BNWL-2207
UC-41

Detailed Accident Analysis for the High Level Waste Preparation Phase of the Commercial Nuclear Waste Vitrification Project

April 1977
(Issued January 1978)

Prepared for the
U.S. Department of Energy
under Contract EY-76-C-06-1830

Battelle
Pacific Northwest Laboratories

BNWL-2207

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BATTELLE
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UNITED STATES DEPARTMENT OF ENERGY
Under Contract EY-76-C-06-1830

Printed in the United States of America
Available from
National Technical Information Service
United States Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22151

Price: Printed Copy $____*; Microfiche $3.00

*Pages	NTIS Selling Price
001-025	$4.50
026-050	$5.00
051-075	$5.50
076-100	$6.00
101-125	$6.50
126-150	$7.00
151-175	$7.75
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DETAILED ACCIDENT ANALYSIS FOR THE HIGH LEVEL WASTE PREPARATION PHASE OF THE COMMERCIAL NUCLEAR WASTE VITRIFICATION PROJECT

by
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APRIL, 1977
(Issued January, 1978)

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SUMMARY

The environmental consequences and the probability of conceivable accidents occurring during the high level waste preparation (HLWP) phase of the Commercial Nuclear Waste Vitrification Project (CNWVP) were analyzed. The maximum environmental consequences of postulated accidents were calculated to result in low radiation doses: a 50-year dose commitment of 0.3 rem to the whole body for a maximum individual, and of 20 man-rem to the whole body for the surrounding population. This may be compared to Department of Energy (DOE) values, in Manual Chapter Appendix 0524, of 0.5-rem whole-body annual dose commitment to individuals at points of maximum probable exposure in uncontrolled areas.[1]

The calculated whole-body relative dose risk to individuals from accidents is low (1.6×10^{-6} rem/yr) as compared to that received from natural background radiation (approximately 1.5×10^{-1} rem/yr)[2] and as compared to levels specified in Nuclear Regulatory Commission (NRC) requirements for routine releases from nuclear power reactors (5.0×10^{-3} rem/yr).[3] Therefore, the design and operational plans for the HLWP phase are judged not to represent an undue environmental risk from accident conditions.

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TABLE 1. Classification of Potential High Level Waste Preparation Accidents

Class 1: Trivial

- Loss of Services
- Loss of Contamination Control
- Equipment Failure

Class 2: Moderate

- Small Solvent Fire
- Small In-Cell Trash Fire
- Ventilation System Failure
- Fuel-Cask Accident
- Transportation Accident
- Pipe/Tank Leak

Class 3: Maximum Credible

- Design Basis Fire
- Design Basis Explosion
- Design Basis Criticality
- Design Basis Flood
- Design Basis Earthquake
- Windstorm

The accident assessment includes both those scenarios arising from a detailed study of the HLWP description and a review of accidents postulated in the Safety Analysis Reports (SARs) for the 324 and 325-A Buildings.[5,6] The essential similarity of CNWVP to previous work in these facilities lends credibility to the use of the building SARs for the initial environmental assessment. Accidents possible in the waste vitrification task are described in the existing 324 Building SAR, but only a small number of the accidents discussed in the 324 and 325-A Building SARs are applicable to the waste preparation task, since it involves processes or equipment that are new to these buildings.

SELECTING ACCIDENTS FOR ANALYSIS

Accidents were selected for analysis by a careful review of the function, description, and design of the project. This review was based on past experience in the Pacific Northwest Laboratory (PNL) facilities and the nuclear industry in general, and was directed toward assuring that no CNWVP accident could have worse consequences than the accidents chosen for analysis.

Since the detailed design of the project is not yet final, the accident conditions were kept broad in scope and nature. To make these conditions manageable for analysis, cause and effect scenarios were developed based on the review described above. The scenarios are more generic than detailed and all assumptions are therefore conservative, tending toward maximum consequences and maximum probability of occurrence. All available DOE and NRC guidance on accident conditions for use in safety analyses (usually designated "design basis accident" - DBA) was taken into account in selecting the accidents and developing the scenarios.

To keep the analysis focused on significant points, the postulated accidents were classified as follows: 1) Trivial, 2) Moderate, and 3) Maximum Credible. Accidents falling into each category are shown in Table 1. These classes rank the postulated accidents in the approximate order of their potential severity. Independent evaluations and fault-tree analyses have indicated that the probability of an accident's occurrence is roughly inversely proportional to its severity[4]--an analysis that is consistent with the objectives of nuclear facility design.

For each accident in the last two categories, relevant aspects of the following topics are discussed:

- possible causes and accident chronology
- material involved
- nature and amount of effluent released to the environment
- probability of occurrence
- engineered safety features provided
- violations or failures necessary for accident occurrence
- radiological consequences of accident.

The purpose of this accident analysis is to evaluate the project design to assure that potential accidents will not result in personnel exposures that exceed the standard of the Department of Energy's (DOE's--formerly the Energy Research and Development Administration's or ERDA's) Manual Chapter 0524.[1] Although CNWVP is a DOE prototype demonstration project and not subject to Nuclear Regulatory Commission (NRC) licensing, the accident dose risks associated with this project may also be compared with those considered acceptable for commercial nuclear power reactors by the NRC.[23] This assurance of low hazard is reached by determining 1) that a postulated accident is impossible because of the nature of the facility or its engineered safety features, or 2) that the consequences of an accident are negligible. When the analysis indicates that an accident could have significant environmental consequences or high probability of occurring, design or operational safety features will be provided to reduce the probability or consequence of that accident.

DETAILED ACCIDENT ANALYSIS FOR THE HIGH LEVEL WASTE PREPARATION PHASE OF THE COMMERCIAL NUCLEAR WASTE VITRIFICATION PROJECT

INTRODUCTION

The operations involved in the Commercial Nuclear Waste Vitrification Project (CNWVP) are essentially identical with work that has previously been performed safely in the 324 and 325-A Buildings at the Hanford Site. The amount of radioactive material in process at a given time will be comparable to amounts that have been successfully processed in prior programs, but larger total quantities of radioactive materials (plutonium, uranium, and fission products) will be handled because of the project's longer scheduled processing period.[a] This larger total throughput may increase the likelihood of a release to the environment and thus present a somewhat greater potential hazard than existed in prior programs.

The equipment for CNWVP is being designed to assure maximum safety. This effort includes careful definition of the general scope and nature of the project, provisions for specifically engineered safety features, and the institution of procedural and operational controls. However, even though safety is a primary design goal, facility operations may involve a small but finite potential for accidents such as a nuclear criticality, direct irradiation, and the spread or release of radioactive contamination. Safety problems of a more conventional industrial nature (e.g., fire, explosion, or release of inert or toxic chemicals or gases) involve a potential for personal injury or property damage, or may result in radiological consequences.

(a) Conceptual Design Report - Commercial Nuclear Waste Vitrification Program. Battelle, Pacific Northwest Laboratories, Richland, WA 99352, December 1976.

METHODOLOGY

The methods used to estimate the potential dose to people residing in the vicinity of CNWVP from postulated accidental releases of radionuclides to the atmosphere are described in the Appendix; included are discussions of the calculation of source terms and dose, and atmospheric dispersion.

In the calculation of consequences and occurrence probabilities, parameters were selected that would result in conservative "worst case" analyses. These assumptions include the following:

- All particles reaching the environment are of respirable size.
- The solubility states used in the tables for radionuclides reaching each critical organ are the most restrictive possible from a dose standpoint.
- The maximum offsite individual is located 2000 meters from the plant.
- High efficiency particulate air (HEPA) filters are 99.95% efficient for all stages.[7]

When doses for accident cases were calculated, the maximum individual was assumed to be exposed to the release for the duration of the accident. For calculation of population doses, the meteorology and population distributions of the region were used.

Most occurrence probabilities in the accident analyses were developed on a frequency-of-occurrence basis for two reasons: 1) because data on industrial accident occurrence already exist and usually have the normalized form, and 2) because data normalized over time permit estimation of annual risk by simply summing frequency-based values to yield the total postulated environmental impact from accidents.

Interpretations of the significance of CNWVP environmental risks are given in the Conclusion section of this report.

ACCIDENT SCENARIOS

The three classes of accidents defined in Table 1 (p. 4) are discussed in further detail below.

