START

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION PRELIMINARY NATURAL RESOURCE SURVEY

Hanford
Richland, Washington
WA7890008967 Site ID: 97
December 9, 1988

FINDINGS OF FACT

SITE EXPOSURE POTENTIAL

Site History

The U.S. Department of Energy's (DOE) Hanford site was originally established in 1943 and was designed, built, and operated by the U.S. Government to conduct research and development work emphasizing nuclear energy technology. The site occupies approximately 1,500 square kilometers and 355 individual waste disposal locations (now inactive) are present. Due to the large area and number of disposal sites, four aggregrate areas have been designated: the 100 Area, 200 Area, 300 Area, and 1,100 Area (Figure 1). Within the aggregrate areas, 75 operable units have been identified. Waste disposal locations within these areas range in size from small gravel-lined open ditches where a few liters of liquid wastes were disposed of, to large multiple-trench burial grounds where hundreds of thousands of cubic meters of solids were placed. A breakdown of the inactive waste disposal sites shows that approximately 6% of the total number of inactive waste disposal sites received only radioactive wastes, 10% received predominantly water and radioactive wastes, and 84% contained mixtures of radioactive and chemical wastes.

The 100 Area is adjacent to the Columbia River in the northern section of the Hanford site and contains nine inactive nuclear reactors which produced plutonium and generated electricity. An estimated 3.3 billion cubic meters of solid and liquid waste comprised of radioactive, mixed, and hazardous constituents were disposed of in cribs, trenches, and burial grounds in over 110 waste disposal locations in the 100 Area (EPA 1987a).

The 200 Area is in the center of the Hanford site and is used by DOE for the recovery of plutonium and also to process and store waste materials. An estimated 765 million cubic meters of solid and dilute liquid wastes comprised of radioactive, mixed, and hazardous constituents were disposed of in over 230 waste disposal locations (EPA 1987b).

The 300 Area is adjacent to the Columbia River in the southern portion of the site and has been used by DOE to fabricate nuclear reactor fuel. An estimated 20.6 million cubic meters of radioactive, hazardous and mixed waste materials have been placed in 14 disposal locations (EPA 1987c).

The 1100 Area is about 1.5 kilometers north of the city of Richland and just south of the 300 Area and is used by DOE for equipment maintenance operations. An estimated 56,775 liters of waste battery acid were disposed of in an unlined sand pit. Also, an unknown amount of waste antifreeze was placed in a 19,000 liter underground tank (EPA 1987d).

In addition to waste disposal areas on-site, the facilities at Hanford also discharged heated effluent from cooling waters to the Columbia River (Becker 1985). From 1943 to 1971, the Columbia River received cooling water from up to nine plutonium production reactors

