

Hickman, John

From: Sokolsky, David [DDS2@PGE.COM]
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John - Per your request

David Sokolsky
Supervisor of Licensing
Humboldt Bay Power Plant
(707)444-0801 office
(707)601-6703 cell

**HUMBOLDT BAY POWER PLANT
CALCULATION COVER SHEET**

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Prepared by:	<u>RSCS (see attached)</u>	<u>Contractor</u>	<u>6/3/09</u>
Checked by:	<u>Joe Davis</u>	<u>RP</u>	<u>6/9/09</u>
Approved by:	<u>John Albers</u> <u>for John Albers</u> <u>Per Telecom</u>	<u>RP</u>	<u>6/10/09</u>

Concurrence for Checker: N/A Signature _____ Date _____

RP CALCULATIONS

Designated RP Approver: John Albers
Print Name

RP Manager: [Signature] for John Albers per Telecom / 6/10/09
Signature Date

Engineering Manager Concurrence: [Signature] / 6/10/09
Signature Date

Registered Engineer Approval: (Complete section A for Civil calcs. Complete A or B for others)

<p>A. Insert Engineer Stamp or Seal Below</p> <p>N/A</p> <p>Expiration Date: _____</p>	<p>B. N/A</p> <p>Engineer's full name: _____</p> <p>Registration Number: _____</p> <p>Expiration Date: _____</p>
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Technical Support Document



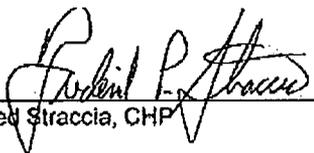
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**Humboldt Bay Power Plant Unit 3,
Radiological Consequences for Breach of
Defueled Spent Fuel Pool**

Revision 00

Originator: Harvey Farr Date: May 28, 2009

Reviewer:  Date: June 3, 2009
Eric L. Darois, CHP

Approval:  Date: June 3, 2009
Fred Straccia, CHP

Humboldt Bay Power Plant Unit 3, Radiological Consequences for Breach of Defueled Spent Fuel Pool

1.0 Introduction

This document evaluates the consequences of a heavy load drop in the spent fuel pool after the fuel has been removed. The consequences of a heavy load drop were previously evaluated for the SAFSTOR Safety Evaluation Report (Ref. 7.17, 7.18) and for the Independent Spent Fuel Storage Installation Safety Evaluation Report.(Ref. 7.19) These evaluations concluded that the only potential consequence from a heavy load drop was contamination of subsurface groundwater and subsequent release of radionuclides to Humboldt Bay. Operating procedures to prevent the movement of Heavy Loads over the Spent Fuel Pool were implemented to reduce the probability of a heavy load drop in the Spent Fuel Pool. The spent fuel has since been removed and placed in dry cask storage. This evaluation examines the radiological impact of a heavy load drop on the Spent Fuel Pool, in the defueled condition, to support determination if restrictions on the transport of heavy loads over the Spent Fuel Pool are still required.

This document calculates the current dispersible radionuclide inventory of the spent fuel pool which could be released in a heavy load drop and uses RESRAD-OFFSITE with site specific hydrogeological data to evaluate the radiological consequences of a heavy load drop in the Spent Fuel Pool.

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3.0 Background

3.1 Regulatory Requirements for Decommissioning Safety Evaluations

On July 29, 1996, a final rule amending the regulations on decommissioning procedures was published in the Federal Register (61 FR 39278). Regulatory Guide 1.184 describes methods and procedures for power reactor licensees for the decommissioning process.(Ref. 7.3) The 1996 rule extended the use of 10 CFR 50.59, "Changes, Tests, and Experiments," to allow licensees to make changes to facilities undergoing decommissioning using the process described in 10 CFR 50.59.(Ref. 7.3) The Post-Shutdown Decommissioning Activities Report (PSDAR) evaluates the environmental impacts associated with the site-specific decommissioning activities. If environmental impacts are identified that have not been considered in existing environmental assessments, the "Final Generic Environmental Impact Statement (GEIS) on Decommissioning of Nuclear Facilities" (NUREG-0586, Ref. 7.7), and the GEIS, "Generic Environmental Impact Statement in Support of Rulemaking on Radiological Criteria for License Termination of NRC Licensed Nuclear Facilities" (NUREG-1496, Ref. 7.9), the licensee must address the environmental impacts regarding the activities and must submit a supplement to the environmental report relating to the additional impacts.(Ref. 7.3, 7.4)

Regulatory Guide 1.185, "Standard Format and Content for Post-shutdown Decommissioning Activities Report" (Ref. 7.4), provides guidance on the contents of the PSDAR. The PSDAR should include a discussion of the reasons for concluding that the environmental impacts associated with site-specific decommissioning activities will be bounded by previously issued environmental impact statements. The potential environmental impacts associated with decommissioning should be compared with similar impacts given in the Final Environmental Statement (FES) for the plant (as supplemented), in the GEIS on decommissioning (NUREG-0586) (Ref. 7.7), site-specific environmental assessments, and the GEIS on radiological criteria for license termination (NUREG-1496) (Ref. 7.9). Examples of potential impacts that should be examined to ensure they are within the envelope of impacts predicted in the GEISs on decommissioning or radiological criteria for license termination, FES, or site-specific analysis include occupational dose; environmental releases to air, water, and soil and the resulting population doses; (Ref. 7.4)

Changes in decommissioning activities should be evaluated as to their potential environmental impact. If the expected impact is greater than that predicted in the GEIS or the site-specific FES, or is outside the bounds of these documents, the licensee must notify the NRC in writing and provide a supplement to the Environmental Report for the facility that evaluates the impact of the change.(Ref. 7.4)

The Final Safety Analysis Report (FSAR), or other comparable document, provides a licensing basis document for the evaluation of licensee activities under 10 CFR 50.59. This licensing basis is updated to cover decommissioning activities. According to 10 CFR 50.71(e)(4), subsequent revisions updating the licensing basis must be filed with the NRC at least every 24 months by nuclear power facilities that have submitted certifications for permanently ceasing operations and for permanent removal of fuel.(Ref. 7.3) As a minimum, the FSAR should be maintained at a level of detail that provides status of all the operating licensing-basis systems, structures and components (SSCs) until the systems are no longer mechanically or electrically active, no longer radioactively contaminated, have no fluid content or other materials that

require special handling considerations, or have been physically removed during the dismantlement process.(Ref. 7.3)

Decommissioning Facilities are typically bounded by the Generic Environmental Impact Statement (NUREG-0586).(Ref. 7.8) Volume 1, Supplement 1 of NUREG 0586 states, "*This document can be considered a stand-alone document for power reactor facilities such that readers should not need to refer back to the 1988 GEIS.*"(Ref. 7.8) Section 4.3.9 Radiological Accidents reiterates the applicable regulations pertaining to evaluation of accidents, "*Regulations governing accidents that must be addressed by nuclear power facilities, both operating and shutdown, are found in 10 CFR Part 50 and 10 CFR Part 100.*"(Ref. 7.8)

Section 4.3.9 of the GEIS refers to the various types of accidents that may be of significance during decommissioning "*fuel removal, organizational changes, stabilization, chemical decontamination, large component removal, decontamination and dismantlement, system dismantlement, entombment, and transportation are activities that may lead to radiological accidents. Many activities that occur during decommissioning are similar to activities, such as decontamination and equipment removal that commonly take place during maintenance outages at operating plants. However, during decommissioning such activities may be more extensive than similar activities during the period of reactor operations. Consequently, potential accidents associated with these activities may have a higher probability during decommissioning than when the plant is operating. Accidents that occur during these activities may result in injury and local contamination; they are not likely to result in contamination offsite.*

Section 4.3.9 of the GEIS focuses on spent fuel accidents as the generically bounding accident for decommissioning facilities. The GEIS states, "*Once the reactor fuel has been moved to the spent fuel pool, the only DBAs contained in the plant's FSAR that are applicable are those associated with the spent fuel pool. These accidents are generally related to fuel handling or dropping heavy objects into the spent fuel pool. As long as the integrity of the spent fuel pool and its supporting systems is maintained, the potential impacts of accidents are bounded by the impacts of those for the spent fuel pool DBAs. After permanent shutdown of the reactor, the only severe accident of concern is one where the fuel in the spent fuel pool becomes uncovered and results in a zircaloy fire.*"(Ref. 7.8) The GEIS refers to NUREG 1738 Technical Study of Spent Fuel Pool Accident Risk at Decommissioning Nuclear Power Plants which evaluated the probability and consequences of the fuel related accidents. This study concluded that, "*The consequences of a zirconium fire event are likely to be severe.*" The GEIS states that "*The consequences for these events are evaluated for the hypothetical maximally exposed individual.*" (Ref. 7.8) "*The impacts of accidents that could result in offsite doses that exceed EPA's protective action guides (PAGs) (EPA 1991) are considered to be destabilizing. The only accidents that are likely to have destabilizing impacts are those that involve pool drainage that leads to a zirconium fire.*" (Ref. 7.8).

Appendix I of NUREG 0586 provides the details of the accidents evaluated and the consequences.

Accident Description	Nuclear Plant	Offsite Whole-Body Dose, rem
Fuel-Related Accidents		
Cask drop into spent fuel pool	Haddam Neck	0.418
Loss of spent fuel pool inventory (loss of heat sink or by inadvertent siphoning)	Maine Yankee	0.23
Shipping cask or heavy load drop into fuel element storage well	La Crosse	0.186
Loss of prestressed concrete reactor vessel shielding water (after fuel has been removed)	Fort St. Vrain	0.035
100% fuel failure	Indian Point, Unit 1	0.027
Simultaneous failure of fuel assemblies	Dresden, Unit 1	0.016
Spent fuel handling accident	Humboldt Bay, Unit 3	0.013
Fuel-handling accident	Rancho Seco	0.01
Heavy load drop	Fort St. Vrain	0.007
Fuel assembly drop	Haddam Neck	0.0026
Radioactive Material-Related Accidents (Non-Fuel)		
Spent resin handling accident (exothermic reaction during dewatering)	Haddam Neck	0.96
Explosion inside vapor container	Yankee Rowe	0.44
Radioactive liquid waste system leaks and failure	Maine Yankee	0.23
Materials-handling event	Yankee Rowe	0.16
Fire	Fort St. Vrain	0.12
Fire in intermodal container of waste	Yankee Rowe	0.1
Fire in D-rings	Three Mile Island, Unit 2	0.049
Decontamination events	Yankee Rowe	0.039
Liquid radioactive waste released to lake through cracks in building (earthquake-induced)	Fermi, Unit 1	0.02364
Release of resins from makeup and purification demineralizer	Three Mile Island, Unit 2	0.02

Figure 1 Table I-4 of NUREG-0586 Accidents and Offsite Dose Consequences

Based upon this review, "The staff has reviewed activities associated with decommissioning and determined that many decommissioning activities not involving spent fuel that are likely to result in radiological accidents are similar to activities conducted during the period of reactor operations. The radiological releases from potential accidents associated with these activities may be detectable. However, work procedures are designed to minimize both the likelihood of an accident and the consequences of an accident, should one occur, and emergency plans and procedures will remain in place to protect health and safety while the possibility of significant radiological accidents exists." (Ref. 7.8) The radioactive material related accidents (Non-Fuel) pertain to this review of a heavy load drop into a defueled spent fuel pool. Liquid releases considered in the GEIS had off-site dose consequences up to 20 mrem.

NEI 96-07 states the following with regard to evaluating the dose consequences of an accident for 50.59 evaluations, "The evaluation should determine the dose that would likely result from accidents associated with the proposed activity. If a proposed activity would result in more than a minimal increase in dose from the existing calculated dose for any accident, then the activity would require prior NRC approval. Where a change in consequences is so small or the uncertainties in determining whether a change in consequences has occurred are such that it cannot be reasonably concluded that the consequences have actually changed (i.e., there is no clear trend towards increasing the consequences), the change need not be considered an increase in consequences." (Ref. 7.11) Therefore dose consequences slightly above those in the GEIS are not necessarily considered to be unbounded by the GEIS.

NEI 96-07 states, "Therefore, for a given accident, calculated or bounding dose values for that accident would be identified in the UFSAR. These dose values should be within the GDC 19 or 10 CFR 100 limits, as applicable, as modified by SRP guidelines (e.g., small fraction of 10 CFR 100), as applicable. An increase in consequences from a proposed activity is defined to be no more than minimal if the increase (1) is less than or equal to 10 percent of the difference between the current calculated dose value and the regulatory guideline value (10 CFR 100 or GDC 19, as applicable), and (2) the increased dose does not exceed the current SRP guideline value for the particular design basis event. The current calculated dose values are those documented in the most up-to-date analyses of record. This approach establishes the current SRP guideline values as a basis for minimal increases for all facilities, not just those that were specifically licensed against those guidelines."(Ref. 7.11) "For some licensees the current calculated dose consequences may already be in excess of the SRP guidelines for some events. In such cases minimal is defined as less than or equal to 0.1 rem." (Ref. 7.11)

A final consideration in the performance of Safety Evaluations for decommissioning facilities is 10 CFR 50.82(a)(6) which states that the licensee must not perform any decommissioning activity that (1) forecloses release of the site for possible unrestricted use, (2) results in any significant environmental impact not previously reviewed, or (3) results in there no longer being reasonable assurance that adequate funds will be available for decommissioning. The NRC staff will, during 50.59 inspections, evaluate the licensee's procedures for ensuring that these three restrictions are part of the screening criteria for changes made to the facility.(Ref. 7.3)

3.2 Previous Evaluations

The consequences of a heavy load drop on the Spent Fuel Pool have been previously evaluated for the SAFSTOR Safety Evaluation Report (Ref. 7.17, 7.18) and for the Independent Spent Fuel Storage Installation Safety Evaluation Report.(Ref. 7.19) These evaluations were performed with the fuel pool containing spent fuel elements and were bounded by the FSAR and PSDAR. The Spent Fuel Elements have since been removed from the pool and placed in Dry Cask Storage. The previous evaluations concluded that the only potential consequence from a heavy load drop was contamination of subsurface groundwater and subsequent release of radionuclides to Humboldt Bay and local potable water wells. The potable water wells in use at the time of these evaluations were on-site wells that have since been discontinued.

The calculations assumed the heavy load drop would breach the bottom of the pool creating a pathway for release to groundwater. The previous calculations assumed the quantity of the release was the initial volume of the pool water that would drain until it equilibrated with the water table. They evaluated the release concentrations and source terms for four radionuclides Co-60, Cs-134, Cs-137, and Sr-90 based upon Technical Specification limits for Spent Fuel Pool activity. Fate and transport calculations for the dispersal of these contaminants were performed by calculation rather than by using modeling software in the previous evaluations. In addition, bioaccumulation and dose consequences for the aquatic foods pathway were performed using Regulatory Guide 1.109 (Ref. 7.1) methodology. No credit was taken for tidal flushing of the bay.

Sludge samples from the Spent Fuel Pool indicate a wider array of radionuclides present including transuranics. RESRAD software approved by the NRC for modeling fate and transport of radionuclides for License Termination criteria has been updated to allow modeling

of the offsite transport and dose consequences for radionuclides. This software allows modeling of radionuclide release and transport to an off-site surface water body for the wider array of nuclide present in the Spent Fuel Pool.

3.3 RESRAD-OFFSITE

The industry has gained considerable experience modeling the fate and transport of radionuclides in the environment while implementing the decommissioning rule. The rule (10CFR20 Subpart B) requires licensees to determine concentration guidelines that ensure radiation doses of future occupants on the site will not exceed 25 mrem in any one year. The Nuclear Regulatory Commission (NRC), Environmental Protection Agency (EPA), Department of Energy (DOE) and Department of Defense (DOD) have endorsed and used the Residual Radioactivity (RESRAD) codes developed at Argonne National Laboratories for fate, transport and dose modeling for decommissioning and remediation. The RESRAD codes have been tested, validated and benchmarked against other environmental modeling codes.

Until recently, these codes evaluated the fate, transport and dose consequences for receptors located onsite, within the contaminated zone. RESRAD-OFFSITE is an extension of the RESRAD (onsite) computer code that was developed to estimate the radiological consequences to a receptor located onsite or outside the area of primary contamination. The code is sponsored by DOE's Office of Health, Safety and Security, and the Office of Environmental Management, with support from the U.S. Nuclear Regulatory Commission. The User's manual is an NRC NUREG.(Ref. 7.21)

- RESRAD-OFFSITE calculates radiological dose and excess lifetime cancer risk with the predicted radionuclide concentrations in the environment, and derives soil cleanup guidelines corresponding to a specified dose limit.
- Nine exposure pathways are considered in RESRAD-OFFSITE: direct exposure from contamination in soil, inhalation of particulates and radon, ingestion of plant foods, ingestion of meat, ingestion of milk, ingestion of aquatic foods, ingestion of water, and incidental ingestion of soil.
- The conceptual model is presented in Figure 2. The code enables a user to evaluate a scenario where an individual might spend some time in buildings that are located either onsite or offsite. That individual could consume plant- and animal-based foods that are grown onsite or derived from offsite agricultural fields that are contaminated by material from the primary contamination. The water the individual drinks and uses can be drawn from a well or a surface water body located onsite or offsite.
- For a surface water body, it can also be the source where the individual obtained aquatic food for consumption.

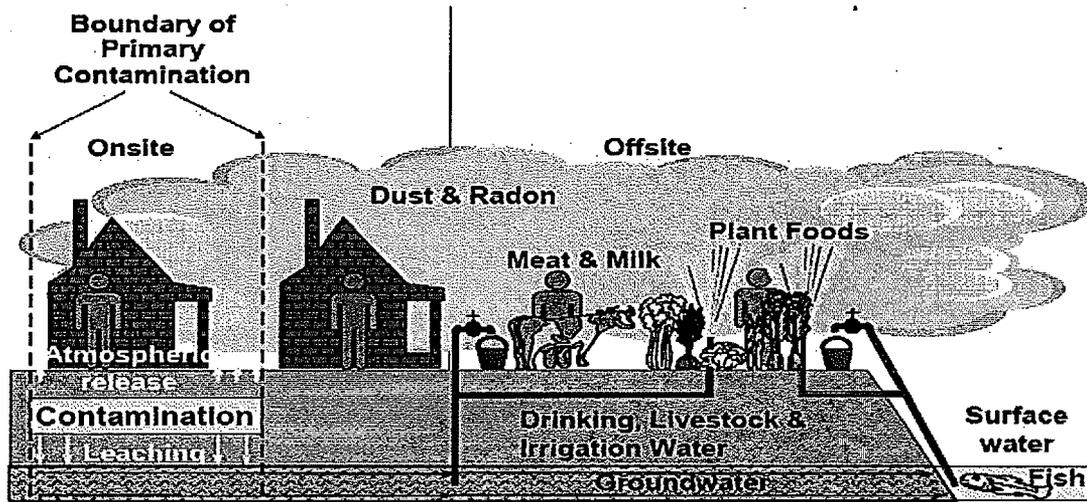


Figure 2 - Graphic Representation of RESRAD-OFFSITE Conceptual Model

This code allows a more complete evaluation of the fate transport and dose consequences for the entire radioactive source term of the spent fuel pool.

4.0 Evaluation and Calculations

4.1 Spent Fuel Pool Structure

A model of the Reactor Caisson which includes the Fuel Building is shown in Figure 3. Section 24 of the Unit 3 Plant Data volume (Ref. 7.1) describes the Reactor Caisson, and Fuel Building as follows. "The station building and turbine pedestal are supported on a 3'-6" thick continuous concrete mat foundation resting on a grid of 30 ton timber piles penetrating to the sand strata at elevation - 24 feet, similar to Units 1 and 2. The pilings are used to minimize differential settlement relative to the reactor caisson, the caisson being expected to exhibit very little, if any, settlement... The reactor caisson consists of a reinforced concrete structure 59'-6" in diameter, 78'-0" inside depth, housing the reactor vessel and auxiliary equipment, the drywell vessel, suppression tank, spent fuel pit and new fuels storage vault...." The caisson above elevation -14 foot and up to grade at elevation 12 foot is rectangular (49'-0" wide x 75'-0" long) and serves as the structural foundation for the refueling building and stack projection."

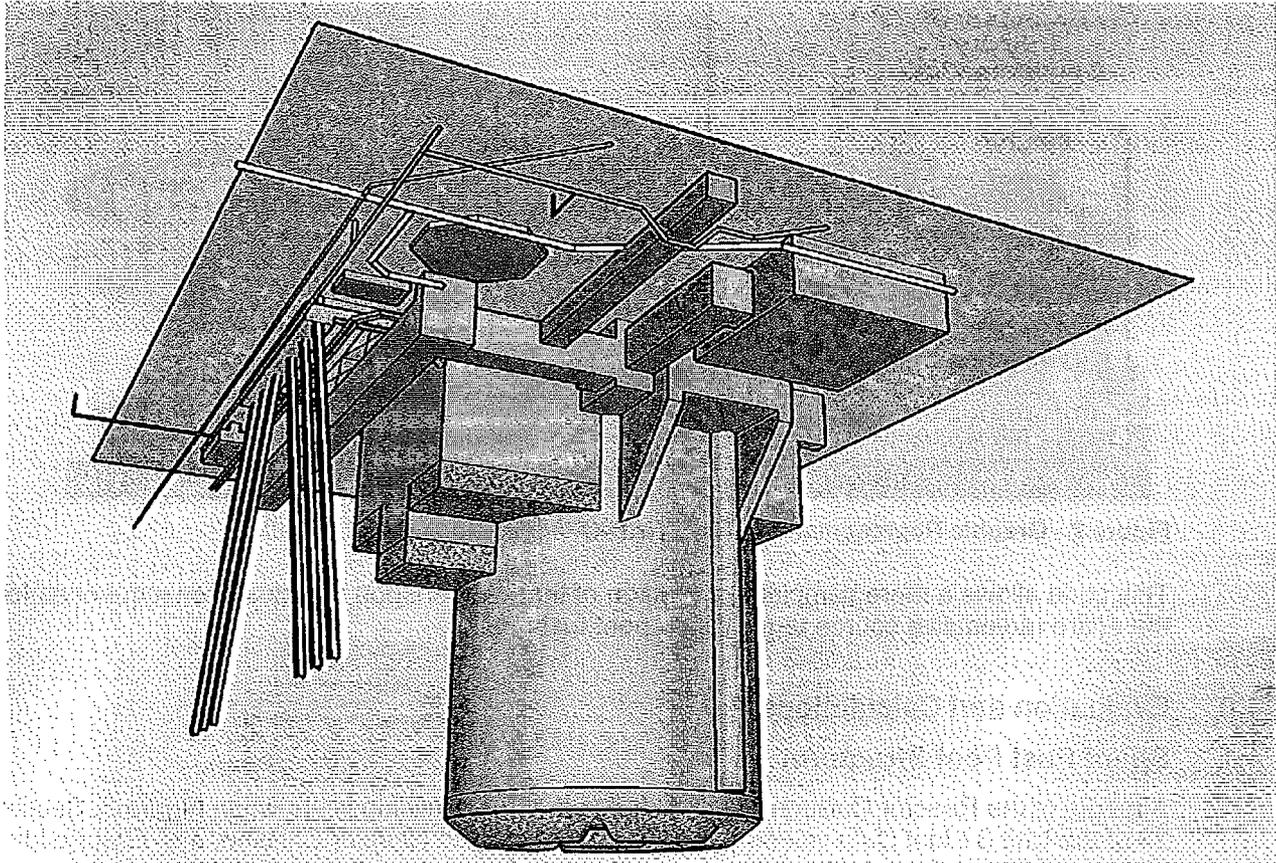


Figure 3 - Southwest Subsurface View of Reactor Caisson

The refueling building is supported on the reactor caisson and six 100 ton H-piles driven to the same strata that supports the caisson. The base of the caisson is sealed with tremie concrete at elevation -66' underneath the drywell and suppression tank, and at elevation -14' and -24' in the fuel pit. A 6" pervious gravel blanket on the tremie and below the 6" floor slab collects any seepage and prevents pressure buildup."(Ref. 7.1) Five feet of tremie concrete also underlie Spent Fuel Pit and Cask Pit floors as seen in Drawing 55433. As seen in Figure 5, this drawing shows the tremie concrete, 6 inch thick floors and 6 inches of gravel between the floor and the tremie concrete fuel pit and cask pit.

Other notable features described in the plant data volume are as follows, "The refueling building is 43 feet wide x 103 feet long x 35 feet high, constructed of reinforced concrete walls with a composite roof of precast prestressed concrete double tee sections and concrete topping. The 12 inch minimum thickness walls and roof provide containment and shielding of any fuel handling accident. A negative pressure of 1/4 inch water is maintained on the refueling building so that any leakage is inward rather than to the environs."(Ref. 7.1)

The Unit 3, Final Hazards Summary Report (Ref. 7.17) states, The Fuel Building is "Designed for a permissible leakage rate not to exceed 100% of its volume per day at 1/4 inch water pressure differential. The structural elements of the Refueling Building have been designed to resist loadings due to earthquake, wind and live load."

