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G. W. Roles
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Engineering Branch
Division of Waste Management, NMSS
Washington, D.C. 20555

Dear Mr. Roles:

Enclosed please find brief descriptions of the various exposure scenarios that we assembled to use in environmental assessments of radioactive waste disposal at the Hanford Site. As we discussed over the telephone, these scenarios are used in the Draft Environmental Impact Statement (DEIS) on "Disposal of Hanford Defense High-Level Transuranic and Tank Wastes" (DOE/EIS-0113 Vols. 1-3 March 1986). This DEIS that was issued in late April contains both scenario descriptions similar to those in the enclosure and results calculated for specific radionuclide inventories. If you are interested in a full copy of this DEIS please let me know. The enclosure is a "cut and paste" summary directly from the DEIS and refers to other information in the DEIS. However, I think that it does provide a good summary of the major modeling considerations that we use. As you can see from the enclosure, both resource exploration and water well drilling are considered. I hope that you find this material useful and I apologize for my delay in sending this material along to you.

Sincerely,

W. E. Kennedy, Jr.

W. E. Kennedy, Jr.
Environmental & Risk Assessment Section
EARTH SCIENCES DEPARTMENT

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Enclosure

R.1.4 Dosimetric Analysis

People do not receive immediate radiation doses once the radionuclides have begun to migrate through the soil. There is a delay while the nuclides are transported through the unsaturated zone and the groundwater before they finally arrive at a point where people can be exposed. The location of the point of exposure is also dependent on future actions. It may be that a domestic well penetrates to contaminated plume, or the contaminated groundwater may eventually reach the Columbia River. For this analysis, wells have been assumed at a distance of 5 km down-gradient from the 200 Areas. The nuclides are also assumed to reach the Columbia River and affect the downstream population. Radiation doses to individuals drinking water and irrigating from the 5-km well have been calculated. (The 5-km distance is a calculational convenience--the calculated water concentrations change relatively little from the point of contaminant entry to downstream locations. The value at 5 km is representative of distances 0 to 10 km or more.) The total integrated population dose to all people living along the Columbia River for the next 10,000 years has also been calculated. These doses are addressed in the following sections.

R.1.4.1 Drinking Well Water

A measure of the level of contamination of groundwater is the radiation dose caused only by drinking the water. EPA regulations for high-level and TRU waste limit the dose allowed by this exposure route to an increased increment of 4 mrem/yr (40 CFR 191) for the first 1,000 years after disposal. Annual and lifetime doses to individuals drinking water from a well located 5 km downstream of each waste site for each disposal alternative and for no disposal action are given.

R.1.4.2 Full Garden Scenario for Well Water

Contaminated well water might be used for irrigation and livestock water, as well as for human drinking water. Radiation doses are estimated for the same well-water concentrations as in Tables R.2 through R.21 but for a scenario in which an individual grows a large percentage of his food using the well for irrigation, as might occur on a small, 2-ha (5 acre) family farm. In addition to drinking water, the individual is exposed to radionuclides deposited on the soil and accumulated in crops and animal products. Doses to individuals are given in Tables R.23 through R.32; these are given for each waste form for no disposal action and for each disposal alternative, both with barriers that function as designed or, for the higher recharge case, with barriers experiencing either the disruptive or functional failure as described in Section R.1.4.1. Only lifetime doses are presented in this set of tables.

R.1.4.3 Radionuclide Migration to the Columbia River

Radionuclides and other contaminants leached into the groundwater would likely reach the Columbia River eventually. The rate at which nuclides enter the river depends on the rate at which they enter the groundwater, their radioactive decay, their chemical characteristics, and the flow of the aquifer and distance to the river. The highly mobile radionuclides (^{14}C, ^{99}Tc) could reach the Columbia within a few hundred years after the initiation of waste leaching if no barriers to migration intervene. The less mobile nuclides (^{137}Cs, ^{241}Am) may entirely decay before ever reaching the water table. The relative rates and proportions of radionuclides eventually reaching the river are functions of the initial inventories (given in Appendix Q and Chapter 3) and the flow rate of the transporting water, if any.

The Columbia River is now used for drinking, irrigation, and recreation by many people living downstream of Hanford. These uses can only be assumed to increase in the future. Presently, only a small fraction of the river's flow below Hanford is used for irrigation or drinking. (Water for the large irrigation projects in the area is primarily derived from the Columbia River upstream of Hanford.) Within 80 km of Hanford, only 2000 people are estimated to eat food grown with irrigation water from the Columbia, 70,000 people drink water from the river, and about 125,000 people swim or boat in the river (McCormack et al. 1984). To conservatively account for all people living downstream along the Columbia between Hanford and the river's mouth, a population growing to nearly 5,000,000 affected individuals is assumed over the next 10,000 yr. For this many people to be affected, a very large increase in the amount of irrigated land in both Washington and Oregon would be required, concurrent with a large increase in overall population. The total number of people thus assumed to live along the Columbia River for the next 10,000 yr is about 410 million. The total dose a group this size would receive from naturally occurring background sources is nearly 3 billion man-rem. As a subset of this population the 70,000 people currently using the Columbia for drinking water, if held constant over the next 10,000 yr, would receive a natural background dose of about 70 million man-rem.

