.388	1.393	.5201
Mo	199.11	214.83	218.73	224.08	228.10	229.77
Tc	56.50	57.66	57.66	57.66	57.66	57.66
Ru	125.57	118.08	117.12	115.98	115.08	114.47
Rh	22.13	28.60	29.30	29.97	30.25	30.31
Pd	19.85	20.87	21.13	21.60	22.22	22.77
Ag	1.025	1.005	1.005	1.004	1.004	1.004
Cd	1.014	1.029	1.029	1.029	1.029	1.029
In	.1386	.1434	.1437	.1439	.1441	.1441
Sn	2.295	2.276	2.275	2.274	2.272	2.271
Sb	1.044	.9364	.9257	.9045	.8737	.8426
Te	33.83	31.57	31.48	31.41	31.38	31.39
I	16.35	15.29	15.39	15.49	15.54	15.57
Xe	318.78	318.97	318.97	318.97	318.97	318.97
Cs	190.09	192.81	192.64	192.29	191.78	191.26
Ba	94.31	87.47	87.60	87.93	88.44	88.97
La	84.16	83.19	83.19	83.19	83.19	83.19
Ce	222.47	205.00	200.78	194.29	187.00	181.06
Pr	66.36	73.19	74.28	75.19	75.50	75.54
Nd	214.03	230.73	233.90	239.49	246.47	252.37
Pm	23.36	23.57	23.06	22.07	20.67	19.29
Sm	29.26	31.28	31.80	32.79	34.18	35.56
Eu	3.228	3.164	3.158	3.148	3.136	3.124
Gd	.8973	1.020	1.028	1.041	1.059	1.077
Tb	.0351	.0346	.0346	.0346	.0346	.0346
Dy	.0045	.0050	.0050	.0050	.0050	.0051
RE	643.80	651.18	651.24	651.25	651.25	651.25
Np	32.38	12.34	12.34	12.34	12.34	12.34
Am	.0657	.1707	.2055	.2744	.3768	.4836
Cm*	2.645	1.849	1.628	1.262	.8615	.5752

* Curium values are in milligrams.

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TABLE II-41 (Continued)

Weight, Grams Per Ton of Uranium

Element	1.5 y	2 y	3.5 y	5 y	7.5 y	10 y	20 y
Ge	.0182	.0182	.0182	.0182	.0182	.0182	.0182
As	.0058	.0058	.0058	.0058	.0058	.0058	.0058
Se	3.908	3.908	3.908	3.908	3.908	3.908	3.908
Br	1.501	1.501	1.501	1.501	1.501	1.501	1.501
Kr	26.66	26.52	26.15	25.82	25.42	24.91	23.80
Rb	27.54	27.68	28.05	28.38	28.78	29.29	30.40
Sr	72.24	71.69	70.10	68.57	66.62	63.87	56.03
Y	37.42	37.41	37.40	37.40	37.40	37.40	37.40
Zr	268.62	269.12	270.71	272.24	274.20	276.95	284.79
Nb	.0756	.0109	.0002	.0002	.0003	.0004	.0008
Mo	230.61	230.73	230.75	230.75	230.75	230.75	230.75
Tc	57.66	57.66	57.66	57.66	57.66	57.66	57.66
Ru	113.64	113.07	112.17	111.85	111.72	111.69	111.68
Rh	30.32	30.33	30.33	30.33	30.33	30.33	30.33
Pd	23.59	24.16	25.06	25.37	25.50	25.54	25.55
Ag	1.004	1.004	1.004	1.004	1.004	1.004	1.004
Cd	1.029	1.029	1.029	1.029	1.029	1.029	1.029
In	.1441	.1441	.1441	.1441	.1441	.1441	.1441
Sn	2.270	2.270	2.269	2.269	2.269	2.269	2.269
Sb	.7875	.7387	.6240	.5459	.4791	.4256	.3831
Te	31.42	31.47	31.58	31.66	31.73	31.78	31.83
I	15.59	15.59	15.59	15.59	15.59	15.59	15.59
Xe	318.97	318.97	318.97	318.97	318.97	318.97	318.97
Cs	190.27	189.29	186.51	183.89	180.59	175.99	162.88
Ba	89.96	90.93	93.71	96.33	99.62	104.23	117.34
La	83.19	83.19	83.19	83.19	83.19	83.19	83.19
Ce	172.94	167.74	160.89	159.07	158.53	158.43	158.42
Pr	75.55	75.55	75.55	75.55	75.55	75.55	75.55
Nd	260	265.69	272.54	274.36	274.90	275.00	275.01
Pm	16.90	14.81	9.956	6.695	3.944	1.783	.1266
Sm	37.93	40.02	44.83	48.06	50.77	52.86	54.31
Eu	3.106	3.093	3.074	3.076	3.094	3.137	3.311
Gd	1.106	1.130	1.183	1.215	1.240	1.261	1.292
Tb	.0346	.0346	.0346	.0346	.0346	.0346	.0346
Dy	.0051	.0051	.0051	.0051	.0051	.0051	.0051
RE	651.25	651.25	651.25	651.25	651.25	651.25	651.25
Np	12.34	12.34	12.34	12.35	12.35	12.37	12.43
Am	.6842	.8793	1.433	1.944	2.561	3.367	5.256
Cm*	.2658	.1235	.0140	.0033	.0021	.0020	.0017