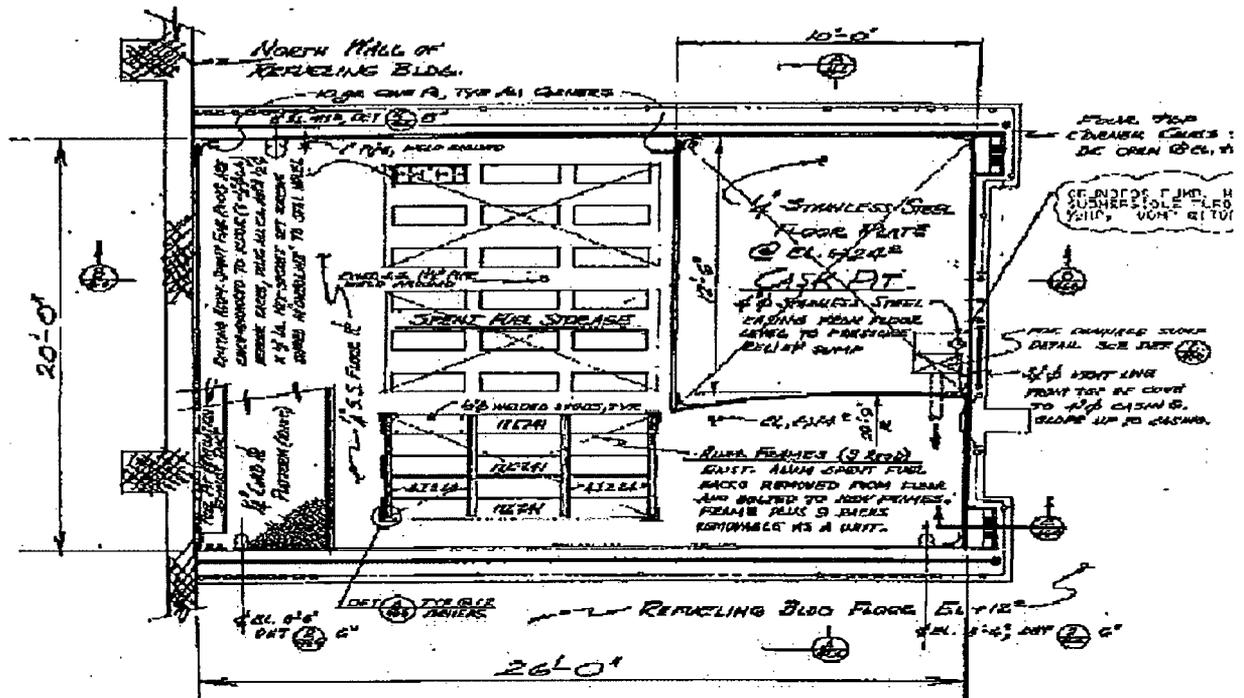


Figure 4 - Top View of Fuel Pit and Cask Pit from Drawing 55466

The Fuel Pit is constructed as part of the Reactor Caisson. As seen in Figure 4, the Fuel Pit is 20 feet wide by 26 feet long. The Cask Pit is 10 feet wide by 12.5 feet long. Figure 4 also shows the Fuel Building Floor to be at grade which is elevation + 12 feet. As seen in Figure 5, the fuel pit is from Elevation 12 feet to Elevation -14 feet, thus the Fuel Pit is 26 feet deep from the floor level. The Cask Pit floor is at -24 foot elevation, or 10 feet deep below the Fuel Pit floor.

The drawings also show design features from the construction of this portion of the caisson. The sheet piling installed to enclose the Fuel Pit excavation area is shown in Figure 5. The sheet piling was installed and soil was excavated from within it. Five feet of tremie concrete was then poured under the water in the excavation to seal the bottom of the excavated pit against the sheet piling. The accumulated water was pumped out and 6 inches of gravel were placed on the tremie concrete base, the gravel was covered with tar paper, and 6 inch thick concrete floors were poured over it as shown in Figure 5 and Figure 6. This gravel void space can be pumped and sampled.

As described in the Unit 3 Decommissioning, Safety Evaluation Report (Ref. 7.18), early in the operation of Unit 3, Spent Fuel Pool leakage was detected, and a stainless steel liner was installed to alleviate the problem. Approximately 50 liters (12 gallons) of water has historically been pumped from the liner void space every 5 to 7 days with leakage from the pool accounting for about 5 percent of this volume. Sampling of the gravel (French drain) under the Fuel Pit/Cask Pit floor, is conducted on a periodic basis. Cs-137 and Cs-134 radionuclide concentrations in the blotter samples are approximately 1 percent of the concentrations found

4.2 Spent Fuel Pool Volume and Source Term

The Spent Fuel Pool was walked down on Wednesday, April 29th, 2009. The level of the Spent Fuel was observed to have a water level that was 2 feet below the 12' floor elevation (e.g., 10' Elev.). Using this water level¹, the water volume in the pool is calculated as shown in Table 1.

Table 1 - Calculated Water Volumes of Fuel Pit and Cask Pit

	Length	Width	Height	Cubic Feet	Gallons	Liters
Fuel Pool	26	20	24	12,480	93,363	3.53E+05
Cask Pit	12.5	10	10	1,250	9,351	3.54E+04
			Total	13,730	102,714	3.89E+05 ²

There is a potential for a layer of high specific activity sludge to be accumulated on the floors of the Fuel Pit and Cask Pit. In order to ensure that all the fuel was recovered prior to sealing the final fuel dry cask storage assembly, the pool was vacuumed removing the bulk of the sludge. The laboratory analysis results for a Spent Fuel Pool Sludge sample obtained in February 2000 and decayed to 05/01/2009 are shown in Table 2.

Table 2 - Spent Fuel Pool Sludge Laboratory Source Term

Nuclide		Part 61 2/17/2000 μCi/gm	Half Life (Years)	Decay Constant y ⁻¹	Decayed μCi/gm
H-3		8.88E-04	1.23E+01	5.64E-02	5.29E-04
C-14		1.14E-02	5.73E+03	1.21E-04	1.13E-02
Fe-55		1.84E+01	2.70E+00	2.57E-01	1.73E+00
Co-60		2.77E+01	5.27E+00	1.31E-01	8.26E+00
Ni-59		1.11E-01	7.50E+04	9.24E-06	1.11E-01
Ni-63		1.82E+01	1.00E+02	6.92E-03	1.71E+01
Sr-90		5.37E-01	2.86E+01	2.42E-02	4.30E-01
Tc-99		1.38E-04	2.13E+05	3.25E-06	1.38E-04
I-129	<	1.19E-04	1.57E+07	4.41E-08	1.19E-04
Cs-134	<	5.27E-02	2.06E+00	3.36E-01	2.39E-03
Cs-137		2.38E+00	3.02E+01	2.30E-02	1.93E+00
U233/234		2.41E-04	1.58E+05	4.39E-06	2.41E-04
U235/236		6.62E-05	2.34E+07	2.96E-08	6.62E-05
U-238		9.62E-05	4.47E+09	1.55E-10	9.62E-05
Eu-154		1.02E-01	8.80E+00	7.88E-02	4.96E-02
Pu-238		1.27E-01	8.78E+01	7.90E-03	1.18E-01
Pu-239/240		1.36E-01	2.41E+04	2.87E-05	1.36E-01
Pu-241		3.31E+00	1.44E+01	4.81E-02	2.13E+00
Am-241		1.17E+00	4.32E+02	1.60E-03	1.19E+00

¹ The height at which the water level is maintained in the pool is not critical since 86% of the source term is in the sludge at the bottom of the pool.

² The dimensions of the contaminated zone in the RESRAD-OFFSITE model were chosen to replicate this volume.

Nuclide	Part 61 2/17/2000 μCi/gm	Half Life (Years)	Decay Constant y ⁻¹	Decayed μCi/gm
Cm-243/244	1.94E-01	2.85E+01	2.43E-02	1.55E-01
Key Nuclide Ratios				
Cs-137/Sr-90	4.43E+00			4.49E+00
Cs-137/Co-60	8.60E-02			2.33E-01
Co-60/Am-241	2.38E+01			6.96E+00
Cs-137/Am-241	2.04E+00			1.62E+00
Gross Beta/Gross Alpha	2.09E+01			7.98E+00

Table 3 - Spent Fuel Pool Sludge Laboratory Analysis Result

The decayed activity was calculated using the standard radioactive decay equation for all radionuclides except Am-241. Am-241 is the daughter of Pu-241 which has a shorter half-life resulting in in-growth of Am-241 as Pu-241 decays. The equation used to calculate the decayed Am-241 activity is shown in Equation 1.

$$A_{Am-241} = A_{0Am} e^{-\lambda_{Am}t} + A_{0Pu} \left(\frac{\lambda_{Am}}{\lambda_{Pu}} \right) (1 - e^{-\lambda_{Pu}t}) (e^{-\lambda_{Am}t})$$

Where:

A_{Am-241} = The decay corrected Am-241 activity

A_{0Am} = The original Am-241 activity

A_{0Pu} = The original Pu-241 activity

λ_{Am} = The Am-241 decay constant yr⁻¹

λ_{Pu} = The Pu-241 decay constant yr⁻¹

t = the decay time in years

The surface area of the bottom of the Fuel Pit and Cask Pit is 26 feet by 20 feet. Assuming a sludge depth of 1/8 inches yields 153,383 cm³ of sludge on the floor. Assuming a density of 1.6 grams/cm³, this volume equals 245,413 grams of sludge. Using the decay corrected specific activities in Table 3, the estimated sludge source term is calculated as shown in Table 4. A small bucket of sludge is also stored in the bottom of the pool. It contains 907 cubic inches (e.g., 14,863 cm³) of sludge. This is less than 10% of the conservative volume estimated in this calculation and is therefore bounded by the assumed 1/8 inch thick sludge layer.

The decay corrected sludge source term, scaling factors and scaling nuclides are provided in Table 4.

Table 4 - Estimated Spent Fuel Pool Sludge Source Term and Scaling Factors

Nuclide	μCi/gram	μCi	CI	pCi/g	% Mix	Scaling Factor	Scaling Nuclide
Am-241	1.19E+00	2.92E+05	2.92E-01	1.19E+06	3.56%	1.79E+04	Am-241
C-14	1.13E-02	2.78E+03	2.78E-03	1.13E+04	0.03%	1.37E-03	Co-60
Cm-243/244	1.55E-01	3.80E+04	3.80E-02	1.55E+05	0.46%	2.34E+03	Am-241
Co-60	8.26E+00	2.03E+06	2.03E+00	8.26E+06	24.78%	1.00E+00	Co-60

Nuclide	$\mu\text{Ci}/\text{gram}$	μCi	CI	pCi/g	% Mix	Scaling Factor	Scaling Nuclide
Cs-134	2.39E-03	5.87E+02	5.87E-04	2.39E+03	0.01%	2.16E-02	Cs-137
Cs-137	1.93E+00	4.73E+05	4.73E-01	1.93E+06	5.78%	1.74E+01	Cs-137
Eu-154	4.96E-02	1.22E+04	1.22E-02	4.96E+04	0.15%	6.00E-03	Cs-137
Fe-55	1.73E+00	4.24E+05	4.24E-01	1.73E+06	5.18%	2.09E-01	Co-60
H-3	5.29E-04	1.30E+02	1.30E-04	5.29E+02	0.00%		
I-129	1.19E-04	2.92E+01	2.92E-05	1.19E+02	0.00%	1.07E-03	Cs-137
Ni-59	1.11E-01	2.72E+04	2.72E-02	1.11E+05	0.33%	1.34E-02	Co-60
Ni-63	1.71E+01	4.20E+06	4.20E+00	1.71E+07	51.28%	2.07E+00	Co-60
Pu-238	1.18E-01	2.91E+04	2.91E-02	1.18E+05	0.35%	1.79E+03	Am-241
Pu-239/240	1.36E-01	3.33E+04	3.33E-02	1.36E+05	0.41%	2.05E+03	Am-241
Pu-241	2.13E+00	5.22E+05	5.22E-01	2.13E+06	6.37%	3.21E+04	Am-241
Sr-90	4.30E-01	1.06E+05	1.06E-01	4.30E+05	1.29%	3.88E+00	Cs-137
Tc-99	1.38E-04	3.38E+01	3.38E-05	1.38E+02	0.00%	1.24E-03	Cs-137
U233/234	2.41E-04	5.91E+01	5.91E-05	2.41E+02	0.00%	3.64E+00	Am-241
U235/236	6.62E-05	1.62E+01	1.62E-05	6.62E+01	0.00%	1.00E+00	Am-241
U-238	9.62E-05	2.36E+01	2.36E-05	9.62E+01	0.00%	1.45E+00	Am-241
Total		8.19E+06	8.19E+00		1.00E+00		

The current (March -2009) concentrations of radionuclides in the Spent Fuel Pool are provided in Table 5. These are the results of routine sampling performed on the Spent Fuel Pool by Radiation Protection.

Table 5 - Spent Fuel Pool Water Concentrations

Nuclide	$\mu\text{Ci}/\text{ml}$
Cs-137	6.04E-07
Co-60	5.21E-07
Am-241	8.69E-08
Np-239	1.90E-08
H-3	3.00E-05

The Table 5 water concentrations and Table 4 scaling factors were used to provide an estimated current water inventory. The scaled water inventory is provided in Table 6.

Table 6 - Scaled Spent Fuel Pool Water Source Term

Nuclide	Scaling Nuclide	Sludge Scaling Factor	$\mu\text{Ci}/\text{ml}$	CI
H-3	N/A	N/A	3.00E-05	1.17E-02
C-14	Co-60	1.37E-03	7.16E-10	2.78E-07
Fe-55	Co-60	2.09E-01	1.09E-07	4.24E-05
Co-60	Co-60	1.00E+00	5.21E-07	2.03E-04
Ni-59	Co-60	1.34E-02	6.99E-09	2.72E-06
Ni-63	Co-60	2.07E+00	1.08E-06	4.19E-04
Sr-90	Cs-137	3.88E+00	2.34E-06	9.11E-04
Tc-99	Cs-137	1.24E-03	7.50E-10	2.92E-07
I-129	Cs-137	1.07E-03	6.47E-10	2.52E-07
Cs-134	Cs-137	2.16E-02	1.30E-08	5.06E-06
Cs-137	Cs-137	1.74E+01	6.04E-07	2.35E-04
U233/234	Am-241	3.64E+00	3.16E-07	1.23E-04

Nuclide	Scaling Nuclide	Sludge Scaling Factor	$\mu\text{Ci/ml}$	Ci
U235/236	Am-241	1.00E+00	8.69E-08	3.38E-05
U-238	Am-241	1.45E+00	1.26E-07	4.91E-05
Eu-154	Cs-137	6.00E-03	3.62E-09	1.41E-06
Pu-238	Am-241	1.79E+03	1.55E-04	6.04E-02
Pu-239/240	Am-241	2.05E+03	1.78E-04	6.93E-02
Pu-241	Am-241	3.21E+04	2.79E-03	1.08E+00
Am-241	Am-241	1.79E+04	8.69E-08	3.38E-05
Cm-243/244	Am-241	2.34E+03	2.03E-04	7.90E-02
Np-239	N/A	N/A	1.90E-08	7.37E-06
Total			3.33E-03	1.30E+00

The combined sludge and water source terms are provided in Table 7. The total volume of the water in the spent fuel pool in Table 1 is used to estimate the overall concentration of the water in the Spent Fuel Pool in the last column of Table 7. The sludge comprises 86% of the overall source term in the Spent Fuel Pool.

Table 7 - Combined SFP Sludge and Water Source Terms and Overall Concentration

Nuclide	Water Ci	Sludge Ci	Total Ci	Overall ³ $\mu\text{Ci/ml}$
H-3	1.166E-02	1.297E-04	1.179E-02	3.033E-05
C-14	2.783E-07	2.785E-03	2.785E-03	7.163E-06
Fe-55	4.241E-05	4.244E-01	4.245E-01	1.092E-03
Co-60	2.027E-04	2.028E+00	2.028E+00	5.217E-03
Ni-59	2.717E-06	2.719E-02	2.719E-02	6.994E-05
Ni-63	4.195E-04	4.198E+00	4.198E+00	1.080E-02
Sr-90	9.107E-04	1.055E-01	1.064E-01	2.738E-04
Tc-99	2.916E-07	3.379E-05	3.408E-05	8.767E-08
I-129	2.516E-07	2.916E-05	2.941E-05	7.564E-08
Cs-134	5.064E-06	5.869E-04	5.919E-04	1.522E-06
Cs-137	2.346E-04	4.734E-01	4.736E-01	1.218E-03
U233/234	1.229E-04	5.909E-05	1.820E-04	4.680E-07
U235/236	3.378E-05	1.624E-05	5.002E-05	1.287E-07
U-238	4.909E-05	2.361E-05	7.270E-05	1.870E-07
Eu-154	1.409E-06	1.218E-02	1.218E-02	3.132E-05
Pu-238	6.041E-02	2.905E-02	8.946E-02	2.301E-04
Pu-239/240	6.928E-02	3.332E-02	1.026E-01	2.639E-04
Pu-241	1.085E+00	5.217E-01	1.606E+00	4.132E-03
Am-241	3.378E-05	2.915E-01	2.915E-01	7.498E-04
Cm-243/244	7.899E-02	3.799E-02	1.170E-01	3.009E-04
Np-239	7.368E-06		7.368E-06	1.895E-08
Total	1.307E+00	8.186E+00	9.493E+00	2.442E-02

³ The Overall Activities concentrations were converted to pCi/gram and used as the Contaminated Zone concentrations in the RESRAD-OFFSITE model.

4.3 Heavy Load Drop Scenario On-Site Consequences

The likely consequences of a heavy load drop in the Spent Fuel Pool are that the sludge would become suspended in the water due to the turbulence created by the drop, some of the water would be splashed to the floor. The liner, cask pit floor or fuel pit floor, and tremie concrete would be damaged creating a pathway for draining and release of spent fuel pool water to the environment, below the caisson. This would cause the water in the Spent Fuel Pool to drain until it equilibrated with groundwater levels in the water table. As will be seen in later section, this will leave sufficient water in the pool to shield direct radiation from any items stored in the lower sections of the Fuel Pit or Cask Pit. Thus direct radiation levels would not hinder the response to the event or pose an on-site threat that is outside those encountered during the course of decommissioning.

Due to the design of the Fuel Building and decommissioning on-site response capabilities the on-site consequences would be minimal. Work such as a heavy load movement in and around the Spent Fuel Pool would require Health Physics coverage. Spill kits and decontamination supplies would enable splashed water to be contained and collected. The contaminated structures and floors would be decontaminated and the building design and ventilation would contain any resulting airborne radioactivity as the splash area and fuel pool wall dried. Similarly, the exposed walls of the fuel pit could be washed down and periodically wetted to minimize airborne radioactivity.

Upon release to the subsurface environment below the caisson, subsequent release and fate and transport of the radionuclides is controlled by the hydrogeological features of the site and the marine environment of Humboldt Bay.

4.4 Stratigraphy and Aquifers Underlying Unit 3

Recently, the groundwater in the ISFSI Site Area was investigated over a several year period by Pacific Gas and Electric (PG&E). The geology and hydrology determined from this investigation are described in Independent Spent Fuel Storage Installation (ISFSI), Final Safety Analysis Report Update (ISFSI FSAR). (Ref. 7.19) The (FSAR) states, "Two areas were investigated in detail, one near the Unit 3 Power Plant and one near the former wastewater pond site that is east of Unit 3. The various borings used to establish the stratigraphy, including those that held piezometers and monitoring wells, are shown in Figure 2.5-3" (provided in Attachment 1). "Table 2.5-1 of the FSAR summarizes the basic information about the 67 borings and monitoring wells used to measure the piezometric levels taken on May 6, 1999..... Based on the information from these borings and analysis of the stratigraphy and aquifer characteristics, several aquifers and zones of perched groundwater in the ISFSI site area are evident. The current interpretation of the groundwater aquifers and zones varies significantly from earlier interpretations because the strata within the Hookton Formation are better understood. Also, in the earlier interpretations the Holocene bay deposits were lumped with the Hookton, but are now separated and shown to unconformably overlie the upper Hookton Formation. In addition, the tectonic tilting and faulting of the Hookton Formation in part controls water movement and piezometric levels." Thus a review of the detailed results of the studies is warranted to ensure calculations and modeling are based upon the current understanding of hydrological conditions.

Drawing 55428 provides detailed information about the geologic strata surrounding the Unit 3 Reactor Caisson. The stratigraphy information has been excerpted from the drawing is provided in Figure 7. The elevations and dimensions shown on the drawing were interpolated

from the image and drawing details. The Humboldt Bay facility is located on Buhne Point which on Humboldt Bay. Figure 2.5-5 of the ISFSI FSAR (Ref. 7.19) shows the geologic cross section of Buhne Point based upon the above review of the hydrogeologic data. This figure is provided as Attachment B in this document. Figure 8 was prepared from Attachment to show the details of the geologic stratigraphy and aquifers underlying Unit 3. The elevations of the bottoms of the Fuel Pit and Cask Pit have been marked on the figure to illustrate the subsurface depths and features into which the contents of the Spent Fuel Pool would be released upon breach.

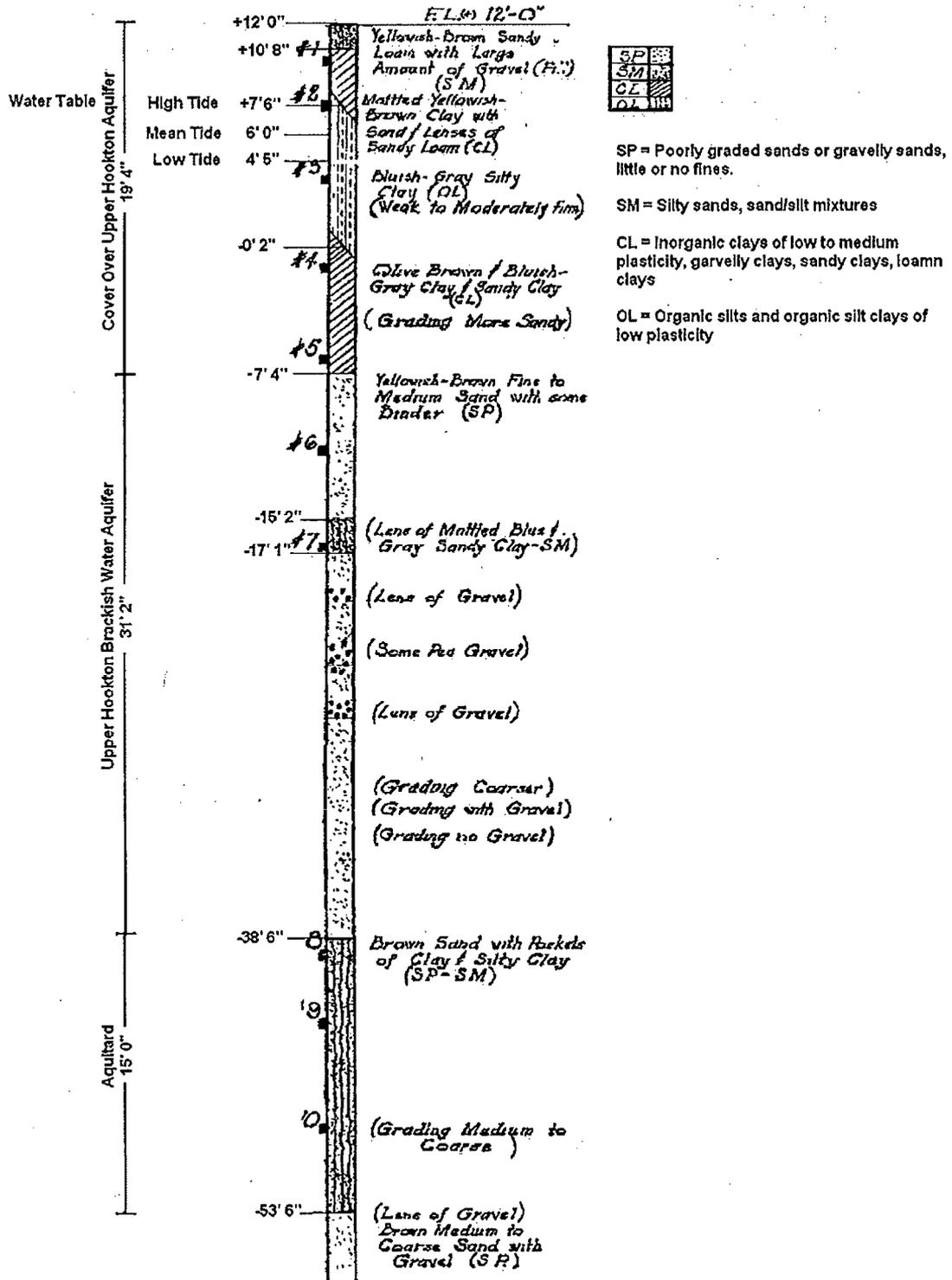
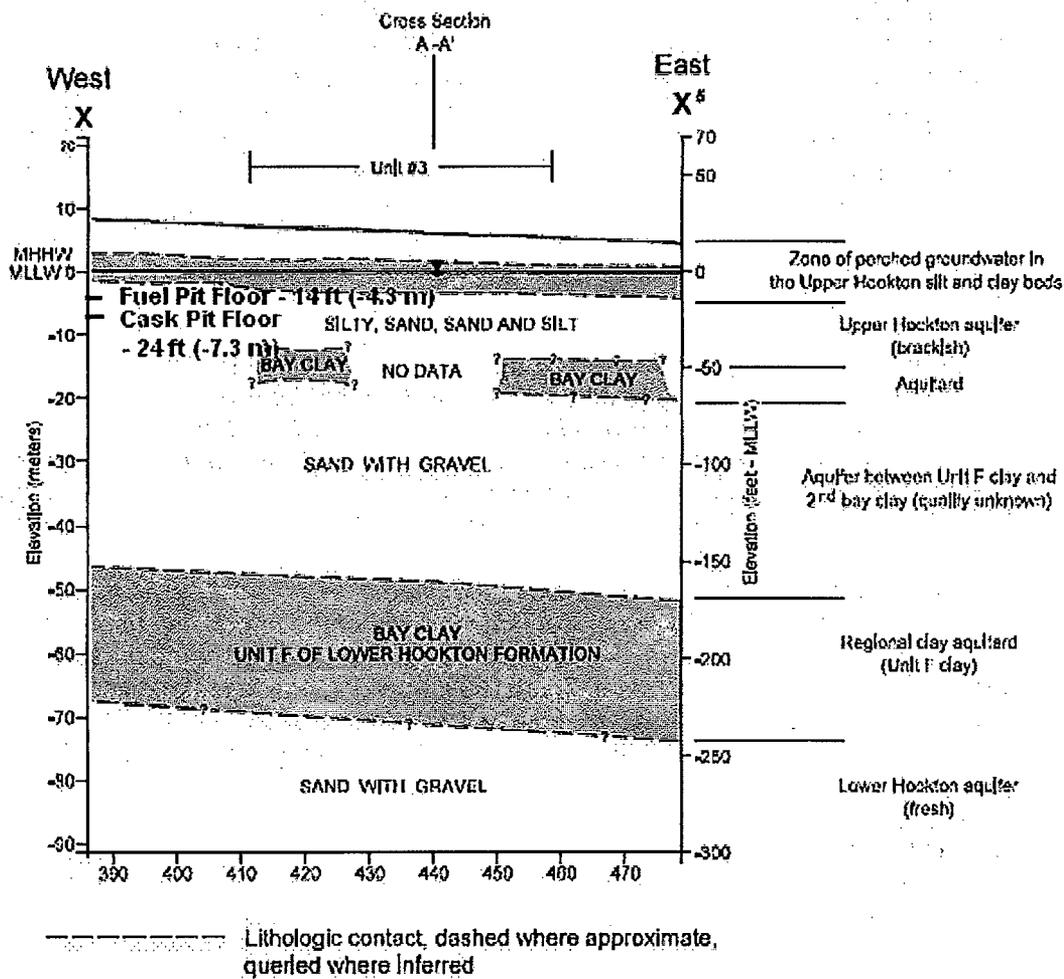


Figure 7 - Detailed Strata for Reactor Calsson from Drawing 55428



Note:
Location of cross section is shown on Figure 2.5-3,
Figure modified from Figure 2.6.4-5.