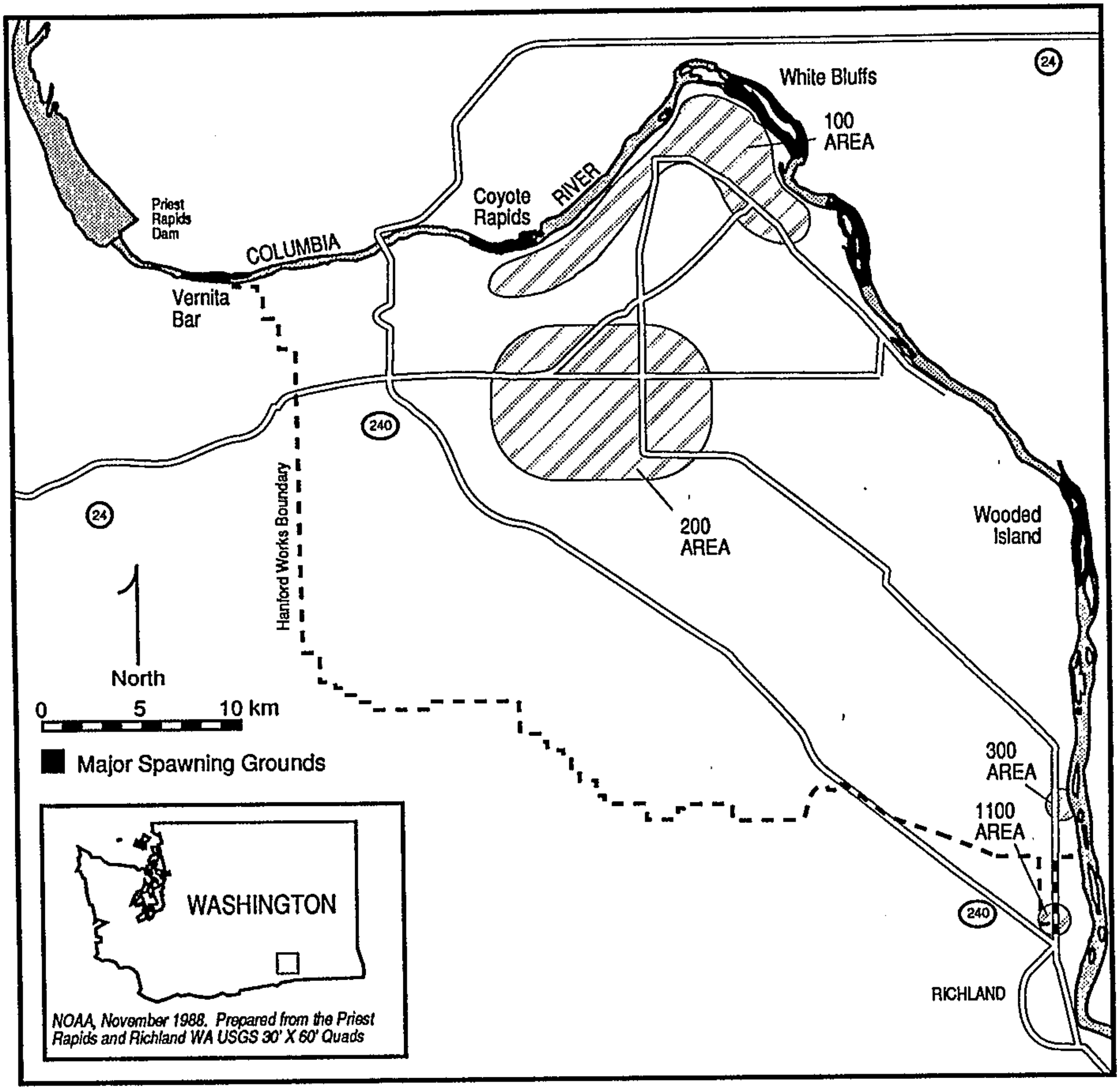

Figure 1. The Hanford Superfund site and the major fall chinook salmon spawning grounds in the Hanford Reach.

with effluent temperatures discharged generally exceeding 85° F. From 1964 to 1971, these single purpose plutonium production reactors were deactivated. Presently, discharges to the Columbia River are regulated by an NPDES permit which covers eight discharges from the Hanford site. Seven of the eight discharges are located in the 100 Area with the other discharge in the 300 Area. Five of the seven discharges in the 100 Area are covered by maximum daily temperature limits which generally range from 69-77° F. The existing NPDES permit was issued on December 7, 1981 and expired December 31, 1985. EPA is currently drafting a new NPDES permit (Mosbaugh, personal communication 1988).

Physical Description

The Hanford site is located in a rural region of southeastern Washington State north of the town of Richland in Benton County and occupies an area of 1,500 square kilometers. The Columbia River borders the northern and eastern boundaries of the Hanford site for approximately 90 kilometers (Fickeisen 1980). This section of the Columbia River is known as the Hanford Reach and is the only remaining free-flowing stretch of the Columbia River within the United States. The Columbia River, which originates in the mountains of eastern British Columbia, Canada, drains a total area of approximately 70,800 square kilometers and flows for 560 kilometers from the site enroute to the Pacific Ocean. The flow of the Columbia River within the United States is regulated by 11 dams, with 7 upstream and 4 downstream from the Hanford site. All of the four dams below Hanford have fish passage facilities that allow anadromous fish access to the site. The Priest Rapids Dam, is approximately 5 kilometers upstream of the site, and the McNary Dam is 80 kilometers below the site.

Flow rates in the Hanford Reach area are primarily regulated by the variable power production requirements of Priest Rapids Dam which can cause significant fluctuation in the Columbia River. The regulated minimum flow rate of 1,000 cubic meters per second (cms) at Priest Rapids Dam can range up to 7,000 cms during typical flows and can increase to as much as 15,300 cms during peak spring flow. The maximum flood of record was 19,250 cms in 1948. The width of the river in the Hanford reach varies between 300 and 600 meters with an average depth of 8 meters. Daily fluctuations in depth caused by release from the Priest Rapids Dam can be as much as 3 meters just below the dam and 1.5 meters along the Hanford site.

The groundwater resources at the Hanford site consist of both confined and unconfined aquifers. In general, the unconfined or water table aquifer slopes downward and flows from west to east towards the Columbia River. The depth from the ground surface to the water table ranges from less than 0.3 meters near the Columbia River to over 106 meters in the center of the Hanford site area. This relatively shallow unconfined aquifer has been affected by wastewater disposal at Hanford more than the confined, deeper aquifers (RHO 1981). It is estimated that some wastewater additions to the groundwater may be as much as 10 times the annual natural recharge. The major contaminant transport pathway from the Hanford site to the Columbia River is groundwater flow. Surface water runoff is negligible due to low rainfall, high evaporation, relatively level topography, and high soil infiltrative rates and capacity.