CLASS 1 - TRIVIAL

The small-scale occurrences listed in Table 1 were reviewed to assure that they would not cause environmental releases of radioactivity from CNWVP. The improbability of environmental releases from most of these occurrences was quickly established by design review.

The loss of various services in the 324 and 325-A Buildings could affect the reaction rates of some processes and cause off-standard products or waste streams. However, in no case would the loss of a single component cause an environmental release. Most of the important systems, such as electricity and ventilation, have redundant capacity to preclude the complete loss of services. Other trivial incidents such as equipment failure or loss of contamination control could result in a small localized spread of contamination inside the facilities without any corresponding environmental release. These incidents are representative of occurrences that may happen occasionally in routine processing operations.

CLASS 2 - MODERATE

The postulated accidents listed under Class 2 in Table 1 are characterized as having some potential for "lesser environmental releases," i.e., a possible radiation dose with small impact on the maximum individual and the general population. These incidents include a majority of the postulated accidents leading to environmental releases from the waste preparation phase of CNWVP.

2.1 Small Solvent Fire

Various high level waste preparation (HLWP) activities could result in a minor fire in "A" cell of the 325-A Building. Slow leaks of the organic solvent (30% tributylphosphate (TBP) in saturated hydrocarbons) could accumulate

in depressions in the sloped stainless steel floor. Assuming the puddle to be 30 cm in diameter with a maximum depth of 6.5 mm (a nominal uniform depth of 3.3 mm), as much as 160 cm^3 of hydrocarbons could be present,[8] with as much as 5000 Btu released by the reaction. At steady state, saturated hydrocarbons such as kerosene burn at the rate of 6 to 8 inches (15 to 20 cm) per hour from a standing pool[8] and the 6.5 mm maximum depth of liquid would be consumed in 2 to 3 minutes. The total burning time was estimated to be 10 minutes to account for the slower burning rates at the beginning and end of the fire. The nominal ventilation flow is 1000 cfm (0.5 m^3/s) and absorption of 500 Btu/min would raise the air temperature by approximately 70°F (20°C). Experimental data indicate that all the iodine and approximately 1% of the nonvolatile fission products (FPs) and actinides in the burning solvent could become airborne.[9] Using the HSP stream (see footnote (a), Appendix Table A.2) as the hydrocarbon source, 2.4 x 10^{-8} Ci of ^{129}I and 1.3 x 10^{-2} Ci of actinides would be released to the cell ventilation. Assuming a 3 x 10^{-7} transmission factor for particulates through the HEPA filters, 3.9 nCi of actinides would be released to the environment. No cleanup factor was postulated for the iodine release, therefore 24 nCi of ^{129}I would be released to the environment If this accident were actually to happen (occurrence probability of 1), the resulting dose potentials would be those shown in Table 2.

TABLE 2. Dose Potentials from a Small Solvent Fire

	Inhalation Doses (Actinides and Iodine)			
	Dose to Maximum Individual at 2000 Meters (rem)		50-Year Dose Commitment to Population Within 50 Miles (80 km) (man-rem)	
Organ of Reference	1-Year Dose	50-Year Dose	1977 Population	1985 Population
Whole Body	5.1E-11[a]	1.3E-9	4.6E-8	4.8E-8
Bone	9.3E-10	2.7E-8	9.9E-7	1.0E-6
Lung	2.7E-9	6.4E-9	2.3E-7	2.4E-7
Thyroid	1.1E-8	1.3E-8	4.7E-7	4.9E-7
GI Tract[b]	1.1E-12	1.2E-12	4.2E-11	4.4E-11

(a) 5.1E-11 = 5.1 x 10^{-11}
(b) GI Tract = gastrointestinal tract

A previous study[4] derived statistics (based on fire data from the chemical industry and applied to fuel fabrication plants) that indicate a probability of $<10^{-2}$/year for localized fires as described in this scenario. Administrative controls of combustible materials in work areas will make this probability estimate conservative for the 325-A facility.

2.2 Small In-Cell Trash Fire

In the 325-A Building hot cells, combustible trash (rags, plastic, small tools and equipment, etc.) will be stored in sheet metal cans 10 inches (25.4 cm) in diameter by 10 1/2 inches (26.7 cm) tall. A thin polyethylene bag will be used as a can-liner to retard the attack of dilute nitric acid solution from rags used to wipe down the cell. Rags could also be used to soak up organic solvent puddles on the floor. Up to 10 cans of trash could accumulate before being removed from the cell. Organic- or acid-soaked rags in containers with poor heat conduction (due to use of a plastic liner) could ignite spontaneously. Rags and plastic would probably smolder in closed containers, but for the purposes of the calculation, we assumed that a container full of rags would burn in 20 minutes. The containers are designed to hold 10 pounds (4.5 kg) of lard and would probably hold less weight in loose rags (5 lb or 2.3 kg). The combustion heat of rags is approximately 7000 Btu/lb. Thus, up to 35,000 Btu could be released. We assumed further that 500 cm^3 of HSP had been wiped from the floor, providing an additional 16,000 Btu for a total release of 2550 Btu/min. Such an input could raise the air temperature 300°F (150°C) and release up to 7.5×10^{-8} Ci of ^{129}I and 4.0×10^{-2} Ci of actinides to the cell ventilation. Applying a 3×10^{-7} transmission factor for particulates through the HEPA filters yielded an environmental release of 12 nCi of actinides. With no cleanup of the iodine release, 75 nCi of ^{129}I would be released to the environment. The resulting dose potentials are shown in Table 3.

As discussed in connection with the previous accident scenario (see above), a probability of $<10^{-2}$/year is conservatively indicated for this fire-related accident.[4]

TABLE 3. Dose Potentials from a Small In-Cell Trash Fire

Organ of Reference	Inhalation Doses (Actinides and Iodine) Dose to Maximum Individual at 2000 Meters (rem) 1-Year Dose	50-Year Dose	50-Year Dose Commitment to Population Within 50 Miles (80 km) (man-rem) 1977 Population	1985 Population
Whole Body	1.6E-10[a]	3.7E-9	1.3E-7	1.4E-7
Bone	2.7E-9	8.1E-8	3.0E-6	3.1E-6
Lung	8.1E-9	1.9E-8	7.1E-7	7.4E-7
Thyroid	3.4E-8	4.2E-8	1.5E-6	1.6E-6
GI Tract[b]	3.4E-12	3.4E-12	1.3E-10	1.3E-10

(a) 1.6E-10 = 1.6×10^{-10}
(b) GI Tract = gastrointestinal tract

2.3 Ventilation System Failure

The ventilation and HEPA filter system is the basis for maintaining control of airborne radioactivity. Ventilation failures within the 324 or 325-A Buildings could lead to an airborne release of radionuclides within the facility or to the environment. Since all potentially contaminated exhausts must pass through a minimum of two HEPA filter stages before release to the environment, failure of any one filter would not be expected to cause a significant external release of radioactive materials.

The postulated ventilation system failure accident involves the complete loss of building ventilation and is based on extremely conservative assumptions. Even if no remedial actions were instituted, the consequences described below represent a "worst case" for this type of accident. In a real accident, a number of factors would tend to mitigate the consequences. One factor is the stack effect in the 324 and (to some extent) the 325-A Buildings, which tends to maintain ventilation flow. Also relevant is the fact that the hot cells are relatively airtight except for ventilation inlets and exhausts. Consequently, any loss of forced ventilation would tend to leave the cell environment in a static condition so that any diffusion out of the cells and into work areas would be very slow. In addition, if ventilation failure is based on complete loss of electrical power to the facility, a portable generator may be brought

in and connected to building emergency power busses. Previous experience at Hanford 300 Area facilities indicates that this emergency electrical hookup could be accomplished within 1/2 to 2 hr of a complete building electrical outage.

A ventilation system failure involving the loss of negative pressure within the hot cells, relative to the surrounding room, might allow some airborne radionuclides to back diffuse through a leaking cell intake filter or manipulator boot. The maximum release potential occurs in the dissolving cycle in the 324 Building, where up to 100 kg of fuel may be dissolved at one time. The cycle duration is 8 hr, but most of the volatile fission products released are assumed to be driven off within the first few hours (90% within 4 hr). We assumed conservatively that 100% of the ^{85}Kr (1060 Ci) and 10% of the ^{3}H (6.7 Ci) were released. Because this material would gradually diffuse to the outside, it can be considered a ground level release to the environment. The dose potentials resulting from this release (assumed to occur over a few hours) are shown in Table 4.