Figure 8 - Unit 3 Geologic Cross Section from FSAR Figure 2.5-5 (Attachment B)

Figure 7 and Figure 8 clearly show that the bottoms of the Fuel Pit and Cask Pit are within the Upper Hookton brackish water aquifer deposits. Thus the postulated breach would result in release of radioactive source term to these deposits. Figure 7 shows that the Upper Hookton brackish water aquifer is overlain by semi-permeable alluvial sand and clay deposits that are approximately 19' 4" or 5.88⁴ meters thick. Due to the clay and semi-permeable nature of the overlying layer, transport will occur mainly via the Upper Hookton Aquifer deposits that underlie this cover material.

The ISFSI FSAR (Ref. 7.19) describes the Upper Hookton deposit as follows, "The upper Hookton Formation in the ISFSI site area can be divided into two informal lithologic units

⁴ This value is used as the thickness of the Contaminated Zone in the RESRAD-OFFSITE Physical and Hydrological – Contaminated Zone and Cover input form.

'upper Hookton silt and clay beds' and the 'upper Hookton sand beds. The upper unit is 60 to 80 ft thick and consists of laterally discontinuous beds of clay and silt, and sand and gravel that change laterally with interfingering, cut-and-fill, and gradational facies changes. The clay beds that are ancient bay sediments have more lateral persistence than interbedded sandy and silty layers..... The upper Hookton sand beds are 25 to 40 ft thick and consist of sand and gravel layers with lesser silt and clay beds. The upper Hookton sand beds overlie a discontinuous clay bed (the 'second bay clay') that underlies the Unit 3 power plant area and the waste disposal ponds where it is 8 to 13 ft thick and is present in much of the site area.' The FSAR describes the aquifer as follows, "Upper Hookton aquifer" - *The upper Hookton aquifer is the brackish water aquifer in the Upper Hookton sand beds above the 2nd bay clay and below the overlying silt and clay beds of the Upper Hookton Formation.*"⁶

Perched groundwater sits atop the 1st Bay Clay which overlies the Upper Hookton sand deposits into which the release will occur. *"Based on the definite piezometric head separation between the zone of perched groundwater and the upper Hookton aquifer and the 1st bay clay that separates them, hydraulic communication between the two aquifers is poor; hence, minimal flow are believed to occur between these two zones. The perched groundwater in the Upper Hookton Formation appears to discharge into the nearby marshes and into the intake and discharge canals. Little discharge is expected to reach the underlying Upper Hookton aquifer because the 1st bay clay that is at the base of the deposit restricts vertical flows. Moreover, in the Unit 3 area the piezometric surface of the underlying upper Hookton aquifer is higher than the base of the 1st bay clay providing upward piezometric pressure into the perched groundwater zone."*⁶ (Ref. 7.19) Thus modeling of site surface contamination should emulate the Saturated Zone of the perched groundwater and discharge into nearby marshes and canals. Modeling of subsurface releases below the first clay layer should emulate the conditions in the Upper Hookton aquifer sand deposits that overlie the second clay layer.⁶

The Lower Hookton deposit includes a clay bed that acts as an aquitard and inhibits migration from the Upper Hookton brackish water aquifer. The ISFSI FSAR (Ref. 7.19) describes the Lower Hookton deposits as follows, "*Lower Hookton Formation - The lower Hookton Formation consists of laterally persistent beds of alternating sand, silty sand, gravel, gravely sand, silty clay, and clay. The upper 26 ft to 150 ft consists of sand and gravel that overlies the Unit F clay. The Unit F clay, which is about 50 ft thick, is a distinctive marker bed (Section 2.6.4) with relatively low permeability that functions as a regional aquitard. Beneath the Unit F clay are alternating layers of clean, well-sorted sand and clay that extend from 200 to about 1,100 ft deep.*" *The lower Hookton aquifer lies below the 50 ft thick, regional aquitard known as the Unit F clay. Beneath this impermeable layer, the aquifer is defined as the freshwater bearing zone of clean, sorted sands that are deeper than about 200 ft below the ISFSI. Although the sand layers extend deeper, they are utilized in wells above 450 ft depth, which defines the boundary of interest for the groundwater flow directions and gradients at the ISFSI. This confined aquifer is artesian in places.*"

From the above description, the coarse sand and gravel beds of the Upper Hookton brackish water aquifer are isolated from the fresh water of the Lower Hookton aquifer by 50 foot thick Unit F clay bed. This aquitard prevents cross contamination by the Upper Hookton brackish waters and will also prevent migration of radionuclides into the fresh water aquifer of the lower

Hookton.⁵ Figure 9 provides further stratigraphic information relevant to evaluating the fate and transport of the released radionuclides.

HOOKTON FORMATION	AQUIFERS IN HOOKTON FORMATION		
	Stratigraphy	This Report	Earlier Interpretations
Silty sand and silt beds with sand lenses	Zone of perched groundwater in Upper Hookton clay and silt beds	A	1st aquifer of Bower (1988) (brackish water) [in TES, 1988]
Silt and clay beds 1 st bay clay		Unconfined first water bearing zone of Bower (1988) [in TES, 1988]	
Sands and gravels	Upper Hookton aquifer	B C Semi-unconfined second water bearing zone of Bower (1988) [in TES, 1988] Upper sand zone of Dames and Moore (reported D in WCC)	
Clay bed 2 nd bay clay	Aquitard discontinuous across site	Clay layer of Bower (1988) [in TES, 1988]	
Sands and gravels	Aquifer between Unit F clay and 2 nd bay clay		
Unit F clay	Unit F clay aquitard	Regional aquitard	
Sands and gravels	Lower Hookton aquifer	2 nd aquifer of Bower 1998 (fresh water) [in TES, 1988]	

Figure 9 - Description of Hookton Geologic Formations and Aquifers from Figure 2.5-4 of FSAR.

The ISFSI FSAR (Ref. 7.19) provides the following details about the Upper Hookton aquifer. "Upper Hookton Aquifer – Above the Unit F clay aquitard and below the upper Hookton silt and clay beds (comprising permeable beds in both the lower and upper Hookton Formation) is the shallow, brackish-water aquifer which is over 100 ft thick. It is semiconfined by the upper silt and clay bed aquitard⁶. The unit is comprised of sand and gravel lenses, including some clean sand strata. A clay bed of varying thickness and extent is about 20 ft below the top of the aquifer. This clay bed is shown as the second bay clay in the geologic sections and has been referred to as a site-wide aquitard (clay layer of Bower, 1988; in TES, 1998, Reference 6). An

⁵ The RESRAD-OFFSITE model assumes there is no viable contamination of a potable water source and no ingestion dose from drinking water.

⁶ Because RESRAD-OFFSITE models release to the groundwater from a Contaminated Zone that is in the Unsaturated Zone above the water table, and the deposits into which the radioactivity release occurs are semi-confined by the overlying deposits, the RESRAD Model places the Saturated Zone water table at the bottom of the 19'4" thick upper silt and clay bed.

analysis, however, shows that it is discontinuous; in Figure 2.5-8, the clay bed bifurcates: the upper part pinches out and the lower part appears to be pinched out to the west of the western most boring; in Figure 2.5-7 the upper bifurcation of the clay bed pinches out. The lower part of the bifurcation is below the borings; however, it is not present in the deeper borings (D&M 59-1A and D&M73-3) on the up-dip projection of the clay bed. The 2nd bay clay is present beneath the ISFSI site as illustrated in Figures 2.5-5 and 2.5-6.” (Ref. 7.19)⁷ The pinching out or bifurcation is a feature underlying the ISFSI on the Buhne Point Hill east of Unit 3. “As evident on the cross sections, the upper Hookton aquifer is confined by the upper Hookton silt and clay beds in the Unit 3 and wastewater ponds area, but is unconfined beneath the higher part of Buhne Point Hill, making it a semi-confined aquifer.”(Ref. 7.19)

In summary, the hydrogeology that underlies Unit 3 indicates that upon breach, the fuel pool water will be injected into the sand deposits of the Upper Hookton aquifer. The aquifer is confined between an upper clay layer and a lower clay layer. The upper clay layer limits transmissivity to the perched groundwater above it. The upper deposits are approximately 19' 4" thick. A second clay layer below the sands in which the release would occur will confine flow and reflect dispersion as is modeled by RESRAD-OFFSITE.(Ref. 7.21) The Unit F clay aquitard separates the Upper Hookton Brackish water aquifer from the lower Hookton fresh water aquifer and will prevent migration of radionuclides into the freshwater aquifer. Thus there is no viable potential for contamination of a potable water supply from the postulated breach and release.

4.5 Water Table Depths and Aquifer Gradients

The ISFSI FSAR (Ref. 7.19) provides the following details about the water table of the perched groundwater overlying the first clay bed for the fuel pool area and the groundwater gradients of Buhne Point. *“The character of the Upper Hookton aquifer is known from several piezometers and monitoring wells in the wastewater pond area and in the Unit 3 area (Table 2.5-1 provided as Figure 10). The monitoring wells were input formed at two intervals: the C-level monitoring wells were input formed in the upper portion of the aquifer and the D-level monitoring wells were input formed at a deeper level in the aquifer but above the second bay clay “aquitard.” Several other wells also record the piezometric surface of the upper Hookton aquifer on Buhne Point Hill.” (Ref. 7.19)*

“The piezometric surface in May 1999 from the Upper Hookton aquifer is shown in the cross sections (Figures 2.5-5 to 2.5-8) and as contours in Figure 2.5-9.” (Ref. 7.19) The portion of this map near Unit 3 is provided as Attachment C. The map shows the Upper Hookton groundwater contours and the well locations. “Analysis of the figures shows that the piezometric levels for both the C and D zones are essentially identical, indicating good vertical communication in the aquifer above the second bay clay bed. The piezometric surface beneath Buhne Point Hill is nearly horizontal, and slopes gradually to the north toward Humboldt Bay. North of the Discharge Canal fault piezometric surface slopes northwest. The difference in the amount and direction of slope of the piezometric surface on either side of the fault indicates that the fault is an aquitard, with higher water levels on the north side than the south.” (Ref. 7.19) The MLLW piezometric surfaces near Unit 3 and approaching the bay are shown in Attachment C.

⁷ The RESRAD-OFFSITE model assumes the Saturated Zone is an unconfined aquifer with a reflective mirror or aquitard that is twice the depth of the modeled water table (e.g., 19' 4"). The calculations reasonably approximate the Upper Hookton aquifer characteristics.

PIEZOMETERS USED IN 1999 GROUNDWATER MEASUREMENTS IN THE
HUMBOLDT BAY ISFSI SITE AREA

Boring Number	Year	Boring Depth/ Elevation (feet)	Top Screen Elevation (feet)	Bottom Screen Elevation (feet)	Geologic/ Hydrologic Unit in screened zone	Piezometric Elevation 5/6/99 (9am-12pm) (feet)
MW-1 (BEC 84-1)	1984	49.5/ -37.6	-28.19	-32.59	upper Hookton aquifer	4.74
MW-2A (BEC 84-2A)	1984	50.0/ -39.2	-28.14	-37.54	upper Hookton aquifer	4.29
MW-4 (BEC 84-4)	1984	50.6/ -38.5	-41.00	-50.20	upper Hookton aquifer	4.43
MW-5 (BEC 84-5)	1984	45.0/ -33.3	-40.50	-44.80	upper Hookton aquifer	4.24
MW-6 (BEC 84-6)	1984	50.0/ -38.6	-32.57	-36.87	upper Hookton aquifer	4.21
MW-7 (BEC 84-7)	1984	45.0/ -20.9	-16.23	-20.53	upper Hookton aquifer	4.10
MW-8 (BEC 84-8)	1984	12.5/ 11.1	17.3	11.8	perched ground-water zone (A) in upper Hookton silts and clays	17.92
MW-9 (BEC 84-9)	1984	45.0/ -33.4	-23.58	-32.78	upper Hookton aquifer	4.76

Figure 10- Monitoring Well Designations in Unit 3 Area from Table 2.5-1 of FSAR

As seen in Figure 11, the tides have a strong influence on the perched groundwater overlying the first clay bed of the Upper Hookton piezometric surfaces. This is illustrated in wells at the wastewater pond site and near Unit 3. The piezometric elevations for these wells are provided in the last column of Figure 10. Figure 10 also provides a cross index to the well designations used in Attachment C. *"The piezometric surface lags the tidal changes by a few hours and has up to about a 3 ft elevation change during a tidal cycle. This indicates that water in Humboldt Bay and in this aquifer at the ISFSI site area is connected in the outcrops below the bay."*(Ref. 7.19)

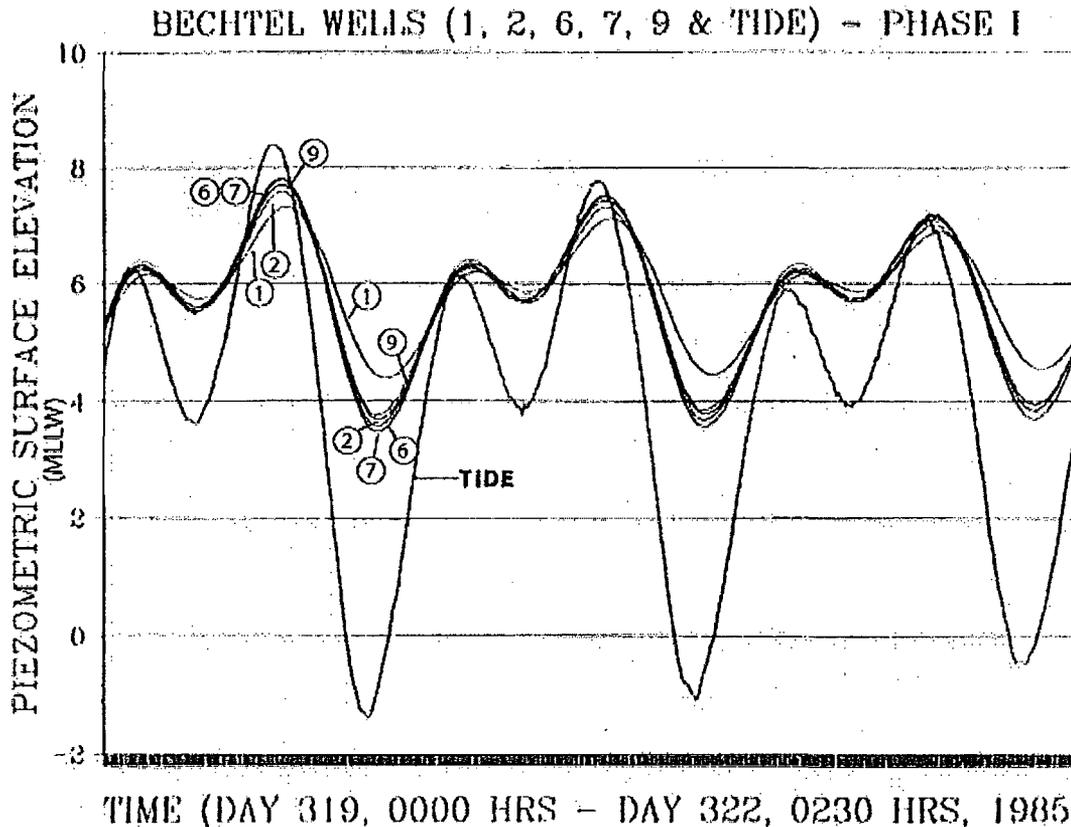


Figure 11 - FSAR Figure 2.5-10 Relationship Between The Tide Levels In Humboldt Bay and Piezometric Levels from Wells MW-1, MW-2, MW-6, MW-7, and MW-9 (Bechtel) Near Unit 3 Humboldt Bay ISFSI Site Area.

Thus the zone of perched ground water is tidally influenced. It is also influenced by the seasonal rainfall and surface water runoff and recharge characteristics. The ISFSI FSAR (Ref. 7.19) describes the perched groundwater as follows, "Recharge into the zone of perched groundwater in the upper Hookton silt and clay beds beneath Buhne Point Hill at the ISFSI site is primarily from direct precipitation and percolation into the interfingering layers of silt, clay and lesser sand lenses that characterize the deposits. Local perched water tables occur in these beds, but the southeast tilting of these layers tends to direct groundwater flow toward the intake and discharge canals. Near Unit 3, the perched water table is at about 8.5 ft elevation. This water is somewhat brackish (salinity about 2600 to 2800 micromhos/cm) reflecting a mixing with some bay water from the nearby marshes and the intake and discharge canals, or from upward migration of water into these beds from the underlying upper Hookton aquifer. The recharge potential on Buhne Point Hill is low because the silty sand, silt and clay deposits directly below ground are relatively impermeable."(Ref. 7.19)

Tidal fluctuations also affect the Upper Hookton aquifer in the sand deposits below the 1st clay layer. "Tidal fluctuations in Humboldt Bay have significant short-term (hours) effects on the groundwater flow directions and rates within the Upper Hookton aquifer at Buhne Point Hill. During rising tides, bay water flows into the formation near Buhne Point Hill in a generally southerly direction; during falling tides, the flow is out of the formation into the bay, generally in

a northerly direction. However, the upper Hookton aquifer is believed to have a net discharge of groundwater into Humboldt Bay and possibly offshore into the Pacific Ocean. Net horizontal flow velocities within the Upper Hookton aquifer range from 2×10^{-7} to 1×10^{-5} cm/s." (Ref. 7.19) This statement makes it clear that the Upper Hookton aquifer in the sand deposits discharges to the bay or to the Pacific and not to the local marshes as described for the perched groundwater. The flow velocities of 2×10^{-7} to 1×10^{-5} cm/s corresponds to a horizontal hydraulic conductivities of 0.0631 m/year to 3.15 m/year. As seen in Table 8, previous calculations used a Lateral Dispersion value of 1.524E-01 meters.

The ISFSI FSAR later states, "*Based on down-hole flow meter measurements in the Upper Hookton aquifer in the Unit 3 area for wells MW-1 through MW-11 and calculated permeability using the tidal method, a flow velocity range of 3,100 to 10,400 ft/yr (3×10^{-3} to 3×10^{-2} cm/sec) was calculated. This range is higher than that calculated for the aquifer beneath the wastewater ponds area (described above) and on the high side of those values calculated for References 6 and 10 (2,000 ft/yr or 1.9×10^{-3} cm/s). The differences most likely reflect different local stratigraphic characteristics in the aquifer." (Ref. 7.19) Previous calculations (Ref. 7.17, 7.18) used the 10,400 ft/yr value as the hydraulic conductivity for the Fuel Pool Breach release. This corresponds to a hydraulic conductivity of 3,170 meters/year.⁸*

The ISFSI FSAR (Ref. 7.19) states, "*A tidal fluctuation analysis method was applied to water level data collected from wells completed in the Upper Hookton aquifer to provide estimates of the transmissivity, hydraulic conductivity, and storativity of that zone. The tidal method was not appropriate for the perched groundwater zone because tidally induced fluctuations in this zone were negligible." (Ref. 7.19) "Little vertical flow occurs within the upper Hookton aquifer. Vertical gradients range from 10 to 20 ft/mile (0.002 to 0.004 ft/ft)⁹. During the 1988 study period, horizontal groundwater gradients within the upper Hookton aquifer in the vicinity of the former wastewater ponds ranged from 0.001 to 0.002 ft/ft, while the vertical gradients ranged from 0.002 to 0.004 ft/ft⁹. The range of horizontal permeability values for this aquifer, estimated by the tidal method, was 7×10^{-5} to 2×10^{-3} cm/s, with most values being close to 1×10^{-3} cm/s. The range of vertical permeability was estimated as 1×10^{-5} to 4×10^{-4} cm/s. Net horizontal flow velocities within the upper Hookton aquifer range from 2×10^{-7} to 1×10^{-5} cm/s, while estimated vertical flow velocities ranged from 2×10^{-6} to 4×10^{-6} cm/s." (Ref. 7.19) "Based on a saturated thickness of approximately 25 ft for the upper Hookton aquifer, the range of transmissivity values is 0.04 cm²/s to 1.21 cm²/s. Estimated storativity values were all in the 10^{-5} range."*

In summary, upon breach, the fuel pool water level will equilibrate to the water table depth. This is assumed in previous calculations and in this calculation to be the perched water table depth. In addition, the perched water table and the Upper Hookton aquifer are influenced tidally. This will result in filling and draining of the breached Spent Fuel Pool with each tidal cycle. The perched water above the first clay layer discharges to the local canals and marshes. The Upper Hookton aquifer in the sand material below the 1st clay layer discharges to Humboldt Bay or the Pacific.

⁸ This value was used as the Hydraulic Conductivity for the Saturated Zone in the Groundwater Transport-Saturated Zone input form. Further explanation is provided below Table 8 in Section 4.9.