CHEMICAL HAZARDS

Contaminants and Concentrations

The major contaminants of concern for the protection of natural resources in the 100, 200, 300, and 1100 Areas are radionuclides and inorganic and organic contaminants. The majority of the data concerning environmental contamination comes from DOE groundwater and surface water monitoring activities for radionuclides. These activities have verified the movement of Hanford-related materials in the unconfined aquifer to the Columbia River but only specific indicator substances were monitored (PNL 1984a). These indicator substances included the radionuclides strontium-90, tritium, iodine-129 and uranium; the inorganic substances chromium and cyanide; and the volatile organic compound carbon tetrachloride. Even though they were known to have been discharged, very little information exists regarding the concentrations of hazardous chemicals and metals in groundwater, surface water, soils, or sediments.

100 Area

The disposal locations and plumes of contaminated groundwater in the 100 Area cover approximately 28.5 square kilometers (EPA 1987a). Chemical substances historically associated with reactor operations in the 100 Area include several radioactive isotopes, industrial acids and bases, various metal salts, and individual metallic species. The compounds with the greatest toxicity and longest persistence would include uranium, lead, mercury, dichromate, and plutonium (DOE 1986).

Groundwater monitoring in the 100 Area included measurements of strontium-90 and chromium (Table 1). Low levels of strontium-90 have been detected in the groundwater beneath the 100 Area as well as in the Columbia River. These levels of radioactivity are less than levels observed to be toxic to aquatic organisms (Blaylock and Trabalka 1978). Chromium has also been detected in the groundwater at levels two orders of magnitude above the ambient water quality criterion of 16 µg/l (EPA 1986) for the protection of freshwater organisms. Chromium in Columbia River surface waters has been detected above ambient water quality criteria.

Table 1. Maximum contaminant levels observed in the groundwater and Columbia River surface water near the 100 Area (EPA 1987a, DOE 1987, and Battelle 1988).

	Groundwater		Columbia River	
Contaminant	Upgradient	Downgradient	Upgradient	Downgradient
strontium - 90	<0.753 pCi/l*	12.5 pCi/l*	0.34 pCi/l*	28 pCi/l*
chromium, hexavalent	10.0 µg/l	1,560.0 µg/l	NA	NA
chromium, dissolved	NA	NA	1.0 µg/l	30.0 µg/l

NA: Not analyzed
* pCi/l Ci is the abbreviation for the curie, which is the official unit of radioactivity, defined as 3.70×10^{10} disintegrations per second. This decay rate is nearly equivalent to that exhibited by one gram of radium in equilibrium with its disintegration products. A picocurie (pCi) is 10^{-12} curie

200 Area

The disposal locations and plumes of contaminated groundwater in the 200 Area cover approximately 557 square kilometers (EPA 1987b). Chemical substances used to historically process irradiated uranium fuel to recover plutonium and probably disposed of in the 200 Area include several radioactive isotopes, industrial acids and bases, solvents, various metal salts, and individual metallic species (DOE 1986).

Groundwater in the 200 Area was monitored for tritium, iodine-129, uranium, cyanide, carbon tetrachloride and several other volatile organic compounds. The surface water monitoring program in the 200 Area of the Columbia River included measurements of tritium and iodine-129. High levels of tritium and uranium were detected in groundwater in the 200 area. Tritium was detected in the Columbia River. These levels of radioactivity are less than levels observed to be toxic to aquatic organisms (Blaylock and Trabalka 1978). Cyanide was detected in the groundwater at concentrations an order of magnitude above the ambient water quality criterion of 22 µg/l (EPA 1986) for the protection of freshwater organisms.

Trace levels of several volatile organic compounds including chloroform, methylene chloride and trichloroethylene were found in the 200 Area ground water. Concentrations of these compounds were well below levels observed to be toxic to freshwater aquatic organisms.

Table 2. Maximum contaminant levels in groundwater from the 200 Area (EPA 1987b and Battelle 1988).

	Groundwater		Columbia River	
Contaminant	Upgradient	Downgradient	Upgradient	Downgradient
tritium	<320.0 pCi/l	>2,000,000.0 pCi/l	119.0 pCi/l	60,600.0 pCi/l
iodine - 129	0.000094 pCi/l	4.89 pCi/l	$1.04X10^{-5}$	$16.1X10^{-5}$
uranium	1.06 pCi/l	14,900.0 pCi/l	NA	NA
cyanide	<10.0 µg/l	1120.0 µg/l	NA	NA
carbon tetrachloride	<10.0 µg/l	4520.0 µg/l	NA	NA

300 Area

The disposal locations and plumes of contaminated groundwater in the 300 Area cover approximately 13 square kilometers (EPA 1987c). Chemical substances historically used in the fuel element fabrication processes in the 300 Area include a few radioactive isotopes, industrial acids and bases, solvents, various salts, and individual, nonradioactive metallic species. The compounds with the greatest toxicity and longest persistence would be uranium, mercury, chromium, and plutonium (DOE 1986).

Uranium was used as an indicator constituent in the 300 Area and its measurement has verified groundwater contamination beneath the site. Levels ranged from 30 pCi/l to 42 pCi/l. There have also been observed releases to surface water via springs along the river bank which are known to discharge into the Columbia River (Battelle 1984b). These levels of radioactivity are less than levels observed to be toxic to aquatic organisms (Blaylock and Trabalka 1978).

