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7. Abstract An analysis of the direct radiation exposures and dose rates to personnel from assumed quantities of radioactive grout, and Double Shell Tank (DST) waste feed. This analysis was based on filling four disposal vaults per year. Whole body doses were analyzed for occupational workers assigned to the Grout Treatment Facility (GTF). The study makes assumptions that must be met by the facility. Otherwise, the GTF will meet all DOE and WHC direct radiation exposure criteria. This analysis will be published in the Grout Final Safety Analysis Report (FSAR).		
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ASSESSMENT OF ANNUAL EXPOSURE FOR GROUT OPERATIONS

WESTINGHOUSE HANFORD COMPANY

January 1994

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LIST OF TERMS

AA	airstream activity
AA _y	airstream activity (vault)
ALARA	as low as reasonably achievable
CAM	continuous air monitor
DF	decontamination factor
DMF	Dry Materials Facility
DST	double-shell tank
EW	excess water
FA	filter activity
GDF	Grout Disposal Facility
GPF	Grout Processing Facility
GTF	Grout Treatment Facility
HEPA	high-efficiency particulate air (filter)
HPT	health physics technician
LCT/MM	liquid collection tank/mixer module
NDE	nondestructive examination
PF	partition fraction
PF	partition fraction for an active vault
PF ^a	partition fraction for a stagnant vault
PF ^s	quality control
QC	radiologically controlled area
RCA	duration of grout operation
t	duration of active vault operation
t _a	duration of stagnant vault operation
t _s	activity passed through a filter in one year
VA	ventilation rate
VR	waste activity
WA	Westinghouse Hanford Company
WHC	

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ASSESSMENT OF ANNUAL EXPOSURE FOR GROUT OPERATIONS

1.0 PURPOSE

The purpose of this safety analysis is to estimate radiation dose rates and doses to personnel from assumed quantities of radioactive grout and grout feed material in the Grout Treatment Facility (GTF). This analysis will provide an estimate of radiological emissions that will be the basis source term for later analysis of airborne dose consequences. This document also identifies projected radiological posting requirements based on the calculated dose rates. If design, plans, or conditions deviate from those stated in this document, a new projection of expected exposures should be made.

2.0 SCOPE

Doses contained in this document are whole body doses resulting from exposure to external radiation from the radiologically controlled areas of the Grout Processing Facility (GPF) and the Grout Disposal Facility (GDF). The Dry Materials Facility (DMF) only has naturally occurring radioactivity contained in fly ash, and is not a radiological facility. The minor dose contribution from airborne radionuclides is not included in this assessment, and must be considered for total effective dose equivalence. The estimated dose consequences of possible internal uptake from projected grout annual emissions is currently under study. Doses received by Tank Farms personnel in performing the required sampling of the grout feed tanks are not reported under grout operations, and are not included. This document addresses the operational period, and does not cover vault closure activities.

3.0 SUMMARY

Based on filling four vaults per year, the annual occupational collective dose resulting from grout operations is approximately 17.45 person-rem (Section 6.0). Hot tie-ins of grout pipes and excess water (EW) return lines from the grout vaults is estimated to result in 4.24 person-rem. The 4.24 figure includes nondestructive examination (NDE), and visual inspection of pipe wall thickness. A further As Low As Reasonably Achievable (ALARA) evaluation of all routine radiological work was prepared (Sontag 1993). The ALARA recommendations may result in exposure reduction modifications.

Grout disposal vault exhauster high-efficiency particulate air (HEPA) filter change accounts for 7.22 person-rem (Section 6.0). This includes an additional 0.96 person-rem associated with moving the exhausters. Conservative partition fractions were used to bound ventilation operations as empirical data was not available. When data from the first vault fill are approved, this analysis should be modified. Direct exposures associated with

GPF ventilation system work total 1.47 person-rem. The additional 10% exposure was added to bound operator and health physics technician (HPT) routine activities.

Doses from maintenance activities in the GPF liquid collection tank/mixer module (LCT/MM) is estimated at 2.68 person-rem. Glovebox sampling doses are calculated at 0.25 person-rem. The summary of annual exposures is presented in table format in Section 6.0. The exposures discussed here do not include significant exposures associated with possible GDF vault sampling.

The bulk of the GDF and GPF will be posted as a radiologically controlled area because dose rates exceed the 0.05 mrem/h posting threshold. Radiation area posting will be required for both the GPF and GDF. The use of containments and decontamination will limit the need for surface contamination area posting of any surfaces outside of the LCT/MM. Airborne contamination area posting will be required for hot tie-in enclosures and any entry into the LCT/MM when grout deposits exist outside of the process equipment or piping. High radiation area postings will be required for the LCT/MM, glovebox sampling, hot tie-ins, and for filter systems during bag and HEPA filter changeouts, as well as around the HEPA enclosures.

3.1 RECOMMENDATIONS

1. Evaluate the need for additional spray nozzles for internal decontamination of piping components in the LCT/MM. Use of spray nozzles will remove residual radioactive grout resistant to normal internal decontamination, thereby reducing maintenance exposure.
2. Evaluate methods to reduce or deentrain radioactive aerosols from the vault exhaust airstream. Reduction of HEPA filter change-out frequency will reduce exposure to maintenance personnel.
3. Perform sampling of vault exhaust airstream before filtration to obtain data for predicting future filter loading rates and controls. This data is needed to correct the presently crude modeling methodology. A corrected model will be of great benefit to other future project plan/designs.
4. Develop plans, procedures, and radiation work procedure to limit exposure and safety risks before performing the first hot tie-in. Experience from the first tie-in will establish future ALARA techniques as well as shielding requirements.

4.0 METHODOLOGY

This document is based on a source term 0.37 Ci of ^{137}Cs /L of feed liquid. The source term was derived from Table A-4 of WHC-SD-WM-RD-019, Revision 1, *Grout Treatment Facility Waste Feed Acceptance Criteria* (Hendrickson 1991). The source term is slightly lower in ^{137}Cs than the adjusted mean concentration for the double-shell tanks, which incorporates one standard deviation. The source term is based on the current long-term grouted

waste heat loading limit. Should this limit ever be raised, the doses presented here should be increased by the same factor. Although the source term actually contains small quantities of ^{90}Sr , ^{106}Rh , and other radionuclides, they would contribute less than 2% of the dose if included. They were omitted in dose calculations, and ^{137}Ba was assumed to be equal to ^{137}Cs . This assumption adds 5% to the dose, more than compensating for the 2% lost by omitting minor nuclides.

An assessment of skin doses resulting from the beta radiation associated with grout operations was performed. It was determined that the skin doses, while not insignificant, are not a limiting factor for exposures and so are not detailed in this document. This is because the beta-to-gamma ratio of the source term is high in gamma radiation. Therefore, the whole body penetration limits are reached before the skin limits are reached.

The waste activity of cesium, the major gamma precursor, will increase slowly over the next three campaigns before reaching the 0.37 Ci/L level that this study is based on. The next campaign (Vault 102) should be 0.165 Ci/L. Vault 103 should be 0.207 Ci/L. Vault 104 will be the first campaign to reach the full anticipated source term of 0.3718 Ci/L. This document does not limit the Grout source term. If Grout chooses to use a higher or lower source term, the estimated doses presented here may be changed in proportion to match the source term processed. Moreover, if as in the case of the next vault (Vault 102), less than four vaults are filled in a year, then both the dose and emission estimates will be affected. Also, should the remote lubrication system be installed and demonstrate that maintenance entries into the LCT/MM are unnecessary, that exposure can be saved (Deffenbaugh 1993). Therefore, these estimates should be revised as experience is gained.

Dose rates within the LCT/MM and on grout piping were based largely on a 2 mil (0.002-in.) layer of residual grout (post flush/decontamination), with revisions as detailed in this document. The residual grout layer assumption is detailed in Section 4.1. The calculated dose rates were combined with estimates of the time and distance that operators, maintenance personnel, and others might spend in various parts of the grout facilities to determine estimated annual doses.

The standard point kernel approach was used to perform dose rate calculations for simple source geometries and conservative wall thicknesses and distances. The IBM-PC compatible MICROSHIELD¹ Version 3.12 was employed for nearly all results reported here. ISOSHL-PC² Version 1.6 (Lourant 1989) was used to verify MICROSHIELD applicability. The reference cited above provides details on ISOSHL-PC validation. The MICROSHIELD code has been validated by running the benchmark shielding problems described in ANSI/ANS-6.6.1-1979. The distances, dimensions, shield thicknesses, source materials, and source activities for each type of operation are listed in the appropriate sections. When the piece of equipment, tank, pipe, etc. is essentially air-filled, it is assumed that the thin layer of grout that actually resides on the wall of the item is dispersed throughout the volume. When the item is filled with grout, an expansion factor of 1.43 is used to account for the nonradioactive portion. That means there is 1/1.43 times as

¹MICROSHIELD is a trademark of Grove Engineering Company.

²ISOSHL is a trademark of Pacific Northwest Laboratory.

much activity in the grout as there is in an equal volume of the feed solution from the tank farm. Due to the high solubility of cesium, excess water will be assumed to be functionally equivalent to feed liquid. Quantities of radioactive grout and liquid waste feed material assumed in this report are highly dependent on the effectiveness of both a nonradioactive grout flush and the use of a decontamination solution to remove the remaining radioactive grout. The numbers reported here may not be conservative if internal decontamination fails to remove the radioactivity explicit in the performance criterion.

4.1 ASSUMPTIONS

Upon startup and major increase of source term, grout HPTs will perform detailed radiation surveys to verify shielding integrity. The safety of penetrations will be analyzed in a separate document. The following assumptions were made to provide a basis for dose rate calculations, occupancy factors, and frequency of select operations.

1. General

- Although the source term actually contains small quantities of ^{90}Sr , ^{106}Rh , and other radionuclides, they contribute <2% of the dose. Only $^{137\text{m}}\text{Ba}$ is used for gamma radiation doses. It is assumed to be equal to ^{137}Cs , allowing an additional 5% to ensure the result is conservative.
- Bremsstrahlung sources (x-rays from beta collisions) are neglected, but skin doses are calculated for unshielded sources based on the assumption that 25% of the ^{137}Cs beta particles penetrate the protective clothing. An additional 5% is added for beta particles from other nuclides.
- Shadowing created by other equipment or structures is conservatively neglected.
- An additional 10% exposure for HPTs and Operations is assumed.
- Doses to tank farms personnel in performing the required sampling are not reportable under the GTF.
- Air filters will be changed out when they reach 100 mrem/h at ≈ 30 cm (basis: WHC-CM-4-10, "High Radiation Area").
- Future planning calls for four campaigns (cycles of operation) to be conducted each year after the initial extended fill of a single vault. Future campaigns plan to fill only one vault at a time.
- Operational periods per campaign used were 30 d for GPF, 20 d active filling of vaults, with 180 d stagnant cooling for the GDF.

- Partition fractions for radionuclides other than tritium are assumed to be 1.93×10^{-9} , during active vault operation, and 2.87×10^{-12} during stagnant vault operation stage. The GPF used 1.93×10^{-9} for the LCT and the Surge Tank. The LCT/MM used 2.87×10^{-11} . Maintenance releases used 2.87×10^{-10} .
- Prefabricated enclosures for HEPA filter changes will be used.