⁹ A hydraulic gradient of 0.003 is used for the well and surface water body in the Groundwater Transport-Saturated Zone input form

4.6 Humboldt Bay

Humboldt Bay is a tidal bay receiving and discharging ocean water through its inlet. Humboldt Bay is divided into an Entrance Bay extending from Buhne Point to the mouth of the Elk River; a South Bay, south of Buhne Point; and a North Bay, north of the mouth of the Elk River and including Arcata Bay. Very little fresh water discharges into Humboldt Bay.(Ref. 7.19, 7.26)

Humboldt Bay is a large, shallow body of water with deep channels. It is separated from the ocean by two long, narrow spits. The middle portion of the bay is joined to the ocean by a narrow channel passing between the north and south spits. The bay is approximately 23 km (14 miles) long, its width ranges from 0.8 km (0.5 miles) near its middle to over 3 km (2 miles) at the south end and 6 km (4 miles) at the north end, with an average depth of 12 ft mean lower low water (MLLW).(Ref. 7.19, 7.26) It is 28 km² (11 mi²) at the mean lower low tide (MLLW).(Ref. 7.26)

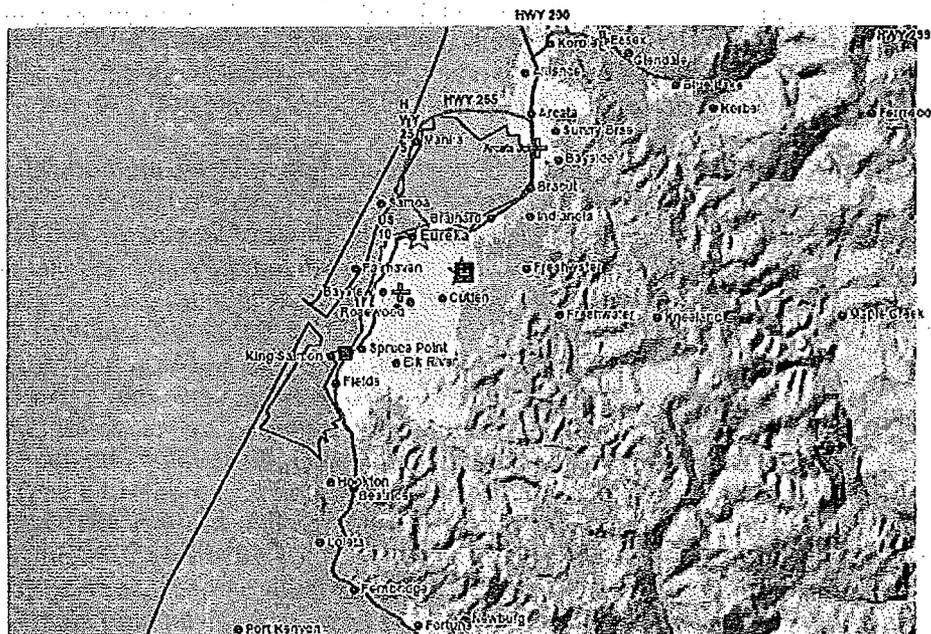


Figure 12 - Topography of Humboldt Bay Area

The tides of Humboldt Bay are of moderate height. The mean and diurnal tide ranges are 4.3 ft and 6.2 ft (1.3 and 1.9 m) at the entrance, 4.8 ft and 6.6 ft at Hookton Slough, and 5.0 ft and 7.0 ft at Arcata Wharf. Because the bay is so shallow, its tidal prism is large in comparison to its low-tide volume. The average volume of the tidal exchange from a higher high to a lower low tide amounts to approximately 61,000 acre-ft, (7.5E+7 m³) or 44 percent of the mean higher high tide volume.(Ref. 7.26) The mean higher high tide volume is thus 138,636.4 acre-ft or 1.70E+8 m³. Since this water is replaced by the subsequent tide, water quality conditions in the ocean have a considerable influence on water quality and ecological characteristics of the bay.(Ref. 7.19) The tidal dilution calculation for the discharge canal used a conservative near field volume of 3.33E+5¹⁰ cubic meters.(Ref. 7.29) It is anticipated that the groundwater

¹⁰ A near field volume of 3.33E+5 cubic meters was used for the calculation as opposed to the much higher volume for the bay.

discharge into the bay will be more diffuse and extend over a larger area than the more limited near field area at the mouth of the discharge canal.

The Bay is 420 feet (128 meters) from the Spent Fuel Pool (Ref 7.17, 7.18) The decommissioning environmental report (Ref. 7.26) states, "To determine the flushing action of the tides, area capacity curves were made of the bay for each tide level. An examination of these curves showed that, on an average, twice during a 24 hour period¹¹, replacement water would be:

- Entire Bay 41%
- South Bay 52%
- North Bay 44%
- Entrance Bay 23%

4.7 Postulated Release to Groundwater

In this scenario a heavy load traversing the fuel pool, is dropped into the cask pit, creating a breach in the cask pit floor and tremie concrete (see Figure 5 and Figure 6). The turbulence caused by the force of the drop would suspend most of the sludge in the water. Water would initially drain to the level of the water table. It would then continue to drain eventually to the level of the initial low tide water table level. The previous bounding calculations used a mean low level water table at 9 foot elevation in the winter rainy season and at 6 foot in the dry summer season. (Ref. (Ref. 7.17, 7.18). Evaluation of Monitoring Well 1 data in Figure 11, shows the water table below Unit 3 is fluctuating between the 4.5 foot and 7.5 foot elevation in response to the tidal cycle. Thus assuming the breach occurred in the summer season and that the water level in the pool is at the 10 foot elevation, approximately 5.5 feet of water would drain from the pool to equilibrate with the bottom of the tide water table at elevation of 4.5 feet.

This initial water loss would disperse and co-mingle with the groundwater below the fuel building. The pool would then refill on the high tide cycle to the 7.5 foot elevation, diluting the radionuclide concentrations in the pool with the incoming water. Draining, refilling, dilution and release of the pool would continue on each tidal cycle until the pool concentrations equilibrate with the groundwater concentrations. The calculated concentration from a well at downgradient edge of the contaminated zone after the initial breach is 0.0486 times the initial pool concentration. If it is assumed that the pool water concentration is diluted to 0.486 times the concentration in the groundwater below the pool and that the pool refills to 7.5 feet with groundwater, the dilution and resulting concentration can be calculated for each tidal cycle. The predicted concentration change over time in the fuel pool is shown in Figure 13.

¹¹ Previous calculations did not consider dilution due to tidal flushing. RESRAD-OFFSITE incorporates annual flushing into the model, the entrance bay daily volume exchange of 23% was applied to the near field volume of 3.33E+5 cubic meters in the model.

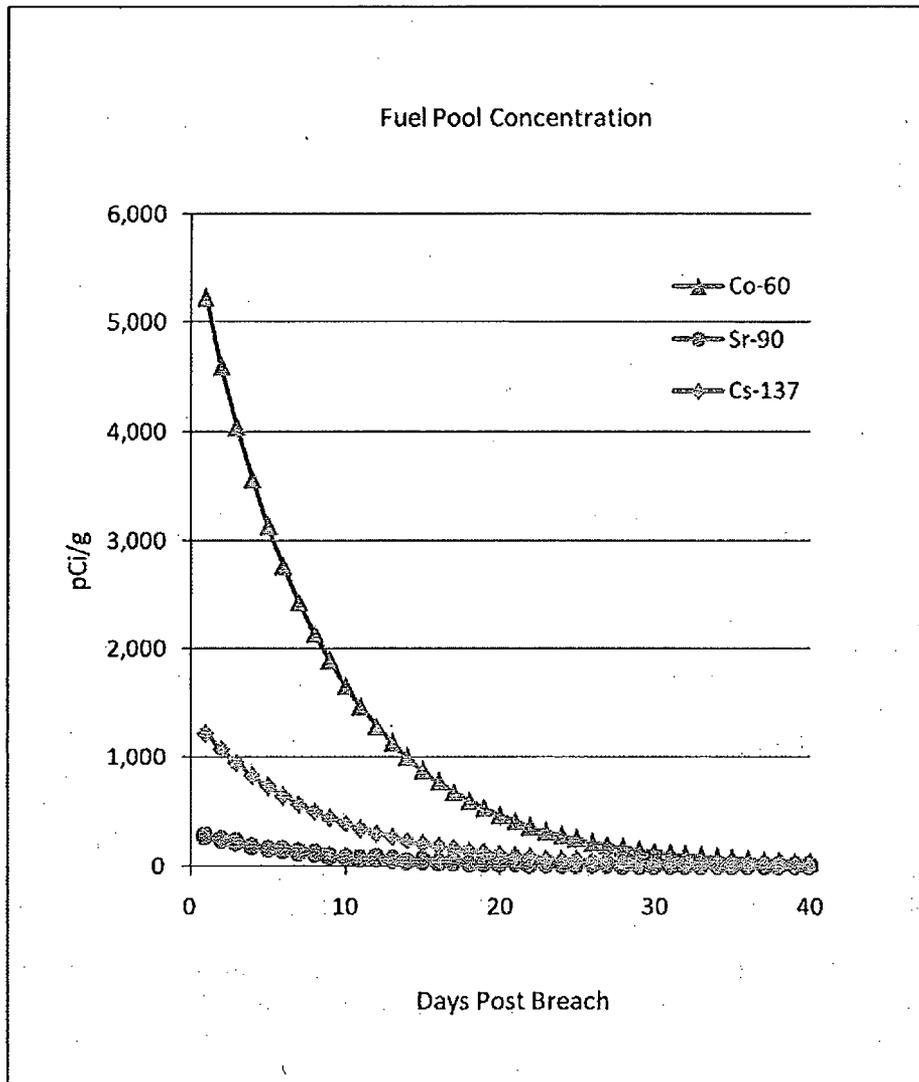


Figure 13 - Pool Concentrations Days Post Breach

Under this scenario the entire overall source term would enter the course sand of the aquifer over a 20 to 40 day period.

The minimum volume of Upper Hookton aquifer sand that could be contaminated by the water released can be calculated based upon the void space in the soil. The course sand of the aquifer has an effective porosity of 0.25 as shown in Table 8. Effective porosity is defined as "The effective porosity, p_e , also called the kinematic porosity, of a porous medium is defined as the ratio of the part of the pore volume where the water can circulate to the total volume of a representative sample of the medium." (Ref. 7.20) Thus the minimum volume of the contaminated area of the aquifer is the volume of the water in the pool divided by the effective porosity of the sand. This assumes the sand is dry. This volume is $1.56E+6$ liters (e.g., $1.56E+3$ m³). This is equivalent to a block of contamination 11.6 meters or 30.06 feet in length, width and height. As seen in Figure 8 and in the discussion below it, the Upper Hookton deposits are sandwiched between two alluvial clay deposits and are only 24 to 40 feet thick.

Thus a 30 foot block of contaminated material would effectively strata of the Upper Hookton aquifer.

Drawing 55428 shows the stratigraphy for the soil adjacent to the reactor caisson. This drawing was edited and is provided in Figure 7. This figure shows that the aquifer is covered by clay and soil deposits. The top of the course sand in the Upper Hookton is at elevation 19 feet 4 inches below grade (Elev. 12 ft). Thus the release from a fuel pool breach would result in contamination being localized 19 feet below grade in the Upper Hookton aquifer.

4.8 RESRAD-OFFSITE Model of Release

As described in Section 3.2, nine exposure pathways may be considered in RESRADOFFSITE:

- direct exposure from contamination in soil,
- inhalation of particulates and radon,
- ingestion of plant foods,
- ingestion of meat,
- ingestion of milk,
- ingestion of aquatic foods,
- ingestion of water,
- and incidental ingestion of soil.

Since a fuel pool breach would result in subsurface introduction of contamination 19 feet below grade, direct radiation exposure, soil ingestion, and inhalation are not viable pathways. In addition, contamination of plant foods, meat and milk from such a release are unlikely due to the clay like nature of the upper strata and poor communication between the perched groundwater and the aquifer as described in Section 4.4 and Section 4.5. As noted previously, the brackish water is not a viable freshwater aquifer for irrigation or a source of potable water. In addition, as noted earlier in Section 4.4 there is little vertical flow within the Upper Hookton aquifer. Therefore contamination injected 5.88 meters (e.g., 19' 4") below grade would not be expected to disperse vertically and become available for uptake in the meat, milk, fruits and vegetable pathways. Vertical gradients range from 10 to 20 ft/mile (0.002 to 0.004 ft/ft). The injection occurs at 19 feet, and the bay is 420 feet down gradient. Therefore, as was the case in previous evaluations, the only viable pathway is from ingestion of aquatic foods such as fish, crustacea, and mollusks from the bay.¹²

RESRAD software models migration of radionuclides using various soil "Zones". As seen in Figure 14 from the RESRAD Version 6 User's Manual (Ref. 7.22), the RESRAD model assumes radionuclides are driven into the aquifer by leaching from a contaminated zone, passing through an unsaturated zone and then into the "Saturated Zone" or aquifer. In order to emulate the fuel pool breach no cover material is assumed over "Contaminated Zone." A 19' 4" (5.88 meter) thick contaminated zone, and very thin, 0.01 meter, unsaturated zone are used. This models the "contaminated zone" as sitting directly on top of the Upper Hookton aquifer. The Contaminated Zone extends from the 12 foot elevation (e.g., grade level) to the -7 foot elevation where the course sand deposits of the aquifer are found. The average annual rainfall values for Humboldt County is 38.7 inches (0.983 meters) per year 100 year average Eureka.(Ref. 7.19) Zero runoff is specified for the contaminated zone and all erosion related

¹² All pathways in RESRAD-OFFSITE were turned off except for the aquatic foods pathway. The groundwater pathway was turned on for calculation of groundwater concentrations via the well at various locations.

parameters are set to zero.¹³ This maximizes the rainfall entering the soil and driving contaminants to the aquifer. This approach simulates the injection of the radionuclides directly into the aquifer from the contaminated zone in much the same manner as would be expected from a fuel pool breach.

The "Contaminated Zone" and "Unsaturated Zone" parameters are chosen to model the rapid release or "breakthrough" of source term into the aquifer or "Saturated Zone" in a manner that emulates the release of radionuclide from the fuel pool due to tidal filling and draining as shown in Figure 13.

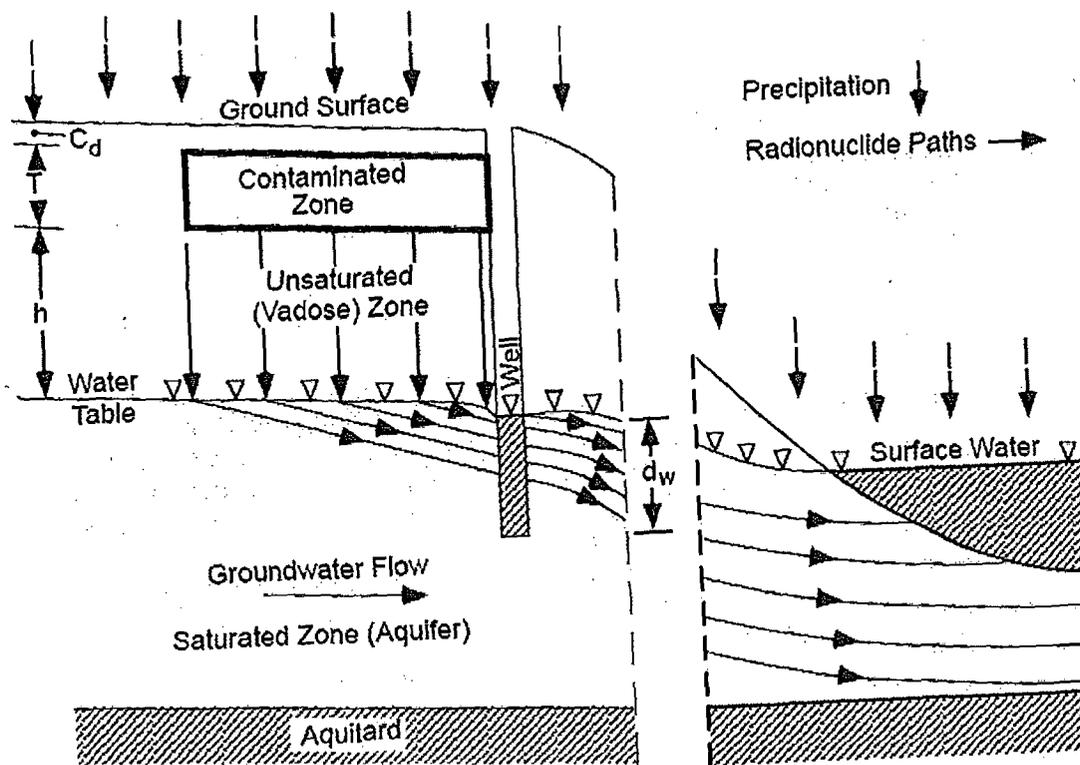


Figure 14 - RESRAD Surface Water Pathway

¹³ See Attachment D for all parameter settings used in the RESRAD-OFFSITE model and the basis for them.

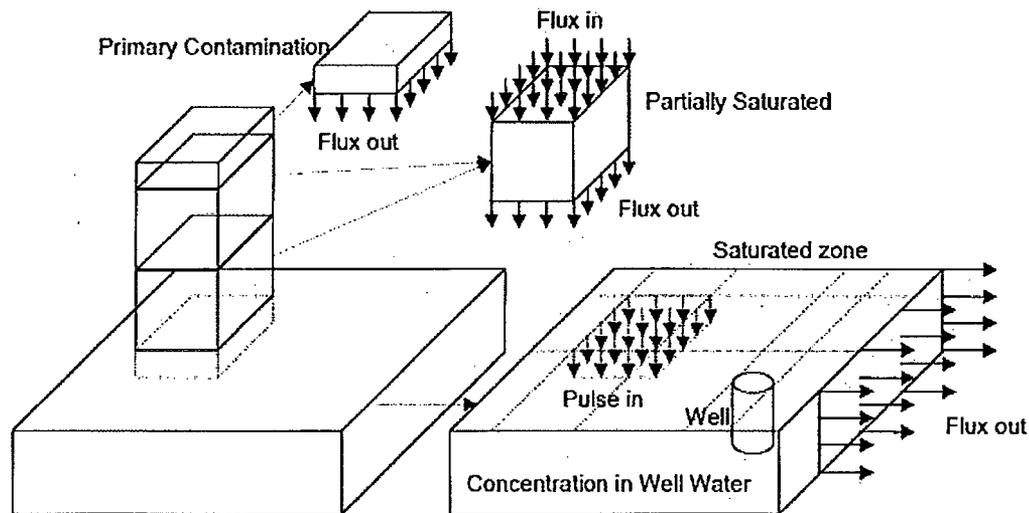


Figure 15 - RESRAD-OFFSITE Conceptualization of Groundwater Transport

By setting the contaminated zone and unsaturated zone distribution coefficients (K_d 's) very low at 0.001 and the b parameter at 0.01, the model assumes minimal retention of the radionuclides in the contaminated zone and unsaturated zone soils. Very low field capacity values of $1.00E-5$ are specified for the contaminated and unsaturated zones. The field capacity is the volumetric moisture content of soil at which (free) gravity drainage ceases. This is the amount of moisture that will be retained in a column of soil against the force of gravity. The field capacity is one of several hydrogeological parameters used to calculate water transport through the unsaturated part of the soil. Acceptable input ranges are from $1E-5$ to 1. (Ref. 7.21) Use of this low value maximizes input to the Saturated Zone aquifer below.

The hydraulic conductivity of contaminated zone and unsaturated zone are set at $1.00E+09$ meters/year. This is the measure of the soil's ability to transmit water when subjected to a hydraulic gradient. The hydraulic conductivity depends on the soil grain size, the structure of the soil matrix, the type of soil fluid, and the relative amount of soil fluid (saturation) present in the soil matrix. The default value is 10. The manual states that the accepted range is $1E-3$ to $1E+10$. (Ref. 7.21) The Unsaturated Zone hydraulic conductivity is set at $1.0E+6$. Using these parameters yields a rate of injection into the aquifer that closely approximates the fuel pool breach.

As seen in Table 1, the calculated combined volume of the Fuel Pits and Cask Pit is 13,730 cubic feet or $3.88E+8$ ml. A contaminated zone that is 29.0 feet (8.84 meters) in length, 24.53 (7.48 meters)¹⁴ wide, and 19.3 feet (5.88 meters) deep yields a volume of 13,730 cubic feet ($3.888E+08$ ml). By setting the density of the contaminated zone to 1 g/ml ¹⁴, the calculated overall fuel pool concentrations in Table 7 can be input as the soil concentration in pCi/g for the contaminated zone. As seen in Figure 16, this yields a loss of source term from the contaminated zone that closely approximates the reduction in fuel pool concentrations shown in Figure 13.

¹⁴ These values are used for the Contaminated Zone in the RESRAD-OFFSITE Physical and Hydrological-Contaminated Zone and Cover input form.

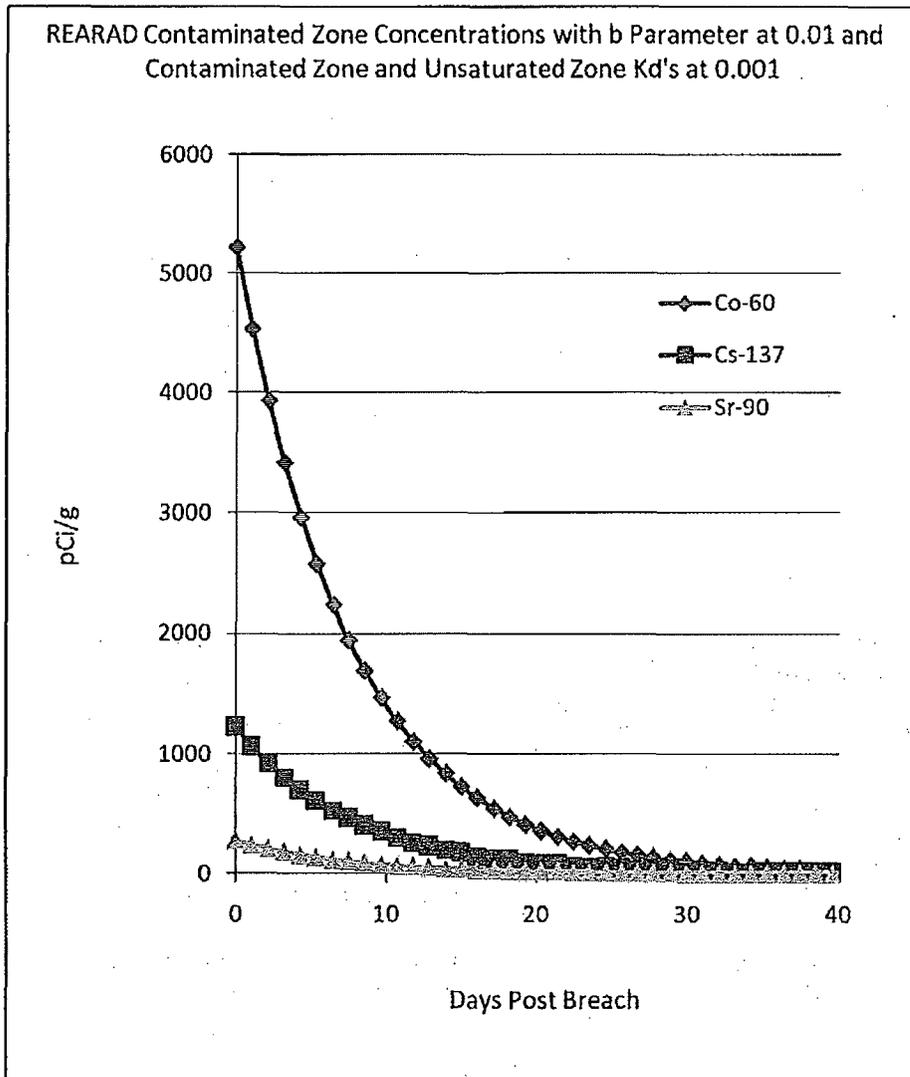


Figure 16 - RESRAD Offsite Predicted Contaminated Zone Concentrations Days Post Breach

This model is very conservative assuming the entire overall source term of the fuel pool is eventually released to groundwater. The model assumes that 100% of the source term is soluble in the water. It should be noted that the vast majority of the source term in Table 7 is contained in the sludge. The sludge consists of debris such as dust and oxides formed from corrosion such as crud as well as the uranium oxides from failed fuels. Fuel crud consists mainly of iron oxide and a small fraction of other metal oxides (e.g. Me: Ni, Cr, Mn, Co, Cu and Zn), depending on the corrosion rates of different materials and the water chemistry used. For BWR fuel crud, the main phases are hematite and nickel ferrite spinels. (Ref. 7.13). Fuel crud from disposed BWR fuel rods usually has a flaccid reddish or black appearance. The primary source of crud is the corrosion products of stainless steel in the feed water system. In early BWRs, corrosion of copper alloy preheaters used in the feedwater system led to the introduction of copper and nickel into the primary system at nearly the same rate as that of iron. The phase compositions of crud, as determined by X-ray powder diffractometry, are

mainly red hematite ($\alpha\text{-Fe}_2\text{O}_3$) and black spinels of type $\text{M}_x\text{Fe}_{3-x}\text{O}_4$ ($x=0 - 1$; $\text{M}=\text{Ni}, \text{Zn}, \text{Cr}, \text{Mn}, \text{Co}$ and Cu). The color appearing on the fuel rod surface may reflect, to some degree, the phase composition of fuel crud.(Ref. 7.13) Thus the high Fe-55, Co-60 and Ni-59, N-63 are nickel, are in the oxidized hematite and spinels from fuel crud. In general, the particle size of crud is in the range of 0.1 to 2 μm .(Ref. 7.13) Hematite and spinel species are relatively insoluble and resistant to weathering.(Ref. 7.16)

The high transuranic concentrations are from failed fuel where cladding was breached releasing the irradiated fuel material. Studies of transuranics in N Reactor Spent Fuel Pool sludge at Hanford found that *"that plutonium and particularly americium are trace constituents in the uranium matrix and that both are readily incorporated into UO_2 , the primary uranium metal corrosion product."* The N reactor used a uranium metal fuel, but once exposed to water it quickly corrodes to uranium oxide.(Ref. 7.15)

Separation of the americium or plutonium from their strong association in the parent uranium matrix would require dissolution of the uranium matrix with the associated plutonium and americium. Uranium dioxide and other uranium phases found in the sludge are only soluble in water under acid conditions (pH below ~1) or under conditions that are both oxidizing (e.g., aerated) and containing high carbonate concentrations.Being negligibly soluble, the PuO_2 and AmO_2 will tend to remain with the poorly soluble uranium phases, even as subsequent UO_2 oxidation to the slightly more soluble U(VI) compounds occurs. On these bases, the plutonium and americium are expected to stay with the solid phase uranium and their concentrations relative to uranium remain unchanged from that of the starting fuel. In particular, the americium is expected to be distributed within the corroded fuel matrix and exhibit the same solubility characteristics as the bulk uranium and plutonium and not show the solubility of pure americium phases in both the as-settled sludge and in the Sludge Treatment Project (STP) process post-corroded sludge.(Ref. 7.14)

The model is therefore very conservative because it assumes rapid flushing and thus high concentrations of radionuclides into the aquifer. In reality crud and uranium oxides in the sludge have low solubility or they would have been dissolved in the fuel pool. They would be filtered the sand and accumulate in the soil adjacent to the breach. This is therefore a very conservative model that assumes high mobility within the coarse sands of the aquifer. This approach will bound and address any concerns regarding enhanced transport through colloids or chelation.