1100 Area

The chemical constituents associated with the maintenance and operation activities in the 1100 Area are sulfuric acid, lead, and ethylene glycol (EPA 1987d). Through 1986, DOE had not detected any radionuclide contaminants in groundwater in the 1100 Area (DOE 1986). Of particular concern in this area, however, is the depth to groundwater. The unconfined aquifer is within 4.2 meters of the bottom of the sand pit and the underground tank.

Radionuclide Toxicology

The major radionuclides detected in groundwater and surface water samples collected from Areas 100, 200, and 300 were tritium, iodine-129, strontium-90, and uranium. The activities of these radionuclides were reported to range from 4.89 pCi/l for Iodine-129 to 1,600,000 pCi/l for tritium (Tables 1 and 2). The toxicity of the radionuclides can result from both their chemical and radiological characteristics. The results from a number of studies demonstrate that developing fish eggs are particularly sensitive to the effects of incorporated radionuclides (i.e., radionuclides taken-up into the tissues through transport across membranes) (Table 3).

The lowest radiological activities reported to elicit significant biological responses in embryonic fish was 200 pCi/l for strontium-90, 25,000 pCi/l for cesium-137, 2.6×10^9 pCi/l for plutonium-238, 1.2×10^9 pCi/l for uranium-238 and 10^9 pCi/l for tritium. None of the values observed in groundwater or surface waters of the Columbia River are above these levels. However, because a number of radionuclides may be present in the Columbia River, their additive radiological effect as well as their potential chemical toxicities must be considered.

A number of studies have investigated the chemical toxicity of uranium-238 to aquatic organisms. Acute toxicity of uranium in Columbia River water was observed at 6 mg/L using *Daphnia magna*. Acute toxicity was found to diminish as hardness increased. *D. magna* reproduction was suppressed in Columbia River water at uranium concentrations between 0.5 and 3.5 mg/l. Based on the specific activity of uranium-238 (present to the extent of 99.28% by weight in natural uranium) of 3.3×10^5 pCi/g (Eisenbud 1987), *D. magna* would have been exposed to an activity of 1,980 pCi/L at a concentration of 6 mg/L. Concentrations an order of magnitude above this (14,900 pCi/l) were detected in the groundwater beneath the 200 Area of Hanford. Reduced growth (28%) in the marine amphipod *Allorchestes compressa* was found at 2 mg/l (Ahsanullah and Williams 1986). The toxicity of uranium to brook trout was observed between 23 mg/l and 59 mg/l at a water hardness of 200 mg/l $CaCO_3$ (Parkhurst et al. 1984).

The concentrations of radionuclides detected at the Hanford Site were presented as the activities rather than as chemical concentrations. Little information is available concerning the chemical toxicity of the radionuclides. It is not known if chemical concentrations in the groundwater or surface waters of the Columbia River are toxic to NOAA trustee resources. However, strontium, tritium, cesium, and iodine are relatively abundant elements in nature. Strontium, cesium, and iodine are found naturally in animal tissues and strontium and iodine are trace nutritional elements necessary for a number of physiological processes (Casarett and Doull 1975).

Table 3. Effects of Incorporated Radionuclides on Developing Fish Eggs (Blaylock and Trabalka 1978).

Radionuclides and Test Organisms	Stage Exposure Commenced	Concentration (pCi/L)*	Biological End Point and Observed Effects
Strontium 90			
Anchovy (*Engraulis encrasicholus*)	Shortly after fertilization	$2x10^4$ $2x10^4$ $2x10^2$	Hatching-decreased Growth rate-retarded Abnormalities-increased
Rock Bass (*Serranus scriba*)	Shortly after fertilization	$2x10^4$ $2x10^4$	Hatching-no effect Growth rate-retarded
Ruff (*Scorpacena porcus*)	Developing eggs	$1x10^3$	Chromosome breaks-increased
Atlantic salmon (*Salmo salar*)	Sixth stage	$5x10^3$	Death of fry and embryos-increased
Pink salmon (*Oncorhynchus gorbuscha*)	Fertilized egg	$1x10^8$	O_2 consumption-depressed
Caspian salmon	Early stage of development	$1.75x10^6$	Mortality-increased
White sturgeon (*Acipenser transmontanus*)	Early stage of development	$1.75x10^6$	O_2 consumption-depressed
Cesium 137			
Atlantic salmon (*Salmo salar*)	Sixth stage	$2.5x10^3$	Death of fry and embryos- increased
Plutonium-238			
Carp (*Cyprinus carpio*)	Immediately after fertilization	$7.5x10^9$ $3.9x10^9$	Hatching-decreased Abnormalities-increased
Fathead minnow (*Pimephales promelas*)	Blastula	$1.3x10^9$ $2.6x10^8$	Hatching-decreased Abnormalities-increased
Pink salmon (*Oncorhynchus gorbuscha*)	Fertilized egg	$1x10^8$	O_2 Consumption-depressed