TABLE 4. Dose Potentials from a Ventilation System Failure

Inhalation Doses (Tritium)

Organ of Reference	Dose to Maximum Individual at 2000 Meters (rem) 1-Year and 50-Year Dose	50-Year Dose Commitment to Population Within 50 Miles (80 km) (man-rem) 1977 Population	1985 Population
Whole Body, Lung, Thyroid and GI Tract[a]	8.9E-5[b]	3.2E-3	3.4E-3
Bone	0	0	0

External Doses (^{85}Kr)

Organ of Reference	Dose to Maximum Individual at 2000 Meters (rem)	Dose to Population Within 50 Miles (80 km) (man-rem) 1977 Population	1985 Population
Whole Body	3.0E-5	7.1E-3	7.5E-3
Skin	1.2E-2	--	--

(a) GI Tract = gastrointestinal tract
(b) 8.9E-5 = 8.9×10^{-5}

The probability of this accident occurring includes the expected frequency of three independent belt-driven fans failing on the same day (5×10^{-7}/yr)[4] and the simultaneous failure of both primary and emergency electrical power systems (1×10^{-4}/yr).[10] Complete electrical failure is the dominant probability term for complete ventilation failure, therefore a release to the operating areas by this means would be expected to have a failure frequency of approximately 10^{-4}/yr.

2.4 Fuel-Cask Accident

Department of Transportation-(DOT-) approved casks will be used to ship spent fuel elements to the 324 Building. While the casks remain sealed there are no credible accidents that could cause the release of radioactive materials. The casks will be unloaded in the air lock of the 324 Building radiochemical engineering cells. The operations involved include loading each cask on a small dolly and transferring it into the air lock, removing the cask's lid, and transferring the fuel elements by jib crane from the cask to metal thimbles for storage and handling.

The operation with the greatest potential for radionuclide release is the transfer of a fuel element by jib hoist from cask to thimble. For this analysis we assumed that a pressurized water reactor (PWR) fuel assembly containing 450 kg of uranium as UO_2 was broken in half while being unloaded, through the incorrect operation or mechanical failure of the jib hoist. If this assembly were sheared while being lifted out of the cask it would be approximately 17 ft (5 m) above the air lock floor. It is highly unlikely that the jib hoist's horizontal motion would be able to shear either a boiling water reactor (BWR) or PWR element, or that the sheared tubes of an element would be able to release more than a few pellets. However, for this analysis we used the highly conservative assumption that the majority of fuel pellets were released and fell the 17 ft (5 m) to the concrete floor of the air lock. We further postulated that a maximum of 1% of the solid material composing the fuel pellets was converted into powder by this action.

Experimental evidence indicates that a maximum of 0.5% of a source of finely divided plutonium dioxide powder becomes airborne at airflows less than 100 cm/sec.[4] Therefore, a maximum of 0.005% (22.5 g) of the solid radioactive material in a fuel element was assumed to become airborne and to challenge

the final two banks of HEPA filters prior to release to the environment. Assuming a 3×10^{-7} transmission factor for particulates through these filter banks, 6.75×10^{-6} g (15.8 μCi) of mixed fission and fuel products would be released to the environment in particulate form. In addition, we assumed conservatively that all of the krypton-85 (4800 Ci) and 10% of the tritium (30 Ci) and iodine-129 (1.7×10^{-2} Ci) were released at the same time. No cleanup factors were postulated for these three isotopes. The resulting dose potentials are shown in Table 5.

Table 5. Dose Potentials from a Cask Accident

Inhalation Doses (Fission and Fuel Products)

Organ of Reference	Dose to Maximum Individual at 2000 Meters (rem) 1-Year and 50-Year Dose		50-Year Dose Commitment to Population Withing 50 Miles (80 km) (man-rem) 1977 Population	1985 Population
Whole Body	1.0E-4[a]	1.0E-4	3.1E-3	3.3E-3
Bone	1.6E-7	1.6E-6	4.9E-5	5.2E-5
Lung	1.2E-4	1.2E-4	3.7E-3	3.8E-3
Thyroid	2.0E-3	2.4E-3	7.1E-2	7.5E-2
GI Tract[b]	1.0E-4	1.0E-4	3.1E-3	3.3E-3

External Doses (Fission and Fuel Products)

Organ of Reference	Dose to Maximum Individual at 2000 Meters (rem)	Dose to Population Within 50 Miles (80 km) (man-rem) 1977 Population	1985 Population
Whole Body	7.8E-5	4.5E-3	4.6E-3
Skin	1.4E-2	--	--

(a) 1.0E-4 = 1.0×10^{-4}
(b) GI Tract = gastrointestinal tract

An occurrence probability of 2×10^{-6} per year was established for this accident based on the recurrence rate of these activities and on data for industrial equipment failure.[10]

2.5 Transportation Accident

Radioactive materials will be transported both to and from the 324 and 325-A Buildings. Materials shipped to the plant will consist of spent PWR and

BWR fuel elements that have been cooled for about 1 yr. Shipments from the facility to the 200 Area contractor will consist of intermediate and low level liquid waste, uranyl nitrate solution, PuO_2 product, and leached hulls. According to present plans, all shipments will be made by truck.

All offsite shipments of radioactive materials are subject to the stringent regulations and requirements of NRC and DOT. These regulations specify that shipping packages shall be designed to withstand both specified normal conditions of transport and hypothetical accident conditions without loss of contents, without significant loss of shielding, and (in the case of fissile materials) without occurrence of a criticality. The accident-damage test series that each shipping container must withstand is as follows:[11]

1. a 30-ft (9-m) drop onto an essentially unyielding surface in the most damaging orientation, followed by
2. a puncture test, consisting of a drop from a height of 40 in. (100 cm) onto a 6-in. (15-cm) diameter steel rod that strikes the container in its most vulnerable spot, followed by
3. a 1/2-hr fire test at 1475°F (800°C), followed by
4. submersion in water to a depth of at least 3 ft (0.9 m) for at least 8 hr (for fissile material only).

Based on regulatory standards and requirements for package design and quality assurance and on the results of these tests and past experience, DOT-approved packages are designed to withstand all but extremely severe, highly unlikely accidents.

A study by the former Atomic Energy Commission (AEC) discussed occurrence frequencies for public motor carrier truck accidents of varying degrees of severity, ranging from minor to extreme.[12] These frequencies range from 1.3×10^{-6} accident per vehicle-mile (1 accident per 770,000 miles or 1.2×10^{6} km) for minor accidents, to 2×10^{-14} accident per vehicle-mile (1 accident per 50 trillion miles or 8×10^{13} km) for extremely severe accidents. The CNWVP is expected to receive 30 shipments of spent fuel per year in DOT-approved containers that have been transported an average distance of 2000 miles (3200 km). Using the above noted frequencies, these expected

figures correspond to 60,000 vehicle-miles of offsite transport, with occurrence probabilities of 8×10^{-2} accident per year (1 accident in 12.5 years) for minor accidents, and 1.2×10^{-9} accident per year (1 accident in 833 million years) for extremely severe accidents.

Transportation in DOT-approved shipping containers is not required for onsite shipments; however, they will be escorted and will travel at low rates of speed (less than 30 mph or 48 km/hr). These precautions should compensate for the use of non-DOT approved containers onsite, and may even reduce by orders of magnitude the probability of serious accidents. In addition, statistics from offsite motor carrier accidents have been applied to onsite shipments (for which statistically significant data are not available), and lead to highly conservative probabilities of accident occurrence.[a]

Approximately 122 onsite shipments of uranyl-nitrate are expected per year in connection with CNWVP, each with an average shipping distance of 35 miles (56 km).[a] Using the above offsite frequency data, the accident probabilities for the resultant 4270 vehicle-miles are 5.6×10^{-3} per year (1 accident in 180 years) for minor accidents and 8.5×10^{-11} per year (1 accident in 12 billion years) for extremely severe accidents. Dry waste, leached hulls and low activity materials will also be shipped onsite for waste disposal. These solid radioactive materials are of low specific activity and are nondispersible, so that even their complete release would not represent a significant environmental hazard. Therefore, the probabilities of occurrence are not presented.