R.3 DRILLING

Drilling into a waste-storage or disposal site means penetration of the waste site from the land surface with actual removal of waste and soil material to the land surface. Drilling on the Hanford Site is considered in the case of loss of active institutional control 100 yr after disposal. Monuments, barriers, and markers may reduce the likelihood of drilling, but they cannot preclude it.

Two distinct types of drilling scenarios are postulated. Because each has different drilling objectives and different size drill holes, different volumes of waste and soil material are brought to the surface:

1. A resource exploration well of large diameter, intended to be a deep (300 m or more) exploration test
2. A water well drilled for domestic water supply, which is comparatively shallow (100 m or less).

Drilling, either for water wells or for mineral exploration, is a potential mechanism for moving buried waste directly to the earth's surface with little indication that the waste has been encountered. Any disposal alternative that results in the waste's remaining near the surface creates the potential for the waste to be struck during drilling, even for relatively shallow wells (as for domestic water supplies). Only in instances where the waste is totally removed to a repository is intrusion by drilling a shallow well impossible.

In the drilling scenario, a well 30 cm in diameter is bored through waste of each category. Doses from larger or smaller drill holes scale in proportion to the cross-sectional area (except for doses from Sr/Cs capsules).

Drilling through the waste form itself is assumed to take 1 hr. During this time, the driller breathes suspended material with a mass loading of 1×10^{-4} g/m^3 of air. For the calculation of external exposure, the exhumed waste is assumed to be spread over a 100-m^2 area.

The drillers are assumed to spend 40 hr working in the immediate vicinity of the exhumed waste. (The maximum annual dose includes that from external radiation received during drilling, plus the longer-term dose that would result from inhalation of nuclides in resuspended contaminated drilling muds.)

Persons living beyond the immediate vicinity of the contaminated area would be exposed to much lower concentrations of radionuclides. Atmospheric dispersion and dilution of resuspended contaminants would greatly reduce the individual doses. Radiation doses to individuals outside the immediate area of the drilling would be caused by long-term resuspension of the drilling muds spread about on the soil surface.

R.4 MAJOR EXCAVATION

Several plausible excavation events can be postulated that represent major ground disturbance. These include construction projects required for highway or canal building, or, on a smaller scale, for basements in buildings. In these cases, workers operating heavy machinery can be assumed to be in a "hole in the ground," essentially surrounded by contaminated soil. The hole could range from relatively small (for a basement) to quite large (for a canal), but the direct exposure source and the resuspended air concentration would be about the same in either case. The workers in the hole would be exposed to direct radiation from radionuclides in the soil and to resuspended dust from the construction activity. Minor excavation or digging is considered similar to a drilling intrusion event (Section R.3) because of the amount of material removed and the similar processes of exposure.

Records and federal ownership would reduce the likelihood of major excavation (see Appendix M), but if records and controls have been lost or ignored, it cannot be prevented. Intrusion by excavation is considered to be credible only in the no disposal action alternative. The barrier and marker system is assumed to preclude excavation; the excavator is assumed to be alerted to the danger by the markers internal to the barrier. Waste in tanks or capsules may be in a recognizable form that would alert the intruder to the hazard, but for the purposes of this analysis, such recognition is not assumed.

An individual operating heavy equipment is assumed to work in a contaminated area for 80 hr. A mass loading of 1×10^{-2} g/m^3 of air is assumed. Density of the material is 1.7 g/cm^3. Waste is assumed to be uniformly mixed with soil. Source of inventory and the assumed total volume for determining concentration are listed in Table R.55.

Persons living beyond the immediate vicinity of the contaminated area would be exposed to much lower concentrations of radionuclides than the excavators would. Atmospheric dispersion and dilution of resuspended contaminants would reduce the doses.

Because it is assumed that the excavation is caused by people who have moved onto the Hanford Site and who are working in the vicinity of abandoned waste sites, a uniform population density is assumed for the Site (see Section R.5). A population of 250 people/km^2 (640/mile^2), compatible with the residential home garden scenario, is used. Materials distributed on the surface would be available for resuspension by wind. A resuspension rate of 10^{-10} sec^{-1} (3×10^{-3} yr^{-1}) is assumed (compatible with the air loading of 10^{-4} g/m^3 used in the residential scenario). The radioactive materials are assumed to be distributed by 200 Area annual average meteorology. Assuming the materials from the excavation are not covered, the wastes would remain a source of release for many years. Lifetime doses to the assumed population within 80 km (50 miles) are presented in Table R.56.