*Curium values are in milligrams

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TABLE II-42

LONG LIVED FISSION PRODUCTS

MWd/T	MW/T	U-235, %	Unit	Se-79	Zr-93	Tc-99	Pd-107	Sn-126	I-129	Cs-135
640	8.17	Natural	Grams	0.117	16.5	17.6	1.38	0.383	3.89	5.40
			Millicuries	7.58	67.2	304	0.658	10.9	0.674	7.15
			Microwatts	2.70	5.61	151	0.039	1.29	0.320	2.46
750	10	Natural	Grams	0.135	19.0	20.2	1.48	0.434	4.43	5.30
			Millicuries	8.70	76.7	347	0.709	12.3	0.768	7.02
			Microwatts	3.10	6.44	173	0.042	1.46	0.364	2.41
900	10	Natural	Grams	0.160	22.5	24.1	1.93	0.525	5.32	6.36
			Millicuries	10.3	91.2	414	0.919	14.9	0.922	8.42
			Microwatts	3.68	7.66	206	0.054	1.77	0.437	2.89
900	9.7	0.947	Grams	0.166	23.3	24.8	1.80	0.432	5.44	8.04
			Millicuries	10.7	94.9	427	0.859	15.1	0.943	10.6
			Microwatts	3.81	7.93	212	0.051	1.79	0.447	3.66
1000	10	0.947	Grams	0.185	25.9	26.7	2.09	0.600	6.06	8.69
			Millicuries	12.0	106	459	0.996	17.0	1.05	11.5
			Microwatts	4.25	8.81	228	0.059	2.02	0.497	3.96
1200	10	0.947	Grams	0.220	30.9	32.2	2.73	0.730	7.31	10.4
			Millicuries	14.3	126	553	1.30	20.7	1.27	13.8
			Microwatts	5.07	10.5	276	0.077	2.45	0.601	4.75
2200	11	0.947	Grams	0.385	54.6	60.0	7.54	1.43	13.9	19.3
			Millicuries	24.9	221	1032	3.60	40.6	2.41	25.6
			Microwatts	8.86	18.6	514	0.213	4.82	1.14	8.79
2200	11	1.25	Grams	0.397	56.0	60.2	5.71	1.36	13.6	23.0
			Millicuries	25.7	227	1036	2.72	38.5	2.35	30.5
			Microwatts	9.12	19.0	516	0.161	4.56	1.11	10.5
2100	10.6	2.1	Grams	0.391	54.9	57.7	3.48	1.21	12.5	31.2
			Millicuries	25.3	224	992	1.66	34.4	2.17	41.3
			Microwatts	8.98	18.7	494	0.099	4.08	1.03	14.2

[redacted] DECLASSIFIED [redacted]