2.6 Pipe/Tank Leak

All process tanks and piping used in CNWVP (both within and between the 324 and 325-A Buildings) will have at least two barriers to prevent the escape of radionuclides to the environment. The space between the primary and secondary barriers will be monitored (either visually or with instruments) to assure that any leak in the primary containment is detected immediately. Corrective action will then be taken to preclude the possibility of an environmental release.

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[a] J. M. Taylor and F. A. Simonen, Safety Analysis for Transportation of Radioactive Materials Associated with the Commercial Nuclear Waste Vitrification Project. Battelle, Pacific Northwest Laboratories, Richland, WA 99352, October 1977.

CLASS 3 - MAXIMUM CREDIBLE

Postulated accidents listed in Class 3 (See Table 1, p. 4) are characterized as having the potential for "greater environmental releases." These accidents are generally defined in this discussion as scenarios resulting in significant offsite radiation doses, or those arising from "design basis" or "maximum credible" accident considerations.

3.1 Design Basis Fire

The "A" Cell in the 325-A Building contains all of the organic solvent in use in the separation process. We postulated that rags soaked with organic solvent and kept in a sheet metal trash container were ignited by spontaneous combustion. We assumed that the container was under one of three organic continuous columns (HA, HS1, and HS2) in the CNWVP conceptual design flowsheet,[a] and that the heat and flames caused failure of connections. The organic solvent was then ejected, with some striking the floor-level exhaust outlet filter. The impact of sufficient organic solvent on the filter would cause failure by the "blow torch" effect and ignite trace quantities of organic material on the surface of the exhaust ducts. The burning of the organic material would transmit heat down the duct, raising the concentration of organic vapor on the surface of the duct.

Most of the 25 ℓ of solvent present in the three columns and two organic headpots would be lost to the drain and unavailable for combustion. We assumed that 10% would cover various surfaces in the cell and fall into the burning trash. Combustion was assumed to be incomplete, providing additional fuel at the HEPA filter banks approximately 20 ft (6 m) from the A-cell. Flame propagation along the exhaust duct surfaces would cause loss of both of these HEPA filter banks. Under the assumptions stated for small solvent fires (Class 2.1 accidents: release of 100% of the iodine and 1% of all other materials), combustion of 2.5 ℓ HSP organic waste (Appendix Table A.2) could release as much as 380 nCi of ^{129}I and 0.2 Ci of actinides to the exhaust ducts.

Current Hanford Engineering Development Laboratory (HEDL) plans call for the installation of a final stage of HEPA filters in the exhaust system just

(a) Conceptual Design Report - Commercial Nuclear Waste Vitrification Program. Battelle, Pacific Northwest Laboratories, Richland, WA 99352, December 1976.

before it reaches the stack. This filter improvement project is scheduled for installation prior to startup of CNWVP. Consequently, all exhaust streams leaving the hot cell area will pass through at least one intact stage of HEPA filters. Assuming a 5×10^{-4} transmission factor for particulates, 1×10^{-4} Ci of actinides would be released to the environment. With no cleanup postulated for the iodine, 380 nCi would be released to the environment. The resulting dose potentials are shown in Table 6.

TABLE 6. Dose Potentials from a Design Basis Fire

	Inhalation Doses (Fission and Fuel Products)			
	Dose to Maximum Individual at 2000 Meters (rem)		50-Year Dose Commitment to Population Within 50 Miles (80 km) (man-rem)	
Organ of Reference	1-Year Dose	50-Year Dose	1977 Population	1985 Population
Whole Body	9.8E-7[a]	3.2E-5	1.2E-3	1.2E-3
Bone	2.3E-5	6.9E-4	2.5E-2	2.6E-2
Lung	6.6E-5	1.6E-4	5.8E-3	6.1E-3
Thyroid	1.8E-7	2.1E-7	7.6E-6	8.0E-6
GI Tract[b]	1.6E-8	1.7E-8	6.3E-7	6.6E-7

(a) 9.8E-7 = 9.8×10^{-7}
(b) GI Tract = gastrointestinal tract

In-cell fire protection will consist of manipulator-controlled fire nozzles dispensing a dry chemical fire-fighting agent. In-cell heads for water fog spray will also be installed and will be controlled by manually operated valves outside the cells, and automatic alarm fire detectors will be placed in each cell. The proper operation and utilization of these fire protection devices should eliminate the type of fire presented in this scenario. However, for conservatism we postulated that these systems did not operate properly through either equipment or human failure.

Fire data derived from statistics of the chemical industry show that 25 major fires occurred in the years 1966-70.[4] Assuming that the population from which this statistic was derived is the total number of plants listed under Chemical Industry (SIC #28: given in the 1967 industrial census as

11,799),[13] the resulting probability for major fires per plant is 4×10^{-4} per year. Recognizing the difference in industry characteristics, we assumed a lower range value of 2×10^{-4}.[4] This value is very conservative since it assumes that the in-cell fire fighting systems do not function.

3.2 Design Basis Explosion

Two conditions in waste preparation activities could potentially result in explosive reactions: 1) ignition of finely divided airborne droplets of organic solvents, or 2) runaway oxidation of ion exchange resins by nitric acid. Almost any material that oxidizes can explode given certain conditions. Those conditions for organic solvents are that the droplets be in the form of a fine mist, distributed widely in the cell, and surrounded by a high strength ignition source without a flame. Such conditions are not likely to occur in the proposed HLWP process.

Both anion[14] and cation[15] exchange resins have been involved in explosive reactions. Anion exchange columns will be used for plutonium separation in "A" cell and plutonium purification in a glovebox in Room 604 of the 325-A Building. The column construction and capacities are similar in both locations. The structural strength of the glovebox is less than that of "A" cell, therefore we considered the potential consequences of an explosion in the plutonium purification column.

Anion exchange resins have been involved in explosions under a variety of conditions.[14] The incidents in nuclear systems have predominantly involved plutonium, high nitric acid concentrations, elevated temperatures, and some indications of drying or oxidation of the resin. In one instance, however, an explosive reaction appears to have occurred at a nominal 2N HNO_3 concentration at room temperature.

We postulated that the plutonium purification column in the glovebox in Room 604 exploded during the loading step. The ion exchange No. 2 (IX2) column is a 4 1/2-inch (11-cm) inner diameter, schedule-10 stainless steel pipe 50 inches (130 cm) long. The resin column is approximately 37 inches (94 cm) long and contains approximately 8 ℓ of resin. The column is jacketed with 5-inch (13-cm) schedule-10 stainless steel pipe to provide temperature

control. The IX2 feed solution contains approximately 5 g of Pu/ℓ in 7.5N HNO_3. The glovebox contains an additional anion exchange column (trailing column) to contain possible plutonium breakthrough from the primary column (when the resin is exhausted).

The explosion was assumed to destroy the glovebox window and exhaust filter and spray hot liquid and resin 10 feet (3 m) into the room.[14] The nominal air velocity from room ventilation in Room 604 is less than 0.15 fps (4.6 cm/s), and an airborne droplet concentration of 10 mg/m^3 can be transported at these velocities due to the intimate mixture of air and water.[16] Assuming that one half of a sphere 10 feet (3 m) in diameter was filled with feed solution droplets that could be transported by the ventilation airflows, up to 0.5 mg of plutonium would be released to the room exhaust system from this source.

Liquid droplets can also be released within the glovebox, and air flows are normally accelerated with loss of integrity (valves at a glovebox exhaust are normally set to maintain a predetermined pressure differential between the glovebox and room atmosphere). If the droplet mass concentration that can be supported by the ventilation flow is equivalent to that of a heavy rain, as much as 100 mg of solution/m^3 could be airborne in the glovebox[16] and 2.6 g of plutonium would be released to the glovebox exhaust system.

The only combustible materials involved in HLWP will be the rubber gloves on the box itself and the resin. Some combustible contaminated waste and uncontaminated materials may be present during operations. Room 604 is equipped with normal fire protection devices (fusible-link water nozzles) and fires are therefore not expected to add significantly to the radiological burden.

Assuming that all the airborne plutonium will pass through two stages of HEPA filters prior to release to the environment, a transmission factor of 3×10^{-7} can be used. Consequently, 7.8×10^{-7} g of plutonium (9.17 μCi) would be released to the environment. The resulting dose potentials are shown in Table 7.