4.9 Fish Pathway Model

Upon release to the Upper Hookton aquifer, radionuclides are transported to Humboldt Bay or the Pacific Ocean. The fish pathway in RESRAD-OFFSITE calculates equilibrium surface water concentrations using the water transport model. Bioaccumulation factors in pCi/kg per pCi/L water are then used to calculate the radionuclide concentrations in edible aquatic foods such as fish, crustaceans, and mollusks. The bioaccumulation factors used are found in TABLE 2-6 of the RESRAD-OFFSITE User's Manual (Ref. 7.21). The radionuclide concentration in the aquatic foods is then converted to an annual intake of activity by multiplying the concentration times the average annual consumption of that food type for the individual. The Regulatory Guide 1.109 (Ref. 7.1) Table E-5 annual consumption rates for an adult were used for the fish pathway rather than the RESRAD default values. An annual

consumption of 21 kg/year¹⁵ for fish and 5 kg/year¹⁵ of other aquatic foods such as crustaceans and mollusks was used in the model. These are more conservative than the RESRAD default values. Dose conversion factors (DCFs) are used to convert ingested radionuclide activity to dose. The default RESRAD-OFFSITE dose conversion factors from Federal Guidance Report 11 (FGR 11) were used for these calculations.¹⁶

The bay is modeled as surface water due north of the fuel pool. A point worth noting is that the RESRAD-OFFSITE "Site Layout" input form and "Groundwater Transport" input form use different distances to the Surface Water body. As seen in Figure 17, the "Site Layout" input form considers the distance to surface water body to be from the upgradient edge of the Contaminated Zone. As noted in Section 4.6, groundwater empties into the Bay 420 feet (128.6 meters)¹⁷ from the Spent Fuel Pool (Ref 7.17, 7.18). The "Groundwater Transport" input form, however, requires the distance to the Surface Water body from the downgradient edge of the Contaminated Zone. As noted in Section 4.8 and Footnote 14, a Y axis width of the Contaminated Zone is 7.48 meters. So the distance to the Surface Water for the "Groundwater Transport" input form is $128.6 - 7.48 = 120.5$ meters¹⁷.

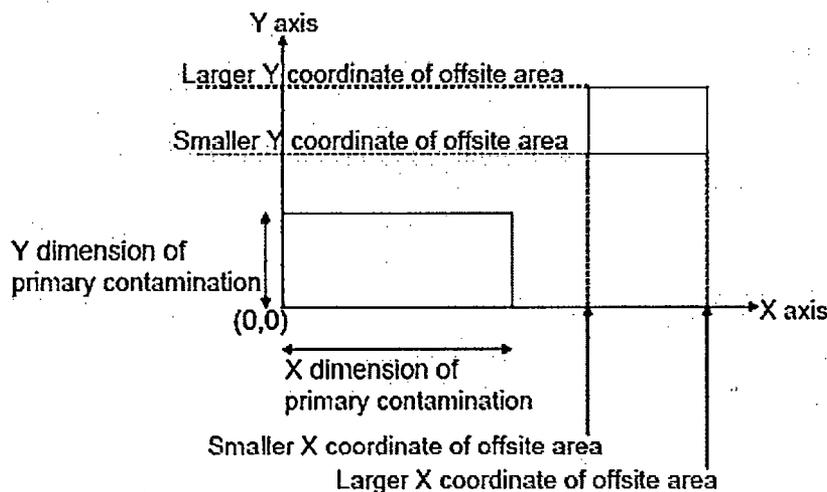


Figure 17 - RESRAD-OFFSITE Site Layout Coordinates

The fish pathway uses a conservative near field volume of $3.33E+5$ cubic meters¹⁸ as the surface water volume. (Ref. 7.29) and assumes a 23% daily replacement volume for the Entrance Bay Area as noted in Section 4.6. This equates to an annual flow quantity of $2.8E+7$ cubic meters/year (e.g., $0.23 \times 3.33E+5$ cubic meters \times 365 days/year). The mean residence time of the surface water is the ratio of the surface water body volume to the annual flow

¹⁵ Annual fish consumption of 21 kg/year and aquatic foods consumption 5 kg/year were used in the RESAD OFF-SITE Model

¹⁶ The Dose Conversion Factor Library to be used is specified RESRAD-OFFSITE-Change Title input form.

¹⁷ Distance to the surface water in Site Layout input form is 128 meters, distance from down gradient edge of contaminated zone in Groundwater Transport input form is 120.5 meters.

¹⁸ Used as surface water volume of surface water body on Groundwater Transport-Surface Water Body input form.

quantity. This provides a mean residence time of 0.084 year¹⁹. Thus the model does not take credit for dispersal throughout the entire bay over the course of a year. This would be based upon a 44% daily replacement volume.

All radionuclides in the Contaminated Zones and Unsaturated Zones were assigned distribution coefficients (K_d s) of 0.001 and b parameter values of 0.001 in order to emulate the rapid release of source term to the Upper Hookton aquifer.

The SAFSTOR Safety Evaluation Report (Ref. 7.18) used the hydrogeological parameters shown in Table 8 for estimating groundwater concentrations at various distances from the fuel pool and rates of travel as the plume migrates toward the bay.

Table 8 - Hydrologic Parameters used by Current SER

Parameter	Value	Units	Value	Units
Mean Tide Level	3.3	ft	1.006	meters
Groundwater Elevation	6 to 9	ft	1.8 to 2.7	meters
Hydraulic Conductivity K	10,400	ft/yr	3.170E+03	m/yr
Effective Porosity	0.25		0.25	
Total Porosity	0.4		0.4	
Longitudinal Dispersion	1	ft	3.048E-01	meters
Lateral Dispersion	0.5	ft	1.524E-01	meters
Distribution Coefficient Cs	20	ml/g	20	ml/g
Distribution Coefficient Sr	0.4	ml/g	0.4	ml/g
Distribution Coefficient Co	1	ml/g	1	ml/g

As seen in Figure 18 and Figure 19 the hydraulic conductivity used in the SARSTOR fuel pool breach calculation are consistent with the values anticipated for sand in the RESRAD Data Collection Handbook (Ref. 7.20). If the lower hydraulic conductivity of 3.15 meters per year noted for the Upper Hookton sand deposits underlying the 1st clay layer is applied, RESRAD-OFSITE provides the following message, "*Under the specified hydrological conditions the recharge through the primary contamination is 64.9991037792915 cubic meters per year. The ground water flow rate under the primary contamination is only 0.6729308 cubic meters per year. Please adjust surface hydrological inputs and / or the thickness of the saturated and unsaturated zones to ensure that the ground water flow under the primary contamination exceeds the recharge through the primary contamination.*" Therefore, the rapid flushing that drives the nuclides from the Contaminated Zone into the Saturated Zone and simulates the release from the Spent Fuel Pool cannot be modeled using the lower hydraulic conductivity value. The same higher hydraulic conductivity value that was used in previous calculations 10,400 ft/yr (3.170E+03 m/yr) was used for this calculation rather than the lower 3.15 m/yr value. The lower hydraulic conductivity would result in a less conservative estimate of dose due to the extended time to migrate to the bay and the intervening radioactive decay. If the hydraulic conductivity in the Upper Hookton is 3.15 m/yr the years in which the peak doses occur would be much further in the future than predicted in this evaluation.

¹⁹ Used as mean residence time in Groundwater Transport-Surface Water Body input form.

Soil Type	Saturated Hydraulic Conductivity, K (m/yr)
Unconsolidated deposits	
Gravel	$1 \times 10^4 - 1 \times 10^7$
Clean sand	$1 \times 10^2 - 1 \times 10^5$
Silty sand	$1 \times 10^1 - 1 \times 10^4$
Silt, loess	$1 \times 10^{-2} - 1 \times 10^2$
Glacial till	$1 \times 10^{-5} - 1 \times 10^1$
Unweathered marine clay	$1 \times 10^{-5} - 1 \times 10^{-2}$
Rocks	
Shale	$1 \times 10^{-6} - 1 \times 10^{-2}$
Unfractured metamorphic and igneous rocks	$1 \times 10^{-7} - 1 \times 10^{-3}$
Sandstone	$1 \times 10^{-3} - 1 \times 10^1$
Limestone and dolomite	$1 \times 10^{-2} - 1 \times 10^1$
Fractured metamorphic and igneous rocks	$1 \times 10^{-1} - 1 \times 10^3$
Permeable basalt	$1 \times 10^1 - 1 \times 10^5$
Karst limestone	$1 \times 10^1 - 1 \times 10^5$

Figure 18 - Range of Saturated Hydraulic Conductivities for Soils

Texture	Saturated Hydraulic Conductivity, K (m/yr)
Sand	5.55×10^3
Loamy sand	4.93×10^3
Sandy loam	1.09×10^3
Silty loam	2.27×10^2
Loam	2.19×10^2
Sandy clay loam	1.99×10^2
Silty clay loam	5.36×10^1
Clay loam	7.73×10^1
Sandy clay	6.84×10^1
Silty clay	3.21×10^1
Clay	4.05×10^1

Figure 19 - Hydraulic Conductivities for Various Soil Textures

As seen in Figure 20 the total porosity and effective porosity in Table 8 are consistent with the values for coarse sand provided in the RESRAD Data Collection Handbook (Ref. 7.20). Course sand is the soil type in the Upper Hookton aquifer.

Material	Total Porosity, n_t		Effective Porosity, n_e	
	Range	Arithmetic Mean	Range	Arithmetic Mean
Sedimentary material				
Sandstone (fine)	^b	-	0.02 - 0.40	0.21
Sandstone (medium)	0.14 - 0.49	0.34	0.12 - 0.41	0.27
Siltstone	0.21 - 0.41	0.35	0.01 - 0.33	0.12
Sand (fine)	0.25 - 0.53	0.43	0.01 - 0.46	0.33
Sand (medium)	-	-	0.16 - 0.46	0.32
Sand (coarse)	0.31 - 0.46	0.39	0.18 - 0.43	0.30
Gravel (fine)	0.25 - 0.38	0.34	0.13 - 0.40	0.28
Gravel (medium)	-	-	0.17 - 0.44	0.24
Gravel (coarse)	0.24 - 0.36	0.28	0.13 - 0.25	0.21
Silt	0.34 - 0.51	0.45	0.01 - 0.39	0.20
Clay	0.34 - 0.57	0.42	0.01 - 0.18	0.06
Limestone	0.07 - 0.56	0.30	0 - 0.36	0.14
Wind-laid material				
Loess	-	-	0.14 - 0.22	0.18
Eolian sand	-	-	0.32 - 0.47	0.38
Tuff	-	-	0.02 - 0.47	0.21
Igneous rock				
Weathered granite	0.34 - 0.57	0.45	-	-
Weathered gabbro	0.42 - 0.45	0.43	-	-
Basalt	0.03 - 0.35	0.17	-	-
Metamorphic rock				
Schist	0.04 - 0.49	0.38	0.22 - 0.33	0.26

^a Effective porosity is discussed in Section 4.

^b A hyphen indicates that no data are available.

Source: McWorter and Sunada (1977).

Figure 20 - RESRAD Data Collection Handbook Total Porosity and Effective Porosity Values for Soil Types

The Saturated Zone distribution coefficients (K_{ds}) shown in Table 8 were used for Co-60, Cs-137, and Sr-90. The basis for the assigned K_{ds} for other dose significant nuclides are discussed below in Section 4.10. A Saturated Zone K_d value of 10 was assigned for Plutonium and all other nuclides were assigned a K_d of 20.

4.10 Saturated Zone Distribution Coefficients for Americium, Plutonium, and Curium

The distribution coefficients used for all radionuclides in the model are provided in Attachment D, RESRAD-OFFSITE Input Parameters. The distribution coefficients for Co-60, Cs-137 and Sr-90 are provided in Table 8 and are the same as those used in the previous fuel pool accident calculations. As discussed in Section 4.4, these K_d s are reasonable and conservative values for the brackish-water coarse sand aquifer of the Upper Hookton aquifer. Carbon 14 is assigned the RESRAD default K_d of zero as is tritium. As seen in Table 9, americium and plutonium radionuclides are also responsible for the majority of the radiation dose in the fish pathway. Therefore the range of K_d values and their basis is provided below.

4.10.1 Americium

Americium readily sorbs to soil, mineral, and crushed rock materials, and exhibits high K_d values. Americium is therefore generally considered to be immobile in soil environments. Americium is a transuranic (actinide) element, and can exist in the +3 oxidation state in natural waters. In moderately to highly acidic conditions dissolved americium III (Am(III)) is present primarily as the uncomplexed cation Am^{3+} . In near neutral to alkaline pH conditions, americium forms aqueous americium carbonate complexes, such as $Am(CO_3)_3^{3-}$ which are increasingly important with increasing concentrations of dissolved carbonate at these pH conditions. (Ref. 7.25) As seen below in Figure 23 in Section 4.4, the pH of the Upper Hookton aquifer is essentially neutral. Therefore, Americium would be expected to form carbonate complexes under these conditions.

Concentrations of dissolved americium may be controlled by precipitation of hydroxide or carbonate solids in some systems. (Ref. 7.25) Concentrations of dissolved Am(III) in soil environments may be controlled by the precipitation of solids such as $Am(OH)_3$ and $AmOHCO_3$, and $Am_2(CO_3)_3$, especially at near neutral and alkaline pH conditions (Felmy et al., 1990; Vitorge, 1992; Silva, 1984; and others). (Ref. 7.25)

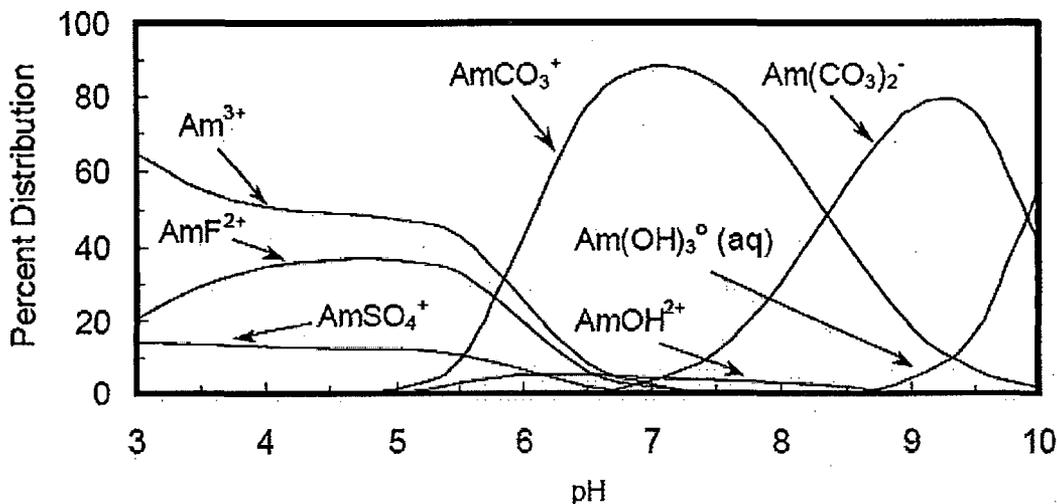


Figure 21 - Thermodynamic Predicted Speciation of Americium at Various pH Values

As shown in Figure 21, at pH 7 the dominant species is a cationic carbonate complex $AmCO_3^+$. For the pH range from 4 to 10, it is suggested that a K_d of 4 ml/g be used as a minimum K_d value for input

forming calculations of americium transport in soils. This value was reported for pH 7.8 by Routson et al.(1975, 1977) and is the lowest K_d value that they gave for experiments conducted with very to moderately dilute calcium and sodium electrolyte solutions. The other K_d values reported by Routson et al.(1975, 1977) for these solution concentrations ranged from 6 ml/g at pH 6.2 to 1,200 ml/g at pH 4.1 and 7.4.(Ref. 7.25)

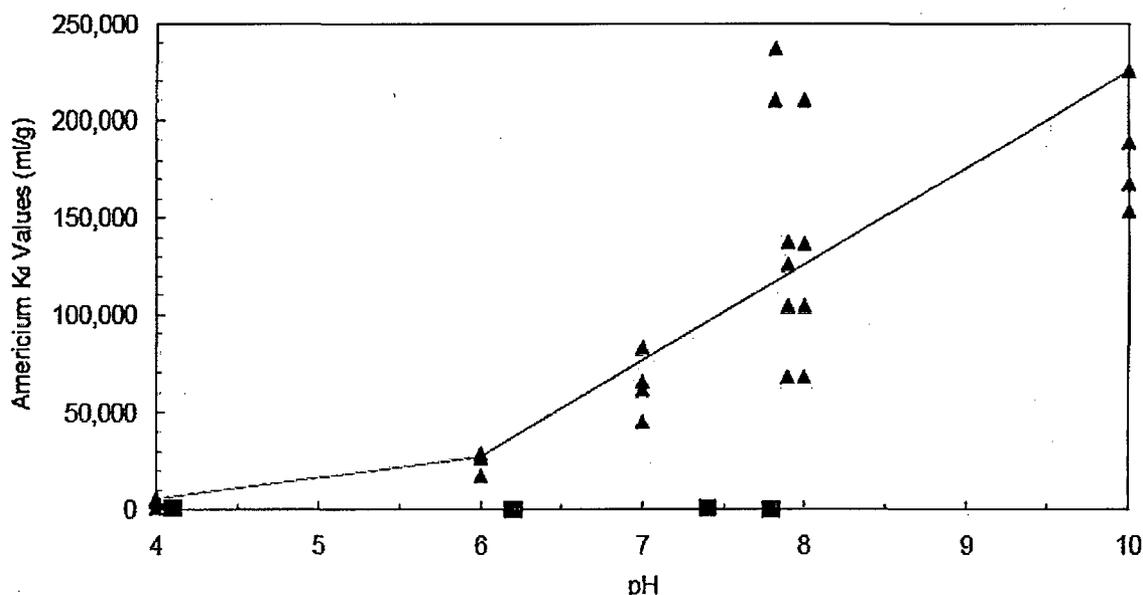


Figure 22 - Maximum Anticipated Am-241 K_d s as a Function of pH

The solid line segments in Figure 22 connects the maximum K_d values reported at pH values of 4, 6, and 10 by Sanchez et al.(1982). The K_d values corresponding to integer pH values between 4 to 10 are, respectively, 5,600, 16,500, 27,300, 76,700, 126,000, 176,000, and 225,000 ml/g based on straight line extrapolations between these 3 K_d values from Sanchez et al.(1982). These values may be considered as conservative maximum K_d values for Am(III) adsorption on soil. Thus at a pH of 7, the minimum K_d would be 4 ml/g with a maximum K_d of 76,700 ml/g.(Ref. 7.25)

Americium(III) is more mobile at low to moderate pH values where the net surface charge on minerals becomes more positive and in high ionic strength solutions. In addition, Americium has been found to be mobilized by colloids such as those of clay and humic acid.

The water quality of the various strata in the Unit 3 area are provided in Figure 23. The Upper Hookton aquifer has nearly neutral pH with high conductivity and high ionic species concentrations such as Sodium, Sulfates and Chlorides. As noted above, these water quality characteristics have bearing on the speciation and sorption on soil of radionuclides that influence the distribution coefficients K_d s that can be expected.

PERCHED GROUNDWATER ZONE (A) IN UPPER HOOKTON SILTS AND CLAYS

South of Unit 3	WCC85-2A	WCC85-3A
Parameter	8/15/85	08/15/85
pH	5.9	6.4
Conductivity	2590	2830
TDS	1510	1620
Sulfate	248	87
Chloride	450	790
Sodium	430	300

PERCHED GROUNDWATER ZONE (A) IN HOLOCENE SILTS AND CLAYS

South of Unit 3	WCC85-4A	WCC85-10B
Parameter	08/15/85	08/15/85
pH	5.8	7.0
Conductivity	5220	6680
TDS	3410	3090
Sulfate	420	405
Chloride	1560	1280
Sodium	780	1000

PERCHED GROUNDWATER ZONE (B) IN HOLOCENE BAY DEPOSITS

Wastewater Pond Site	WCC85-5B	WCC85-7B	WCC85-9B
Parameter	08/15/85	08/15/85	08/15/85
pH	5.4	5.7	6.7
Conductivity	8900	11100	17300
TDS	288	358	9870
Sulfate	1450	1190	987
Chloride	1850	3500	4650
Sodium	1200	2000	1900

UPPER HOOKTON AQUIFER

Southeast of Unit 3	DER85-1	DER85-4	DER85-5	DER85-7	DER85-8	DER85-10
Parameter	04/11/85	04/11/85	04/11/85	04/11/85	04/11/85	4/11/1985
pH	7.0	6.9	7.2	7.0	7.1	7.2
Conductivity	1058	2363	5638	13022	9048	25776
TDS						
Sulfate	49	23	67	77	174	103
Chloride	200	640	1990	4550	3010	9050
Sodium	150	370	1000	2600	2000	5600

LOWER HOOKTON AQUIFER

PG&E Water Supply Wells	Well No. 1	Well No. 1	Well No. 2
Parameter	11/18/93	02/24/94	02/24/94
pH	7.4	7.8	7.7
Conductivity	140	200	150
TDS	130	130	100
Sulfate	1.9	5.8	4.3
Chloride	12	26	13
Sodium	12	18	11

Note: 1. pH is in pH units; conductivity is in micromhos/cm, and others are ppm.
2. See Figures 2.5-1, -9, -12, -13 for location of wells.

Figure 23 - Water Quality Data for Groundwater

The salinity in the Upper Hookton aquifer as measured by the conductivity ranges between 1,100 and 26,000 micromhos/cm and chloride ranges from 200 to 9,000 ppm. The lowest conductivity readings, 1,000 to 2,500, are south of Unit 3. The conductivity is higher around the wastewater pond site where the conductivity is 5,500 to 26,000, probably reflecting salt water intrusion from the marshes in this area.(Ref. 7.19)

Studies of Americium K_d 's in marine estuaries where high salinity and brackish water conditions are encountered yielded K_d s in the 10^4 to 10^8 range.(Ref. 7.25) But these may have been in silt with high organic content. The K_d values have also been shown to decrease with increasing concentrations of dissolved calcium and sodium. Course sandy soils from Washington state were investigated, the K_d values were $>1,200$ ml/g, and were independent of the concentrations of dissolved calcium and sodium. Their calculated K_d values ranged from 1,200 to 8,700 ml/g this was greater than anticipated by the researchers.(Ref. 7.25)

Soil Type	K_d Values (ml/g)		
	Geometric Mean	Number of Observations	Range
Sand	1,900	29	8.2 - 300,000
Silt	9,600	20	400 - 48,309
Clay	8,400	11	25 - 400,000
Organic	112,000	5	6,398 - 450,000

Figure 24 - Range of Americium K_d s for Various Soil Types Listed by Thibault et al.(Ref. 7.25)

The RESAD-OFFSITE default K_d for Americium is 20 ml/g. This is at the lower end of the potential K_d s that could be expected for course sandy soil at a pH of 7. Given the above discussion concerning sodium ion competition, clay colloid mobilization, and lower K_d s in high ionic strength solutions, this K_d is appropriate for the course sand brackish water conditions of the Upper Hookton aquifer which is bounded at the top and bottom by clay deposits.