2. Grout Processing Facility

- Shielding will be used, or decontamination spray heads will be installed internally for the components of the LCT/MM, to control "Hot Spots" (i.e. strainers).
- Glovebox samples are 100% double-shell tank (DST) waste, and not diluted with dry grout.
- There are no entries planned for the liquid collection tank/mixer module (LCT/MM) during a campaign.
- One planned entry will be made into the LCT/MM each year for 1 h of preventative maintenance. This will require one craft person and one equivalent support person. The equivalent person is a compilation of health physics, management, engineering, and operations personnel.
- Four additional entries into the LCT/MM are assumed for corrective maintenance. The work party will consist of two craft persons in the LCT/MM for 8 h each and one equivalent person in the LCT/MM for 4 h. The work will be evenly divided between the mixer/surge tank assembly, the instrument skid, the LCT, and the sump.
- The dose contribution caused by backscatter is not calculated and is considered to be negligible when compared to direct and forward scattered components.
- No credit was taken for the bag filter cleaning mechanism.
- Floor sprays will be fully operational, i.e., there will no need for workers to enter the LCT/MM to wash down the floor with a hose and push the water/grout into the sump.
- Workers will not have to chip grout manually out of the bottom of the LCT/MM sump. The grout buildup in the bottom of the sump will be prevented via installation of the remote lubrication system or the buildup will be remotely removed (i.e., decontamination solution).
- The residual quantities of radioactive grout for non-operational conditions are based on the development by Pacific Northwest Laboratory of a specific decontamination solution for each grout formulation. The performance specification requires a solution efficient enough to leave no more than a nominal

0.002-in. film of grout. This would be especially important if a mechanical/electrical failure prevented following the radioactive grouting operation with a nonradioactive grout flush.

- For non-operational conditions, it is assumed that all equipment, structures, and piping have been flushed and vented, and therefore are air filled.
- An additional 111 mL of grouted waste is included as a spill in the LCT/MM for conservatism.
- A remote lubrication system will be installed to supply grease to the grout mixer and the group pump.
- Except for calculated doses in the vicinity of the LCT and the Surge Tank, the radioactive source material is assumed to be uniformly distributed throughout the source volume.
- The motor pit pump room is free of any significant quantity of radioactive material.
- Just 30 sampling operations per year will occur in a redesigned motor pit pump room glovebox. Assumed dose rate was 46 mrem/h at 50 cm.
- Tongs will be used to handle the samples during sampling operations.
- After samples are drawn, they will immediately be placed in a lead pig, and removed before drawing another sample.

3. Grout Disposal Facility

Based on vault fill splashing causing additional aerosolized particles, the vault exhaustor HEPA filter loading projections will be revised once the methodology is approved or we have operational experience.

- Both exhausters will be moved in the course of a year.
- HEPA's will not add to the dose rate for exhaustor duct disconnection/connection activities.
- All 9 first-stage HEPA filters will each hold 0.11 Ci ¹³⁷Cs.
- Shielding will be added to keep the connecting vent (or pipe) on the portable GDF exhaustors within the estimated dose (20 mrem/h averaged).
- Shielding will be added to the exhaustor first stage HEPA section and covers, to keep the change out dose rate ALARA. In addition, and when possible, standing to the side and out of the beam path will reduce exposure.

- Shielding will also be added to the exhauster first stage HEPA section to reduce exposure ALARA for CAM work.
- Spent HEPAs will immediately be removed from the work enclosure, or be shielded to prevent additional exposure.
- An ALARA method will reduce exposure associated with hand excavation for hot tie-ins.
- Vault cameras will be left in place until a layer of cold cap as thick as practical reduces the dose rate. Once the camera moving procedure is developed, camera removal exposure will be added to this document.
- Pumps at the vault to remove excess water will not be necessary due to evaporation from active ventilation.
- 0.1 in. of residual grouted waste will remain in the grout line. Should actual build-up prove this assumption non-conservative, ALARA work procedures and additional shielding will be needed to keep the Hot Tie-in exposure estimate bounded.
- The equivalent of 0.01 in. of residual grouted waste will remain in the EW line. Should actual build-up prove this assumption non-conservative, ALARA work procedures and additional shielding will be needed to keep the Hot Tie-in exposure estimate bounded.
- The Non-Destructive Examination (NDE) average dose rate was conservatively assumed at 155 mrem/h.

5.0 ACTIVITY ANALYSIS

Times estimated in this document are based on current Westinghouse Hanford Company (WHC) ALARA practices, and reflect the average amount of time a trained worker would spend in a radiation field. These estimated times are based on a review of the work involved. The reviews were performed by interviewing supervisors and workers who routinely perform the exact task. Where work is performed at varying distances, an average whole body distance was used. Only the as-built (existing) shielding was considered. No additional shielding was factored in except for the hot tie-ins. The use of additional shielding on any job, as well as other ALARA methods, requires that costs and benefits be considered. Section 6.0 includes tables which highlight areas that are candidates for ALARA reduction. WHC guidance on implementing cost/benefit analysis per U.S. Department of Energy Order 5480.11 (DOE 1992), is available in WHC-SD-SQA-CSD-20003, *Cost Benefit Analysis* (Brown 1991). Sontag (1993) provides ALARA modification recommendations.

5.1 LIQUID COLLECTION TANK/MIXER MODULE

5.1.1 Maintenance Activities

Estimates of LCT/MM maintenance activities are based on revised assumptions developed at a meeting of Grout Operations and Grout Engineering and are documented in Section 4.1. The grout project plans to procure and install a remote lubrication system for the grout pump and the grout mixer pump to reduce direct maintenance and leakage. Remote lubrication is expected to eliminate spills, or leakage from the grout mixer pump. The assumptions divided maintenance into two categories, annual preventative maintenance and major corrective maintenance. The residual volumes of grouted waste used for the LCT/MM source term are shown in Table 1. The dimensions used to calculate these volumes (Table 2) were used to determine the dose rates for the entries (Table 3), a dose rate map (Figure 1), and develop annual collective dose estimates (Table 4).

Table 1. Liquid Collection Tank/Mixer Module Source Term
(Post Flush/Decontamination).

Location	Volume (mL)	Activity (mCi)	Source of volume
Surge tank	91.8	23.8	0.002 in. grout film
Grout pump	85.2	22.1	0.002 in. grout film
Mixer	115.4	29.9	0.002 in. grout film
Liquid collection tank	638.3	165.3	0.002 in. grout film
Sump	101.3	26.2	0.002 in. grout film
Grout pipe	6.8	1.8	0.002 in. grout film
Leak (spill)	111	28.7	0.111 cm grout film

Table 2. Liquid Collection Tank/Mixer Module Source Geometry
(Post Flush/Decontamination).

Item	Radius or width (cm)	Height (cm)	Shield thickness ^a (cm)	Source material
Surge tank (cylindrical)	31.67	75	0.32	Air
Pump (cylindrical)	6.57	400	0.48	Air
Mixer (cylindrical)	28.2	100	0.31	Air
Liquid collection tank (cylindrical)	100	100	0.32	Air
Sump	46	23	0.00	Air
Grout pipe (cylindrical)	2.7 ^b	76.2	0.32	Air
Leak (spill) (rectangle)	31.62	31.62	0.00	Air

^aThe shield material is steel in all cases.

^bOnly the highest dose portion shown.

Table 3. Whole Body Dose Rates (mrem/h) in the Liquid Collection Tank/Mixer Module.

Item	Distance (cm)				
	Working*	100	200	300	400
Surge tank	21	4.6	1.5	0.7	0.4
Pump	12	3.5	1.3	0.7	0.4
Mixer	26	6.0	1.9	0.9	0.5
Liquid collection tank	44	N/A	16	6.5	3.5
Grout pipe	4.0	0.5	0.1	neg	neg
Leak (spill)	N/A	59	5.3	1.8	0.9

*30 cm from surface.

neg = negligible.

N/A = not applicable.

Table 4. Annual Personnel Exposures for Liquid Collection Tank/Mixer Module.

Activity performed	Number of persons	Hours	Times per year	Annual manhours	Dose rate (rem/h)	Annual collective dose
Preventative maintenance-crafts	1	1	1	1	0.040 ^a	0.040
Preventative maintenance-support	1	1	1	1	0.020 ^b	0.020
Corrective maintenance-crafts	2	8	4	64	0.040 ^a	2.56
Corrective maintenance-support	1	4	4	16	0.004	0.064
Total (per year)	--	--	--	82	--	2.68

^aMixer/surge tank field (Figure 1).^bAveraged.

The dose rate selected for the LCT/MM exposure estimate was based on probable maintenance of the grout mixer. This should prove conservative for all operations. The grout mixer is an active component, and in a higher, combined radiation field.

5.1.2 Liquid Collection Tank/Mixer Module Operations

When the LCT/MM is operating, the estimated potential volume of grouted waste or equivalent liquid in the LCT/MM is 3.86×10^3 L with 81% of the total volume attributable to the LCT. It should be noted that no one is allowed inside the LCT/MM while it is operating. Outside the module, the dose rates were assessed for the top of the cover blocks, the motor pit pump room at the level of the mixer module, and at ground level for the east wall (1 m from northeast corner). The dose rate, < 0.05 mrem/h, at contact with the motor pit east wall was the highest dose calculated outside the LCT/MM. The shielding dimensions are provided by Table 5.

Figure 1. Liquid Collection Tank/Mixer Module Dose Map.

29201034.3a

Table 5. Liquid Collection Tank/Mixer Module Shielding.

Item	Material	Density (g/cc)	Shield thickness (cm)
Steel roof	Stainless Steel	7.86	0.635
Cover blocks	Concrete	2.35	83.82
Module liner	Stainless Steel	7.86	0.476
Other module walls	Concrete	2.35	76.2
Module south wall	Concrete	2.35	83.82

This shielding evaluation is based on a source term 0.53 Ci of ^{137}Cs per liter of feed liquid derived from Section 2.2 of SD-WM-TI-355, Revision 1. This is the bounding source term for the GTF. The approach used added 20% to the total volume of the major vessels to account for piping volume. The source was conservatively modeled as a rectangle flush against the wall of interest.

5.2 MOTOR PIT PUMP ROOM

Personnel are not normally stationed in the motor pit pump room. The following are the three potential sources of exposure in the motor pit pump room: (1) the grouted waste samples that are piped into a glovebox in the motor pit pump room, (2) the LCT/MM, and (3) the sump. Sampling operations are the only significant source of exposure in the motor pit pump room. As Table 6 shows, a small fraction of the radiation from the operating LCT/MM will penetrate the wall into the motor pit pump room, and result in a dose rate of <0.05 mrem/h. This should not cause a measurable contribution to total dose, especially as personnel are not stationed full time in the area. The motor pit pump room sump provides no significant dose rates during normal operations and would be a source of exposure only in extreme upset (i.e., sump backflow) conditions. The conservative source dimensions used in the dose calculations were 10 cm x 646.53 cm x 646.53 cm.

Table 6. Whole Body Dose Rates (mrem/h).

Item	Dose rate (mrem/h)
Top of cover blocks	<0.05
Module exterior ^a	<0.05
Module south wall	<0.05
Glovebox exterior	46 ^b

^aGround level.

^bAssumption (during sampling).

Sampling operations in the motor pit pump room are estimated to occur ≈ 30 times per year. Each sample will require two 100 mL bottles of LCT liquid. As stated in Section 4.1, Assumptions, tongs will be used to handle the samples. Extremity doses have been calculated based on the use of tongs. The present sample glovebox is inadequate and subject to upgrading. This analysis assumes a minimally shielded glovebox. It is also assumed that one sample bottle will be loaded in a lead pig and removed, before another sample is received in the glovebox. Sample box and shielded pig dimensions are provided in Table 7. If not diluted with dry materials, the possible activity in a bottle of feed is calculated by Equation 1 to be 37 mCi/bottle.

$$\frac{0.37 \text{ Ci}}{L_{\text{Feed}}} \times \frac{0.1 L_{\text{Feed}}}{\text{bottle}} = \frac{37 \text{ mCi}}{\text{bottle}} \quad (1)$$

Table 7. Source Geometries for Items Contributing Dose to the Motor Pit Pump Room.

Component	Radius or width (cm)	Height (cm)	Shield (cm)
Glovebox sample (cylindrical)	2	7.955	0.32 (glass bottle) 0.32 (steel box wall)*
Shielded pig sample (cylindrical)	2	7.955	0.32 (glass bottle) 2.54 (lead pig)

*Same shielding as thin 0.32-cm (1/8-in.) leaded glass.

An operator is estimated to spend ≈ 5 min at the glovebox each time the sampling operation is performed. Based on the existing glovebox, a working distance of 50 cm was used. This includes loading samples in a shielded transport cask. The dose rates for a sample are shown in Table 8.