Table 3 (continued)

Radionuclides and Test Organisms	Stage Exposure Commenced	Concentration (pCi/L)*	Biological End Point and Observed Effects
<u>Tritium</u>			
Stickleback (*Gasterosteus aculeatus*)	Immediately after fertilization	$2x10^{12}$ $2x10^{12}$ $1x10^{12}$	Mortality- no effect Abnormalities-no effects Eye diameter-reduced
Puffer (*Fugu niphobles*)	2-cell stage	$1x10^{10}$	Hatching-decreased
Rainbow trout (*Salmo gairdneri*)	6 hrs. after fertilization	$1x10^{9}$	Immune response of fry - suppressed
<u>Uranium</u>			
Carp (*Cyprinus carpio*)	Immediately after fertilization	$5.0x10^{9}$ $1.2x10^{9}$	Hatching-decreased Abnormalities-increased
Fathead minnow (*Pimephales promelas*)	Blastula	$5.0x10^{8}$ $2.0x10^{8}$	Hatching-decreased Abnormalities-increased

* pCi/L: Ci is the abbreviation for the curie, which is the official unit of radioactivity, defined as 3.70×10^{10} disintegrations per second. Picocurie (pCi) is 10^{-12} curie.

Extent of Contamination

Monitoring programs have detected low levels of radioactive constituents in the ground water at the 100, 200, and 300 Areas of Hanford over large areas of the site (approximately 600 square kilometers). Very low levels of radioactive constituents have been observed in the Columbia River near the 100, 200, and 300 areas. Higher levels of radionuclides may have been observed in the aggregrate areas, but not used in the Hazard Ranking System scoring for the sites (Bennett, personal communication, 1988).

Complete characterization of the site has not been performed. Current monitoring programs have not measured all of the radioactive constituents that have infiltrated to the groundwater from the site. Full characterization of radiological activity as well as chemical concentrations has not been performed. Inorganic and organic contaminants historically used at the site areas were also not monitored for. No systematic investigations of surface water and sediments have been performed on the Columbia River in the Hanford Reach.

Duration of Contaminant Release

Since the Hanford site has been operating since 1943, the disposal of waste radionuclides and other contaminants may have occurred for 45 years.

TRUST HABITATS AND SPECIES IN SITE VICINITY

Habitats and Species

Chinook, coho, sockeye salmon and steelhead trout use Hanford Reach as spawning grounds, nursery areas, foraging areas, and as a migratory corridor (Fickeisen et al. 1980; Becker 1985). From 1980 to 1984 between 99,166 and 183,876 adult salmonids used this critical habitat each year.

Hanford Reach, the only remaining free-flowing stretch of the Columbia River, provides the only significant spawning grounds in the river for fall chinook salmon and steelhead trout (Fickeisen et al. 1980; Becker 1985). From 1960 to 1984, the number of redds observed in the Hanford Reach increased from 295 to 7,310 (Becker 1985) (Figure 2), representing a fifteen-fold increase since 1960 in fall chinook spawning in the Hanford Reach (based on a pre-McNary Dam mean of 500 redds). This increase is attributed to the loss of upstream spawning grounds after the construction of the Priest Rapids Dam and to the upstream translocation of fish whose spawning grounds were inundated by dams below Hanford (Becker 1985). Recent field investigations of redd distribution in the Hanford Reach indicated that substantial spawning occurred in deeper water areas not previously identified by aerial surveys (Swan et al. 1988).

Four major fall chinook salmon and steelhead spawning grounds have been identified in Hanford Reach: the Vernita Bar, Coyote Rapids, White Bluffs and the Wooded Island stretches of the river. The latter three areas are adjacent or near the Hanford site areas 100 and 300 (Fickeisen et al. 1980; Becker 1985) (Figure 1). Spawning activity occurs for over a six month period with fall chinook salmon spawning from September to mid-November and steelhead spawning from February through May (Figure 3). The upriver fall chinook stock, which spawns in the Hanford Reach, contributes to sport, commercial, and Indian fisheries in the Columbia River and in coastal waters from the Columbia River mouth to southeast Alaska. In addition, it is one of the key stocks addressed in the U.S. - Canada Pacific Salmon Treaty.

Hanford Reach provides critical nursery and foraging habitat for juvenile fall chinook salmon and steelhead over the entire year (Fickeisen et al. 1980; Becker 1985) (Figure 3). Back water sloughs, nearshore pools and other areas in close proximity to the shore are used extensively by juvenile salmonids (Fickeisen et al. 1980). Juvenile fall chinook salmon use this habitat for up to six months between March and August before outmigration. Steelhead juveniles may over-winter in the Hanford Reach, so are present over the entire year. Juvenile spring and summer chinook, coho, and sockeye salmon use upstream tributary streams as nursery areas and use the Hanford Reach in the vicinity of the site as a migratory corridor.