TABLE 7. Dose Potentials from a Design Basis Explosion

Organ of Reference	Inhalation Doses (Plutonium) Dose to Maximum Individual at 2000 Meters (rem) 1-Year Dose	50-Year Dose	50-Year Dose Commitment to Population Within 50 Miles (80 km) (man-rem) 1977 Population	1985 Population
Whole Body	9.1E-8[a]	2.7E-6	9.9E-5	1.0E-4
Bone	2.2E-6	6.2E-5	2.2E-3	2.3E-3
Lung	6.2E-6	1.5E-5	5.4E-4	5.6E-4
Thyroid	0	0	0	0
GI Tract[b]	1.5E-9	1.6E-9	5.8E-8	6.1E-8

(a) 9.1E-8 = 9.1×10^{-8}
(b) GI Tract = gastrointestinal tract

An occurrence probability of about 10^{-3} per year was established for this accident based on a previous study of nuclear facilities and industrial equipment failure data.[4]

3.3 Design Basis Criticality

All processes and equipment in CNWVP that may contain more than 45% of a minimum critical mass (MCM) of fissile material will be designed and fabricated to meet the Two Contingency Policy. This policy states that at least two unlikely and independent limits must be violated (i.e., errors or accidents must occur) simultaneously before criticality is possible. Violation of a limit constitutes an "error" under the Two Contingency Policy; however, if only a single limit is broken, a criticality accident cannot occur. Almost all of the process vessels that will be used for CNWVP will be critically safe by virtue of their geometry. Consequently, a criticality in these vessels would be impossible under all conditions. In all other vessels, multiple failures would be necessary to achieve a critical configuration.

Even though a criticality accident of any kind is unlikely, the effects of one should be evaluated because the possibility for such an accident does exist. A criticality accident would probably change the composition of the critical assembly, reducing it to a subcritical state, but would probably not

physically destroy the equipment unless the fissile material were contained in a sealed vessel. Containment of the criticality within the hot cells would limit the radiation dose to building personnel.

We postulated a criticality event with multiple excursions involving 4×10^{19} fissions extending over a 24-hour interval.[4,17] Different atmospheric dilution factors were assumed for selected time intervals following the onset of the release. The number of fissions occurring within each time interval was determined to be as follows: during the first half hour, three 1/2-second bursts of 10^{18} fissions each would occur, followed by 1.8×10^{19} fissions in 1/2-second bursts every 10 minutes for the next 7.5 hours and 1.9×10^{19} fissions in 1/2-second bursts every 10 minutes for the balance of a 24-hour interval.

We used a fission product buildup and decay computer program, RIBD,[18] to compute the quantities of noble gases and iodines resulting from 10^{18} fissions occurring over a 1/2-sec interval (32 MW-sec). We then scaled the results of these calculations to yield the quantities of noble gases and iodines released to the atmosphere for each of the time periods.

Most of the nuclides would reach a maximum concentration within the first day after the burst. For each period we assumed that 25% of the maximum iodines formed and 100% of the maximum noble gases formed were released to the environs, regardless of the decay time at which these concentrations were reached (within the first day).[19] We then scaled the release to the number of fissions occurring within each time interval.

Source terms for calculating the population doses were derived by summing the quantities released for the three time intervals. The resulting inventories are listed in Appendix Table A-3. The radioactive source terms presented in this table were used to derive the dose potentials shown in Table 8.

Estimates of the probability of a criticality accident have often been based on the total number of all inadvertent criticalities divided by the total plant-years of operation in the nuclear field. These numbers include many criticality accidents associated with approach to critical experiments conducted during the early days of weapons design and are not at all relevant to today's commercial nuclear industry. Consequently, such numbers were not used in this analysis.

TABLE 8. Dose Potentials from a Design Basis Criticality

Inhalation Doses (Fission Products)

Organ of Reference	Dose to Maximum Individual at 2000 Meters (rem) 1-Year and 50-Year Dose	50-Year Dose Commitment to Population Within 50 Miles (80 km) (man-rem) 1977 Population	1985 Population
Whole Body	1.2E-2[a]	2.7	2.8
Bone	8.3E-2	19	20
Lung	1.3E-1	29	30
Thyroid	1.2	280	300
GI Tract[b]	3.2E-2	7.5	7.8

External Doses (Fission Products)

Organ of Reference	Dose to Maximum Individual at 2000 Meters (rem)	Dose to Population Within 50 Miles (80 km) (man-rem) 1977 Population	1985 Population
Whole Body	3.0E-1	17	18
Skin	7.8E-1	--	--

(a) 1.2E-2 = 1.2×10^{-2}
(b) GI Tract = gastrointestinal tract

An upper limit estimate of the probability of a criticality accident in CNWVP facilities may be calculated by examining the number and types of equipment failures and human errors necessary for such an occurrence. Most of the tanks and process vessels used in CNWVP will be critically safe because of their geometry. The other tanks in this process will be protected against criticality by control of the concentrations of fissile material in the streams emptying into the tanks. For these latter cases, at least three separate equipment failures or operator errors would be necessary to transfer enough fissile material for one of the tanks to become critical. The most probable sequence of events would lead to a transfer of plutonium product solution from the IX1 column through the rework tank and into intermediate level waste (ILW) storage tank No. 1. This sequence of events would require at least two equipment failures (1.5/plant/yr for each)[4] and one operator error (1.1/plant/yr),[4] all occurring within the same 8-hour period. The resultant frequency of each equipment failure would be 1.4×10^{-3} per 1/3 plant-day; the frequency of an operator error would be 1.0×10^{-3} per 1/3 plant-day. Consequently, the cumulative probability of this accident would be less than 1.9×10^{-9} per 1/3 plant-day or

2×10^{-6}/plant-year. If other pathways are included, the total probability would be less than 5×10^{-6}/year (1 accident in 200 thousand plant-years).

3.4 Design Basis Flood

Flooding of CNWVP facilities by natural causes is extremely improbable, as shown by the following data. The basement of the 325-A building is at 387.5 ft (118 m) above median sea level, and the first floor is at 402 ft (123 m). The 324 Building's basement is at 391 ft (119 m) with the first floor at 401 ft (122 m). The estimated 100-yr flood level is 356 $\pm$2 ft (109 $\pm$0.6 m) and the probable maximum flood level is 382 $\pm$4 ft (116 $\pm$1.2 m) as estimated from Corps of Engineers data.[20] The maximum short-term rainfalls that have been recorded at Hanford are as follows:

0.55 inches (1.4 cm) in 20 minutes
1.68 inches (4.3 cm) in 6 hours
1.91 inches (4.9 cm) in 24 hours

The maximum statistically predicted rainfall is as follows:

Return Time, years	Rainfall, inches/24 hr; cm/24 hr	
100	1.99	5.05
500	2.47	6.27
1000	2.68	6.81

Neither building has external openings through which rain can enter, and the main floors of both buildings are above ground level. Thus, entry of rainfall to the extent that any accident conditions would occur appears impossible.

3.5 Design Basis Earthquake

Both the 324 and 325-A Buildings were designed and built in compliance with provisions of the Uniform Building Code's seismic design requirements, which designate Hanford as Zone II. The shielded cells in which processing activities will occur were designed for a uniform lateral loading of 0.125 g, which corresponds to a Modified-Mercalli intensity of VII. This also corresponds to the ground acceleration specified in the Hanford Standard Architectural Civil Design Criteria, SDC-4.1, for the Operating Basis Earthquake (OBE).[21] This is the maximum expected earthquake for the Hanford area. However, the

latest design standards specify that Class I facilities should be constructed to withstand a 0.25-g earthquake[21] (twice the maximum expected value). The integrity of the 324 and 325-A Buildings would probably be breached by a 0.25-g earthquake, but the hot cells, containing most of the radioactive materials, should remain intact. Consequently, no significant environmental releases are expected to be caused by earthquakes over the term of this project.