Table 8. Dose Rates (mrem/h) from a Liquid Collection Tank Sample.

Component	Distance (cm)				
	20	50	100	200	300
Glovebox sample	258*	46	12	3.0	1.3
Shielded pig sample	N/A	2.5	0.6	0.2	0.07

*Tong distance (inside glovebox).

Whole body dose rates used to estimate annual doses for the persons taking the samples are taken at 50 cm from the source as this was the actual working distance with the present glovebox design. Dose to hands was based on 20 cm (tongs). Annual doses for sampling activities are shown in Table 9.

Table 9. Annual Personnel Doses for Sampling Operations.

Activity	Number of persons	Hours	Times per year	Annual manhours	Dose rate (rem/h)	Annual collective dose (person-rem)
Sampling (hand)	1	0.083	30	2.5	0.258	0.13*
Sampling (body)	1	0.083	30	2.5	0.046	0.12

*Dose to the hand divided by 5 to convert to person-rem.

5.3 VENTILATION SYSTEMS

Grout facility ventilation systems consist of GPF ventilation and GDF ventilation. Each system ultimately exhausts through dual HEPA filters. The only radionuclide of interest for filter loading changeout is ^{137}Cs as it is the major gamma emitter. The formulas used to derive the activity in the airstream and deposited on the filters are based on the methodology used in WHC-SD-WM-TI-427, *Grout Treatment Facility Airborne Emissions Projections* (Hendrickson 1991), and a source term of 0.37 Ci/L as stated in Section 4.0, Methodology. The ratio of a radionuclide in an airspace to its concentration in liquid waste is called a partition fraction (PF). The PF for airborne radionuclides were derived from the characterization of mixed and stagnant tank vapor space and slurry concentrations (Kimura and Lindsey 1987).

The PF provided by the above study most relevant to filter loading is ^{137}Cs . Cesium is the major gamma emitter and, due to penetration and abundance, the major contributor to filter change-out frequency. The PF for ^{137}Cs should prove conservative for all radionuclides, because the treatment conditions will be the same, and the concentrations of other radionuclides are much lower. Moreover, cesium is the second most volatile radionuclide behind tritium. Tritium is handled separately for air emission estimates. A separate report on air emission dose consequences will consider all radionuclides. The partition fraction used for all mixing and pouring operations was the most conservative value found. The partition fraction used for GPF operation was 1.93×10^{-9} , equivalent to the value for an active DST. Two different partition fractions were used for the GDF. Active vaults in the process of being filled used 1.93×10^{-9} . Stagnant vaults used 2.78×10^{-12} .

The vapor space concentration of ^{137}Cs was considered equal to the grouted concentration of ^{137}Cs multiplied by the partition fraction appropriate to the specific operation. A separate filter efficiency is used depending on the application. We use a high efficiency value to be conservative when doing filter loading calculations. Conservative nuclear

industry practice is followed when doing emission estimates by using a lower efficiency factor. The efficiency values used for bag and HEPA filter loading are conservative for loading rate when we are looking at filter loading. When we looked at air emissions, separate standard HEPA filter performance (efficiency) factors were used for emissions estimating and are based on conservative nuclear industry practice. The decontamination factor (DF), is obtained by taking the inverse of 1 minus the efficiency of the filter, as shown in Equation 2. Hence, the standard conservative decontamination factors of 2,000 for the first stage and 200 for the second stage were used for emission estimates.

$$DF = \frac{1}{(1 - \text{eff})} \quad (2)$$

5.3.1 Grout Process Facility Ventilation

The GPF ventilation system consists of three separate streams. The highest PF found in the Kimura (1987) study was 1.93×10^{-9} . This conservative value was used for the surge, and liquid collection tanks. The GPF LCT/MM used a PF of 2.87×10^{-11} for the module ventilation, which is equivalent to an active tank. Air is drawn from three streams: the surge tank, 70.8 L/s; the LCT, 28.3 L/s; and the LCT/MM, 236 L/s. Filter dimensions are listed in Table 10. The LCT/MM will be maintained essentially clean of smearable contamination per the opening procedure requirements. Air from the surge tank is channeled through a bag filter before being passed through the HEPA filters. Air from the LCT/MM and the LCT goes directly through the HEPA. All potential radiological emissions are given in Ci/campaign. A campaign is the planned operating period required to fill a vault. The "Time" column in Table 11 lists the operational duration.

Table 10. Grout Processing Facility Filter Dimensions.

Item	Width or radius (cm)	Height (cm)	thickness (cm)	Shield thickness ^a (cm)	Source material
HEPA filter (rectangular)	61	61	29	0.32	air/paper
Bag filter ^b (cylindrical)	7.62	45.72	--	--	air/paper

^aSteel shields.

^bEach cartridge.

Table 11. Grout Processing Facility Bag Filter and First Stage High-Efficiency Particulate Air Filter.

Source	Waste activity (Ci/L)	Partition fraction	Ventilation rate (L/s)	Time (d)	Efficiency (%)	Filter activity (Ci)	Unfiltered activity (Ci)	First stage (Ci)
Surge tank	2.59 E-01	1.93 E-09	70.8	30	0.9000*	8.26 E-02	9.17 E-03	9.17 E-03
Liquid collection tank	2.59 E-01	1.93 E-09	28.3	30	0.9997	3.67 E-02		3.67 E-02
Module	2.59 E-01	2.87 E-11	236.0	30	0.9997	4.55 E-03		4.55 E-03
Total			335.1					5.04 E-02

*Additional bag filter (surge tank only).

Equation 3 provides the calculation of the activity released to the airstream by a given source term per the methodology given in Hendrickson (1991). Equation 4 shows the activity removed from the airstream and retained by a given filter. Equation 5 shows the activity passing through a filter.

Airstream Activity

$$AA = WA \times PF \times VR \times t \quad (3)$$

where:

- AA = Airstream activity in Ci/campaign
- WA = Waste activity in Ci/L
- PF₁ = Partition fraction, 1.93×10^{-9} (for tanks)
- PF₂ = Partition fraction, 2.87×10^{-11} (for module)
- VR = Ventilation rate, L/s
- t = Duration of grout operation in days ($\times 8.64 \times 10^4$ S/d).

Activity Retained by a Filter per Campaign Period

$$FA = \text{eff} \times AA \quad (4)$$

where:

FA = Filter Activity (Ci/campaign).

The amount of activity on a given filter in the GPF ventilation system calculated using the above equations is shown in Table 11.

Activity Passed Through a Filter (Ci/campaign)

$$UA = AA - FA \quad (5)$$

where:

UA = Activity passed through a filter (Ci/campaign).

This activity is either passed on to another filter or released.

As per Section 4.1, Assumptions, HEPA and bag filters will be changed when they read 100 mrem/h at 30 cm. The 100-mrem/h dose rate at 30 cm is caused by 0.11 Ci on the single HEPA and 0.12 Ci for three cartridges of the bag filter. Based on four campaigns each year, the bag filter will have to be changed four times each year and the first-stage HEPA filter will have to be changed two times each year. The bag filter change-out frequency contains one additional changeout for conservatism. Moreover, the bag filter must be changed out before reaching 100 mrem/h or the process is shutdown. This assumption is prudent for two reasons: (1) the negligible experience with the cleaning system and (2) the severe dust service environment. The bag filter will not require changing out in mid campaign if replaced before operations.

It will not be necessary to change the HEPA second-stage filter because it would take more than 300 yr (neglecting radioactive decay) for the dose to build to 100 mrem/h. With radioactive decay considered, the dose from the filter would be less than 5 mrem/h after 30 yr. Vault inlet filters will have even less of a source term than the second-stage HEPA filter because of the added efficiency of the second-stage HEPA filter and the dilution factor of the outside air. A summary of dose rates at various distances (based on no shielding) is shown in Table 12.

Table 12. Dose Rates (mrem/h) from Grout Processing Facility
Particulate Air Filters.

Component	Distance (cm)									
	30	50	100	200	300	600	1,000	1,600	2,200	2,500
HEPA filter	100	60	18	4.5	1.9	0.5	0.3	0.1	0.05	0.04
Bag house filters (3)	288	129	39	10	4.5	1.2	0.4	0.2	0.09	0.07

HEPA = high-efficiency particulate air.

From past experience, two craftpersons will spend ≈ 1 h in the radiation field to change the HEPA filter. This work will have to be done inside a HEPA filtered enclosure. Assuming that a prefabricated unit is used, the assembly

and disassembly will take two craftpersons 2 h each. Enclosure assembly/disassembly is calculated from an average distance of ≈ 3 m. Annual collective dose figures for four campaigns per year are shown in Tables 13, 14, and 15.

Table 13. Annual Personnel Exposure for Grout Processing Facility Bag Filter Changes.

Activity performed	Number of persons	Hours	Times per year	Annual manhours	Dose rate (rem/h)	Annual collective dose (person-rem)
Bag house containment-carpenters	2	2	4	16	0.005	0.08
Bag house containment- operations	1	2	4	8	0.005	0.04
Bag change- millwrights	2	1	4	8	0.129	1.032
Bag change-health physics technician	1	1	4	4	0.005	0.02
Total	--	--	--	36	--	1.172

Table 14. Annual Personnel Exposure for Grout Processing Facility High-Efficiency Particulate Air Changes.

Activity performed	Number of persons	Hours	Times per year	Annual manhours	Dose rate (rem/h)	Annual collective dose (person-rem)
HEPA change-millwrights	2	1	2	4	0.060*	0.24
HEPA change-HPT	1	4	2	8	0.002	0.016
HEPA filter containment-carpenters	2	2	2	8	0.002	0.016
HEPA filter containment-operations	1	2	2	4	0.002	0.008
Total	--	--	--	24	--	0.28

*Averaged.

HEPA = high-efficiency particulate air.

HPT = health physics technician.

Table 15. Annual Personnel Exposure for Grout Processing Facility Continuous Air Monitor Routines.

Activity performed	Number of persons	Hours	Times per year	Annual manhours	Dose rate* (rem/h)	Annual collective dose (person-rem)
CAM daily inspection-HPT	1	0.05	365	18.25	0.0005	0.009
CAM weekly inspection-HPT	1	0.17	52	8.84	0.0005	0.004
CAM monthly inspection-HPT	1	0.33	12	3.96	0.0005	0.002
CAM monthly inspection- instrument	1	0.40	12	4.8	0.0005	0.002
CAM quarterly maintenance- instrument	1	1.00	4	4.0	0.0005	0.002
CAM annual maintenance-instrument	2	2.00	1	4.0	0.0005	0.002
Total	--	--	--	43.85	--	0.021

*Fully loaded HEPA at 600 cm.

CAM = continuous air monitor.

HEPA = high-efficiency particulate air.

HPT = health physics technician.

5.3.2 Grout Disposal Facility Ventilation

The potential increase in HEPA filter loading from the splash created by grout pouring into a vault is not known. Therefore, conservative partition fractions were used.

5.3.2.1 High-Efficiency Particulate Air Filter Changes. The GDF ventilation system's HEPA filters will capture radioactive material from the exhaust of four vaults filled in the course of a year (Table 16). It is assumed that two exhausters may be in use at a given time, and that 1,699 L/s (3,600 ft³/min) of air will be removed from each vault. It is further assumed that there will be nine primary HEPA filters per exhauster (Figure 2). Each primary HEPA filter is followed by a secondary HEPA filter. The partition fraction of 1.93×10^{-9} was used for active vaults (i.e., those undergoing filling operations). A partition fraction of 2.87×10^{-12} was used for the stagnant vaults.

Table 16. Single Vault Exhauster First-Stage High-Efficiency Particulate Air Filter.

Source	Waste activity (Ci/L)	Partition fraction	Ventilation rate (L/s)	Time (d)	Airstream activity (Ci)	Efficiency (%)	Filter activity (Ci)	Unfiltered activity (Ci)
Active	2.59 E-01	1.93 E-09	1,699	20	1.47 E+0	0.9997	1.470E+0	4.40E-04
Stagnant	2.59 E-01	2.87 E-12	1,699	180	1.96 E-02	0.9997	1.96E-02	5.89E-06
Total					1.49 E+0		1.49E+0	4.46E-04

Equation 6 was used to determine the amount of radioactive material captured on the filters.