Hanford Reach provides foraging habitat and a migratory corridor for all of the salmonids. (Fickeisen et al. 1980; Becker 1985). Adult chinook salmon can be found in the Reach from mid-February to mid-December while adult steelhead are present over the entire year (Figure 2). Adult chinook salmon and steelhead are found in Hanford Reach for long periods due to several distinct genetic stocks which migrate to spawning grounds at different periods of time. Chinook salmon in the Hanford Reach are comprised of spring, summer and fall arriving stocks and steelhead are comprised of summer and winter arriving stocks. Coho salmon are present in the Reach from September through December and sockeye salmon are present from July through August. Spring and summer chinook, coho and sockeye salmon do not spawn in the Hanford Reach but use it as a migratory corridor to upstream tributary streams of the Columbia River.

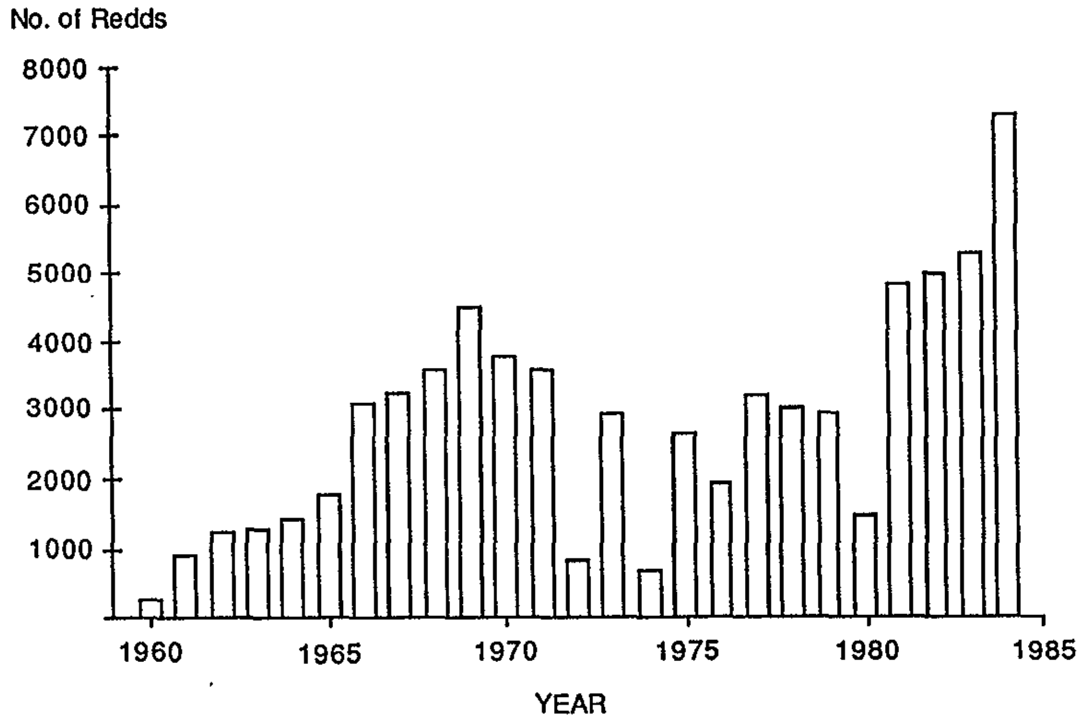

Figure 2. Chinook salmon redds observed in the Hanford Reach from 1960 to 1984 (not including deep water redds) (Becker 1985).