3.6 Windstorm

Hanford is not an area of possible hurricane activity. Tornado funnels have been observed locally twice in the past 18 years and neither time was damage reported. Hanford buildings generally are designed to withstand a wind load equivalent to 88-mph (140-km/hr) winds with an estimated safety factor between 2 and 3.[6] An all-time peak gust of approximately 80 mph (130 km/hr) was recorded on January 11, 1972.[20,22]

The 324 and 325-A Buildings are not structurally designed to withstand the effects of the Hanford Standard tornado.[21] Consequently, the building shells would probably be breached by the direct impact of even a moderate tornado. However, the hot cells containing most of the process equipment in both buildings are constructed of such thick concrete for shielding purposes that even a Hanford Standard tornado should not breach their integrity.[a] Therefore, no significant releases of radioactive material are expected from a Hanford Standard tornado.

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[a] Conceptual Design Report - Commercial Nuclear Waste Vitrification Program. Battelle, Pacific Northwest Laboratories, Richland, WA 99352, December 1976.

CONCLUSION: CONSIDERATION OF CNWVP ACCIDENT ENVIRONMENTAL RISK

To evaluate the overall environmental risk represented by accident conditions, both the consequences of an accident and its likelihood (probability of occurrence) must be considered. To keep environmental risk low, any accident with severe consequences should have a very remote chance of occurring, because of facility design or engineered safeguards. Conversely, any accident calculated to have a high occurrence probability must have insignificant consequences or the requirement for additional design or procedural controls. Our analysis of each of the credible accidents for CNWVP demonstrates that the maximum consequences would be whole-body doses of 0.3 rem (50-yr dose commitment) to an individual and 20 man-rem (50-yr dose commitment) to the surrounding population (Section 3.3, Design Basis Criticality).

A further perspective on the two variables of consequence and occurrence probability is gained by formation of a risk index, which is the product of consequence (in this case, dose) and probability. Risk indexes for the postulated CNWVP accidents are given in Table 9 for both the maximum individual and the surrounding population.

A summation of all the risk indices has been defined by previous research (for NRC)[4] as the total imposed environmental risk from accident conditions at the facility. No regulatory guidance is currently available on the absolute risk acceptable from fuel reprocessing plant accidents; however, the CNWVP-imposed accident risk index for the maximum individual (1.6×10^{-6} rem/yr to the whole body) is much less than NRC limits for routine release risks from nuclear power reactors (5×10^{-3} rem/yr[3] with a probability of 1), which indicates that accident conditions from CNWVP represent a very low environmental hazard. These accident risks may also be compared to the estimated annual environmental doses due to routine operation of CNWVP (maximum individual whole-body exposure of 3×10^{-5} rem/yr).[a] In addition, the total imposed lung risk is less than 5×10^{-6} of the risk caused by natural background dose to the lung (1.5×10^{-1} rem/yr[2] with a probability of 1) and the maximum individual's

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(a) B. V. Andersen, E. E. Oscarson, H. H. VanTuyl, E. C. Watson and E. J. Wheelwright, Commercial Nuclear Waste Preparation Task - Environmental Assessment. Battelle, Pacific Northwest Laboratories, Richland, WA 99352, August 10, 1976.

TABLE 9. Annual Environmental Risk from Postulated CNWVP Accidents

Accident	Source Term (Ci)	Contaminant	Maximum Individual Critical Organ	Maximum Individual 1-Year Dose(rem)	50-Year Population Critical Organ	50-Year Population Dose ÷ 50[a] (man-rem)	Release Probability (year^{-1})	Relative Annual Risk Individual (rem-year)	Relative Annual Risk Population (man-rem/year)
Class 2									
Small Solvent Fire	3.9E-9[b]	Actinides	Lung	2.7E-9	Bone	2.0E-8	$<10^{-2}$	2.7E-11	2.0E-10
	2.4E-8	Iodine-129	Thyroid	1.1E-8	Thyroid	4.7E-7	$<10^{-2}$	1.1E-10	4.7E-9
Small In-Cell Trash Fire	1.2E-8	Actinides	Lung	8.1E-9	Bone	6.0E-8	$<10^{-2}$	8.1E-11	6.0E-10
	7.5E-8	Iodine-129	Thyroid	3.4E-8	Thyroid	1.5E-6	$<10^{-2}$	3.4E-10	1.5E-8
Ventilation System Failure	1.06E+3	Krypton-85	Skin	1.2E-2	Whole Body	7.1E-3	10^{-4}	1.2E-6	7.1E-7
	6.7	Tritium	Whole Body	8.9E-5	Whole Body	3.2E-3	10^{-4}	8.9E-9	3.2E-7
Fuel-Cask Accident	1.6E-5	Fission & Fuel	Whole Body	1.0E-4	Whole Body	3.1E-3	2.0E-6	2.0E-10	6.2E-9
	3.0E+1	Tritium	Lung	1.2E-4	Lung	3.7E-3	2.0E-6	2.4E-10	7.4E-9
	1.7E-2	Iodine-129	Thyroid	2.0E-3	Thyroid	7.1E-2	2.0E-6	4.0E-9	1.4E-7
	4.8E+3	Krypton-85	Skin	1.4E-2	Whole Body	4.5E-3	2.0E-6	2.8E-8	9.0E-9
Class 3									
Design Basis Fire	1.0E-4	Actinides	Whole Body	9.8E-7	Whole Body	2.4E-5	2.0E-4	2.0E-10	4.8E-9
	3.8E-7	Iodine-129	Bone	2.3E-5	Bone	5.0E-4	2.0E-4	4.6E-9	1.0E-7
			Lung	6.6E-5	Lung	1.2E-4	2.0E-4	1.3E-8	2.4E-8
			Thyroid	1.8E-7	Thyroid	7.6E-6	2.0E-4	3.6E-11	1.5E-9
Design Basis Explosion	9.2E-6	Plutonium	Lung	6.2E-6	Bone	4.4E-5	$\approx 10^{-3}$	6.2E-9	4.4E-8
Design Basis Criticality	See	Fission Prod.	Whole Body	3.1E-1	Whole Body	2.0E+1	5.0E-6	1.6E-6	1.0E-4
	Table	Halogens	Bone	8.3E-2	Bone	1.9E+1	5.0E-6	4.2E-7	9.5E-5
	A.3		Lung	1.3E-1	Lung	2.9E+1	5.0E-6	6.5E-7	1.5E-4
			Thyroid	1.2	Thyroid	2.8E+2	5.0E-6	6.0E-6	1.4E-3
			Skin	7.8E-1	--	---	5.0E-6	3.9E-6	-- --
					TOTAL	Whole Body		1.6E-6	1.0E-4
						Bone		4.2E-7	9.5E-5
						Lung		6.5E-7	1.5E-4
						Thyroid		6.0E-6	1.4E-3
						Skin		3.9E-6	--

(a) One-year population doses from tritium, iodine, and halogens are essentially equal to the 50-year population doses

(b) 3.9E-9 = 3.9 x 10^{-9}

exposure from a single accident is less than the guidance limits given in 10 CFR 100 (25 rem to the whole body, 300 rem to the thyroid) for reactor accidents of very low probability.[23]

Our conclusion, based on the calculated maximum doses and supported by the consideration of risk indexes, is that the present functional design and planned operation of CNWVP[a] represents a very low accident risk to the environment.

(a) Conceptual Design Report - Commercial Nuclear Waste Vitrification Program. Battelle, Pacific Northwest Laboratories, Richland, WA 99352, December 1976.

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APPENDIX

DOSE CALCULATIONS FOR ACCIDENTAL ATMOSPHERIC RELEASES OF RADIONUCLIDES FROM CNWVP

APPENDIX

DOSE CALCULATIONS FOR ACCIDENTAL ATMOSPHERIC RELEASES OF RADIONUCLIDES FROM CNWVP

Described below are the methods used to estimate the potential dose to people residing in the vicinity of CNWVP from postulated accidental releases of radionuclides to the atmosphere. Source terms will be described first, followed by dispersion models and dose models.

SOURCE TERMS

Two approaches were used to assess source terms for postulated accidents. The first includes all but one of the scenarios and deals exclusively with the dispersal of fuel or fission products resulting from various stages of the chemical separations process. The second is an accidental criticality that disperses volatile fission products. The derivation of source terms for these two types of accidents is described below.