Activity in GDF Airstream for One Vault

$$AA_v = (WA \times PF_a \times VR \times t_a) + (WA \times PF_s \times VR \times t_s) \quad (6)$$

where:

- AA_v = Total airstream activity in Ci from 1 vault
- PF_a = Partition fraction for an active vault; 1.93×10^{-9}
- PF_s = Partition fraction for a stagnant Vault; 2.87×10^{-12}
- t_a = Duration of active vault operation (20 d) ($\times 8.64 \times 10^4$ sec/d)
- t_s = Duration of stagnant vault operation (180 d) ($\times 8.64 \times 10^4$ sec/d)
- VR = Ventilation rate for all vaults; 1,699 L/s
- WA = Waste activity in Ci.

Figure 2. Vault Exhauster

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Activity Retained by Each First-Stage HEPA Filter in One Campaign

$$FA = 1/9 \times (\text{eff} \times AA_v) \quad (7)$$

Activity Passed Through Each First-Stage HEPA Filter in One Campaign

$$UA = 1/9 \times (AA_v - FA) \quad (8)$$

The calculated activity required to give a dose rate of 100 mrem/h at 30 cm from one filter is 0.11 Ci. For two exhausters servicing 4 vaults, this results in 6 change-outs each year, requiring 54 individual first-stage HEPA filters. In addition to the dose rates from the HEPA filters, personnel working on the changes will be exposed to radiation from the ducts used to connect the exhauster to the vault. It is assumed that the ducts are cleaned, shielded, or replaced as the dose gradually builds up over time. The dimensions of the HEPA filter and ducts are given in Table 17.

Table 17. Filter and Connecting Trunk Dimensions.

Item	Width or radius (cm)	Height (cm)	Thickness (cm)	Shield thickness (cm)	Source material
HEPA filter (rectangular)	61	61	29	29	Air
Ventilation duct (cylindrical)	30.48	243.84	--	0.32 (steel)	Air

HEPA = high-efficiency particulate air.

The duct connection/disconnection dose rate is assumed at an average of 20 mrem/h. Calculated dose rates from the nine fully loaded and enclosed HEPA filters and the ducts are shown in Table 18. Dose rates as a function of distance are shown in Table 18. Estimated exposures associated with ventilation work on two exhausters (four campaigns per year) are shown in Tables 19 and 20. The doses from changing filters include contributions from adjacent filters, and assume use of the built-in reach rod so only one filter is removed at once.

Table 18. Dose Rates (mrem/h) from Grout Disposal Facility Exhausters as a Function of Distance (cm).

Component	Distance (cm)								
	30*	60	100	200	300	600	1,000	1,600	2,200
First-stage HEPA filters	134	362	203	68	32	8.2	2.9	1.1	0.58
Ventilation duct	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

*Shielded changout dose rate.

HEPA = high-efficiency particulate air.

Table 19. Annual Personnel Exposure for Grout Disposal Facility High-Efficiency Particulate Air Filter Change.

Activity	Number of persons	Hours	Times per ¹ year	Annual manhours (4 vaults)	Dose rate (rem/h)	Annual collective dose (person-rem)
HEPA change-millwrights	2	2.5	6	30	0.134	4.02
HEPA change-operations	1	4	6	24	0.016 ²	0.384
HEPA filter containment-carpenters	2	2	6	24	0.032	0.768
HEPA filter containment-HPT	1	2	6	12	0.032	0.384
Total	--	--	--	90	--	5.556

¹Based on 4 vaults.

²Averaged.

HEPA = high-efficiency particulate air.

HPT = health physics technician.

Table 20. Annual Personnel Exposure for Grout Disposal Facility Continuous Air Monitor Operation.

Activity performed	Number of persons	Hours	Times per ¹ year	Annual manhours	Dose rate ² (rem/h)	Annual collective dose (person-rem)
CAM daily inspection-HPT	1	0.05	365	36.5	0.008	0.292
CAM weekly inspection-HPT	1	0.17	52	17.68	0.008	0.142
CAM monthly inspection-HPT	1	0.33	12	7.92	0.008	0.063
CAM monthly inspection-instrument	1	0.40	12	9.6	0.008	0.077
CAM quarterly maintenance-instrument	1	1.0	4	8	0.008	0.064
CAM annual maintenance-instrument	2	2.0	1	8	0.008	0.064
Total	--	--	--	87.7	--	0.702

¹Based on 2 exhausters.

²Assumed dose rate.

CAM = continuous air monitor.

HEPA = high-efficiency particulate air.

HPT = health physics technician.

Table 20 contains an assessment of time spent working on the continuous air monitors (CAM) associated with the two exhausters. The CAMs on the exhausters were conservatively modeled at 10 ft from the HEPAs. The daily inspection of the CAM and the weekly, monthly, quarterly, and annual maintenance or operational inspection activities provide a measurable and accountable annual exposure. The dose rate shown is assumed, and requires the exhauster to be shielded.

The time required to change nine primary HEPA filters in a 3-by-3 array is estimated to be 2.5 contact hours. The dose rate to a craft person on a HEPA filter change is at a distance of 30 cm from one filter and 150 cm from

two other filters. In this conservative worst-case beam path model (truncated cone), contribution from both top and bottom rows is considered. The other dose rates given in Table 19 are based on a fully loaded and unshielded first stage HEPA section.

5.3.2.2 Exhauster Relocations. Each of the two exhausters for the GDF will be connected and disconnected twice each year for a total of four operations. It is assumed the ducting connecting the exhauster to the riser will not be allowed to build to a significant source of exposure.

An average dose rate from the ducting of 20 mrem/h was applied to the two moving operations each year. Actually, the dose rate on the duct is negligible. This estimate does not consider additional exposure from contaminated HEPA filters, as it is prudent to change out HEPAs prior to this work. Each connection and disconnection was estimated to take 2 h. Assuming a prefabricated and easy to install HEPA filtered enclosure, it will take about 1 h to install and 1 h to remove containment for the job. The dose rate and person-hours are shown in Table 21.

Table 21. Annual Personnel Exposure for Grout Disposal Facility Ventilation Movement.

Activity performed	Number of persons	Hours	Times per year	Annual manhours	Dose rate (rem/h)	Annual collective dose (person-rem)
Exhauster connection or disconnection-craft	2	4	2	16	0.020	0.32
Exhauster connection/disconnection HPT support	1	4	2	8	0.020	0.16
Install and remove containment-craft	2	4	2	16	0.020	0.32
Install and remove containment operations support	1	4	2	8	0.020	0.16
Total	--	--	--	48	--	0.96

HPT = health physics technician.

5.4 ESTIMATE OF AIRBORNE EMISSIONS

Total annual airborne emissions are based on the assumption that Grout will fill four vaults each year. Emission estimates consider each facility separately, except for the most significant radioisotope. For accuracy, tritium was modeled conservatively and independently, as described in Section 5.4.1.

Based on filling four vaults each year, the results of the calculations described below were totaled, multiplied by four, and summed with the maintenance and tritium emission results. This discussion is valid for all other radionuclides except tritium.

The GPF flows were divided into three separate streams. The LCT contributes 28.3 L/s, the Surge Tank 70.8 L/s, and the LCT/MM (module) ventilation 236 L/s, for a total flow rate of 335 L/s. The Surge Tank first flows through a bag filter with a DF of 10, then cascades into the GPF dual HEPA filters. The duration of operations at the GPF were calculated at 30 d per campaign. This was deemed conservative, because fewer than 17 d are required to fill a vault. The partition fractions used at the GPF were 1.93×10^{-9} , except for the module ventilation, which used 2.87×10^{-11} . Maintenance emissions are discussed separately in Section 5.4.2.

The GDF differentiation was based on operational mode. The partition fraction changed from 1.93×10^{-9} for the active filling operation, to 2.87×10^{-12} for stagnant operations. The duration of active operations was 20 d. Stagnant operations are 180 d. Both operations used the same flow rate of 1,700 L/s (3,600 ft³/min).

5.4.1 Tritium Emissions

For accuracy, tritium was modeled separately as a mass transfer function. The internal contribution of all other radionuclides was insignificant compared to the dose from ³H. To be conservative, the entire inventory of ³H contained in the four GDF vaults was assumed to be released. No credit was taken for ³H decontamination by the HEPA filters, because Tritium is not controlled by these devices; consequently, ³H has a DF of 1 for all operations. The release model is not dependant on exhauster flow rate or duration. The release estimate assumes that four vaults will be filled each year. Based on four vaults, the total emissions of tritium from the GTF was determined to be 2.4×10^2 Ci, as shown in Section 5.4.1.1. Emission calculations were performed for all radionuclides except ³H. The emission estimates for all other radionuclides used the partition fractions, ventilation rates, and durations described previously.

5.4.1.1 Single Campaign Emission of Tritium. The concentration limit of ³H (1.6×10^{-5} Ci ³H/L of waste) in the waste stream was specified in WHC-SD-WM-RD-019, Revision 1, *Grout Treatment Facility Waste Acceptance Criteria* (Hendrickson 1991). With a liquid waste volume of 1 Mgal in each vault, the total ³H inventory of four vaults is approximately 242 Ci, as calculated by Equation 9. No credit was taken for ³H decontamination. To be conservative, the entire inventory of ³H contained in the four GDF vaults was assumed to be released. This is considered to be conservative, because grout is expected to hold approximately 35% of the ³H bound up (as water). This conservative approach yields figures that are high in proportion to the amount of water retained in the grout. Thus, the calculated ³H emission rate of 2.42×10^2 Ci/yr represents 100% of the ³H processed, and is, by several orders of magnitude, the dominant radionuclide affecting internal dose consequence.

The total emissions of ³H from GTF were determined as follows:

$$E_{H3,tot} = 1.6 \times 10^{-5} \text{ Ci/L} \times 3.7854 \text{ L/gal} \times 1.0 \times 10^6 \text{ gal/vault} \times 4 \text{ vaults} = 2.4 \times 10^2 \text{ Ci} \quad (9)$$

This equation provides conservative results because no credit is taken for the normal 30-45% water content that remains trapped in the grout. Calculations using Equation 9 give total ^3H emissions for a four vault annual grout operation.

5.4.2 Annual Maintenance Emissions

Annual maintenance emission estimates are based on the conservative assumption of uncontrolled releases from the air space of the LCT/MM during maintenance periods. The GPF ventilation system will be adequate for air control during manway access, if no equipment removal is required. To the extent possible, the module will be enclosed by a HEPA-filtered enclosure, if it is necessary to open the module fully. The air space is assumed to be contaminated to the partition fraction of a vault and to be lost instantaneously on removal of module cover blocks. An equivalent volume is assumed to be lost every hour that the module remains open. The airspace volume, 125.5 m^3 , is that of the module, neglecting the equipment. The duration and frequency of open module maintenance are not expected to exceed one 16-h preventative maintenance operation, and four 16-h, unplanned, corrective, maintenance operations annually (Section 4.1).

Total emissions from these operations would be:

$$[(1 + 16 \text{ h}) + 4(1 + 16 \text{ h})] = 85 \text{ airspace volumes of each constituent.}$$

Maintenance emissions from each constituent are determined as follows:

$$E_i (\text{Ci/yr}) = C_i (\text{Ci/L feed}) \times (\text{L feed}/1.43 \text{ L grout}) \times PF \times (125.5 \text{ m}^3) \times (1,000 \text{ L/m}^3) \times (85/\text{yr}) \quad (10)$$

For example, maintenance emissions of ^{137}Cs are determined as follows:

$$E^{137}\text{Cs} = 3.7 \text{ E-01 Ci/L} \times (1/1.43) \times (2.87 \text{ E-10}) \times 125.5 \text{ m}^3 \times 1,000 \text{ L/m}^3 \times 85 = 7.92 \text{ E-04 Ci/yr} \quad (11)$$

5.4.3 Total Annual Radiological Emissions

Total annual emissions are four times the sum of the GPF and GDF campaign emissions, plus the maintenance emissions (refer to Table 22). Thus, for ^{137}Cs :

$$\begin{aligned}
 E^{137}\text{Cs} &= \left[4 \times (1.26 \times 10^{-7} \text{ Ci} + 3.72 \times 10^{-6} \text{ Ci}) \right] + 7.92 \times 10^{-4} \text{ Ci} \\
 &= 8.08 \times 10^{-4} \text{ Ci/yr}
 \end{aligned}
 \tag{12}$$

Total radiological emissions from process operations and maintenance operations are presented in summary in Table 22. The supporting tables (Tables 23 through 28) are included for details. The total annual radiological release is predominately ^3H at 242 Ci/yr.