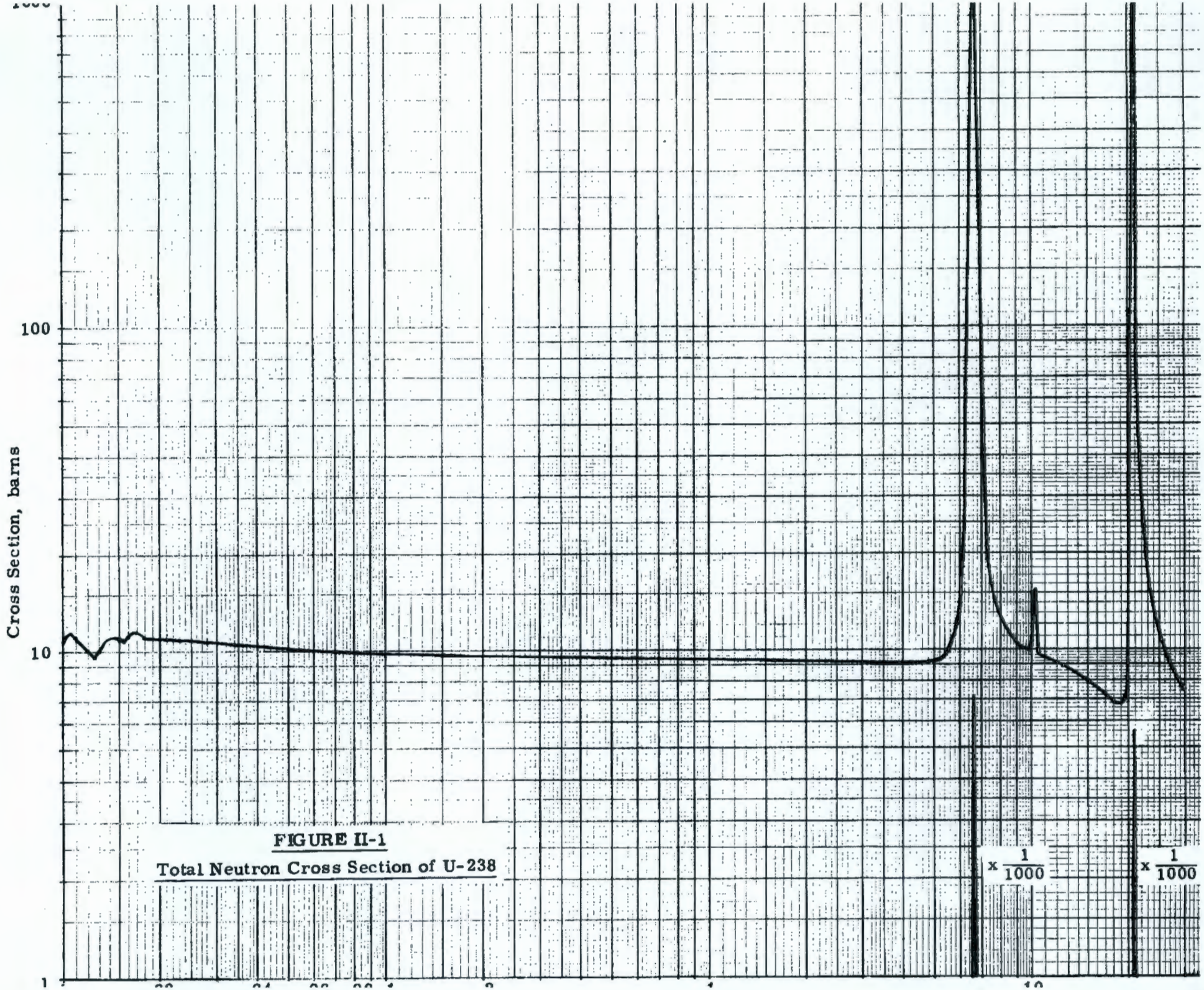

FIGURE II-1

Total Neutron Cross Section of U-238

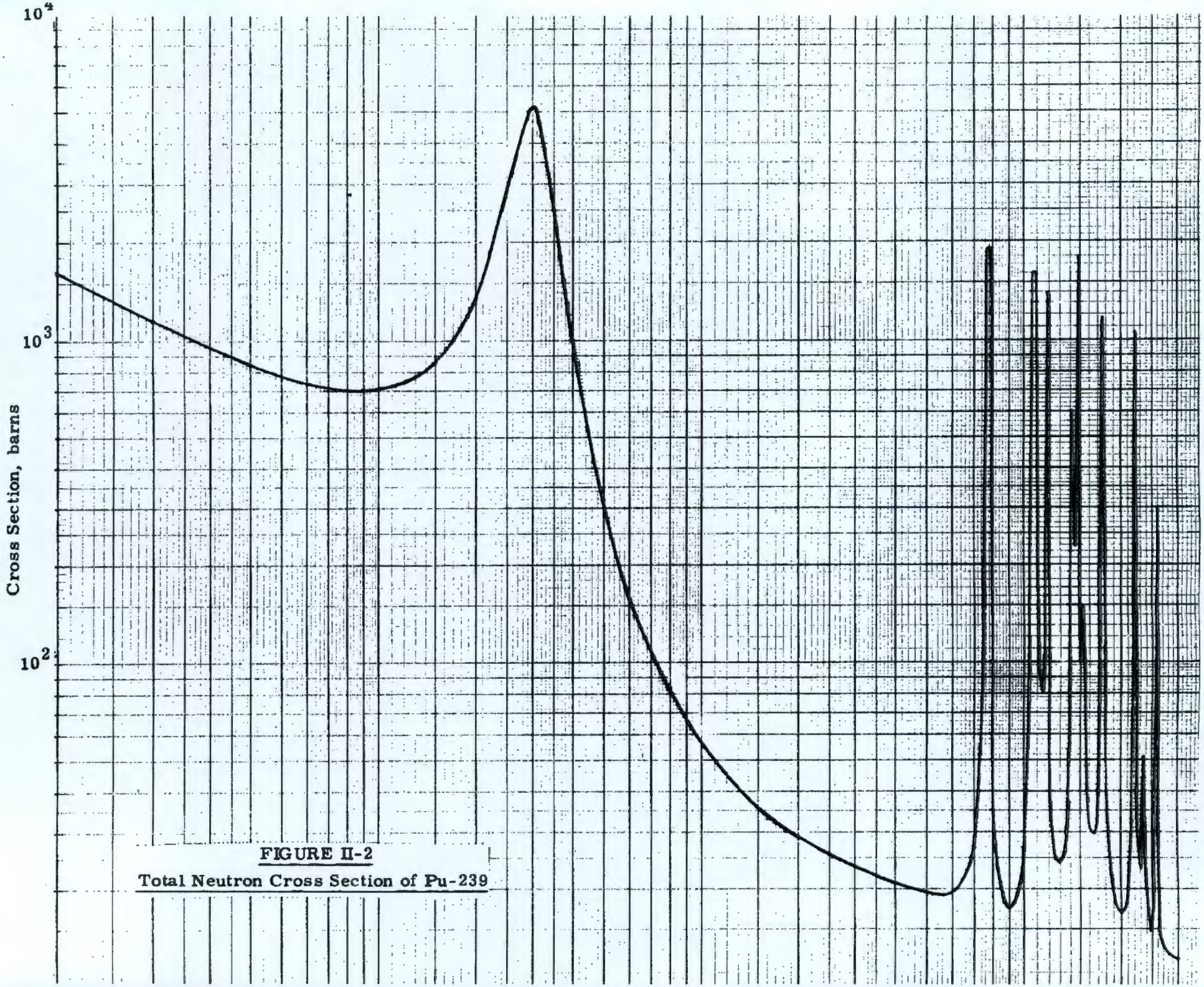

FIGURE II-2

Total Neutron Cross Section of Pu-239