4.10.2 Curium

Curium is a transuranic (actinide) element, and can exist in the +3 oxidation state in natural waters. Cm(III) geochemistry is expected and widely accepted to be very similar to that of Am(III) and trivalent lanthanide elements, such as europium (III), Eu(III). Compared to other actinides, Cm(III) and Am(III) are considered to be immobile in soil environments, and both exhibit high K_d values. Figure 25 indicates that curium can exist as several aqueous species at a neutral pH.(Ref. 7.25)

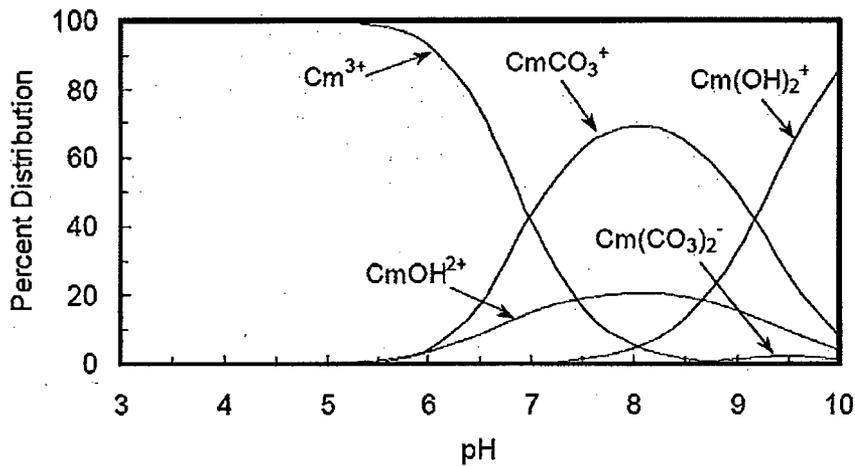


Figure 25 - Calculated Distribution of Cm Aqueous Species Using MINTEQA2 Thermodynamic Database
Available curium sorption studies indicate that sorption of curium is strongly pH dependent and increases with increasing pH with peak adsorption occurring between pH values of 5 and 6. The observed pH dependence is expected, because the dominant aqueous species of curium in the pH range of natural waters are primarily cations such as Cm³⁺ and Cm(III) carbonate complexes at acidic and basic pH values, respectively. (Ref. 7.25)

The limited number of K_d adsorption studies for Cm(III) in soils prevents calculation of K_d look-up tables. However, the sorption behavior of Cm(III) is very similar to that of Am(III) (see Section 5.2) and trivalent lanthanide elements, such as Eu(III). Guidance given above for K_d values for Am(III) in Section 5.2 can be used for input forming calculations of Cm(III) migration in soils. (Ref. 7.25)

Soil Type	K _d Values (ml/g)		
	Geometric Mean	Number of Observations	Range
Sand	4,000	2	780 - 22,970
Silt	18,000	4	7,666 - 44,260
Clay	6,000	1	
Organic	6,000	1	

Figure 26 - Curium K_d values (ml/g) listed in Thibault et al. (1990, Tables 4 to 8).

The RESRAD-OFFSITE default K_d for curium is 1,378 ml/g. Because of the lack of pH specified K_ds and the similarity of curium to americium the same low K_d of 20 was assigned for the Saturated Zone curium K_ds.

4.10.3 Plutonium

In the ranges of pH and conditions typically encountered in the environment, plutonium can exist in all 4 oxidation states, namely +3, 4, +5, and +6. Under oxidizing conditions, Pu(IV), Pu(V), and Pu(VI) are common, whereas, under reducing conditions, Pu(III) and Pu(IV) would exist. Dissolved plutonium forms very strong hydroxy-carbonate mixed ligand complexes, therefore, its adsorption and mobility is strongly affected by these complex species. (Ref. 7.24) Plutonium is known to adsorb onto soil components such as clays, oxides, hydroxides, oxyhydroxides, aluminosilicates and organic matter. Depending on the properties of the substrate, pH, and the composition of solution, plutonium would adsorb with affinities varying from low ($K_d = 11$ ml/g) to extremely high ($K_d = 300,000$ ml/g) (Baes and Sharp, 1983; Coughtrey et al., 1985; Thibault et al., 1990). Plutonium in the higher oxidation state adsorbed on iron oxide surfaces may be reduced to the tetravalent state by Fe(II) present in the iron oxides. At pH values exceeding 6.5, the bulk of the dissolved plutonium (~90 percent) would be comprised of the $\text{Pu}(\text{OH})_2(\text{CO}_3)_2^{2-}$ species with a minor percentage of $\text{Pu}(\text{OH})_4^{0}(\text{aq})$. These illustrative computations indicate that, under pH conditions that typically exist in surface and groundwaters (>6.5), the dominant form of dissolved plutonium would be the tetravalent complex species, $\text{Pu}(\text{OH})_2(\text{CO}_3)_2^{2-}$.

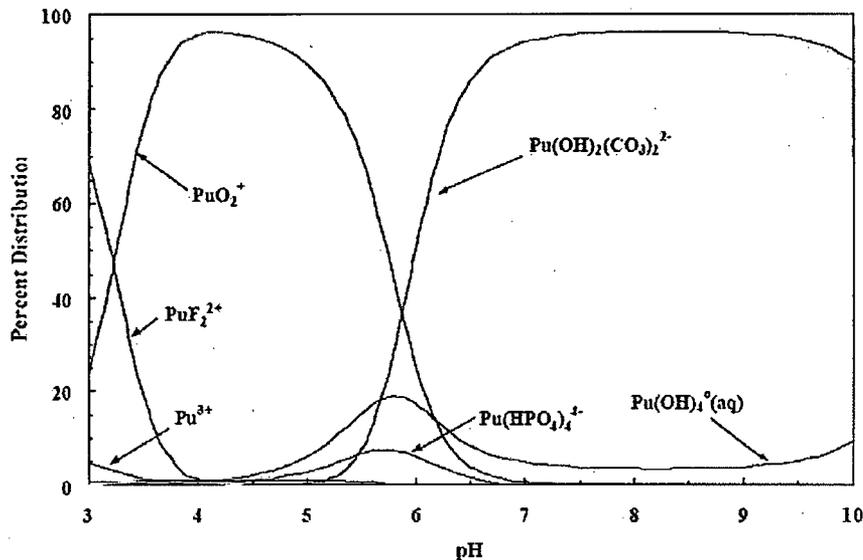


Figure 27- Calculated Distribution of Pu Aqueous Species Using MINTEQA2 Thermodynamic Database

K_d (ml/g)	Clay Content (wt.%)								
	0 - 30			31 - 50			51 - 70		
	Soluble Carbonate (meq/l)			Soluble Carbonate (meq/l)			Soluble Carbonate (meq/l)		
	0.1 - 2	3 - 4	5 - 6	0.1 - 2	3 - 4	5 - 6	0.1 - 2	3 - 4	5 - 6
Minimum	5	80	130	380	1,440	2,010	620	1,860	2,440
Maximum	420	470	520	1,560	2,130	2,700	1,980	2,550	3,130

Figure 28 - Estimated range of K_d values for plutonium as a function of the soluble carbonate and soil clay content values

Figure 28 shows that for low clay soils such as the course sand of the Upper Hookton, K_d can range from a low of 5 ml/g to a maximum of 520 ml/g. The REDRAD-OFFSITE default K_d for plutonium is 2000 ml/g. Given the above considerations, a value of 10 ml/g is used as the Saturated Zone K_d for plutonium radionuclides. (Ref. 7.24)

4.11 Calculated Pathway Annual Doses

Using these parameters and distribution coefficients for the other radionuclides the following doses were predicted for the fish pathway.

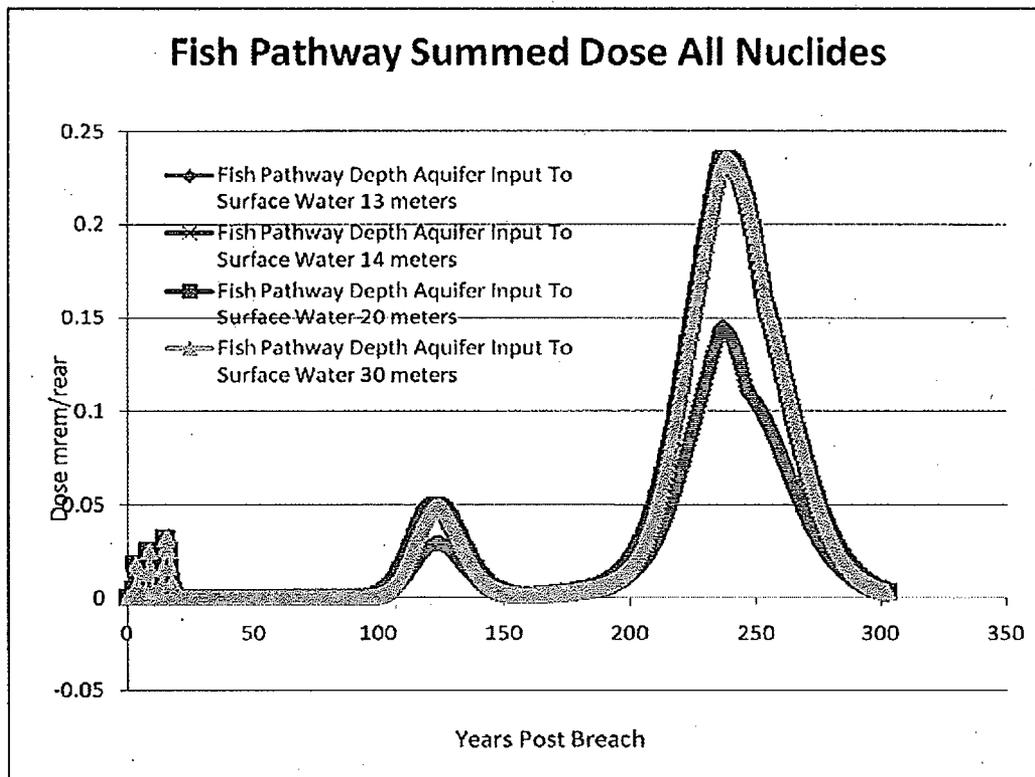


Figure 29 - Temporal Graph of Fish Pathway Dose at various Aquifer Input Depths

The graph in Figure 29 shows that the highest dose in any one year occurs at year 250 and is about 0.24 mrem/year. This graph also shows that once the depth of the aquifer input to the surface water exceeds 14 meters, the calculated doses remain constant. RESRAD OFFSITE assumes a reflective aquitard that is twice the depth of the water table.(Ref. 7.21) As seen in Figure 7, this means the aquitard mirror is modeled at approximately 40 feet below the top of the Upper Hookton aquifer. Concentrations equalize across the aquifer using this method due to reflection off the lower aquitard. The RESRAD-OFFSITE manual states "*Dispersion is considered to be inactive in the vertical direction, if the concentration profile in the vertical direction becomes essentially uniform because of repeated reflection of the plume by the lower impermeable layer and the water table. It is also inactive if a zero value is specified for the vertical-lateral dispersivity.*"(Ref. 7.21) Thus, groundwater concentrations calculated by RESRAD-OFFSITE are representative of those that would be anticipated in a semi-confined aquifer such as the Upper Hookton course sand aquifer.

Table 9 shows the calculated peak dose for each radionuclide and the year in which it is predicted to occur. Peak doses include the contribution from the daughter radionuclides. The variance in the year in which the peak dose occurs for different nuclides is driven mainly by the distribution coefficient, which controls the rate at which the nuclide migrates through the aquifer. Nuclides such as H-3 and C-14 which have K_d s of zero reach the bay within a few years. If the lower hydraulic conductivity value of 3.15 meters per year was used, breakthrough times to the bay would be much longer than those in this model.

The table shows that the sum of the peak doses is 0.371 mrem/year. Thus, if all of the radionuclides reached the bay in the same year, the fish pathway dose would be approximately 0.4 mrem/year. Since it unlikely that all radionuclides would migrate at the same rate, the best estimate of the peak dose that would result in any one year is the 0.24 mrem value at 250 years.

Table 9- Fish Pathway Peak Doses

Nuclide	Contaminated Zone Concentration pCi/g	Peak Dose	%Peak Dose Total	Peak Year	Fuel Pool Concentration 1 mrem/year per µCi/ml
Ac-227	7.00E+00	2.76E-06	0.00%	231.4	2.54E+00
Am-241	7.50E+02	0.187	50.49%	242.6	4.00E-03
C-14	7.16E+00	1.85E-02	4.99%	3.0	3.86E-04
Cm-243	1.51E+02	7.22E-05	0.02%	234.4	2.08E+00
Cm-244	1.51E+02	8.36E-05	0.02%	128.4	1.80E+00
Co-60	5.22E+03	3.27E-02	8.80%	14.8	1.60E-01
Cs-137	1.22E+03	1.19E-04	0.03%	234.4	1.02E+01
Eu-154	3.13E+01	9.65E-14	0.00%	217.2	3.24E+08
Fe-55	1.09E+03	2.03E-29	0.00%	179.9	5.36E+25
H-3	3.03E+01	0.000	0.00%	3.0	6.41E+02
Ni-59	6.99E+01	0.000	0.00%	243.2	9.85E+01

Nuclide	Contaminated Zone Concentration pCi/g	Peak Dose	%Peak Dose Total	Peak Year	Fuel Pool Concentration 1 mrem/year per µCi/ml
Ni-63	1.08E+04	0.000	0.01%	240.3	2.39E+02
Pu-238	2.30E+02	0.011	2.87%	122.5	2.16E-02
Pu-239	1.32E+02	0.019	5.21%	123.1	6.82E-03
Pu-240	1.32E+02	0.019	5.16%	123.1	6.89E-03
Pu-241	4.13E+03	0.057	15.44%	236.1	7.20E-02
Sr-90	2.74E+02	0.026	6.95%	8.3	1.06E-02
U-233	2.34E-01	0.000	0.00%	244.4	8.87E-02
U-234	2.34E-01	0.000	0.00%	243.8	3.08E-01
U-235	6.45E-02	0.000	0.00%	244.4	9.42E-02
U-236	6.45E-02	0.000	0.00%	243.2	3.91E-01
U-238	1.87E-01	0.000	0.00%	243.2	3.91E-01
Total Peak Dose		3.71E-01	1.00E+00		

The last column in Table 9 shows the concentration in the fuel pool which results in 1 mrem/year through the fish pathway for each radionuclide. It can be seen that very high fuel pool concentrations would be required to reach the emergency planning protective action guideline (PAG) of 1000 mrem at the Site Boundary. This should help provide a basis for evaluating the off-site dose consequences as source terms in the fuel pool change over the course of the decommissioning, such as during reactor vessel internals segmentation.

4.12 Groundwater Concentrations Released to the Bay

The radionuclide concentrations in groundwater entering the bay can be estimated by modeling a well down gradient at 119.5 meters from the Contaminated Zone. This will yield the calculated groundwater concentrations 1 meter before it enters the bay. Table 10 shows the peak concentration and the year in which it occurs for all radionuclides, including daughter nuclides. The MPC values are from the January 1, 1992, 10 CFR 20 Appendix B, Table 2 Liquid Effluent Values. If all the radionuclides reached the bay at their peak concentrations simultaneously, the sum of the MPC fractions would be 1.17. Thus there would be no significant environmental impact on the Bay.

Table 10 - Calculated Groundwater Concentrations Entering Humboldt Bay

Nuclide	Year	Max µCi/ml	NRC Limit µCi/ml	NRC Limit Fraction	Nuclide	Year	Max µCi/ml	NRC Limit µCi/ml	NRC Limit Fraction
Ac-227	252.7	3.22E-14	5.00E-09	6.45E-06	Pu-238	132.8	2.30E-09	2.00E-08	1.15E-01
Am-241	257.8	8.88E-09	2.00E-08	4.44E-01	Pu-239	134.1	3.76E-09	2.00E-08	1.88E-01
Am-243	263.6	1.97E-14	2.00E-08	9.87E-07	Pu-240	134.1	3.73E-09	2.00E-08	1.86E-01
C-14	3.9	1.06E-08	3.00E-05	3.54E-04	Pu-241	128.9	2.19E-10	1.00E-06	2.19E-04
Cm-243	253.9	4.08E-12	3.00E-08	1.36E-04	Ra-226	264.3	4.72E-16	6.00E-08	7.87E-09

Nuclide	Year	Max μCi/ml	NRC Limit μCi/ml	NRC Limit Fraction	Nuclide	Year	Max μCi/ml	NRC Limit μCi/ml	NRC Limit Fraction
Cm-244	248.8	1.23E-13	3.00E-08	4.11E-06	Ra-228	265.5	1.18E-20	6.00E-08	1.96E-13
Co-60	16.8	1.43E-07	3.00E-06	4.77E-02	Sr-90	9.0	9.32E-08	5.00E-07	1.86E-01
Cs-137	254.6	4.50E-11	1.00E-05	4.50E-06	Th-228	265.5	1.17E-20	2.00E-07	5.83E-14
Eu-154	235.9	1.45E-18	7.00E-06	2.08E-13	Th-229	265.5	8.33E-14	2.00E-08	4.16E-06
Fe-55	195.3	1.82E-33	1.00E-04	1.82E-29	Th-230	263.0	8.62E-15	1.00E-07	8.62E-08
H-3	3.9	3.75E-08	1.00E-03	3.75E-05	Th-232	265.5	1.22E-20	3.00E-08	4.06E-13
Ni-59	263.6	1.01E-09	3.00E-04	3.36E-06	U-233	263.6	3.38E-12	3.00E-07	1.13E-05
Ni-63	261.0	2.36E-08	1.00E-04	2.36E-04	U-234	261.0	3.68E-12	3.00E-07	1.23E-05
Np-237	260.4	9.15E-13	2.00E-08	4.58E-05	U-235	263.6	9.33E-13	3.00E-07	3.11E-06
Pa-231	265.5	5.20E-15	6.00E-09	8.66E-07	U-236	263.6	9.35E-13	3.00E-07	3.12E-06
Pb-210	264.9	3.72E-16	1.00E-08	3.72E-08	U-238	263.6	2.71E-12	3.00E-07	9.02E-06
Po-210	264.9	3.70E-16	4.00E-08	9.26E-09				Total	1.17E+00

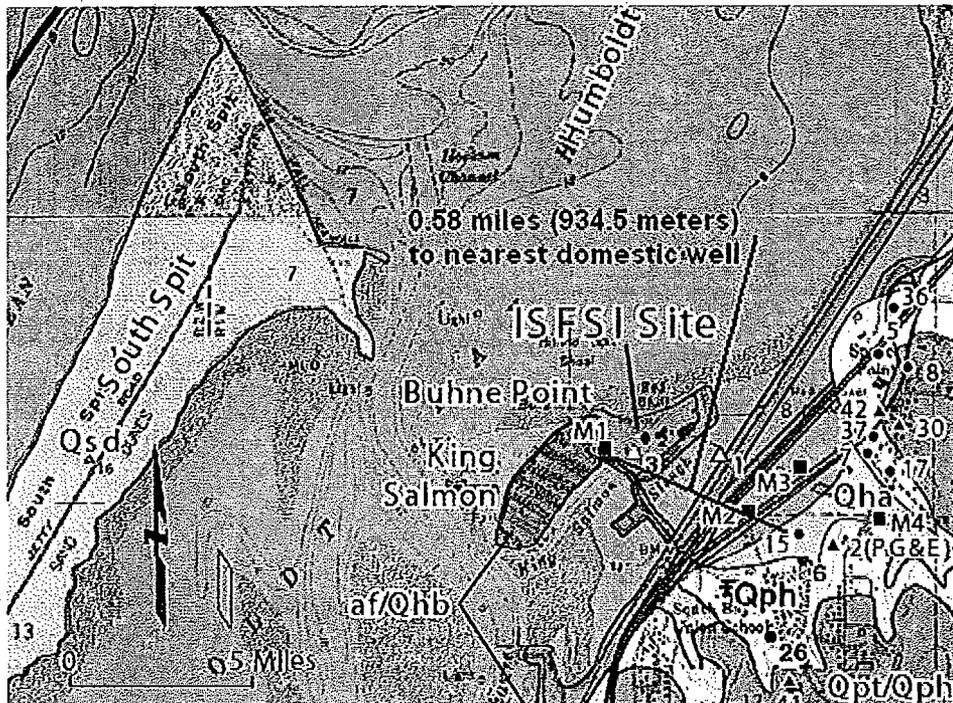
4.13 Drinking Water Pathway

As noted in Section 4.4, the Upper Hookton aquifer is a brackish water aquifer. The confined nature of the deeper, lower Hookton aquifer (the two PG&E industrial wells were artesian at the time of installation) also serves to protect this zone by preventing downward vertical migration of brackish water.

The two potable water wells nearest the spent fuel pool were owned by PG&E. Well No. 1 is about 600 feet east of the site and Well No. 2 is about 2,980 feet southeast of the site. These wells, which were sampled quarterly for activity, provided onsite water supplies but are no longer used. (Ref. 7.18) The nearest potable water wells in use at present are south of the facility on the other side of Route 101. It is not feasible for radionuclides to migrate upgradient for this distance. The distance from the Contaminated Zone to the well is the "Distance in the Direction Parallel to Aquifer Flow from Contamination to Well:" on the REDRAD Groundwater Transport input form. The user's manual states, "*This is the distance, in meters (m), along a groundwater flow line from the downgradient edge of the primary contamination to the well. It is used in the computation of transport in the saturated zone to the well. A negative value indicates that the well is either upgradient of or within the primary contamination. If this value is negative or if the combination of water and land usage and exposure pathways indicates that well water has no influence on dose, the computational code will skip the well water concentration computations.*" (Ref. 7.21) Thus upgradient concentrations cannot be calculated by RESRAD-OFFSITE.

The ISFSI FSAR states (Ref. 7.19) "*The Humboldt Bay Municipal Water District (HBMWD) provides water to residential and industrial users in the Humboldt Bay area. The district operates two separate water systems. Drinking water is supplied through the domestic water system. Raw water, used only for industrial purposes, is taken directly from the surface of the Mad River and delivered, untreated, to industrial customers. HBMWD produces a capacity of 20 million gallons per day of water from five Ranney wells in the Mad River near Essex. The*

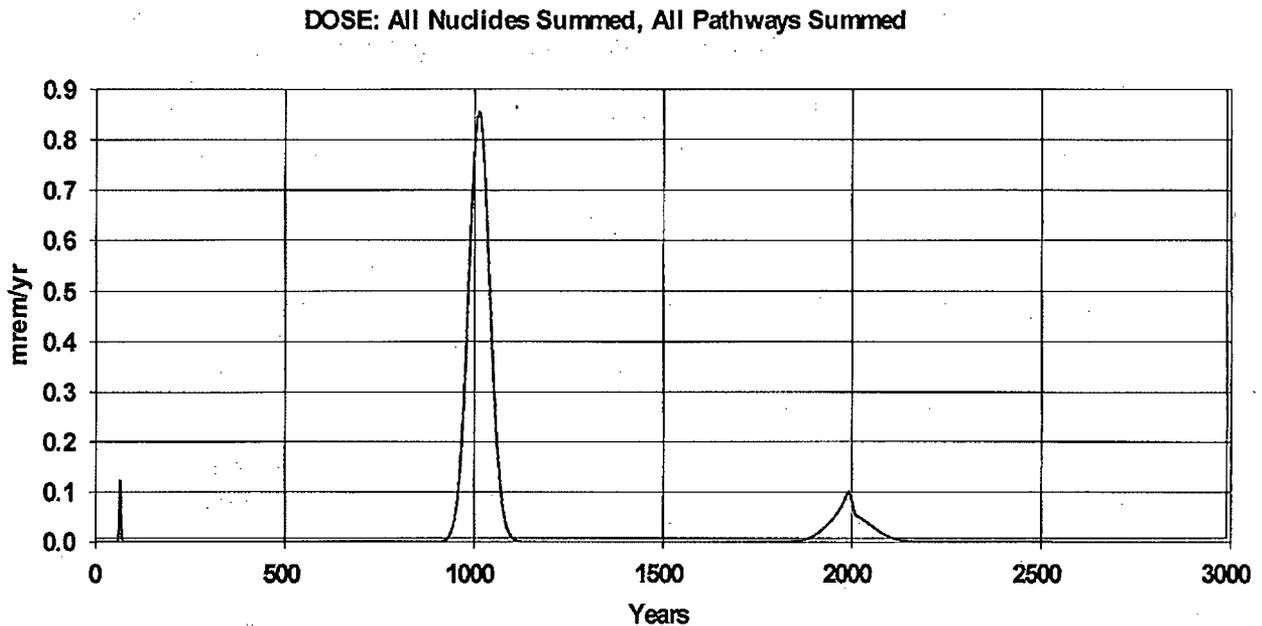
City of Eureka General Plan Background Report identifies three groundwater wells located within 1 mile of the ISFSI site."



- 13 • Domestic wells
- 12 ▲ Industrial/irrigation/monitoring wells

Figure 30 - Excerpt from ISFSI FSAR Figure 2.5-1 Showing Nearest Domestic Wells to Site

As seen in Figure 30 the interpolated distance based upon the key, which is 0.5 miles, to the nearest domestic water well is 0.58 miles or 934.5 meters. To evaluate worst case potential doses for the nearest Domestic Well, the fish pathway is turned off, such that only the water pathway is turned on, and the downgradient well was located 934.5 meters from the Spent Fuel Pool. As seen in Attachment B, the ingestion rates assumes 730 liters per of potable water from the well. This is the Regulatory Guide 1.109 annual drinking water ingestion quantity from Table E-5.(Ref. 7.1) This assumes that the domestic well is the only source of potable water. The water use parameters in the Groundwater Transport input form also assume that 225 liters per day is used in the indoor dwelling. As seen in Figure 31, the predicted maximum annual dose occurs at around 1000 years post breach and would result in a peak annual dose of approximately 0.85 mrem/year.