5.5 HOT TIE-INS

To redirect piping from one vault to another a hot tie-in must be performed. Each vault has two pipe lines connecting it to the GPF; a grout feed line and an EW return line. The feed line and EW return line work include 1 h for NDE of pipe wall thickness. The final hot tie-in enclosure and method is not settled. An ALARA evaluation needs to be completed. Currently, a hot tie-in requires cutting a section of each pipe, capping the downstream piping, and reconnecting the upstream piping to a new line. To access the lines, a HEPA filtered containment must be erected. The hot tie-in operation is a multi-craft function requiring laborers, pipefitters, welders, quality control (QC), and HPT support.

For the purpose of estimating occupational exposures received during a hot tie-in, the following assumptions are made:

- An ALARA method will reduce exposures associated with hand excavation
- 0.1 in. of grout build up will remain in the grout line
- The equivalent of 0.01 in. of grout will remain in the EW line.

The pipes were modelled as cylinders with the dimensions and shielding as presented in Table 29.

The listed thicknesses of grout buildup will create a source term of $\approx 5.95 \times 10^{-2}$ Ci in the grout pipe and 6.99×10^{-3} Ci in the EW return line. An unobstructed 2-ft pipe length is required for performing a hot tie-in. The resulting dose rates for an exposed 2 ft section are shown in Table 30. The source term is the same for both the EW and the grouted waste. The grout (or water, if present) offers little self-shielding in the quantities possible in the pipes. The significant grout buildup in the pipe carrying grout to the vault is based on no decontamination solution being used in the pipe. The EW return pipe is assumed to be drained of liquid before hot tie-in work begins.

Table 22. Summary of Air Emission Projections (Ci).

Isotope	LCT	Surge tank	Module	GPF total	GDF active	GDF stagnant	GDF total	Campaign total	Maintenance	Annual total
^3H	0.00 E+00	0.00 E+00	0.00 E+00	0.00 E+00	6.05 E+01	0.00 E+00	6.05 E+01	6.05 E+01	0.00 E+00	2.42 E+02
^{14}C	2.72 E-13	6.81 E-14	3.38 E-14	3.74 E-13	1.09 E-11	1.46 E-13	1.11 E-11	1.14 E-11	2.36 E-09	2.40 E-09
^{60}Co	6.93 E-12	1.73 E-12	8.59 E-13	9.52 E-12	2.78 E-10	3.73 E-12	2.82 E-10	2.91 E-10	5.99 E-08	6.11 E-08
^{79}Se	6.19 E-12	1.55 E-12	7.67 E-13	8.50 E-12	2.48 E-10	3.33 E-12	2.51 E-10	2.60 E-10	5.35 E-08	5.46 E-08
^{90}Sr	2.72 E-09	6.81 E-10	3.38 E-10	3.74 E-09	1.09 E-07	1.46 E-09	1.11 E-07	1.14 E-07	2.36 E-05	2.40 E-05
$^{90}\text{Y}^*$	0.00 E+00	0.00 E+00	0.00 E+00	0.00 E+00	0.00 E+00	0.00 E+00	0.00 E+00	0.00 E+00	0.00 E+00	0.00 E+00
^{94}Nb	8.66 E-12	2.17 E-12	1.07 E-12	1.19 E-11	3.47 E-10	4.66 E-12	3.52 E-10	3.64 E-10	7.49 E-08	7.64 E-08
^{99}Tc	2.23 E-11	5.57 E-12	2.76 E-12	3.06 E-11	8.93 E-10	1.20 E-11	9.05 E-10	9.36 E-10	1.93 E-07	1.96 E-07
^{106}Ru	4.21 E-09	1.05 E-09	5.22 E-10	5.78 E-09	1.69 E-07	2.26 E-09	1.71 E-07	1.77 E-07	3.64 E-05	3.71 E-05
$^{106}\text{Rh}^*$	0.00 E+00	0.00 E+00	0.00 E+00	0.00 E+00	0.00 E+00	0.00 E+00	0.00 E+00	0.00 E+00	0.00 E+00	0.00 E+00
^{129}I	7.67 E-14	1.92 E-14	9.51 E-15	1.05 E-13	3.08 E-12	4.12 E-14	3.12 E-12	3.22 E-12	6.64 E-10	6.77 E-10
^{134}Cs	1.16 E-09	2.91 E-10	1.44 E-10	1.60 E-09	4.66 E-08	6.25 E-10	4.73 E-08	4.89 E-08	1.01 E-05	1.03 E-05
^{137}Cs	9.16 E-08	2.29 E-08	1.14 E-08	1.26 E-07	3.67 E-06	4.92 E-08	3.72 E-06	3.85 E-06	7.92 E-04	8.08 E-04
$^{137\text{m}}\text{Ba}^*$	0.00 E+00	0.00 E+00	0.00 E+00	0.00 E+00	0.00 E+00	0.00 E+00	0.00 E+00	0.00 E+00	0.00 E+00	0.00 E+00
^{234}U	7.92 E-15	1.98 E-15	9.82 E-16	1.09 E-14	3.18 E-13	4.26 E-15	3.22 E-13	3.33 E-13	6.85 E-11	6.98 E-11
^{235}U	5.20 E-16	1.30 E-16	6.45 E-17	7.14 E-16	2.08 E-14	2.79 E-16	2.11 E-14	2.18 E-14	4.50 E-12	4.58 E-12
^{238}U	3.96 E-15	9.91 E-16	4.91 E-16	5.44 E-15	1.59 E-13	2.13 E-15	1.61 E-13	1.66 E-13	3.43 E-11	3.49 E-11
^{237}Np	5.20 E-14	1.30 E-14	6.45 E-15	7.14 E-14	2.08 E-12	2.79 E-14	2.11 E-12	2.18 E-12	4.50 E-10	4.58 E-10
^{238}Pu	1.96 E-13	4.89 E-14	2.42 E-14	2.69 E-13	7.84 E-12	1.05 E-13	7.94 E-12	8.21 E-12	1.69 E-09	1.72 E-09
$^{239/240}\text{Pu}$	4.21 E-13	1.05 E-13	5.22 E-14	5.78 E-13	1.69 E-11	2.26 E-13	1.71 E-11	1.77 E-11	3.64 E-09	3.71 E-09
^{241}Am	4.95 E-13	1.24 E-13	6.14 E-14	6.80 E-13	1.98 E-11	2.66 E-13	2.01 E-11	2.08 E-11	4.28 E-09	4.37 E-09
^{244}Cm	5.94 E-14	1.49 E-14	7.37 E-15	8.16 E-14	2.38 E-12	3.19 E-14	2.41 E-12	2.50 E-12	5.14 E-10	5.24 E-10
Totals	9.97 E-08	2.49 E-08	1.24 E-08	1.37 E-07	6.05 E+01	5.36 E-08	6.05 E+01	6.05 E+01	8.63 E-04	2.42 E+02

*Contribution of daughter products included in parent radionuclide

GDF = Grout Disposal Facility.

GPF = Grout Processing Facility.

LCT = liquid collection tank.

Table 23. Grout Processing Facility Liquid Collection Tank.

Isotope	Mean feed concentration (Ci/L)	Grout source concentration (Ci/L)	Flow rate (28.3 L/s)	Duration (30 d)	Partition fraction	Total decontamination factor	Campaign emissions (Ci)
^3H							N/A
^{14}C	1.1 E-06	7.69 E-07	2.83 E+01	2.59 E+06	1.93 E-09	4.00 E+05	2.72 E-13
^{60}Co	2.8 E-05	1.96 E-05	2.83 E+01	2.59 E+06	1.93 E-09	4.00 E+05	6.93 E-12
^{79}Se	2.5 E-05	1.75 E-05	2.83 E+01	2.59 E+06	1.93 E-09	4.00 E+05	6.19 E-12
^{90}Sr	1.1 E-02	7.69 E-03	2.83 E+01	2.59 E+06	1.93 E-09	4.00 E+05	2.72 E-09
$^{90}\text{Y}^*$	0.0 E+00	0.00 E+00	2.83 E+01	2.59 E+06	1.93 E-09	4.00 E+05	0.00 E+00
^{94}Nb	3.5 E-05	2.45 E-05	2.83 E+01	2.59 E+06	1.93 E-09	4.00 E+05	8.66 E-12
^{99}Tc	9.0 E-05	6.29 E-05	2.83 E+01	2.59 E+06	1.93 E-09	4.00 E+05	2.23 E-11
^{106}Ru	1.7 E-02	1.19 E-02	2.83 E+01	2.59 E+06	1.93 E-09	4.00 E+05	4.21 E-09
$^{106}\text{Rh}^*$	0.0 E+00	0.00 E+00	2.83 E+01	2.59 E+06	1.93 E-09	4.00 E+05	0.00 E+00
^{129}I	3.1 E-07	2.17 E-07	2.83 E+01	2.59 E+06	1.93 E-09	4.00 E+05	7.67 E-14
^{134}Cs	4.7 E-03	3.29 E-03	2.83 E+01	2.59 E+06	1.93 E-09	4.00 E+05	1.16 E-09
^{137}Cs	3.7 E-01	2.59 E-01	2.83 E+01	2.59 E+06	1.93 E-09	4.00 E+05	9.16 E-08
$^{137\text{m}}\text{Ba}^*$	0.0 E+00	0.00 E+00	2.83 E+01	2.59 E+06	1.93 E-09	4.00 E+05	0.00 E+00
^{234}U	3.2 E-08	2.24 E-08	2.83 E+01	2.59 E+06	1.93 E-09	4.00 E+05	7.92 E-15
^{235}U	2.1 E-09	1.47 E-09	2.83 E+01	2.59 E+06	1.93 E-09	4.00 E+05	5.20 E-16
^{238}U	1.6 E-08	1.12 E-08	2.83 E+01	2.59 E+06	1.93 E-09	4.00 E+05	3.96 E-15
^{237}Np	2.1 E-07	1.47 E-07	2.83 E+01	2.59 E+06	1.93 E-09	4.00 E+05	5.20 E-14
^{238}Pu	7.9 E-07	5.52 E-07	2.83 E+01	2.59 E+06	1.93 E-09	4.00 E+05	1.96 E-13
$^{239/240}\text{Pu}$	1.7 E-06	1.19 E-06	2.83 E+01	2.59 E+06	1.93 E-09	4.00 E+05	4.21 E-13
^{241}Am	2.0 E-06	1.40 E-06	2.83 E+01	2.59 E+06	1.93 E-09	4.00 E+05	4.95 E-13
^{244}Cm	2.4 E-07	1.68 E-07	2.83 E+01	2.59 E+06	1.93 E-09	4.00 E+05	5.94 E-14
Totals							9.97 E-08

*Contribution of daughter products included in parent radionuclide.

Table 24. Grout Processing Facility Surge Tank.