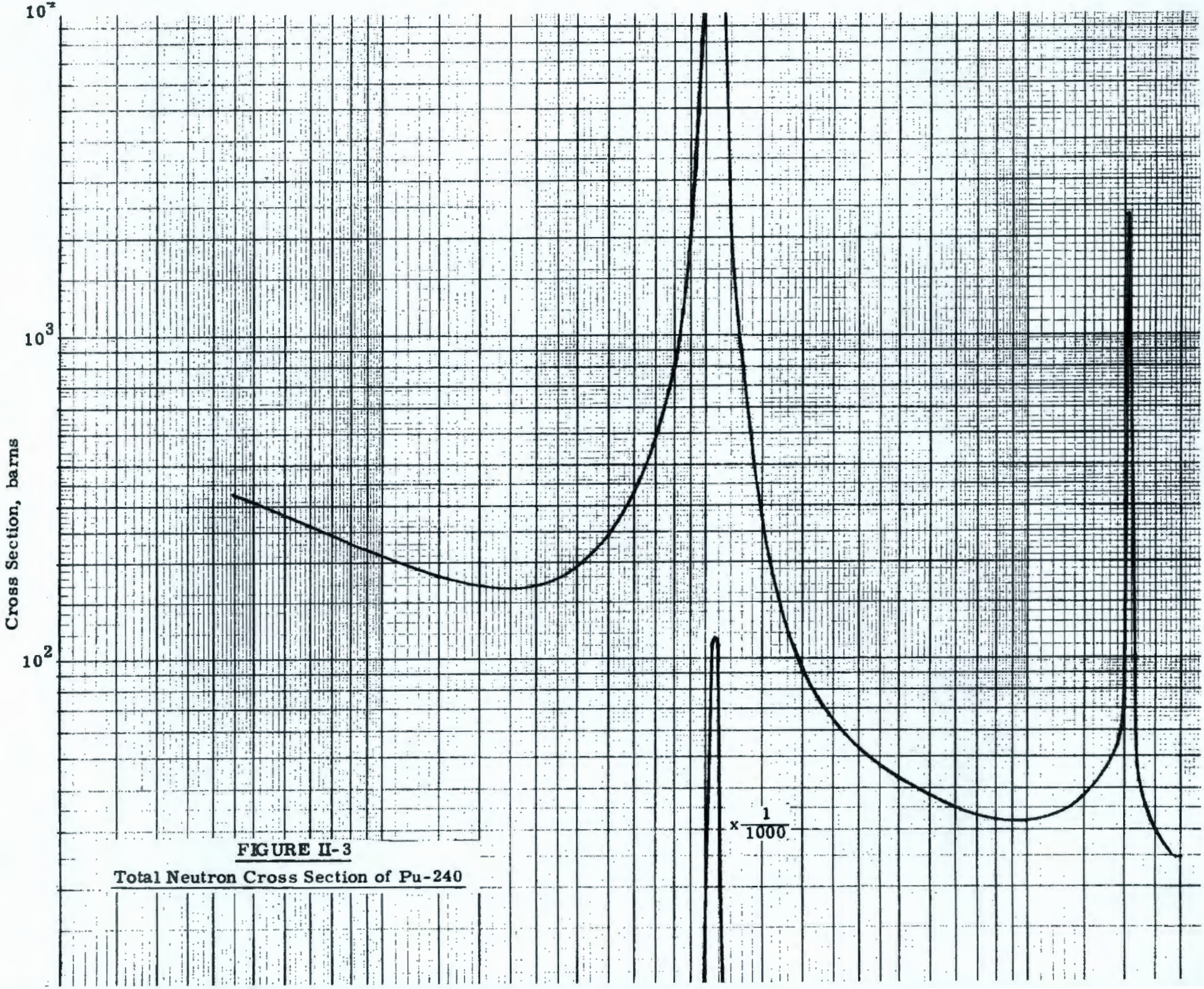

FIGURE II-3

Total Neutron Cross Section of Pu-240

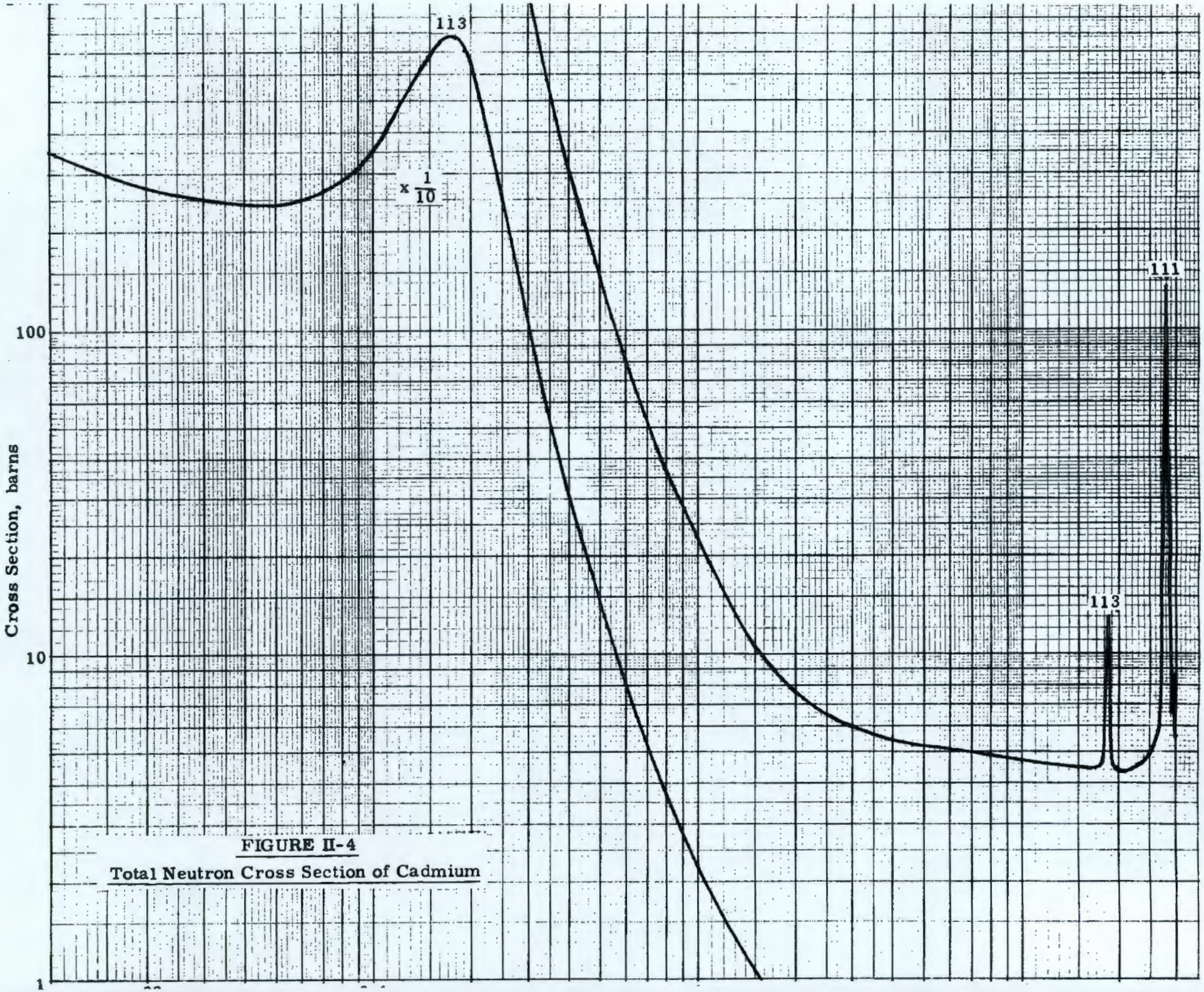

FIGURE II-4