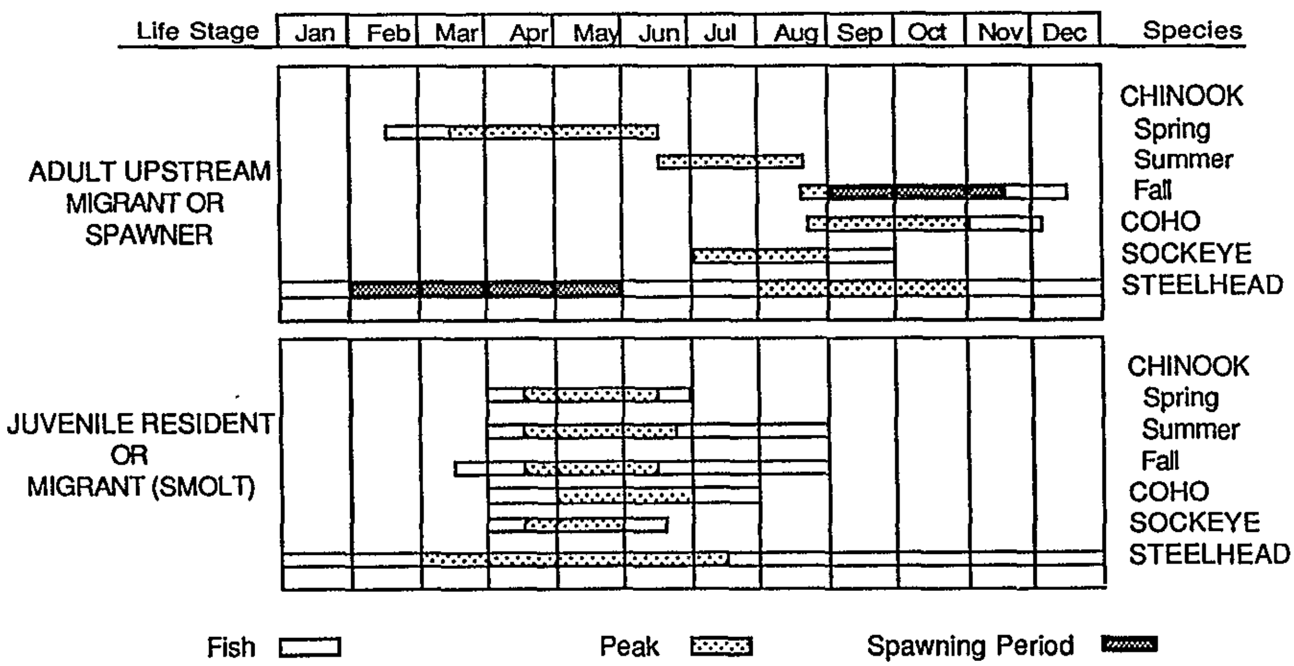

Figure 3. Seasonal distribution of anadromous salmonids using the Hanford Reach (Fickeisen et al. 1980; Becker 1985).

Two artificial rearing facilities on Hanford Reach plant salmonids in the Columbia River. As many as 20 million juvenile chinook salmon and steelhead trout are planted in Hanford Reach each year (Becker 1985).

American shad may use Hanford Reach as a spawning ground and nursery although not in great numbers (Gray and Dauble 1977). White sturgeon use the Hanford Reach as a spawning ground, nursery area and adult habitat. It is not known if sturgeon in Hanford Reach are anadromous, since sturgeon populations above the Bonneville Dam are considered landlocked (Fickeisen et al. 1980).

Contaminants in Habitats and Species

Radionuclides are known to bioaccumulate in the tissues of aquatic organisms adding food chain impacts as another potential route of exposure for these contaminants. Boneless fillets of whitefish and bass from the 100 Area along the Hanford Reach were analyzed for cobalt-60, strontium-90, and cesium-137 with the remaining carcasses analyzed to estimate strontium-90 levels in bone. Cesium-137, strontium-90, and cobalt- 60 were detected in a few of the white fish muscle samples collected along the 100 Area, as well as upstream of the site near the Priest Rapids Dam, but there were no statistical differences between the two locations. Strontium-90 in whitefish carcasses, however, was measurably higher in samples collected from the 100 Area than in samples collected upstream of the site. Samples of bass muscle and carcasses collected from the slough near the 100 Area showed concentrations similar to those measured in whitefish also collected near the 100 Area (Battelle 1987). Anadromous fish, juveniles, or eggs have not been sampled.

Bioconcentration factors (BCFs) have been determined for some of the radionuclides in various aquatic organisms (Blaylock 1982). Of the piscivorous fish analyzed, bioconcentration factors ranged from <1 for uranium, approximately 1 for tritium, 125 for strontium-90 and over 1,000 for iodine-190 (Table 4). It is not known to what extent tissue burdens of radioactive constituents affect fish species.

Table 4. Range of bioconcentration factors for Strontium-190, Iodine 131, uranium, and tritium (Blaylock 1982).

		Bioconcentration Factor		
Biota	Strontium-90	Iodine-190	Uranium	Tritium
Fish				
Piscivorous	1.3-125	7.9-1,109	0.5-0.7	~1*
Planktivorous	28	NR	8	~1
Omnivorous	0.7-198	25-50	0.7-38	~1
Benthic invertebrates	300-720	150-450	2-33,500	~1

* It has been determined that the BCF for tritium is ~1. The biological half-life of tritium in fish is <1 day; thus the concentration of tritium in fish will follow closely the concentration of tritium in ambient water.

REFERENCES

Ahsanullah, M. and A. R. Williams. 1986. Effect of uranium on growth and reproduction of the marine amphipod *Allorchestes compressa*. Marine Biology. 93, pp. 459-464.

Battelle Pacific Northwest Laboratory (PNL). 1984a. Groundwater Surveillance at the Hanford Site for CY 1983, PNL-5041. Battelle Pacific Northwest Laboratory, Richland, WA.

Battelle Pacific Northwest Laboratory.(PNL). 1984b. Investigation of Groundwater Seepage from the Hanford Shoreline of the Columbia River, PNL-5289. Battelle Pacific Northwest Laboratory, Richland, WA.

Battelle Pacific Northwest Laboratory (PNL). 1987. Environmental Monitoring at Hanford for 1986, PNL-6120. Battelle Pacific Northwest Laboratory, Richland, WA.