R.5 RESETTLEMENT/FARMING/GARDENING

For purposes of analysis, the resettlement or reoccupation of the Hanford Site is assumed after its hypothetical abandonment. Though not an expected event, this case is analyzed to provide a basis of one aspect of radiologic impacts in the long term for unprotected waste sites.

It is believed that hypothetical resettlement would occur first along parts of the Hanford Site relatively close to the Columbia River because of the availability of water from both the river and groundwater at shallow depths. However, for the sake of conservatism, potential future occupancy is also assumed near or at locations of waste for the various disposal alternatives. For waste sites in the 200 Areas plateau, this type of resettlement is believed to be applicable only to a few individuals (rather than a systematic settlement). However, resettlement could occur near the river without consideration of the wastes located in the 200 Areas.

Resettlement could lead to the following types of plausible scenarios related to small farm/garden activities that could furnish exposure pathways to the individuals involved:

1. A home garden with exposure coming from consuming crops or garden produce grown over a shallow, unbarriered waste site. The mechanism would be plant uptake by roots growing into waste or contaminated soil. This scenario is described in detail in Section R.5.1.

2. A home garden where waste has been brought to the surface from an unbarriered waste site by plants, animals, and insects, resulting in surface contamination by biotic transport. The primary exposure pathways to individuals would be through direct exposure, inhalation of resuspended material, and ingestion of crops grown at the location. A detailed scenario for this event is described in Section R.5.2.

3. A home garden at the site of former drilling or excavation activity. This drilling has resulted in a higher level of radioactivity at the land surface where individuals carry out their activities. Direct exposure, resuspension, and ingestion of food products grown in contaminated soil are the primary exposure pathways to the inhabitants. This scenario is detailed in Section R.5.3.

4. A small garden/livestock operation where the exposure pathway is by use of water from a domestic well that intercepts water from a contaminated aquifer. The aquifer is assumed to have been contaminated by waste leached through the unsaturated zone and into the groundwater. Because of the existing uncertainties in the groundwater leaching and transport, this scenario was described in detail for individuals separately in Section R.1. This scenario has the potential to impact a larger number of families. The possibilities of population exposure via this scenario are discussed in Section R.5.4.

R.5.1 Residential/Home Garden

Without active institutional controls, and with disregard of passive institutional controls such as permanent markers and public records, waste disposal areas could possibly be used eventually for residential purposes. People could build homes over buried waste sites and conduct routine activities. Food crops, for either domestic or animal consumption, could be grown over the waste site. The resident would consequently be exposed to low levels of direct radiation from the buried material and also to ingestion of radionuclides via crops grown in the site. Crop contamination would be a function of the depth of waste burial, the integrity of the waste container, the overall surface area used for gardening, and other considerations that affect the fraction of plant roots that contact the waste.

The protective barrier and marker system (Appendices B and M) to be applied to the waste site can be designed, among other things, to prevent penetration of roots to the waste and to discourage farming there. Removal of waste to a deep geologic repository makes any farming harmless in terms of radioactive contamination. Thus, only for no disposal action (continued storage) followed by loss of site control is this scenario applicable.

The effects of this scenario on populations depend directly on the number of people involved; if a family of five were to reside over the unprotected waste site as postulated for this scenario, each would receive the dose indicated.

R.5.2 Biotic Transport

Transport of buried radioactive waste to the soil surface by indigenous plants and animals is a very slow process but, continued over long periods, it may result in substantial exposure to humans from unprotected waste sites. At Hanford biotic transport has resulted in "nuisance" contamination from past practices. The overall processes of waste-form degradation, followed by plant or animal uptake, are relatively poorly understood, but are continuing to be researched. A preliminary model of biotic transport processes has recently been developed (McKenzie et al. 1982a,b). This model indicates that, for sites without barriers to prevent intrusion by plants and animals, the quantity of radionuclides transported to the soil surface can be significant. However, radionuclides could be transported to the surface only under the no disposal action (continued storage), followed by loss of maintenance and regulative controls. Any positive action to dispose of the waste greatly reduces or eliminates the potential exposure, because the barrier is designed to preclude this pathway.

Maintenance and vegetation control are assumed for unprotected sites for 100 yr, thus preventing the accumulation of nuclides at the surface before institutional control is assumed to be lost. Following loss of site control, a plant and animal community representative of arid, western sites is assumed to establish itself over the wastes. The description of the biotic community is taken from McKenzie et al. 1982b. The animal community is summarized in Table R.60 and the plant community in Table R.61. The plant community is assumed to be established after loss of site control, with the initial distribution shown in Table R.61 changing as larger plants become dominant in the final community in 100 yr.