HUMBOLDT-SFP FINAL Domestic Water:ROF 05/25/2009 17:19 GRAPHICS ASC. Includes All Pathways

Figure 31 - Hypothetical Annual Doses if Nearest Domestic Water Well was Located Down Gradient

This represents a worst case bounding dose which assumes the domestic water well is in the Upper Hookton aquifer, rather than the fresh water aquifer of the Lower Hookton and that the well is down gradient. There is no viable drinking water pathway. It is also unlikely that a brackish water aquifer would be use for irrigation.

4.14 Potential Impact on Decommissioning

The regulation 10 CFR 50.82(a)(6) states that the licensee must not perform any decommissioning activity that (1) forecloses release of the site for possible unrestricted use, (2) results in any significant environmental impact not previously reviewed, or (3) results in there no longer being reasonable assurance that adequate funds will be available for decommissioning.(Ref. 7.3)

As noted in Section 4.8, 4.9, and 4.10 very conservative assumptions were made in this evaluation relative the amount of sludge and source term that would be dispersed below the Spent Fuel Pool in the Upper Hookton aquifer and the solubility and mobility of that material. It is unlikely that the entire sludge source term would be released to from the breach. It is also unlikely that the less soluble radionuclides such as the transuranics, would be released rapidly to the surrounding groundwater given the insoluble nature of the hematite, spinels and uranium oxides in which they are concentrated. A large fraction of the source term would be retained in the localized area under the spent fuel building with the insoluble sludge. In addition a very high hydraulic conductivity that was several orders of magnitude higher then the measured value of 3.15 meters/year for the Upper Hookton was used. This will also slow the dispersal of the material.

The material could be recovered by excavating the contaminated soil using equipment in the bottom of the spent fuel pool during the decommissioning. It is unlikely that the consequences of a breach would impact the 50.82(a)(6) criteria since soil decontamination equipment and associated personnel will be available to immediately initiate decontamination activities at the site.

5.0 Conclusion

This evaluation did not find a condition or consequence that has not been previously evaluated or that is outside the licensing basis for Humboldt Bay Unit 3. A breach of the spent fuel pool would occur with trained radiation workers, supervision, and Health Physics technicians present. Due to the high water table, there would be no direct radiation levels that exceed those encountered during decommissioning activities as a result of the breach and lowering of the spent fuel pool water level. In addition, the materials and resources to contain, control, decontaminate and mitigate airborne and removable contamination that might result from a heavy load drop are available on site. There would be no on-site dose consequences that would lead to excessive personnel exposures or pose a risk to future decommissioning activities.

Off-Site and environmental consequences due to a heavy load accident are likely to result from the release of the source term to the Upper Hookton aquifer. Due to the 19' 4" thick layer of material, which includes a 1st layer clay aquitard and a lower Unit F Clay aquitard, which semi-confine the aquifer, the contaminants are likely to remain in the Upper Hookton brackish water aquifer until they are discharged to the Bay or the Pacific Ocean. Due to the 1st clay aquitard and depth at which the release would occur, the radionuclides are unlikely to migrate into near surface perched groundwater above it. Due to the Unit F clay aquitard below the Upper Hookton aquifer, migration to the Lower Hookton freshwater aquifer is also unlikely. Since the Upper Hookton aquifer is brackish water, there are no down gradient domestic water or industrial water wells. Thus the only viable off-site exposure pathway is through consumption of aquatic foods harvested from the near field region where the Upper Hookton aquifer discharges into the bay. The modeled doses using RESRAD-OFFSITE were 0.24 mrem/year from the fish pathway, with a worst-case sum of the peak dose of 0.4 mrem/year. The worst case sum of the peaks concentration for the groundwater discharging into the bay was 1.17 times the 1992 10 CFR 20, Appendix B, Table 2, Liquid Effluent MPCs. These calculations were very conservative and assumed 100% of the source term in the fuel pool was liberated to the aquifer within 40 days of the breach. It also assumed very low distribution coefficient (K_d values) for the radionuclides released, even though over 90% of the source term released was from insoluble sludge at the bottom of the fuel pool. A conservative surface water volume of 3.33E+5 cubic meters was used even though the Bay is on the order of 7E+8 cubic meters in volume. The lowest daily volume exchange from tidal action 23% for the three bay areas was used to calculate the surface water mean residence time. The more conservative annual aquatic food consumption values from Regulatory Guide 1.109 were also applied to the calculation.

In addition, although the nearest domestic well is located 0.58 miles upgradient from the fuel pool, the potential dose from drinking water and domestic water use at this distance was evaluated. This assumed the well was located 0.58 miles or 934.5 meters downgradient from the Contaminated Zone created by the release. The peak calculated annual dose occurred 1000 years post breach and resulted in 0.85 mrem/year assuming the well was the only

source of drinking water and water for domestic use. Based upon the results of this evaluation there are no significant off-site dose consequences of a heavy load drop for the spent fuel pool under current conditions and the consequence of the accident are bounded by the Liquid Tank release accidents evaluated in the Decommissioning FSAR.

6.0 Attachments

- 6.1 Attachment A – Map of ISFSI and Unit 3 Site Area Showing Geological Borings and Monitoring Wells**
- 6.2 Attachment B – Buhne Point Geological Strata and Aquifers**
- 6.3 Attachment C – Upper Hookton Groundwater Contours at MLLW**
- 6.4 Attachment D – RESRAD-OFFSITE Input parameters**

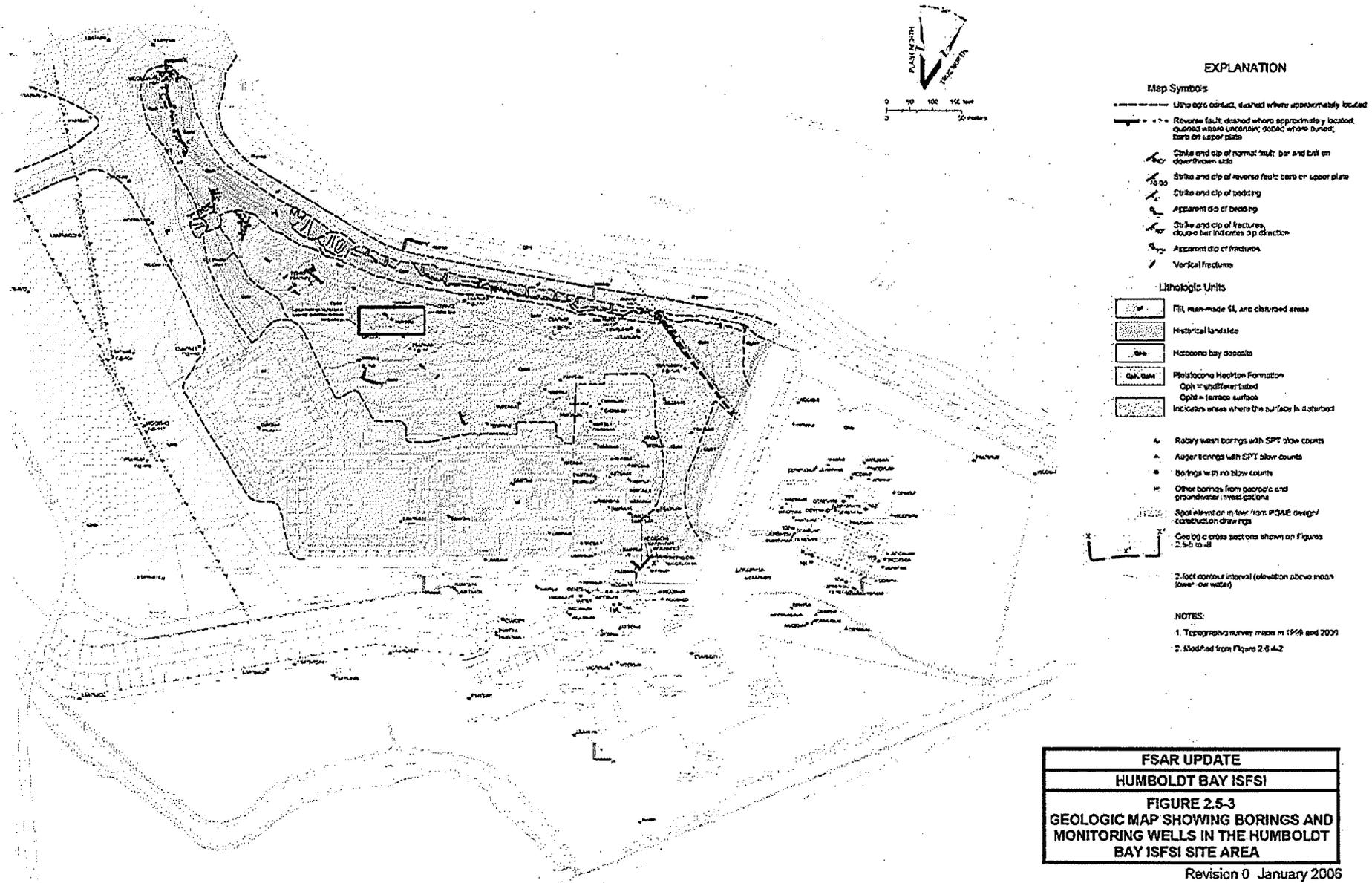
7.0 References

- 7.1 NRC Regulatory Guide 1.109, Calculation of Annual Doses To Man From Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10 CFR Part 50, Appendix I.**
- 7.2 NRC Regulatory Guide 1.179, Standard Format and Content of License Termination Plans for Nuclear Power Reactors, January 1999**
- 7.3 NRC Regulatory Guide 1.184, Decommissioning of Nuclear Power Reactors, July 2000**
- 7.4 NRC Regulatory Guide 1.185, "Standard Format and Content for Post-shutdown Decommissioning Activities Report, July 2000**
- 7.5 NRC Regulatory Guide 1.186, Guidance and Examples for Identifying 10 CFR 50.2 Design Bases, December 2000**
- 7.6 NRC Regulatory Guide 1.187, Guidance for Implementation of 10 CFR 50.59, Changes, Tests, And Experiments, November 2000**
- 7.7 NUREG-0586, Final Generic Environmental Impact Statement (GEIS) on Decommissioning of Nuclear Facilities, August 1988**
- 7.8 NUREG-0586, Volume 1, Supplement 1, Final Generic Environmental Impact Statement (GEIS) on Decommissioning of Nuclear Facilities, November 2002.**
- 7.9 NUREG-1496, Generic Environmental Impact Statement in Support of Rulemaking on Radiological Criteria for License Termination of NRC Licensed Nuclear Facilities, Volume 1, July 1997**
- 7.10 NUREG-1738, Technical Study of Spent Fuel Pool Accident Risk at Decommissioning Nuclear Power Plants, October 2000**
- 7.11 Nuclear Energy Institute 96-07 Guidelines for 10 CFR 50.59 Evaluations Final Draft -February 22, 2000**
- 7.12 PG&E 652969, Humboldt Bay Power Plant, Unit No. 3, Plant Data, Bechtel Corporation Power Industrial Division, 1963**

- 7.13 Swedish Nuclear Power Inspectorate (SKI) Report 00:5, On the interaction between fuel crud and water chemistry in nuclear power plants, Part 1 A Literature Survey, by Jiaxin Chen, Studsvik Material AB, SE-611 82 Nykoping Sweden, January 2000
- 7.14 PNNL-16018, Transportability Class of Americium in K Basin Sludge under Ambient and Hydrothermal Processing Conditions, C. H. Delegard, B. E. Schmitt, A. J. Schmidt, Prepared for the U.S. Department of Energy under Contract DE-AC05-76RL01830 Pacific Northwest National Laboratory Richland, Washington 99352, August 2006
- 7.15 IAEA-TECDOC-1012, Durability of Spent Nuclear Fuels and Facility Components in Wet Storage, IAEA, VIENNA, April 1998
- 7.16 Assessing the Origin and Fate of Cr, Ni, Cu, Zn, Pb, and V in an Industrial Polluted Soil by Combined Microspectroscopic Techniques and Bulk Extraction Methods, R. Terzano et al., Environ. Sci. Technol., 41, 6762-6769.
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- 7.18 NRC Humboldt Bay Power Plant, Unit No. 3, Decommissioning, Safety Evaluation Report, Docket No. 50-133, April 29, 1987.
- 7.19 Humboldt Bay Independent Spent Fuel Storage Installation, Pacific Gas and Electric Company, Final Safety Analysis Report Update, Revision 1 November 2007, PG&E Letter HIL-07-002, NRC Docket No. 72-27.
- 7.20 Data Collection Handbook To Support Modeling Impacts Of Radioactive Material In Soil, by C. Yu, C. Loureiro*, J.-J. Cheng, L.G. Jones, Y.Y. Wang, Y.P. Chia,* and E. Faillace Environmental Assessment and Information Sciences Division Argonne National Laboratory, Argonne, Illinois April, 1993
- 7.21 NUREG/CR-6937, DOE/HS-0005 User's manual for RESRAD Offsite Version 2, Argonne National Laboratory, C. Yu, et al., June 2007.
- 7.22 ANL/EAD-4, User's Manual for RESRAD Version 6, Environmental Assessment Division Argonne National Laboratory, by C. Yu, A.J. Zielen, J.-J. Cheng, D.J. LePoire, E. Gnanapragasam, S. Kamboj, J. Arnish, A. Wallo III,* W.A. Williams,* and H. Peterson*, July 2001
- 7.23 EPA 402-R-99-004A, Understanding Variation In Partition Coefficient, Kd, Values; Volume I: The Kd Model, Methods of Measurement, and Application of Chemical Reaction Codes, United States Environmental Protection Agency, August 1999.
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- 7.26 Environmental Report for the Decommissioning of Humboldt Bay Power Plant Unit No. 3, Prepared by Beverly S. Ausmus, et al, Bechtel Advanced Technology Division,

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- 7.29 RSCS Technical Support Document (TSD) 08-041, Evaluation of the Radiological Impact of No Circulating Water Flow in the Humboldt Bay Discharge Canal, April 2009.
- 7.30 Regulatory Guide 4.21 (Draft was issued as DG-4012) Minimization of Contamination and Radioactive Waste Generation: Life-Cycle Planning, June 2008
- 7.31 10 CFR Part 20, Standards for Protection Against Radiation, Section 20.1406, Minimization of Contamination, U.S. Nuclear Regulatory Commission, Washington, DC.



EXPLANATION

Map Symbols

- Lithologic contact, dashed where approximately located
- - - Reverse fault, dashed where approximately located, equalized where uncertain; solid where buried; zero on upper plate
- Strike and dip of normal fault; bar and tail on downthrown side
- Strike and dip of reverse fault; bar on upper plate
- Strike and dip of bedding
- Apparent dip of bedding
- Strike and dip of fractures, double bar indicates dip direction
- Apparent dip of fractures
- Vertical fractures

Lithologic Units

- Fill, man-made fill, and disturbed areas
- Historical landslide
- Katooma bay deposits
- Pleistocene Haeffern Formation
- Open to underdrifted
- Cyrt = terrace surface
- Indicates areas where the surface is a disturbed

- Rotary well borings with SPT blow counts
- Auger borings with SPT blow counts
- Borings with no blow counts
- Other borings from geologic and groundwater investigations
- Spot elevations in feet from PCME design construction drawings
- Geologic cross sections shown on Figures 2.5-5 to 2.5-11
- 2-foot contour interval (elevation above mean lower low water)

NOTES:

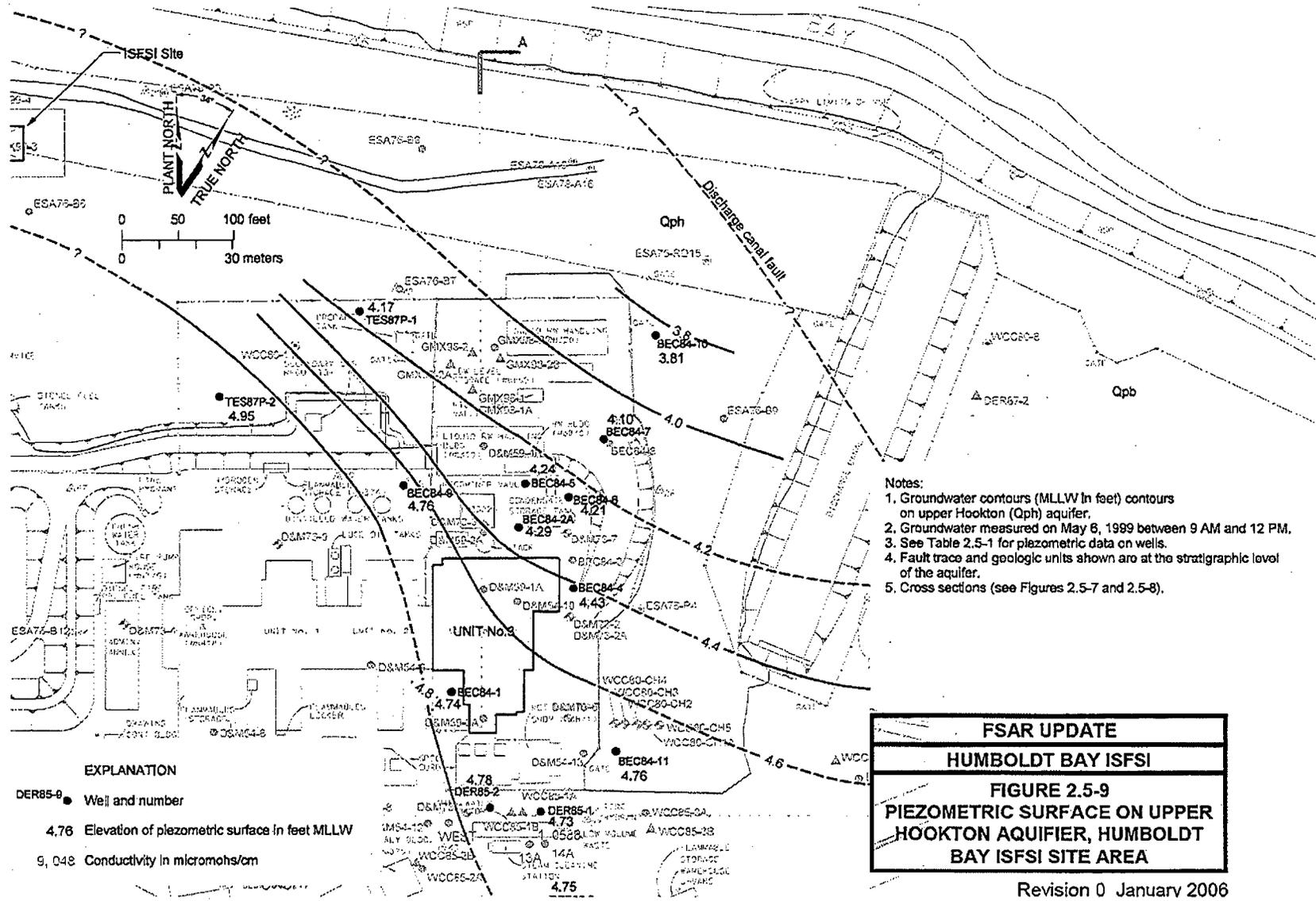
1. Topographic survey made in 1969 and 2001
2. Modified from Figure 2.6-4.2

FSAR UPDATE
HUMBOLDT BAY ISFSI
FIGURE 2.5-3
GEOLOGIC MAP SHOWING BORINGS AND
MONITORING WELLS IN THE HUMBOLDT
BAY ISFSI SITE AREA

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ATTACHMENT C
Upper Hookton Groundwater Contours at MLLW

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- Notes:
1. Groundwater contours (MLLW in feet) contours on upper Hookton (Qph) aquifer.
 2. Groundwater measured on May 6, 1999 between 9 AM and 12 PM.
 3. See Table 2.5-1 for piezometric data on wells.
 4. Fault trace and geologic units shown are at the stratigraphic level of the aquifer.
 5. Cross sections (see Figures 2.5-7 and 2.5-8).

- EXPLANATION**
- DER85-9 Well and number
 - 4.76 Elevation of piezometric surface in feet MLLW
 - 9, 048 Conductivity in micromohs/cm

FSAR UPDATE
HUMBOLDT BAY ISFSI
FIGURE 2.5-9
PIEZOMETRIC SURFACE ON UPPER
HOOKTON AQUIFER, HUMBOLDT
BAY ISFSI SITE AREA

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**ATTACHMENT D
RESRAD-OFFSITE Input Parameters**

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Menu	Parameter	Value	Default	Comment	References
Change Title					
	Title	Humboldt Heavy Load SFP	N		
	Location Dose Slope and Transfer factor Database	C:\PROGRAM FILES\RESRAD-FAMILY\OFFSITE\DCF	N		
	Slope Factor (Risk) Library	FGR 13 Morbidity	Y		
	Dose Conversion Factor Library	FGR 11	Y		
	Transfer Factor Library	RESRAD Default Transfer Factors	Y		
	Cut Off Half Life (days)	3	N		
	Total Available Nuclides	209	Y		
	Total Number DCF or SF Nuclides	8	Y		
	Intermediate Time Points - Number of Time Points	512	N	Reduce calculation time	
	Linear or Log Spacing	Linear	Y		
	Update Progress of Computation Message Every (Seconds)	2	N	Default is 0.0 seconds, to run faster	
	Use Line Draw Character	Checked	Y		
Set Pathways					
	External Gamma	OFF	N	Release is 36 feet below grade	
	Inhalation	OFF	N	Release is 36 feet below grade	
	Plant Ingestion	OFF	N	Release is 36 feet below grade	
	Meat Ingestion	OFF	N	Release is 36 feet below grade	
	Milk Ingestion	OFF	N	Release is 36 feet below grade	
	Aquatic Foods	ON	Y	Pathway fish and invertebrates in bay	
	Drinking Water	OFF	N	Pathway upgradient on-site potable water wells. RESRAD will not calculate upgradient concentrations. Turn on for well concentrations of groundwater entering bay.	
	Soil Ingestion	OFF	N	Release is 36 feet below grade	
	Radon	OFF	Y	Release is 36 feet below grade	
Modify Data - Preliminary Inputs					
	Activity	pCi	Y		
	Dose	mrem	Y		
	Basic Radiation Dose Limit (mrem)	25	N	Same as decommissioning guideline	
	Exposure Duration (years)	30	Y		
	Number of Unsaturated Zones	1	Y		

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Modify Data - Site Layout				
Bearing of X Axis (clockwise angle from north)	90 degrees		Y	
X dimension of Primary Contamination in meters	8.84		N	Emulates fuel pool volume for 19.3 feet deep. See Section 4.8
Y dimension of Primary Contamination in meters	7.48		N	
Surface Water Body	X Coordinate Smaller -98.53 Larger 101.5 Y coordinate Smaller 128 Larger 178		N	
Modify Data - Physical and Hydrological				
Site-Properties				
Precipitation (meters/year)	9.83E-01		N	38.7 inches per year 100 year average Eureka Ref 7.19 http://www.met.utah.edu/jhorel/html/wx/climate/windavg.html
Wind Speed meters/sec	3.04		N	3.04 m/s
Contaminated Zone and Cover				
Length of Contaminated Zone Parallel to aquifer flow (meters)	8.84		N	Emulates fuel pool volume for 19.3 feet deep.
Depth of Soil Mixing (meters)	0		N	No mixing modeling immediate release to saturated zone aquifer
Deposition Velocity of dust (meters/sec)	0		N	No dust deposition since injection of nuclides is subsurface
Irrigation applied per year (meters/year)	0		N	No irrigation of contaminated zone
Evapotranspiration Coefficient	0		N	No evaporation or transpiration since Saturated Zone is below root depth and covered with alluvial clay.
Run Off Coefficient	0		N	This is the fraction of precipitation that does not penetrate the topsoil but leaves the area of concern as surface runoff; no loss is assumed for irrigation water. Zero was chosen to increase the leach rate to groundwater.
Rainfall and Run Off	0		N	Rainfall and Runoff Index: This is a measure of the energy of the rainfall. It is used to compute the erosion rate. No erosion due to subsurface injection of contamination into saturated zone.