Battelle Pacific Northwest Laboratory (PNL). 1988. Environmental Monitoring at Hanford for 1987, PNL-6464. Battelle Pacific Northwest Laboratory, Richland, WA.

Becker, C.D. 1985. Anadromous salmonids of the Hanford Reach, Columbia River: 1984 status. Prepared for the U.S. Department of Energy, Battelle Pacific Northwest Laboratory, Richland, WA. September 1985.

Bennett, David, Environmental Protection Specialist, U.S. Environmental Protection Agency, Seattle, Washington, personal communication, December 9, 1988.

Blaylock, B.G. and J. R. Trabalka. 1978. Evaluating the effects of ionizing radiation on aquatic organisms. In: Advances in Radiation Biology, Vol. 7. (J. T. Lett and H. Adler, Eds.). pp 103-152.

Blaylock, B.G. 1982. Radionuclide data bases available for bioaccumulation factors for freshwater biota. In: Environmental effects. (R. O. Chester and C.T. Garten, Jr., Eds.) Nuclear Safety, 23: 4, pp. 427-438.

Casarett, L.J. and J. Doull. 1975. Toxicology: The Basic Science of Poisons. Macmillan Publishing Co., Inc. New York, New York. 768 pp.

Eisenbud, M. 1987. Environmental Radioactivity from Natural, Industrial, and Military Sources. Academic Press, Orlando, Florida.

Gray, R.H. and D.D. Dauble. 1977. Checklist and relative abundance of fish species from the Hanford Reach of the Columbia River. Northwest Science, 51(3) 208-215 August 1977.

Fickeisen, D.H., D.D. Dauble, D.A. Neitzel, W.H. Rickard, R.L Skaggs and J.L. Warren. 1980. Aquatic and riparian resource study of the Hanford Reach, Columbia, River, Washington. Prepared for the U.S. Corps of Engineers, Seattle District, WA. Battelle Pacific Northwest Laboratories, Richland, WA. April 1980.

Kulikov, I. V., N. A. Timofeeva, and L. K. Shishenkova. 1968. Radiosensitivity of tench (*Tinca tinca*) embryos at early stages of development. Radiobiologiya. 8: 391 (AEC-tr-6916).

Mosbaugh, Ken, Environmental Scientist, U.S. Environmental Protection Agency, Seattle, Washington, personal communication, November 14, 1988.

Parkhurst, B. R., R. G. Elder, J.S. Meyer, D. A. Sanchez, R.W. Pennak, and W. T. Waller. 1984. An environmental hazard evaluation of uranium in a rocky mountain stream. Environmental Toxicology and Chemistry. 3: 113-124.

Polikarpov, G.G. and V. N. Ivanov. 1962. The harmful effect of ^{90}Sr-^{90}Y in the early development of the red mullet, the green wrasse, the horse mackerel and the Black Sea anchovy. Doklady Akademii Nauk SSSr, Seriya Biologiya. 144: 219-222.

Poston, T.M., R.W. Hanf, Jr., and M. A. Simmons. 1984. Toxicity of uranium to *Daphnia magna* . Water, Air, and Soil Pollution. 22: 289-298.

Rockwell Hanford Operations (RHO). 1979. Hydrologic Studies Within the Columbia Plateau, WA: An Integration of Current Knowledge, RHO-BWI-ST-5. Rockwell Hanford Operations, Richland, WA.

Rockwell Hanford Operations (RHO). 1981. Hydrology of the Separations Area, RHO-ST-42. Rockwell Hanford Operations, Richland, WA.

U.S. Department of Energy (DOE). 1986. Draft Phase I Installation Assessment of Inactive Waste-Disposal Sites at Hanford. Vols. I & II. U.S. Department of Energy.

U.S. Department of Energy (DOE). 1987. Final Environmental Impact Statement, Disposal of Hanford Defense High-Level, Transuranic and Tank Wastes. Vol. I. U.S. Department of Energy.

Swan, G.A., E.M. Dawley, R.D. Ledgerwood, W.T. Norman, W.F. Cobb, and D.T. Hartman. 1988. Distribution and relative abundance of deep-water redds for spawning fall chinook salmon at selected study sites in the Hanford Reach of the Columbia River. Final Repot of Research. Financed by the U.S. Army Corps of Engineers and CZES, National Marine Fisheries Service, Seattle Washington. March 1988.

U.S. EPA. 1987a. Hazard Ranking System (HRS) Scoring Package for 100 Area. U.S. Environmental Protection Agency, Region X, Seattle, WA.

U.S. EPA. 1987b. HRS Scoring Package for 200 Area. U.S. Environmental Protection Agency, Region X, Seattle, WA.

U.S. EPA. 1987c. HRS Scoring Package for 300 Area. U.S. Environmental Protection Agency, Region X, Seattle, WA.

U.S. EPA. 1987d. HRS Scoring Package for 1100 Area. U.S. Environmental Protection Agency, Region X, Seattle, WA.