For accident scenarios involving dispersal of fuel or fission products, an "inventory--release fraction--source term" approach was taken. In the analysis of each accident, the radionuclide inventory at the site of the incident was determined. The specific radionuclides in the fuel elements were calculated using the computer program ORIGEN.[1] The radionuclide activities in the fuel elements and several of the reprocessing stages are shown in Tables A.1 and A.2. The chemical and physical form of each inventory contributed to calculation of the fractional airborne releases. Other elements affecting the final release fraction included: dispersal mechanisms (fire, explosion, air movement, etc.); plate-out on solid surfaces; air velocity and direction; and filtration of the inventory prior to reaching the environment. Multiplication of the derived inventory by calculated or experimentally determined release fractions yielded the source term released to the environment.

The source term for the postulated criticality event assumes multiple excursions involving 4×10^{19} fissions extending over a 24-hr interval. Atmospheric dilution factors are defined for selected time intervals following the

TABLE A.1. Isotopic Composition of Fuel for CNWVP
(3.3% Initial Enrichment, 33,000 MWd/MTU[a] Burnup, 1-Year Cooled)

Nuclide	Inventory In Fuel (Ci/MTU)	Conc. in Dissolver (Ci/l)	Conc. in HAW[b] (Ci/l)
Fission Products			
^{3}H	6.70E+2[c]	2.5E-1	1.2E-1
^{85}Kr	1.06E+4	0	0
^{89}Sr	5.52E+3	2.3E+0	1.1E+0
^{90}Sr	7.57E+4	3.2E+1	1.4E+1
^{91}Y	1.27E+4	5.3E+0	2.4E+0
^{93}Zr	1.81E+0	7.9E-4	3.6E-4
^{93m}Nb	2.31E-1	9.6E-5	4.4E-5
^{95}Zr	2.79E+4	1.2E+1	5.5E+0
^{95m}Nb	5.93E+2	2.5E-1	4.4E-5
^{95}Zr	2.79E+4	1.2E+1	5.5E+0
^{95m}Nb	5.93E+2	2.5E-1	1.2E-1
^{95}Nb	5.94E+4	2.5E+1	1.2E+1
^{99}Tc	1.43E+1	6.0E-3	2.8E-3
^{103}Ru	2.04E+3	8.5E-1	3.9E-1
^{103m}Rh	2.04E+3	8.5E-1	3.9E-1
^{106}Ru	2.73E+5	1.1E+2	5.1E+1
^{106}Rh	2.73E+5	1.1E+2	5.1E+1
^{107}Pd	1.10E-1	4.6E-5	2.1E-5
^{110m}Ag	1.35E+3	5.6E-1	2.6E-1
^{110}Ag	1.76E+2	7.3E-2	3.4E-2
^{113m}Cd	1.00E+1	4.2E-3	1.9E-3
^{119m}Sn	5.96E+0	2.5E-3	1.1E-3
^{123}Sn	1.17E+3	4.9E-1	2.3E-1
^{124}Sb	5.97E+0	2.5E-3	1.1E-3
^{125}Sb	6.83E+3	2.8E+0	1.3E+0
^{125m}Te	2.82E+3	1.2E+0	5.4E-1
^{127m}Te	1.56E+3	6.5E-1	3.0E-1
^{127}Te	1.55E+3	6.5E-1	3.0E-1
^{129m}Te	3.36E+1	1.4E-2	6.5E-3
^{129}Te	2.16E+1	9.0E-3	4.2E-3
^{129}I	3.74E-2	1.6E-5	3.6E-6
^{134}Cs	1.76E+5	7.3E+1	3.4E+1
^{135}Cs	2.86E-1	1.2E-4	5.5E-5
^{137}Cs	1.05E+5	4.4E+1	2.0E+1
^{137m}Ba	9.85E+4	4.1E+1	1.9E+1
^{141}Ce	5.64E+2	2.4E-1	1.1E-1
^{144}Ce	4.56E+5	1.9E+2	8.8E+1

TABLE A.1. (contd)

Nuclide	Inventory In Fuel (Ci/MTU)	Conc. in Dissolver (Ci/l)	Conc. in HAW(b) (Ci/l)
Fission Products (contd)			
^{144}Pr	4.56E+5	1.9E+2	8.8E+1
^{147}Pm	8.39E+4	3.5E+1	1.6E+1
^{148m}Pm	9.36E+1	3.9E-2	1.8E-2
^{148}Pm	7.52E+0	3.1E-3	1.4E-3
^{151}Sm	1.24E+3	5.2E-1	2.4E-1
^{152}Eu	1.18E+1	4.9E-3	2.3E-3
^{153}Gd	1.25E+1	5.2E-3	2.4E-3
^{154}Eu	6.69E+3	2.8E+0	1.3E+0
^{155}Eu	5.10E+3	2.1E+0	9.8E-1
^{160}Tb	3.83E+1	1.6E-2	7.4E-3
Actinides			
^{234}Th	3.14E-1	1.3E-4	6.0E-5
^{233}Pa	3.40E-1	1.4E-4	6.5E-5
^{234m}Pa	3.14E-1	1.3E-4	6.5E-5
^{237}Np	3.40E-1	1.4E-4	6.5E-5
^{239}Np	1.82E+1	7.6E-3	3.5E-3
^{238}Pu	2.86E+3	1.2E+0	1.6E-5
^{239}Pu	3.23E+2	1.3E-1	1.8E-6
^{240}Pu	4.77E+2	2.0E-1	2.7E-6
^{241}Pu	9.89E+4	4.1E+1	5.6E-4
^{242}Pu	1.38E+0	5.8E-4	7.9E-9
^{241}Am	2.47E+2	1.0E-1	4.5E-2
^{242m}Am	9.00E+0	3.8E-3	1.7E-3
^{242}Am	9.00E+0	3.8E-3	1.7E-3
^{243}Am	1.82E+1	7.6E-3	3.5E-3
^{242}Cm	7.02E+3	2.9E+0	1.4E+0
^{243}Cm	3.58E+0	1.5E-3	6.9E-4
^{244}Cm	2.35E+3	9.8E-1	4.5E-1
^{245}Cm	3.41E-1	1.4E-4	6.6E-5
^{234}U	7.59E-1	3.2E-4	1.3E-10
^{235}U	1.71E-2	7.1E-6	2.9E-12
^{236}U	2.88E-1	1.2E-4	5.0E-11
^{237}U	2.48E+0	1.0E-3	4.1E-10
^{238}U	3.14E-1	1.3E-4	5.4E-11

(a) MTU = metric tons of uranium
(b) HAW = high activity waste
(c) 6.70E+2 = 6.70×10^2

TABLE A.2. Isotopic Composition of Process Streams in CNWVP

Nuclide	Conc. in HSP[a] (Ci/l)	Conc. in HCP[b] (Ci/l)	Conc. in IX1W[c] (Ci/l)	Conc. in PCP[d] (Ci/l)	Activity in PuO_2 Product (Ci/g)
^{129}I	1.5E-7[e]	0	0	0	0
^{234}U	6.0E-5	1.5E-4	7.6E-5	0	0
^{235}U	1.3E-6	3.4E-6	1.7E-6	0	0
^{236}U	2.3E-5	5.6E-5	2.9E-5	0	0
^{237}U	1.9E-4	4.9E-4	2.5E-4	0	0
^{238}U	2.5E-5	6.2E-5	3.2E-5	0	0
^{238}Pu	2.2E-1	5.6E-1	2.9E-4	3.4E+1	2.9E-1
^{239}Pu	2.5E-2	6.3E-2	3.2E-5	3.8E+0	3.3E-2
^{240}Pu	3.7E-2	9.4E-2	4.8E-5	5.6E+0	4.8E-2
^{241}Pu	7.8E+0	1.9E+1	9.7E-3	1.1E+3	1.0E+1
^{242}Pu	1.1E-4	2.7E-4	1.4E-7	1.6E-2	1.4E-4

(a) HSP = solvent extraction scrub column; U and Pu effluent stream scrubbed with 2*M* HNO_3 for fission product decontamination
(b) HCP = solvent extraction column; U and Pu effluent stream extracted into aqueous phase
(c) IX1W = ion exchange, column 1, waste stream
(d) PCP = plutonium concentrate product
(e) 1.5E-7 = 1.5×10^{-7}

onset of the release. The number of fissions occurring within each time interval was determined in the following manner: during the first 1/2 hr, three 0.5-sec bursts of 10^{18} fissions each occur, followed by 1.8×10^{19} fissions in 0.5-sec bursts every 10 min for the next 7.5 hr and 1.9×10^{19} fissions in 0.5-sec bursts every 10 min for the balance of a 24-hr interval.