Isotope	Mean feed concentration (Ci/L)	Grout source concentration (Ci/L)	Flow rate (70.8 L/s)	Duration (30 d)	Partition fraction	Total decontamination factor	Campaign emissions (Ci)
^3H							N/A
^{14}C	1.1 E-06	7.69 E-07	7.08 E+01	2.59 E+06	1.93 E-09	4.00 E+06	6.81 E-14
^{60}Co	2.8 E-05	1.96 E-05	7.08 E+01	2.59 E+06	1.93 E-09	4.00 E+06	1.73 E-12
^{79}Se	2.5 E-05	1.75 E-05	7.08 E+01	2.59 E+06	1.93 E-09	4.00 E+06	1.55 E-12
^{90}Sr	1.1 E-02	7.69 E-03	7.08 E+01	2.59 E+06	1.93 E-09	4.00 E+06	6.81 E-10
$^{90}\text{Y}^*$	0.0 E+00	0.00 E+00	7.08 E+01	2.59 E+06	1.93 E-09	4.00 E+06	0.00 E+00
^{94}Nb	3.5 E-05	2.45 E-05	7.08 E+01	2.59 E+06	1.93 E-09	4.00 E+06	2.17 E-12
^{99}Tc	9.0 E-05	6.29 E-05	7.08 E+01	2.59 E+06	1.93 E-09	4.00 E+06	5.57 E-12
^{106}Ru	1.7 E-02	1.19 E-02	7.08 E+01	2.59 E+06	1.93 E-09	4.00 E+06	1.05 E-09
$^{106}\text{Rh}^*$	0.0 E+00	0.00 E+00	7.08 E+01	2.59 E+06	1.93 E-09	4.00 E+06	0.00 E+00
^{129}I	3.1 E-07	2.17 E-07	7.08 E+01	2.59 E+06	1.93 E-09	4.00 E+06	1.92 E-14
^{134}Cs	4.7 E-03	3.29 E-03	7.08 E+01	2.59 E+06	1.93 E-09	4.00 E+06	2.91 E-10
^{137}Cs	3.7 E-01	2.59 E-01	7.08 E+01	2.59 E+06	1.93 E-09	4.00 E+06	2.29 E-08
$^{137\text{m}}\text{Ba}^*$	0.0 E+00	0.00 E+00	7.08 E+01	2.59 E+06	1.93 E-09	4.00 E+06	0.00 E+00
^{234}U	3.2 E-08	2.24 E-08	7.08 E+01	2.59 E+06	1.93 E-09	4.00 E+06	1.98 E-15
^{235}U	2.1 E-09	1.47 E-09	7.08 E+01	2.59 E+06	1.93 E-09	4.00 E+06	1.30 E-16
^{238}U	1.6 E-08	1.12 E-08	7.08 E+01	2.59 E+06	1.93 E-09	4.00 E+06	9.91 E-16
^{237}Np	2.1 E-07	1.47 E-07	7.08 E+01	2.59 E+06	1.93 E-09	4.00 E+06	1.30 E-14
^{238}Pu	7.9 E-07	5.52 E-07	7.08 E+01	2.59 E+06	1.93 E-09	4.00 E+06	4.89 E-14
$^{239/240}\text{Pu}$	1.7 E-06	1.19 E-06	7.08 E+01	2.59 E+06	1.93 E-09	4.00 E+06	1.05 E-13
^{241}Am	2.0 E-06	1.40 E-06	7.08 E+01	2.59 E+06	1.93 E-09	4.00 E+06	1.24 E-13
^{244}Cm	2.4 E-07	1.68 E-07	7.08 E+01	2.59 E+06	1.93 E-09	4.00 E+06	1.49 E-14
Totals							2.49 E-08

*Contribution of daughter products included in parent radionuclide.

Table 25. Grout Processing Facility Module.

Isotope	Mean feed concentration (Ci/L)	Grout source concentration (Ci/L)	Flow rate (236 L/s)	Duration (30 d)	Partition fraction	Total decontamination factor	Campaign emissions (Ci)
^3H							N/A
^{14}C	1.1 E-06	7.69 E-07	2.36 E+02	2.59 E+06	2.87 E-11	4.00 E+05	3.38 E-14
^{60}Co	2.8 E-05	1.96 E-05	2.36 E+02	2.59 E+06	2.87 E-11	4.00 E+05	8.59 E-13
^{79}Se	2.5 E-05	1.75 E-05	2.36 E+02	2.59 E+06	2.87 E-11	4.00 E+05	7.67 E-13
^{90}Sr	1.1 E-02	7.69 E-03	2.36 E+02	2.59 E+06	2.87 E-11	4.00 E+05	3.38 E-10
$^{90}\text{Y}^*$	0.0 E+00	0.00 E+00	2.36 E+02	2.59 E+06	2.87 E-11	4.00 E+05	0.00 E+00
^{94}Nb	3.5 E-05	2.45 E-05	2.36 E+02	2.59 E+06	2.87 E-11	4.00 E+05	1.07 E-12
^{99}Tc	9.0 E-05	6.29 E-05	2.36 E+02	2.59 E+06	2.87 E-11	4.00 E+05	2.76 E-12
^{106}Ru	1.7 E-02	1.19 E-02	2.36 E+02	2.59 E+06	2.87 E-11	4.00 E+05	5.22 E-10
$^{106}\text{Rh}^*$	0.0 E+00	0.00 E+00	2.36 E+02	2.59 E+06	2.87 E-11	4.00 E+05	0.00 E+00
^{129}I	3.1 E-07	2.17 E-07	2.36 E+02	2.59 E+06	2.87 E-11	4.00 E+05	9.51 E-15
^{134}Cs	4.7 E-03	3.29 E-03	2.36 E+02	2.59 E+06	2.87 E-11	4.00 E+05	1.44 E-10
^{137}Cs	3.7 E-01	2.59 E-01	2.36 E+02	2.59 E+06	2.87 E-11	4.00 E+05	1.14 E-08
$^{137\text{m}}\text{Ba}^*$	0.0 E+00	0.00 E+00	2.36 E+02	2.59 E+06	2.87 E-11	4.00 E+05	0.00 E+00
^{234}U	3.2 E-08	2.24 E-08	2.36 E+02	2.59 E+06	2.87 E-11	4.00 E+05	9.82 E-16
^{235}U	2.1 E-09	1.47 E-09	2.36 E+02	2.59 E+06	2.87 E-11	4.00 E+05	6.45 E-17
^{238}U	1.6 E-08	1.12 E-08	2.36 E+02	2.59 E+06	2.87 E-11	4.00 E+05	4.91 E-16
^{237}Np	2.1 E-07	1.47 E-07	2.36 E+02	2.59 E+06	2.87 E-11	4.00 E+05	6.45 E-15
^{238}Pu	7.9 E-07	5.52 E-07	2.36 E+02	2.59 E+06	2.87 E-11	4.00 E+05	2.42 E-14
$^{239/240}\text{Pu}$	1.7 E-06	1.19 E-06	2.36 E+02	2.59 E+06	2.87 E-11	4.00 E+05	5.22 E-14
^{241}Am	2.0 E-06	1.40 E-06	2.36 E+02	2.59 E+06	2.87 E-11	4.00 E+05	6.14 E-14
^{244}Cm	2.4 E-07	1.68 E-07	2.36 E+02	2.59 E+06	2.87 E-11	4.00 E+05	7.37 E-15
Totals							1.24 E-08

*Contribution of daughter products included in parent radionuclide.

Table 26. Grout Processing Facility Maintenance Emissions.

Isotope	Waste-to-air partition fraction	Mean concentration	Standard deviation	Mean feed concentration (Ci/L)	Grout source concentration (Ci/L)	Module air concentration (Ci/L)	Module content per volume	Preventative, 1 x 16 h (Ci)	Corrective (unplanned), 4 x 16 h (Ci)	Annual maintenance emissions total (Ci)
^3H										N/A
^{14}C	2.87 E-10	1.43	0.0 E+00	1.1 E-06	7.69 E-07	2.21 E-16	2.77 E-11	4.71 E-10	1.88 E-09	2.36 E-09
^{60}Co	2.87 E-10	1.43	0.0 E+00	2.8 E-05	1.96 E-05	5.62 E-15	7.05 E-10	1.20 E-08	4.80 E-08	5.99 E-08
^{79}Se	2.87 E-10	1.43	0.0 E+00	2.5 E-05	1.75 E-05	5.02 E-15	6.30 E-10	1.07 E-08	4.28 E-08	5.35 E-08
^{90}Sr	2.87 E-10	1.43	0.0 E+00	1.1 E-02	7.69 E-03	2.21 E-12	2.77 E-07	4.71 E-06	1.88 E-05	2.36 E-05
$^{90}\text{Y}^*$	2.87 E-10	1.43	0.0 E+00	0.0 E+00	0.00 E+00	0.00 E+00	0.00 E+00	0.00 E+00	0.00 E+00	0.00 E+00
^{94}Nb	2.87 E-10	1.43	0.0 E+00	3.5 E-05	2.45 E-05	7.02 E-15	8.82 E-10	1.50 E-08	5.99 E-08	7.49 E-08
^{99}Tc	2.87 E-10	1.43	0.0 E+00	9.0 E-05	6.29 E-05	1.81 E-14	2.27 E-09	3.85 E-08	1.54 E-07	1.93 E-07
$^{106}\text{Ru}^*$	2.87 E-10	1.43	0.0 E+00	1.7 E-02	1.19 E-02	3.41 E-12	4.28 E-07	7.28 E-06	2.91 E-05	3.64 E-05
^{106}Rh	2.87 E-10	1.43	0.0 E+00	0.0 E+00	0.00 E+00	0.00 E+00	0.00 E+00	0.00 E+00	0.00 E+00	0.00 E+00
^{129}I	2.87 E-10	1.43	0.0 E+00	3.1 E-07	2.17 E-07	6.22 E-17	7.81 E-12	1.33 E-10	5.31 E-10	6.64 E-10
^{134}Cs	2.87 E-10	1.43	0.0 E+00	4.7 E-03	3.29 E-03	9.43 E-13	1.18 E-07	2.01 E-06	8.05 E-06	1.01 E-05
^{137}Cs	2.87 E-10	1.43	0.0 E+00	3.7 E-01	2.59 E-01	7.43 E-11	9.32 E-06	1.58 E-04	6.34 E-04	7.92 E-04
$^{137\text{m}}\text{Ba}^*$	2.87 E-10	1.43	0.0 E+00	0.0E+00	0.00 E+00	0.00 E+00	0.00 E+00	0.00 E+00	0.00 E+00	0.00 E+00
^{234}U	2.87 E-10	1.43	0.0 E+00	3.2 E-08	2.24 E-08	6.42 E-18	8.06 E-13	1.37 E-11	5.48 E-11	6.85 E-11
^{235}U	2.87 E-10	1.43	0.0 E+00	2.1 E-09	1.47 E-09	4.21 E-19	5.29 E-14	8.99 E-13	3.60 E-12	4.50 E-12
^{238}U	2.87 E-10	1.43	0.0 E+00	1.6 E-08	1.12 E-08	3.21 E-18	4.03 E-13	6.85 E-12	2.74 E-11	3.43 E-11
^{237}Np	2.87 E-10	1.43	0.0 E+00	2.1 E-07	1.47 E-07	4.21 E-17	5.29 E-12	8.99 E-11	3.60 E-10	4.50 E-10
^{238}Pu	2.87 E-10	1.43	0.0 E+00	7.9 E-07	5.52 E-07	1.59 E-16	1.99 E-11	3.38 E-10	1.35 E-09	1.69 E-09
$^{239/240}\text{Pu}$	2.87 E-10	1.43	0.0 E+00	1.7 E-06	1.19 E-06	3.41 E-16	4.28 E-11	7.28 E-10	2.91 E-09	3.64 E-09
^{241}Am	2.87 E-10	1.43	0.0 E+00	2.0 E-06	1.40 E-06	4.01 E-16	5.04 E-11	8.56 E-10	3.43 E-09	4.28 E-09
^{244}Cm	2.87 E-10	1.43	0.0 E+00	2.4 E-07	1.68 E-07	4.82 E-17	6.05 E-12	1.03 E-10	4.11 E-10	5.14 E-10
Totals										8.63 E-04

*Contribution of daughter products included in parent radionuclide.

Table 27. Grout Disposal Facility Active Operation.