Only localized concentrations of radionuclides would be expected near the waste sites; once the material is brought to the surface, normal erosional processes would tend to disperse it. The effects of this scenario on populations also depend directly on the number of people involved.

R.5.3 Postdrilling/Excavation Habitation

The doses to persons contacting wastes presented in Sections R.3 and R.4 represent only a portion of the impact of intrusion into waste. Drilling or excavation results in waste being physically disturbed and distributed in the local environment. These wastes could represent a source of radiation exposure to people living on or near the site of the original disturbance long after the original redistribution. As in the example of the residential/home garden scenario (Section R.5.1), people who live on or near the waste would be exposed to direct radiation from it in the soil, to inhalation of resuspended material, and to ingestion of garden-grown foods.

The protective barrier and marker system planned for the waste sites (with the disposal alternatives) is designed to discourage human use of that land. Hence this scenario is most likely if the waste is left with no remedial actions. It is effectively prevented by removing the waste to a geologic repository, or made less likely by installing barriers, since the barriers result in an inhospitable environment even after an intrusive event. For the purposes of analysis, the drilling event is assumed to occur regardless of the presence of barriers and markers.

Waste brought to the surface by the drilling scenario (Section R.3) is assumed to be spread uniformly throughout a 15-cm plow layer in a garden 2,500-m^2 in area. Twenty-five percent of the individual's vegetable intake is assumed to come from this garden. The individual is assumed to spend 2000 hr/yr outside, exposed to resuspended dust and to surface contamination.

Persons living beyond the immediate vicinity of the contaminated area would be exposed to much lower concentrations of radionuclides than would the residents. Atmospheric dispersion and dilution of resuspended contaminants would reduce the doses. The residents of the farm are assumed regularly to resuspend the contaminated soil by plowing or otherwise working it. Because it is assumed that other people have also moved onto the Hanford Site and live in the vicinity of the waste sites, a uniform population density of 250 persons/km^2 (640/$mile^2$) is assumed (see Section R.4). A resuspension rate of 10^{-10} sec^{-1} (3×10^{-3} yr^{-1}) is used, compatible with the assumed mass loading of 10^{-4} g/m^3. The radioactive materials are assumed to be distributed by winds described by 200 Area annual average meteorology. Because the drilled wastes could remain a source of release for many years under this scenario, lifetime doses to the projected population within 80 km (50 mi) are presented

R.5.4 Multiple Small Farms

The water-well scenarios presented in Section R.1 were developed to describe the potential impact on individuals. It is likely that, should such an event occur, it would affect more than one person. A simple analysis of the flow of groundwater provides an estimate of the total population that could be supported for this irrigated homestead scenario.

Infiltration at a rate of 0.5 cm/yr results in a low water table with gradients sloping gently to the east. Integration of the flow across a north-south line connecting Gable Mountain and Rattlesnake Mountain east of the 200 East Area (see Figure O.3) provides a conservative estimate of the total amount of water that could possibly become contaminated. The quantity of available groundwater in the unconfined aquifer can thus be estimated to be about 2×10^6 m^3/yr (1,600 acre-ft/yr).

The scenario with a 5-cm/yr infiltration rate results in a changed water table with flow beneath the 200 Areas funnelling nothward through the gap between Gable Mountain and Gable Butte (see Figure O.2). The total flow northward through this gap for the 5-cm/yr infiltration scenario is about 1×10^7 m^3/yr (9,500 acre-ft/yr). The most conservative assumption would be to assume that all the water is uniformly contaminated.

The individual farms described in Section R.1.4.2 are postulated to be about 2 ha (5 acres), each providing food for a family of four persons. Present irrigation practices in the Columbia Basin area include use of about 1.5×10^4 m^3 of water per ha (about 5 acre-ft/yr per acre) for typical crops. For a 2-ha farm, about 3×10^4 m^3/yr of water (25 acre-ft/yr) are required. The flow of potentially contaminated water beneath the 200 Areas plateau is therefore sufficient to supply the requirements of only 65 family farms in the 0.5-cm/yr recharge case. This implies an affected population of about 260 people at any one time. (It may be assumed that radionuclides brought to the surface by the wells would eventually erode to the Columbia River, and thus the total population doses downstream would remain about as presented in Section R.1.4.3). As illustrated in Figure R.3, the water could become contaminated about 5,000 yr from the time of disposal, and essentially remain constantly contaminated from then on. Assuming the area is continuously populated and that the groundwater is uniformly contaminated at the highest levels of Section R.1.4.2, the cumulative population doses could be as shown in Table R.67.