A fission product buildup and decay computer program, RIBD,[2] was used to compute the quantities of noble gases and iodines resulting from 10^{18} fissions occurring over a 1/2-sec interval (64 MW). The results of this calculation were then scaled to yield the quantities of noble gases and iodines released to the atmosphere for each of several time periods.

The activities of most of the noble gases and radioiodines change rapidly during the first day after fission, growing-in in some cases and decaying away in others. The quantities available for release during each period were based on the maximum activity occurring within the first day, regardless of the time at which that maximum is reached. For each period, 25% of the maximum iodines formed and 100% of the maximum noble gases formed were assumed to be released.[3] The release was then scaled to the number of fissions occurring within each time interval.

Source terms for calculating the population doses were derived by summing the quantities released for the three time intervals. The resulting inventories are listed in Table A.3.

ATMOSPHERIC DISPERSION

For the internal doses received via inhalation, the dispersion of radionuclides released to the atmosphere was based on diffusion factors taken from the graphs in Regulatory Guides 1.3 and 1.5,[4,5] with one exception. No diffusion factors are shown in the Regulatory Guides for ground level releases under fumigation conditions. These values were calculated using the following equation:[6]

$$X/Q = \frac{1}{\pi \sigma_y \sigma_z \bar{u}} \left\{ 1 + 2 \left[\exp -(2h_i)^2 / 2\sigma_z^2 \right] \right\} \qquad (1)$$

TABLE A.3. Radioactive Source Terms for Postulated Criticality Event (4×10^{19} Fissions)

Isotope	Quantity Released, Ci			
	$(\Delta\tau)_1$[a]	$(\Delta\tau)_2$	$(\Delta\tau)_3$	Total
^{83m}Kr	1.1E+1[b]	6.7E+1	7.1E+1	1.5E+2
^{85m}Kr	4.8E+1	2.9E+2	3.1E+2	6.5E+2
^{85}Kr	4.6E-4	2.8E-3	2.9E-3	6.2E-3
^{87}Kr	3.0E+2	1.8E+3	1.9E+3	4.0E+3
^{88}Kr	1.9E+2	1.2E+3	1.2E+3	2.6E+3
^{89}Kr	1.2E+4	7.4E+4	7.8E+4	1.6E+5
^{90}Kr	4.6E+4	2.8E+5	2.9E+5	6.2E+5
^{91}Kr	2.0E+5	1.2E+6	1.2E+6	2.6E+6
^{129}I	1.3E-10	7.7E-10	8.1E-10	1.6E-9
^{131}I	5.5E-1	3.3	3.5	7.3
^{132}I	2.0	1.2E+1	1.3E+1	2.5E+1
^{133}I	1.1E+1	6.3E+1	6.7E+1	1.4E+2
^{134}I	1.4E+2	8.6E+2	9.0E+2	1.8E+3
^{135}I	3.7E+1	2.2E+2	2.3E+2	4.8E+2
^{131m}Xe	1.2E-3	6.9E-3	7.3E-3	1.5E-2
^{133m}Xe	1.6E-1	9.9E-1	1.1	2.2
^{133}Xe	3.9	2.3E+1	2.5E+1	5.2E+1
^{135m}Xe	3.3E+1	2.0E+2	2.1E+2	4.4E+2
^{135}Xe	4.7E+1	2.8E+2	3.0E+2	6.3E+2
^{137}Xe	1.1E+4	6.8E+4	7.2E+4	1.5E+5
^{138}Xe	3.6E+3	2.2E+4	2.3E+4	4.8E+4
^{139}Xe	4.1E+4	2.5E+5	2.6E+5	5.5E+5
^{140}Xe	1.3E+5	7.7E+5	8.1E+5	1.7E+6

(a) $(\Delta\tau)_1$ = 0-0.5 hour after first excursion
$(\Delta\tau)_2$ = 0.5-8 hours after first excursion
$(\Delta\tau)_3$ = 8-24 hours after first excursion

(b) 1.1E+1 = 1.1×10^1

where σ_y = crosswind lateral standard deviation of cloud concentration, m

σ_z = crosswind vertical standard deviation of cloud concentration, m

$\bar{u}$ = average wind speed, m/sec ($\bar{u}$ = 1)

h_i = height of inversion, m (h_i = 30)

Values used for σ_y and σ_z are for Pasquill Type F.[6]

Fumigation conditions were assumed to exist during the first half-hour period and appropriate diffusion factors were used. The 0- to 8-hr diffusion factors were used for the second time interval for each postulated release and the 8- to 24-hr sector average diffusion factors were used for the balance of the release.

For external exposure, where dose calculations were performed for finite clouds, the point kernel integration scheme required that mathematical models describing the normalized air concentration be used, rather than diffusion factors. However, the equations used are based on procedures suggested in Regulatory Guide 1.3 and are shown below.

Release Period	Expression for χ/Q[7]	
0-0.5 hr	$\dfrac{\exp[-y^2/2\sigma_y^2]}{\sqrt{2\pi}\,\bar{u}\,h_i\sigma_y}$	(2)
0.5-8 hr	$\dfrac{\exp[-(h-z)^2/2\sigma_z^2]\ \exp[-y^2/2\sigma_y^2]}{2\pi\ \bar{u}\ \sigma_y\ \sigma_z}$	(3)
8-24 hr	$\sqrt{\dfrac{2}{\pi}}\ \dfrac{n\ \exp[-(h-z)^2/2\sigma_z^2]}{2\pi\ x\ \bar{u}\ \ \sigma_z}$	(4)

where z = vertical distance between the height of release and the point of interest, m

y = crosswind distance to the point of interest, m

x = downwind distance to the point of interest, m

$\bar{u}$ = average wind speed, m/sec

σ_y = crosswind vertical standard deviation of cloud concentration, m

σ_z = crosswind vertical standard deviation of cloud concentration, m

h_i = height of inversion, m

h = height of release, m

n = number of sectors (n = 16 for 22-1/2° sector width)

Pasquill Type F dispersion parameters were used for all releases.

Atmospheric diffusion factors for population dose estimates are based on the crosswind averaged dispersion (Equation 4). The dispersion factors are weighted by the joint frequency of occurrence of wind speed and stability in the direction of each sector. These factors are coupled with population distribution data and dose factors to give the cumulative population dose within 50 miles (80 km).

DOSE CALCULATIONS

Models used in evaluating environmental consequences of accidental releases to the atmosphere are described in References 7, 8, 9, and 10. Following is a brief discussion of some of the specifics used in this analysis.

Internal doses from inhalation of airborne radionuclides were calculated using the Task Group on Lung Dynamics' Lung Model (TGLM)[11] as implemented in the computer program DACRIN.[7] Basic radionuclide data used in calculating the organ doses (such as the effective absorbed energy, the effective half life, and the fractions of the inhaled material moving from blood to organ and GI tract to blood) were those recommended by the ICRP.[8,12,13]

TGLM calculations were carried out for a particle size of 1 μm (mass median aerodynamic diameter). The calculated depositions for the nasopharyngeal, tracheobronchial, and pulmonary regions of the respiratory tract would be 0.3, 0.08, and 0.25 of the total amount inhaled, respectively.

The ventilation rate was assumed to be 350 cm^3/sec for the first 8-hr period and 175 cm^3/sec for the balance of the day, for an average of 230 cm^3/sec. The daily average ventilation rate was used in computing the population doses. The total-body, bone, and thyroid doses were calculated assuming all material inhaled to be soluble (Class D). The lung doses assumed PuO_2 to be insoluble (Class Y).

External exposure from the airborne radionuclides was calculated for individuals using the computer program SUBDOSA[9] and for populations using a modified version of the computer program KRONIC.[10] The total-body and skin doses were determined for the individual exposure cases, with the total-body dose and genetic doses determined for the population exposure cases. The total-body dose is defined as the dose from gamma radiation at a tissue depth of 5 cm; and the skin dose is the sum of the surface gamma dose and the beta dose at a depth of 7 mg/cm^2.

The total-body dose from external exposure was calculated using a point kernel integration scheme and integrating over the active volume of the plume. Buildup and attenuation were calculated as a function of photon energy.

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