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	Slope-Length-Steepness Factor	0	N	Slope-Length-Steepness Factor: This factor accounts for the profile of the terrain on the erosion rate. No erosion due to subsurface injection of contamination into saturated zone.	
	Cover and management factor	0.003	Y	Grass no cover 95% of year	Ref 7.21 Table 2.6-2
	Support Practice Factor	1	Y		
	Thickness Cover Material (meters)	0	N	To increase percolation out of contaminated zone	
	Thickness- Contaminated Zone (meters)	5.88	N	This is the 19.3 feet of cover above the Hookton reservoir	
	Total Porosity Contaminated Zone	0.9	N	Top maximize water percolation to aquifer	
	Erosion Rate Contaminated Zone (meters/year)	0	N	Calculated by RESRAD	
	Bulk Density Contaminated Zone (g/cm ³)	1	N	for comparison to SPF Water Concentrations	
	Soil Erodability Factor Contaminated Zone (tons/acre)	0	N	To minimize input to surface water from erosion since the source term is injected at depth	
	Field capacity contaminated zone	1.00E-05	N	It is the volumetric moisture content of soil at which (free) gravity drainage ceases. This is the amount of moisture that will be retained in a column of soil against the force of gravity. The field capacity is one of several hydrogeological parameters used to calculate water transport through the unsaturated part of the soil. Range from 1E-5 to 1	
	Soil b parameter of contaminated zone	0.01	N	an empirical and dimensionless parameter that is used to evaluate the saturation ratio (or the volumetric water saturation) of the soil according to a soil characteristic function called the conductivity function. Default is 5.3 range from 0-15	
	Hydraulic conductivity of contaminated zone (meters/year)	1.00E+09	N	measure of the soil's ability to transmit water when subjected to a hydraulic gradient. The hydraulic conductivity depends on the soil grain size, the structure of the soil matrix, the type of soil fluid, and the relative amount of soil fluid (saturation) present in the soil	

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				matrix. Default 10 Range 1E-3 to 1E+10.	
	Volumetric water content	0.05	Y	represents the fraction of the total volume of porous medium that is occupied by the water. The value should be less than the total porosity of the medium. Default 0.05. Range 0 - 1	
Modify Data - Groundwater Transport					
	<i>Distance in direction parallel to aquifer flow from edge of contaminated Zone down gradient</i>				
	well (meters)	119.500	N	To determine groundwater concentrations entering the bay.	
	surface water (meters)	120.5	N	420 feet from spent fuel pool as in previous calculations, contaminated zone is 7.48 meters wide on Y axis. 128.6-7.48	Ref 7.18 Ref 7.17 pg 149
	<i>Distance in the Direction Perpendicular to Aquifer Flow</i>				
	well (meters)	0	N	Distance in the Direction Perpendicular to Aquifer Flow from Contamination to Well: This the distance, in meters (m), between two groundwater flow lines, one through the center of the contamination and the other thorough the well. It is used in the computation of dilution due to dispersion in the saturated zone, and it applies to water extracted from a well.	
	Right Edge of Surface Water Body (meters)	-98.53	N	distance, in meters (m), between two groundwater flow lines, one through the center of the contamination and the other through the near edge of the surface water body. It is used to compute the contamination flux from the groundwater into the surface water body.	

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	Left Edge of Surface Water Body (meters)	101.5	N		
	Convergence Criterion:	0.01	N	This is the fractional accuracy desired in the Romberg integration used to calculate the contaminant flux or concentration in groundwater. A lower value will likely require the use of a larger number of points in this numerical integration technique and thus a longer computation time. For each Romberg refinement or cycle number, the number of integrand function evaluations is 2N, where N is the cycle number. Thus, if the convergence criterion is set too low, the computation time becomes excessive, and convergence may not be achieved. Default is 0.001	
	Main Sub Zones in Saturated Zone	1	Y		
	Main Sub Zones in Each Partially Saturated Zone	1	Y		
Modify Data - Unsaturated Zone Properties					
	Unsaturated Zone Thickness (meters)	0.01	N	This creates a very thin unsaturated zone placing the contaminated zone directly on the top of the aquifer.	
	Dry Bulk Density (g/cm ³)	1	N	Set the density to the same as the fuel pool water to allow direct input of water concentration values	
	Effective porosity	0.99	N	A high value is used to maximize flow through the zone	
	Field capacity	1.00E-05	N	See contaminated zone description	
	Hydraulic conductivity (meters/year)	1.00E+06	N	Note message in field says upper bound is 1E6	
	Soil b parameter of contaminated zone	0.01	N	Provides rapid radionuclide removal through zone.	
	Longitudinal Dispersivity	0.01	N	This is the ratio between the longitudinal dispersion coefficient and pore water velocity. It has the dimension of length. This parameter depends on the thickness of the zone and ranges from one one-hundredth of the thickness to the order of the thickness.	
Modify Data - Saturated Zone Properties					
	Saturated Zone Thickness (meters)	9.52	N	Meters thick Upper Hookton Aquifer see Rad Data Sheet	Dwg 55428, Ref 7.19

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Total Porosity of Saturated Zone	0.4	N	Same as previous calculation	Ref 7.19
Effective Porosity of Saturated Zone	0.25	N	Same as previous calculation	Ref 7.19
Hydraulic Conductivity of Saturated Zone (meters/year)	3169.92	N	Same as previous calculation. Based on down-hole flow meter measurements in the upper Hookton aquifer in the Unit 3 area (Reference 2) for wells MW-1 through MW-11 and calculated permeability using the tidal method, a flow velocity range of 3,100 to 10,400 ft/yr (3×10^{-3} to 3×10^{-2} cm/sec) was calculated. This equals 10,400 ft/year.	Ref 7.19
Hydraulic gradient to well of saturated zone	0.003	N	Hydraulic Gradient of Saturated Zone: This is the slope of the surface of the water table. Ref 15 Little vertical flow occurs within the upper Hookton aquifer. Vertical gradients range from 10 to 20 ft/mile (0.002 to 0.004 ft/ft)	Ref 7.19
Hydraulic gradient to surface water body of saturated zone	0.003	N	Places it in highest concentrations calculated in model	
Depth of Aquifer contributing to well (meters below water table)	14	N	Places it in highest concentrations calculated in model	
Depth of Aquifer contributing to surface water (meters below water table)	14	N		
Longitudinal dispersivity of saturated zone for well in meters	0.3048	N	Same as Previous Calculation This is the ratio between the longitudinal dispersion coefficient and pore water velocity. It has the dimension of length. This parameter depends on the thickness of the zone and ranges from one one-hundredth of the thickness to the order of the thickness.	Ref 7.18 Ref 7.17
Longitudinal dispersivity of saturated zone for surface water in meters	0.3048	N		Ref 7.18 Ref 7.17
Horizontal dispersivity of saturated zone for well in meters	0.1524	N	Same as Previous Calculation This is the ratio between the horizontal lateral dispersion coefficient and pore water velocity. It has the dimension of length.	Ref 7.18 Ref 7.17
Horizontal dispersivity of saturated zone for surface water in meters	0.1524	N	Same as Previous Calculation	Ref 7.18 Ref 7.17

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	Vertical lateral dispersivity of saturated zone for well in meters	Do not disperse vertically	N	Dispersion is considered to be inactive in the vertical direction, if the concentration profile in the vertical direction becomes essentially uniform because of repeated reflection of the plume by the lower impermeable layer and the water table. It is also inactive if a zero value is specified for the vertical-lateral dispersivity. This is likely due to upper strata clay and aquitard below as well as tidal influence.	Ref 7.21
	Vertical lateral dispersivity of saturated zone for surface water in meters	Do not disperse vertically	N		
	Irrigation applied per year (meters/year) well	0	N	No irrigation in area and not likely to make it through upper strata to brackish water aquifer of Upper Hookton	
	Irrigation applied per year (meters/year) surface water body	0	N		
	Evapotranspiration coefficient	0	N	Assumes no removal of water through dispersion to atmosphere since release is subsurface under clay deposits.	
	Evapotranspiration coefficient	0	N		
	Runoff coefficient	0	N		
	Runoff coefficient	0	N		
Modify Data - Water Use					
	Consumption by humans (liters/year)	730	N	Reg Guide 1.109 Table E-5 Adult	
	Use indoors of dwelling (liters/day)	225	Y		
	Consumption by humans fraction from Well	1	Y		
	Use indoors of dwelling fraction from Well	1	Y		
	Number of individuals	1	Y		
	Well pumping rate (cubic meters per year)	5100	Y		
Modify Data - Surface Water Body					
	Sediment delivery ratio	1	Y		
	Volume of surface water body (cubic meters)	3.33E+05	N	Same Near Field as TSD (Ref 7.29)	Ref 7.29, 7.26
	Mean residence time of water in surface water body (years)	8.40E-02	N	23% for Entrance Bay	Ref 7.29, 7.26, as defined Ref 7.21
Modify Data - Ingestion Rates					
	Drinking Water (liters/year)	730	N	Reg Guide 1.109 Table E-5 Adult	Ref 7.1
	Fish (kg/yr)	21	N	Reg Guide 1.109 Table E-5 Adult	Ref 7.1

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	Crustacea and mollusks (kg/yr)	5	N	Reg Guide 1.109 Table E-5 Adult Other Seafood	Ref 7.1
	Drinking Water fraction from affected area	1	N	Assume 100% from contaminated zone as in RG 1.109	
	Fish fraction from affected area	1	N	Assume 100% from contaminated zone as in RG 1.109	
	Crustacea and mollusks fraction from affected area	1	N	Assume 100% from contaminated zone as in RG 1.109	
Modify Data - Inhalation, Gamma		None			
Modify Data - Radon		None			
Modify Data - Soil Concentrations - Ac-227, Np-237, Pa-231, Pb-210, Po-210, Ra-226, Ra-228, Th-228, Th-229, Th-230, Th-232					
	Contaminated Zone (pCi/g)	7.00E+00	N	RESRAD calculated value a daughter radionuclide	
	Release and Air Transport - Leach Rate	0.00E+00	Y	The fraction of the available radionuclide leached out from the contaminated zone per unit of time. Accepted values range from 0 to 1E+34. If the user does not input a leach rate, RESRAD-OFFSITE will estimate a leach rate by equating the initial release rate to the equilibrium desorption release rate, computed using the user-specified distribution coefficient. Default is used since Kds are specified for each nuclide so leach rate has no impact on calculation.	
	Distribution Coefficient Contaminated Zone (cm ³ /g)	0.001	N	To ensure rapid release to aquifer	
	Unsaturated Zone (cm ³ /g)	0.001	N	To ensure rapid release to aquifer	
	Saturated Zone (cm ³ /g)	20	N	Not a dose significant nuclide low Kd used.	
	Sediment in surface water body	1000	Y		
	Fruit, grain, non-leafy fields	1000	Y		
	Leafy Vegetable Fields	1000	Y		
	Livestock feed grain fields	1000	Y		
	Dwelling Site	1000	Y		
Modify Data - Soil Concentrations - Am-241					
	Contaminated Zone (pCi/g)	7.50E+02	N	Calculated overall fuel pool concentration	

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	Release and Air Transport - Leach Rate	0.00E+00	Y	See Ac-227 explanation calculated by RESRAD based on Kd	
	Distribution Coefficient Contaminated Zone (cm ³ /g)	0.001	N	To ensure rapid release to aquifer. RESRAD has run time error when 0 values are used for elements other than carbon and hydrogen.	
	Unsaturated Zone (cm ³ /g)	0.001	N	To ensure rapid release to aquifer	
	Saturated Zone (cm ³ /g)	20	N	Based upon evaluation of americium Kds for course sand in EPA (Ref 7.25) and choice of conservative, low Kd as discussed in Technical Support Document for the calculation.	Ref 7.25, Section 4.10.1
	Sediment in surface water body	1000	Y		
	Fruit, grain, non-leafy fields	1000	Y		
	Leafy Vegetable Fields	1000	Y		
	Livestock feed grain fields	1000	Y		
	Dwelling Site	1000	Y		
Modify Data - Soil Concentrations - Am-243					
	Contaminated Zone (pCi/g)	0.00E+00	N	RESRAD Calculated Value a daughter radionuclide	
	Release and Air Transport - Leach Rate	0.00E+00	Y	See Ac-227 explanation calculated by RESRAD based on Kd	
	Distribution Coefficient Contaminated Zone (cm ³ /g)	0.001	N	To ensure rapid release to aquifer	
	Unsaturated Zone (cm ³ /g)	0.001	N	To ensure rapid release to aquifer	
	Saturated Zone (cm ³ /g)	20	N	Based upon evaluation of americium Kds for course sand in EPA (Ref 7.25) and choice of conservative, low Kd as discussed in Technical Support Document for the calculation.	Ref 7.25, Section 4.10.1
	Sediment in surface water body	1000	Y		
	Fruit, grain, non-leafy fields	1000	Y		
	Leafy Vegetable Fields	1000	Y		
	Livestock feed grain fields	1000	Y		
	Dwelling Site	1000	Y		
Modify Data - Soil Concentrations - C-14					
	Contaminated Zone (pCi/g)	7.16E+00	N	Calculated overall fuel pool concentration	
	Release and Air Transport - Leach Rate	0.00E+00	Y	See Ac-227 explanation calculated by RESRAD based on Kd	

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	Distribution Coefficient Contaminated Zone (cm ³ /g)	0	Y	Default Kd that assumes carbon is moving with water with no sorption or other soil interactions as in dissolved CO ₂ . This is a very conservative assumption since it is likely in the oxides in the sludge.	
	Unsaturated Zone (cm ³ /g)	0	Y		
	Saturated Zone (cm ³ /g)	0	Y		
	Sediment in surface water body	0	Y		
	Fruit, grain, non-leafy fields	0	Y		
	Leafy Vegetable Fields	0	Y		
	Livestock feed grain fields	0	Y		
	Dwelling Site	0	Y		
Modify Data - Soil Concentrations - Cm-243, Cm-244					
	Contaminated Zone (pCi/g)	1.50E+02	N	One half the calculated Cm-243/244 concentration in the fuel pool water.	
	Release and Air Transport - Leach Rate	0.00E+00	Y	See Ac-227 explanation calculated by RESRAD based on Kd	
	Distribution Coefficient Contaminated Zone (cm ³ /g)	0.001	N	To ensure rapid release to aquifer	
	Unsaturated Zone (cm ³ /g)	0.001	N	To ensure rapid release to aquifer	
	Saturated Zone (cm ³ /g)	20	N	Based upon evaluation of Curium Kds for course sand in EPA (Ref 7.25) and choice of conservative, low Kd as discussed in Technical Support Document for the calculation.	Ref 7.25, Section 4.10.2
	Sediment in surface water body	1000	Y		
	Fruit, grain, non-leafy fields	1000	Y		
	Leafy Vegetable Fields	1000	Y		
	Livestock feed grain fields	1000	Y		
	Dwelling Site	1000	Y		
Modify Data - Soil Concentrations - Co-60					
	Contaminated Zone (pCi/g)	5.22E+03	N	Calculated overall fuel pool concentration	
	Release and Air Transport - Leach Rate	0.00E+00	Y	See Ac-227 explanation calculated by RESRAD based on Kd	
	Distribution Coefficient Contaminated Zone (cm ³ /g)	0.001	N	To ensure rapid release to aquifer	
	Unsaturated Zone (cm ³ /g)	0.001	N	To ensure rapid release to aquifer	

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	Saturated Zone (cm ³ /g)	1	N	Same as previous calc	Ref 7.18 Ref 7.17 Section 4.4
	Sediment in surface water body	1000	Y		
	Fruit, grain, non-leafy fields	1000	Y		
	Leafy Vegetable Fields	1000	Y		
	Livestock feed grain fields	1000	Y		
	Dwelling Site	1000	Y		
Modify Data - Soil Concentrations - Cs-137					
	Contaminated Zone (pCi/g)	1.22E+03	N	Calculated overall fuel pool concentration	
	Release and Air Transport - Leach Rate	0.00E+00	Y	See Ac-227 explanation calculated by RESRAD based on Kd	
	Distribution Coefficient Contaminated Zone (cm ³ /g)	0.001	N	To ensure rapid release to aquifer	
	Unsaturated Zone (cm ³ /g)	0.001	N	To ensure rapid release to aquifer	
	Saturated Zone (cm ³ /g)	20	N	Same as previous calc	Ref 7.18 Ref 7.17 Section 4.4
	Sediment in surface water body	4600	Y		
	Fruit, grain, non-leafy fields	4600	Y		
	Leafy Vegetable Fields	4600	Y		
	Livestock feed grain fields	4600	Y		
	Dwelling Site	4600	Y		
Modify Data - Soil Concentrations - Eu-154					
	Contaminated Zone (pCi/g)	3.13E+01	N	Calculated overall fuel pool concentration	
	Release and Air Transport - Leach Rate	0.00E+00	Y	See Ac-227 explanation calculated by RESRAD based on Kd	
	Distribution Coefficient Contaminated Zone (cm ³ /g)	0.001	N	To ensure rapid release to aquifer	
	Unsaturated Zone (cm ³ /g)	0.001	N	To ensure rapid release to aquifer	
	Saturated Zone (cm ³ /g)	20	N	Not a dose significant nuclide low Kd used.	
	Sediment in surface water body	4600	Y		
	Fruit, grain, non-leafy fields	4600	Y		
	Leafy Vegetable Fields	4600	Y		
	Livestock feed grain fields	4600	Y		
	Dwelling Site	4600	Y		
Modify Data - Soil Concentrations - Fe-55					
	Contaminated Zone (pCi/g)	1.09E+03	N	Calculated overall fuel pool concentration	

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	Release and Air Transport - Leach Rate	0.00E+00	Y	See Ac-227 explanation calculated by RESRAD based on Kd
	Distribution Coefficient Contaminated Zone (cm ³ /g)	0.001	N	To ensure rapid release to aquifer
	Unsaturated Zone (cm ³ /g)	0.001	N	To ensure rapid release to aquifer
	Saturated Zone (cm ³ /g)	20	N	Not a dose significant nuclide low Kd used.
	Sediment in surface water body	4600	Y	
	Fruit, grain, non-leafy fields	4600	Y	
	Leafy Vegetable Fields	4600	Y	
	Livestock feed grain fields	4600	Y	
	Dwelling Site	4600	Y	
Modify Data - Soil Concentrations - H-3				
	Contaminated Zone (pCi/g)	3.03E+01	N	Calculated overall fuel pool concentration
	Release and Air Transport - Leach Rate	0.00E+00	Y	See Ac-227 explanation calculated by RESRAD based on Kd
	Distribution Coefficient Contaminated Zone (cm ³ /g)	0	N	To ensure rapid release to aquifer
	Unsaturated Zone (cm ³ /g)	0	N	To ensure rapid release to aquifer
	Saturated Zone (cm ³ /g)	0	Y	Default Kd that assumes tritium is moving with water.
	Sediment in surface water body	0	Y	
	Fruit, grain, non-leafy fields	0	Y	
	Leafy Vegetable Fields	0	Y	
	Livestock feed grain fields	0	Y	
	Dwelling Site	0	Y	
Modify Data - Soil Concentrations - Ni-59				
	Contaminated Zone (pCi/g)	6.99E+01	N	Calculated overall fuel pool concentration
	Release and Air Transport - Leach Rate	0.00E+00	Y	See Ac-227 explanation calculated by RESRAD based on Kd
	Distribution Coefficient Contaminated Zone (cm ³ /g)	0.001	N	To ensure rapid release to aquifer
	Unsaturated Zone (cm ³ /g)	0.001	N	To ensure rapid release to aquifer
	Saturated Zone (cm ³ /g)	20	N	Not a dose significant nuclide low Kd used.
	Sediment in surface water body	4600	Y	
	Fruit, grain, non-leafy fields	4600	Y	
	Leafy Vegetable Fields	4600	Y	

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	Livestock feed grain fields	4600	Y		
	Dwelling Site	4600	Y		
Modify Data - Soil Concentrations - Ni-63					
	Contaminated Zone (pCi/g)	1.08E+04	N	Calculated overall fuel pool concentration	
	Release and Air Transport - Leach Rate	0.00E+00	Y	See Ac-227 explanation calculated by RESRAD based on Kd	
	Distribution Coefficient Contaminated Zone (cm ³ /g)	0.001	N	To ensure rapid release to aquifer	
	Unsaturated Zone (cm ³ /g)	0.001	N	To ensure rapid release to aquifer	
	Saturated Zone (cm ³ /g)	20	N	Not a dose significant nuclide low Kd used.	
	Sediment in surface water body	4600	Y		
	Fruit, grain, non-leafy fields	4600	Y		
	Leafy Vegetable Fields	4600	Y		
	Livestock feed grain fields	4600	Y		
	Dwelling Site	4600	Y		
Modify Data - Soil Concentrations - Pu-238					
	Contaminated Zone (pCi/g)	2.30E+02	N	Calculated overall fuel pool concentration	
	Release and Air Transport - Leach Rate	0.00E+00	Y	See Ac-227 explanation calculated by RESRAD based on Kd	
	Distribution Coefficient Contaminated Zone (cm ³ /g)	0.001	N	To ensure rapid release to aquifer	
	Unsaturated Zone (cm ³ /g)	0.001	N	To ensure rapid release to aquifer	
	Saturated Zone (cm ³ /g)	10	N	Based upon evaluation of Plutonium Kds for course sand in EPA (Ref 7.25) and choice of conservative, low Kd as discussed in Technical Support Document for the calculation.	Ref 7.25, Section 4.10.3
	Sediment in surface water body	4600	Y		
	Fruit, grain, non-leafy fields	4600	Y		
	Leafy Vegetable Fields	4600	Y		
	Livestock feed grain fields	4600	Y		
	Dwelling Site	4600	Y		
Modify Data - Soil Concentrations - Pu-239, Pu-240					
	Contaminated Zone (pCi/g)	1.32E+02	N	One half the calculated Pu-239/240 concentration in the fuel pool water.	
	Release and Air Transport - Leach Rate	0.00E+00	Y	See Ac-227 explanation calculated by RESRAD based on Kd	

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	Distribution Coefficient Contaminated Zone (cm ³ /g)	0.001	N	To ensure rapid release to aquifer	
	Unsaturated Zone (cm ³ /g)	0.001	N	To ensure rapid release to aquifer	
	Saturated Zone (cm ³ /g)	10	N	Based upon evaluation of Plutonium Kds for course sand in EPA (Ref 7.25) and choice of conservative, low Kd as discussed in Technical Support Document for the calculation.	Ref 7.25, Section 4.10.3
	Sediment in surface water body	4600	Y		
	Fruit, grain, non-leafy fields	4600	Y		
	Leafy Vegetable Fields	4600	Y		
	Livestock feed grain fields	4600	Y		
	Dwelling Site	4600	Y		
Modify Data - Soil Concentrations - Pu-241					
	Contaminated Zone (pCi/g)	4.13E+03	N	Calculated overall fuel pool concentration	
	Release and Air Transport - Leach Rate	0.00E+00	Y	See Ac-227 explanation calculated by RESRAD based on Kd	
	Distribution Coefficient Contaminated Zone (cm ³ /g)	0.001	N	To ensure rapid release to aquifer	
	Unsaturated Zone (cm ³ /g)	0.001	N	To ensure rapid release to aquifer	
	Saturated Zone (cm ³ /g)	10	N	Based upon evaluation of Plutonium Kds for course sand in EPA (Ref 7.25) and choice of conservative, low Kd as discussed in Technical Support Document for the calculation.	Ref 7.25, Section 4.10.3
	Sediment in surface water body	4600	Y		
	Fruit, grain, non-leafy fields	4600	Y		
	Leafy Vegetable Fields	4600	Y		
	Livestock feed grain fields	4600	Y		
	Dwelling Site	4600	Y		
Modify Data - Soil Concentrations - Sr-90					
	Contaminated Zone (pCi/g)	2.74E+02	N	Calculated overall fuel pool concentration	
	Release and Air Transport - Leach Rate	0.00E+00	Y	See Ac-227 explanation calculated by RESRAD based on Kd	
	Distribution Coefficient Contaminated Zone (cm ³ /g)	0.001	N	To ensure rapid release to aquifer	
	Unsaturated Zone (cm ³ /g)	0.001	N	To ensure rapid release to aquifer	

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	Saturated Zone (cm ³ /g)	0.4	N	Same as previous calc	Ref 7.18 Ref 7.17, Section 4.4
	Sediment in surface water body	30	Y		
	Fruit, grain, non-leafy fields	30	Y		
	Leafy Vegetable Fields	30	Y		
	Livestock feed grain fields	30	Y		
	Dwelling Site	30	Y		
Modify Data - Soil Concentrations - U-233, U-234					
	Contaminated Zone (pCi/g)	2.34E-01	N	One half the calculated U-233/234 concentration in the fuel pool water.	
	Release and Air Transport - Leach Rate	0.00E+00	Y	See Ac-227 explanation calculated by RESRAD based on Kd	
	Distribution Coefficient Contaminated Zone (cm ³ /g)	0.001	N	To ensure rapid release to aquifer	
	Unsaturated Zone (cm ³ /g)	0.001	N	To ensure rapid release to aquifer	
	Saturated Zone (cm ³ /g)	20	N	Not a dose significant nuclide low Kd used.	
	Sediment in surface water body	4600	Y		
	Fruit, grain, non-leafy fields	4600	Y		
	Leafy Vegetable Fields	4600	Y		
	Livestock feed grain fields	4600	Y		
	Dwelling Site	4600	Y		
Modify Data - Soil Concentrations - U-235, U-236					
	Contaminated Zone (pCi/g)	6.43E-02	N	One half the calculated U-235/236 concentration in the fuel pool water.	
	Release and Air Transport - Leach Rate	0.00E+00	Y	See Ac-227 explanation calculated by RESRAD based on Kd	
	Distribution Coefficient Contaminated Zone (cm ³ /g)	0.001	N	To ensure rapid release to aquifer	
	Unsaturated Zone (cm ³ /g)	0.001	N	To ensure rapid release to aquifer	
	Saturated Zone (cm ³ /g)	20	N	Not a dose significant nuclide low Kd used.	
	Sediment in surface water body	4600	Y		
	Fruit, grain, non-leafy fields	4600	Y		
	Leafy Vegetable Fields	4600	Y		
	Livestock feed grain fields	4600	Y		
	Dwelling Site	4600	Y		