Isotope	Mean feed concentration (Ci/L)	Grout source concentration (Ci/L)	Flow rate [1.70 E+03 L/s (3,600 ft ³ /min)]	Duration (20 d/yr)	Partition fraction	Total decontamination factor	Emission per vault (Ci)	Total emissions (4 vaults)
³ H							6.05 E+01	2.42 E+02
¹⁴ C	1.1 E-06	7.69 E-07	1.70 E+03	1.73 E+06	1.93 E-09	4.00 E+05	1.09 E-11	4.37 E-11
⁶⁰ Co	2.8 E-05	1.96 E-05	1.70 E+03	1.73 E+06	1.93 E-09	4.00 E+05	2.78 E-10	1.11 E-09
⁷⁹ Se	2.5 E-05	1.75 E-05	1.70 E+03	1.73 E+06	1.93 E-09	4.00 E+05	2.48 E-10	9.92 E-10
⁹⁰ Sr	1.1 E-02	7.69 E-03	1.70 E+03	1.73 E+06	1.93 E-09	4.00 E+05	1.09 E-07	4.37 E-07
⁹⁰ Y*	0.0 E+00	0.00 E+00	1.70 E+03	1.73 E+06	1.93 E-09	4.00 E+05	0.00 E+00	0.00 E+00
⁹⁴ Nb	3.5 E-05	2.45 E-05	1.70 E+03	1.73 E+06	1.93 E-09	4.00 E+05	3.47 E-10	1.39 E-09
⁹⁹ Tc	9.0 E-05	6.29 E-05	1.70 E+03	1.73 E+06	1.93 E-09	4.00 E+05	8.93 E-10	3.57 E-09
¹⁰⁶ Ru	1.7 E-02	1.19 E-02	1.70 E+03	1.73 E+06	1.93 E-09	4.00 E+05	1.69 E-07	6.75 E-07
¹⁰⁶ Rh*	0.0 E+00	0.00 E+00	1.70 E+03	1.73 E+06	1.93 E-09	4.00 E+05	0.00 E+00	0.00 E+00
¹²⁹ I	3.1 E-07	2.17 E-07	1.70 E+03	1.73 E+06	1.93 E-09	4.00 E+05	3.08 E-12	1.23 E-11
¹³⁴ Cs	4.7 E-03	3.29 E-03	1.70 E+03	1.73 E+06	1.93 E-09	4.00 E+05	4.66 E-08	1.87 E-07
¹³⁷ Cs	3.7 E-01	2.59 E-01	1.70 E+03	1.73 E+06	1.93 E-09	4.00 E+05	3.67 E-06	1.47 E-05
^{137m} Ba*	0.0 E+00	0.00 E+00	1.70 E+03	1.73 E+06	1.93 E-09	4.00 E+05	0.00 E+00	0.00 E+00
²³⁴ U	3.2 E-08	2.24 E-08	1.70 E+03	1.73 E+06	1.93 E-09	4.00 E+05	3.18 E-13	1.27 E-12
²³⁵ U	2.1 E-09	1.47 E-09	1.70 E+03	1.73 E+06	1.93 E-09	4.00 E+05	2.08 E-14	8.34 E-14
²³⁸ U	1.6 E-08	1.12 E-08	1.70 E+03	1.73 E+06	1.93 E-09	4.00 E+05	1.59 E-15	6.35 E-13
²³⁷ Np	2.1 E-07	1.47 E-07	1.70 E+03	1.73 E+06	1.93 E-09	4.00 E+05	2.08 E-12	8.34 E-12
²³⁸ Pu	7.9 E-07	5.52 E-07	1.70 E+03	1.73 E+06	1.93 E-09	4.00 E+05	7.84 E-12	3.14 E-11
^{239/240} Pu	1.7 E-06	1.19 E-06	1.70 E+03	1.73 E+06	1.93 E-09	4.00 E+05	1.69 E-11	6.75 E-11
²⁴¹ Am	2.0 E-06	1.40 E-06	1.70 E+03	1.73 E+06	1.93 E-09	4.00 E+05	1.98 E-11	7.94 E-11
²⁴⁴ Cm	2.4 E-07	1.68 E-07	1.70 E+03	1.73 E+06	1.93 E-09	4.00 E+05	2.38 E-12	9.53 E-12
Totals							6.05 E+01	2.42 E+02

*Contribution of daughter products included in parent radionuclide.

Table 28. Grout Disposal Facility Stagnant Operation.

Isotope	Mean feed concentration (Ci/L)	Grout source concentration (Ci/L)	Flow rate [1.70 E+03 L/s (3,600 ft ³ /min)]	Duration (180 d/yr)	Partition fraction	Total decontamination factor	Emission per vault (Ci)	Total emissions (4 vaults)
³ H							0.00 E+00	N/A
¹⁴ C	1.1 E-06	5.87 E-07	1.70 E+03	1.56 E+07	2.87 E-12	4.00 E+05	1.46 E-13	5.85 E-13
⁶⁰ Co	2.8 E-05	7.69 E-06	1.70 E+03	1.56 E+07	2.87 E-12	4.00 E+05	3.73 E-12	1.49 E-11
⁷⁹ Se	2.5 E-05	4.69 E-06	1.70 E+03	1.56 E+07	2.87 E-12	4.00 E+05	3.33 E-12	1.33 E-11
⁹⁰ Sr	1.1 E-02	4.62 E-03	1.70 E+03	1.56 E+07	2.87 E-12	4.00 E+05	1.46 E-09	5.85 E-09
⁹⁰ Y*	0.0 E+00	0.00 E+00	1.70 E+03	1.56 E+07	2.87 E-12	4.00 E+05	0.00 E+00	0.00 E+00
⁹⁴ Nb	3.5 E-05	6.99 E-06	1.70 E+03	1.56 E+07	2.87 E-12	4.00 E+05	4.66 E-12	1.86 E-11
⁹⁹ Tc	9.0 E-05	5.38 E-05	1.70 E+03	1.56 E+07	2.87 E-12	4.00 E+05	1.20 E-11	4.79 E-11
¹⁰⁶ Ru	1.7 E-02	3.01 E-03	1.70 E+03	1.56 E+07	2.87 E-12	4.00 E+05	2.26 E-09	9.05 E-09
¹⁰⁶ Rh*	0.0 E-03	3.01 E-03	1.70 E+03	1.56 E+07	2.87 E-12	4.00 E+05	0.00 E+00	0.00 E+00
¹²⁹ I	3.1 E-07	1.19 E-07	1.70 E+03	1.56 E+07	2.87 E-12	4.00 E+05	4.12 E-14	1.65 E-13
¹³⁴ Cs	4.7 E-03	8.39 E-04	1.70 E+03	1.56 E+07	2.87 E-12	4.00 E+05	6.25 E-10	2.50 E-09
¹³⁷ Cs	3.7 E-01	2.17 E-01	1.70 E+03	1.56 E+07	2.87 E-12	4.00 E+05	4.92 E-08	1.97 E-07
^{137m} Ba*	0.0 E+00	0.00 E+00	1.70 E+03	1.56 E+07	2.87 E-12	4.00 E+05	0.00 E+00	0.00 E+00
²³⁴ U	3.2 E-08	8.39 E-09	1.70 E+03	1.56 E+07	2.87 E-12	4.00 E+05	4.26 E-15	1.70 E-14
²³⁵ U	2.1 E-09	4.90 E-10	1.70 E+03	1.56 E+07	2.87 E-12	4.00 E+05	2.79 E-16	1.12 E-15
²³⁸ U	1.6 E-08	5.73 E-09	1.70 E+03	1.56 E+07	2.87 E-12	4.00 E+05	2.13 E-15	8.52 E-15
²³⁷ Np	2.1 E-07	4.06 E-08	1.70 E+03	1.56 E+07	2.87 E-12	4.00 E+05	2.79 E-14	1.12 E-13
²³⁸ Pu	7.9 E-07	3.01 E-07	1.70 E+03	1.56 E+07	2.87 E-12	4.00 E+05	1.05 E-13	4.20 E-13
^{239/240} Pu	1.7 E-06	6.29 E-07	1.70 E+03	1.56 E+07	2.87 E-12	4.00 E+05	2.26 E-13	9.05 E-13
²⁴¹ Am	2.0 E-06	9.79 E-07	1.70 E+03	1.56 E+07	2.87 E-12	4.00 E+05	2.66 E-13	1.06 E-12
²⁴⁴ Cm	2.4 E-07	5.38 E-08	1.70 E+03	1.56 E+07	2.87 E-12	4.00 E+05	3.19 E-14	1.28 E-13
Totals							5.36 E-08	2.14 E-07

*Contribution of daughter products included in parent radionuclide.

Table 29. Pipe Dimensions.

Item	Radius (cm)	Height (cm)	Grout thickness (cm)	Shield (cm)	Source
Grout pipe	2.46	60.96	0.254	0.55 (steel)	Grout
Excess water pipe	2.46	60.96	0.0254	0.55 (steel)	Excess water

Table 30. Hot Tie-in Dose Rates (mrem/h). (Working Shielding)

Item	5 cm	0.5 m	1 m	2 m
Grout slurry line	839	57	16	4.2
Excess water line	104	6.9	1.9	0.5
Shielded slurry line ¹	28	5.6	2.9	1.3
Shielded EW line ¹	2.9	0.6	0.3	0.1

¹At end of pipe.

The following calculations were used to develop the source term for hot tie-ins. The feed tank source term will be blended with dry grout at a blending ratio of 1:1.43. Because ¹³⁷Cs has no photons, its daughter isotope ¹³⁷Ba_m was used as the source radionuclide. Equation 13 shows the method used to arrive at 2.59 x 10⁻¹ Ci/L of ¹³⁷Ba_m.

$$\frac{0.37 \text{ Ci } ^{137}\text{Cs}}{L_{\text{feed}}} \times \frac{L_{\text{feed}}}{1.43 L_{\text{grout}}} = 0.259 \text{ Ci/L } ^{137}\text{Ba}_m \quad (13)$$

Equation 14 was used to find the total volume (in cm³) of an exposed 2-ft section of 2-in. Schedule 80 pipe. The pipe dimensions are 1.939-in. inner diameter by 24 in. in length. Converting to metric gives a diameter of 4.9251 cm by 60.96 cm in length. The standard volume formula requires radius. Therefore, a radius of 2.46 cm is shown.

$$V_1 = \pi r^2 \times h = 3.14159 \times (2.46 \text{ cm})^2 \times 60.96 \text{ cm} = 1,162 \text{ cm}^3 \quad (14)$$

Equation 15 shows the volume calculation for the non-contaminated pipe section. Note that 0.254 cm, or 0.1 in. of grout buildup was subtracted from the V₂ radius.

Equations 16 and 17 show the method used to calculate the remaining contaminated volume.

$$V_2 = \pi r^2 \times h = 3.14159 \times (2.21 \text{ cm})^2 \times 60.96 \text{ cm} = 935 \text{ cm}^3 \quad (15)$$

$$V_1 - V_2 = V_c \quad (16)$$

$$1,162 \text{ cm}^3 - 935 \text{ cm}^3 = 227 \text{ cm}^3 \quad (17)$$

There are 1,000 cm³/L. Rounding to two significant digits, the total activity in a 0.23 L pipe segment is 5.95×10^{-2} Ci of ¹³⁷Ba_m.

$$0.259 \text{ Ci/L } ^{137}\text{Ba}_m \times 0.23 \text{ L} = 5.95 \times 10^{-2} \text{ Ci } ^{137}\text{Ba}_m \quad (18)$$

The dose rates listed in Table 30 show the required 2-ft exposed section, and the effects of shielding. The grout slurry line and the EW line is again shown with 0.5 in. of temporary lead shielding. Shielding thickness was based on standard thickness required to reduce exposure to ALARA levels. Credit was taken for the shielding afforded by the outer 4-in. Schedule 40 piping only for the section modeled as shielded.