Total Neutron Cross Section of Cadmium

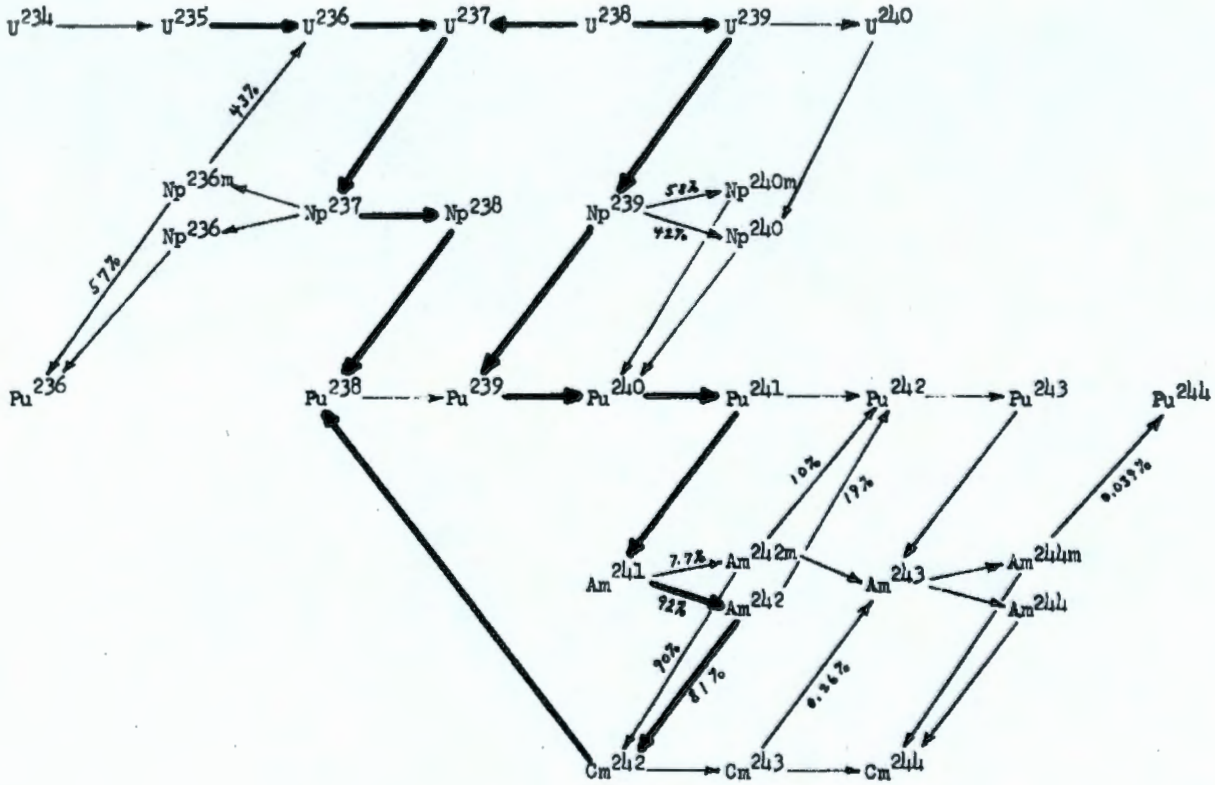

FIGURE II-5

Methods of Forming Transuranic Nuclides

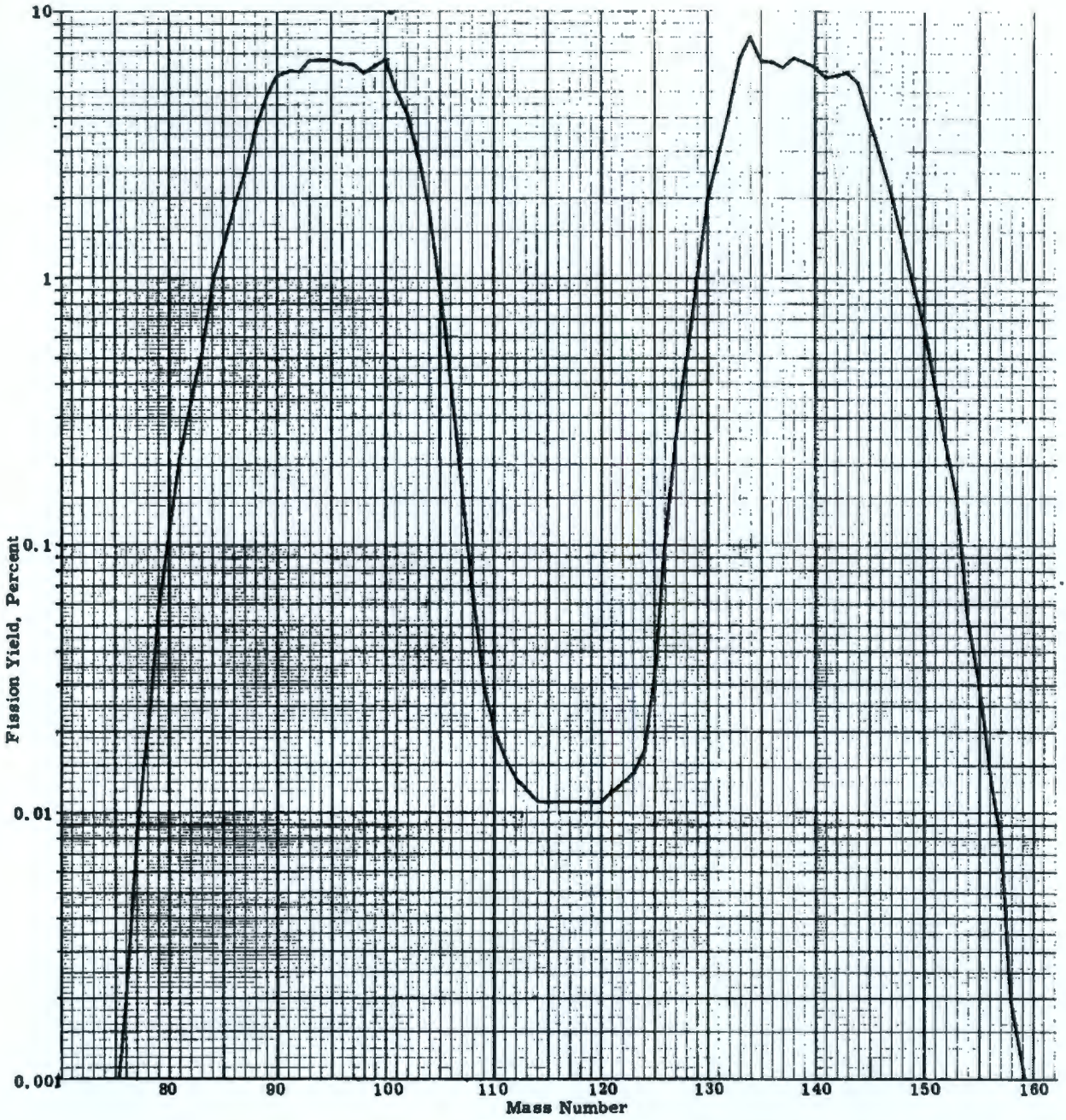

FIGURE II-6

Cumulative Yields from U-235 Thermal Fission

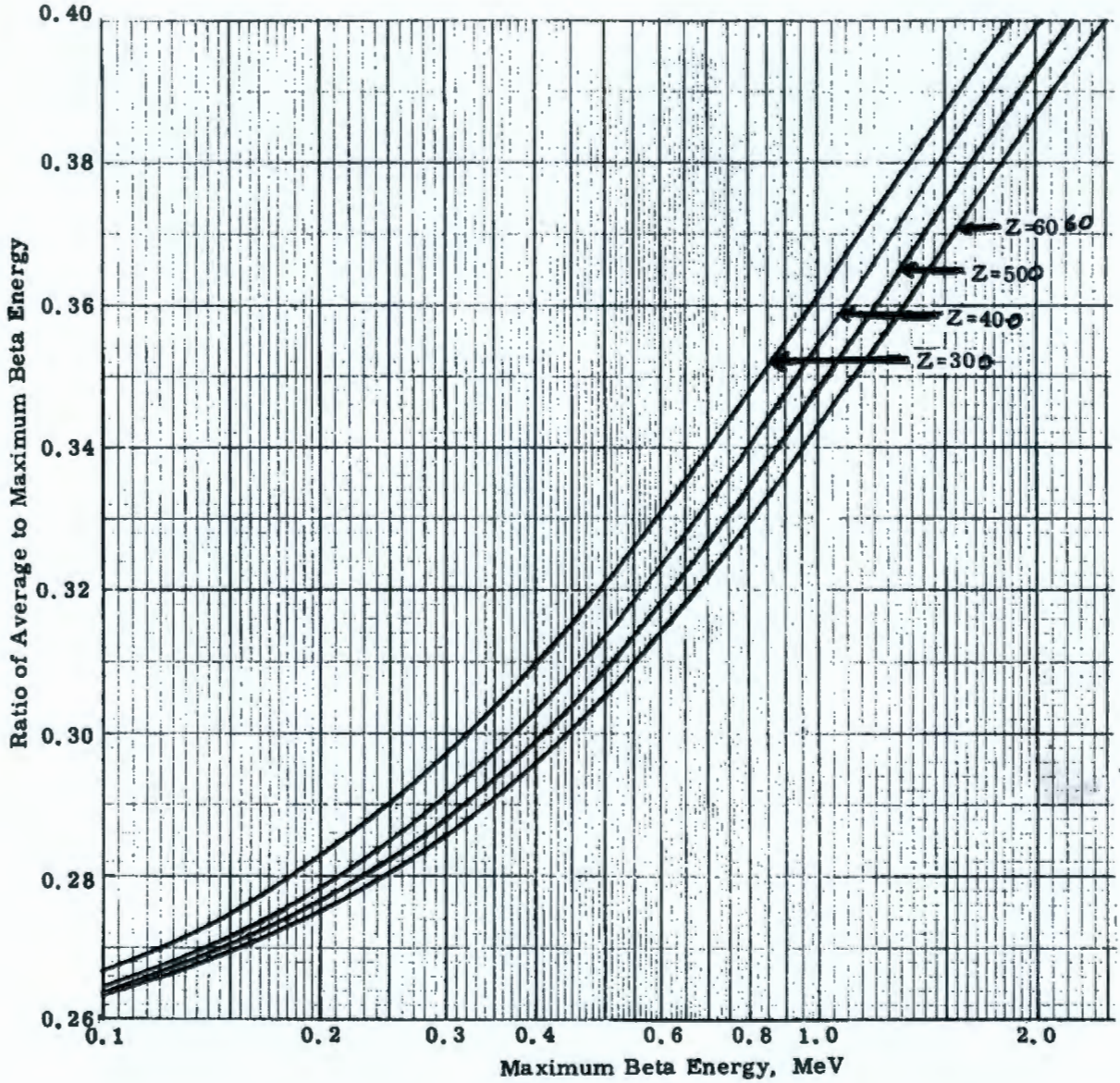

FIGURE II-7

Average Energy for Allowed Beta Spectra

PART II, Continued

FEED MATERIAL

CHAPTER III

SOURCES OF FEED MATERIAL

By

D. E. Larson

PART III

PROCESS

CHAPTER IV

PROCESS CHEMISTRY AND ENGINEERING

By

G. L. Richardson

and

W. W. Schulz

PACIFIC NORTHWEST LABORATORY

PART III: PROCESS

CHAPTER IV: PROCESS CHEMISTRY AND ENGINEERING

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