Hot tie-ins were modeled following the ALARA practices as explained below. Times based here are from consultations with supervisors and crafts who timed and performed this work. All applicable preparation work (e.g., weld preps) will be performed in the shop. The use of slip-on end caps saved considerable time by eliminating set-up, and fit-up tasks. No credit was taken for the use of temporary shielding draped over the exposed section. No credit was taken for the removal of the cut section, due to concerns for increased radiation streaming from the cut end. This work is currently under study to determine additional ALARA techniques, i.e., additional shielding for the pipe section during cutting. Annual personnel exposures from grout lines are shown in Table 31. The 62.9 mrem/h dose rate shown in Table 31 is based on the sum of exposures 50 cm from the exposed 2 foot section, 50 cm from the end of the shielded section, and a small percentage from the 1 meter distant shielded EW line. The annual personnel exposures from the EW return lines are shown in Table 32. Table 33 summarizes the annual personnel exposures from hot tie-ins. The NDE dose rate is conservatively assumed at 155 mrem/h.

Table 31. Annual Personnel Exposures from Grout Lines.

Activity	Number of persons	Hours	Times per year	Annual manhours	Dose rate (rem/h)	Annual collective dose (person-rem)
Construct containment	2	4	4	32	0.001	0.03
Layout and 4-in. encasement cuts	1	2	4	8	0.063	0.504
Hot taps	1	1.5	4	6	0.063	0.378
Layout and 2-in. cuts	1	1.5	4	6	0.063	0.378
Weld 2-in. caps	1	0.50	4	2	0.063	0.126
Prep 4-in.	1	0.50	4	2	0.063	0.126
Weld 4-in. spool to 4-in. line	1	1.0	4	4	0.063	0.252
Prep 2-in.	1	0.50	4	2	0.063	0.126
Weld 2-in. new to 2 in. existing	1	0.50	4	2	0.063	0.126
Install and weld 4-in. saddle	1	1.0	4	4	0.063	0.252
Remove tools, equipment, and containment	2	1	4	8	0.005*	0.04
Support, all tasks	1	23	4	92	0.010*	0.92
Total grout line				168		3.258

*Assumption.

Table 32. Annual Personnel Exposures from Excess Water Return Lines.

Activity	Number of persons	Hours	Times per year	Annual manhours	Dose rate (rem/h)	Annual collective dose (person-rem)
Layout and 4-in. encasement cuts	1	2	4	8	0.010	0.08
Hot taps	1	1.5	4	6	0.010	0.06
Layout and 2-in. cuts	1	1.5	4	6	0.010	0.06
Weld 2-in. caps	1	0.5	4	2	0.010	0.02
Prep 4-in.	1	0.5	4	2	0.010	0.02
Weld 4-in. spool to 4-in. line	1	1.0	4	4	0.010	0.04
Prep 2-in.	1	0.5	4	2	0.010	0.02
Weld 2 in. new to 2 in. existing	1	0.50	4	2	0.010	0.02
Install and weld 4-in. saddle	1	1.0	4	4	0.010	0.04
Total excess water line				36		0.36

Table 33. Summary of Annual Personnel Exposures from Hot Tie-ins.

Activity	Times/yr	Annual manhours	Annual collective dose (person-rem)
Grout lines	4	168	3.258
Excess water lines	4	36	0.36
Nondestructive Examination	4	4	0.62
Total	--	208	4.238

6.0 SUMMARY OF ANNUAL EXPOSURE

Annual exposures received from operating the GTF are summarized in Table 34. An additional 10% has been added to account for expected operator and HPT exposure. Annual exposures for each job are summarized in Table 35. Based on 4 vaults annually, with the full source term, the estimated exposure to HPTs exceeds the new lower limit of 300 mrem per year.

Table 34. Summary of Annual Occupational Exposures for Grout Operations.

Activity performed	Total manhours	Percentage of total exposure	Annual dose (person-rem)
LCT/MM maintenance	82	16.9	2.68
Motor pit pump room sampling activities	2.5	1.6	0.25
GPF filter operation	104	9.3	1.47
GDF portable exhauster operation (including relocation)	225.7	45.5	7.22
Hot tie-ins	208	26.7	4.24
Subtotals	622.2	100	15.86
HPT/Operations routines	N/A	+10.0	1.59
Totals	N/A	110	17.45

GDF = Grout Disposal Facility.
 GPF = Grout Processing Facility.
 HPT = Health Physics Technician.
 LCT/MM = liquid collection tank/mixer module.
 N/A = not applicable.

Table 35. Summary of Annual Direct Exposures by Job.

Activity	Annual dose (person-rem)	Available manpower	Average dose (rem)
Maintenance	9.6	53	0.181
Construction contractor (hot tie-ins)	4.24*	25	0.170
Operators	1.674	16	0.105
HPTs	1.924	6	0.321

*Subject to review/revision.
HPT = Health Physics Technician.

7.0 FACILITY POSTING

7.1 ROUTINE OPERATIONS

The posting requirements applicable to grout operations are defined in WHC-CM-4-10, Section 9.0, Revision 3 (WHC 1991). During normal operations, only the following three postings will be required at the GTF: (1) radiation area, (2) radiologically controlled area, and (3) surface contamination area.

Radiation areas are required when whole body dose rates of 2 mrem/h or greater can be encountered within 30 cm of a source, or a surface covering a source. Radiation area posting will be required at ≈ 3 m from the bag filter and each active HEPA filter. This will require chaining off the area and posting radiation area signs. Radiation area signs will also be required for the motor pit pump room door during sample operations.

Radiologically controlled area (RCA) signs are required where dose rates exceed 0.05 mrem/h (100 mrem/yr) or where fixed contamination is present. Unless shielded, dose rates of 0.05 mrem/h may be encountered at up to 70 m from the nine fully loaded GDF vault exhausters HEPA filters. For the GPF, the fence will provide adequate containment for the RCA during most operations but the entrances will require posting. The GDF fencing will be posted as a high-radiation area, and enclose the active disposal vaults.

The glovebox in the motor pit pump room will be posted both as a surface contamination area and as a high-radiation area. Therefore, the motor pit pump room will not require separate posting.

7.2 MAINTENANCE

7.2.1 High-Efficiency Particulate Air Filter Changes

While the HEPA filters are being changed, the containment will require posting as a high-radiation area until verification of the dose rates on an unshielded HEPA filter are confirmed by an HPT.

The containments will also require posting as surface contamination areas. If the containments are a walk-in style, airborne radioactive area posting will be required. No change in posting of the general area will be required during filter changes, provided containments are used.

7.2.2 Liquid Collection Tank/Mixer Module Maintenance

Upon initial opening of the LCT/MM, the area must be posted as a high-radiation area, airborne radioactive area, and surface contamination area. Following initial surveys and decontamination, persons in the area may no longer require respiratory protection. Even though surface contamination will be maintained at less than detectable levels in the generally accessible areas of the LCT/MM, the high dose rates may not allow the in-depth survey required to release the area from a surface contamination status. The area will be maintained as a high-radiation area and surface contamination area whenever it is open and will be placed on respiratory protection status depending on what activities are occurring.

7.2.3 Hot Tie-Ins

Hot tie-ins will require the use of containment. Such a containment will be posted as a high radiation area whenever the pipes are exposed. Between the time the old pipes are removed and the new pipes are installed, the containment will be a surface contamination area and an airborne contamination area unless surveys by HPTs dictate otherwise.

The posting of a radiologically controlled area around the hot tie-in containment will be required because of the expected high radiation area and to control access.

7.2.4 Grout Disposal Facility Direct Radiation

Dose rates were calculated for the outside surface of a full grout disposal vault. The highest dose rate calculated was 2.4 mrem/h. Based on this low dose rate, there appears to be no need to provide radiation protection by fencing off the areas of the GDF beyond the vicinity of the grout pipes and ventilation system.

8.0 REFERENCES

- ANSI/ANS-6.6.1-1979, January, 1979. *American National Standard for Calculation and Measurement of Direct and Scattered Gamma Radiation from LWR Nuclear Power Plants.*
- Brown, R. L., 1991, *Cost Benefit Analysis*, WHC-SD-SQA-CSD-20003, Westinghouse Hanford Company, Richland, Washington.
- Deffenbaugh, M. L., 1993, *Grout Facilities Mixer Module Lubrication Study*, WHC-SD-WM-ES-204, Westinghouse Hanford Company, Richland, Washington.
- DOE, 1992, *Radiation Protection for Occupational Workers*, DOE Order 5480.11, U.S. Department of Energy, Washington, D.C.
- Hendrickson, D. W., 1991, *Grout Treatment Facility Airborne Emissions Projections*, WHC-SD-WM-TI-427, Rev 0, Westinghouse Hanford Company, Richland, Washington.
- Hendrickson, D. W., 1991, *Grout Treatment Facility Waste Feed Acceptance Criteria*, WHC-SD-WM-RD-019, Rev 1, Westinghouse Hanford Company, Richland, Washington.
- Hey, B. E., 1991, *Validation of the MICROSIELD 3 Computer Program*, WHC-SD-SQA-CSWD-306, Westinghouse Hanford Company, Richland, Washington.
- Kimura, R. T., and D. W. Lindsey, 1987, *Characterization of Airborne Radionuclide Particulates in Ventilated Liquid Waste Tanks*, RHO-RE-SA-216P, Rockwell Hanford Company, Richland, Washington.
- Lourant, I. O., 1989, *Validation of ISOSHLD-PC on the IBM-PC (PS-2/AT/XT)*, WHC-SD-SQA-CSWD-303, Westinghouse Hanford Company, Richland, Washington.
- Sontag, S. P., 1993, *Grout FSAR ALARA Engineering Study*, WHC-SD-WM-ES-245, Rev. 0, Westinghouse Hanford Company, Richland, Washington.
- Welsh, T. L., 1991, *Tank 241-AN-106 Characterization Results*, WHC-SD-CP-TP-065, Rev 0, Westinghouse Hanford Company, Richland, Washington.
- WHC, 1991, *Radiation Protection*, WHC-CM-4-10, Westinghouse Hanford Company, Richland, Washington.

WHC-SD-WM-DP-018 REV 0

Document Reviewed: ASSESSMENT OF ANNUAL EXPOSURE FOR GROUT OPERATIONS
(WHC-SD-WM-DP-018 Rev. 0)

Scope of Review: Arithmetic and dose calculations using assumptions
presented in the reviewed document. The validity of
those assumptions were not evaluated.

Yes	No	NA	
☐	☐	☒	* Previous reviews complete and cover analysis, up to scope of this review, with no gaps.
☒	☐	☐	Problem completely defined.
☒	☐	☒	Accident scenarios developed in a clear and logical manner.
☒	☐	☒	Necessary assumptions explicitly stated and supported.
☒	☐	☐	Computer codes and data files documented.
☒	☐	☐	Data used in calculations explicitly stated in document.
☒	☐	☐	Data checked for consistency with original source information as applicable.
☒	☐	☐	Mathematical derivations checked including dimensional consistency of results.
☒	☐	☐	Models appropriate and used within range of validity or use outside range of established validity justified.
☒	☐	☐	Hand calculations checked for errors. Spreadsheet results should be treated exactly the same as hand calculations.
☒	☐	☐	Software input correct and consistent with document reviewed.
☒	☐	☐	Software output consistent with input and with results reported in document reviewed.
☒	☐	☐	Limits/criteria/guidelines applied to analysis results are appropriate and referenced. Limits/criteria/guidelines checked against references.
☒	☐	☐	Safety margins consistent with good engineering practices.
☒	☐	☐	Conclusions consistent with analytical results and applicable limits.
☒	☐	☐	Results and conclusions address all points required in the problem statement.
☐	☐	☒	Format consistent with appropriate NRC Regulatory Guide or other standards
☐	☒	*	Review calculations, comments, and/or notes are attached.
☒	☐	☐	Document approved.

Edward R. Selle

Reviewer (Printed Name and Signature)

Edward R. Selle

4/16/93

Date

* Any calculations, comments, or notes generated as part of this review should be signed, dated and attached to this checklist. Such material should be labeled and recorded in such a manner as to be intelligible to a technically qualified third party.

DATE

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END