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ENGINEERING CHANGE NOTICE

Page 1 of 2 MGP

1 ECN 656335

Proj ECN

2 ECN Category (mark one)	3 Originator's Name, Organization, MSIN and Telephone No	4 USQ Required?	5 Date
Supplemental [ ] Direct Revision [x] Change ECN [ ] Temporary [ ] Standby [ ] Supersedure [ ] Cancel/Void [ ]	Mel G Piepho R3-26 372-8009	a [x] Yes [] No	12 28-99 MGP
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13a. Description of Change

13b Design Baseline Document? ~~[x]~~ Yes [x] No MGP 12-28-99

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Releases caused by a diesel fuel fire were added. Leak path factors for annual filter vessel shielding enclosure and for building were derived Dose calculations were also revised

14a. Justification (mark one)

Criteria Change	[x]	Design Improvement	[ ]	Environmental	[ ]	Facility Deactivation	[ ]
As Found	[ ]	Facilitate Const	[ ]	Const. Error/Omission	[ ]	Design Error/Omission	[ ]

14b Justification Details

Four bounding accidents postulated for the K West Basin integrated water treatment system are evaluated against applicable risk evaluation guidelines The accidents are a spray leak during fuel retrieval spray leak during backflushing, a hydrogen explosion, and a fire breaching filter vessel and enclosure Event trees and accident probabilities are estimated In all cases the unmitigated dose consequences are below the risk evaluation guidelines

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16 Design Verification Required	17 Cost Impact						18 Schedule Impact (days)		
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[x] No	Savings	[ ]		Savings	[ ]		Delay	[ ]	

19 Change Impact Review Indicate the related documents (other than the engineering documents identified on Side 1) that will be affected by the change described in Block 13 Enter the affected document number in Block 20

SDD/DD	[]	Seismic/Stress Analysis	[]	Tank Calibration Manual	[]
Functional Design Criteria	[]	Stress/Design Report	[]	Health Physics Procedure	[]
Operating Specification	[]	Interface Control Drawing	[]	Spares Multiple Unit Listing	[]
Criticality Specification	[]	Calibration Procedure	[]	Test Procedures/Specification	[]
Conceptual Design Report	[]	Installation Procedure	[]	Component Index	[]
Equipment Spec	[]	Maintenance Procedure	[]	ASME Coded Item	[]
Const. Spec.	[]	Engineering Procedure	[]	Human Factor Consideration	[]
Procurement Spec.	[]	Operating Instruction	[]	Computer Software	[]
Vendor Information	[]	Operating Procedure	[]	Electric Circuit Schedule	[]
OM Manual	[]	Operational Safety Requirement	[]	ICRS Procedure	[]
FSAR/SAR	[X]	IEFD Drawing	[]	Process Control Manual/Plan	[]
Safety Equipment List	[]	Cell Arrangement Drawing	[]	Process Flow Chart	[]
Radiation Work Permit	[]	Essential Material Specification	[]	Purchase Requisition	[]
Environmental Impact Statement	[]	Fac Proc Samp Schedule	[]	Tickler File	[]
Environmental Report	[]	Inspection Plan	[]		[]
Environmental Permit	[]	Inventory Adjustment Request	[]		[]

20 Other Affected Documents (NOTE Documents listed below will not be revised by this ECN) Signatures below indicate that the signing organization has been notified of other affected documents listed below

Document Number/Revision	Document Number/Revision	Document Number Revision
	HNF-1778	

21 Approvals

	Signature	Date	Signature	Date
Design Authority N/A				
Design Authority N/A				
Cog. Eng. M Piepho	Mel Piepho	12/28/99		
Cog. Mgr R. Garrett	[signature]	~~1/6/99~~ 1/6/00 RLG		
QA N/A				
Safety C T Miller	[signature]	1/5/00		
Environ N/A				

DEPARTMENT OF ENERGY

Signature or a Control Number that tracks the Approval Signature

ADDITIONAL

DISTRIBUTION SHEET

To	From	Page 1 of 1
Distribution	Nuclear Safety	Date 12/28/99
Project Title/Work Order		EDT No N/A
HNF-1777, Rev 5 K West Basin Integrated Water Treatment System Annular Filter Vessel Accident Calculations and Derivation of Leak Path Factors		ECN No 656335

Name	MSIN	Text With All Attach.	Text Only	Attach./ Appendix Only	EDT/ECN Only
W C Alaconis	R3-86	X			
R L Boyleston	R3-26	X			
J D Carlson	R3-26	X			
G A Chaffee	X3-79	X			
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D S Leach	B4-45	X			
M A Medsker	R3-26	X			
C T Miller	X3-79	X			
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C R Miska	R3-86	X			
A L Pajunen	R3-86	X			
S H Peck	R3-26	X			
M G Piepho (5)	R3-26	X			
D R. Precechtel	X3-85	X			
P D Rittmann	R3-26	X			
L S Semmens	X3-79	X			
C J Udell	G3-43	X			
R H Webb	R3-26	X			
Central Files	B1-07	X			
SNF Project Files	R3-11	X			

K West Basin Integrated Water Treatment System Annular Filter Vessel Accident Calculations and Derivation of Leak Path Factors

M. G Piepho, P D Rittmann
Fluor Federal Services, Richland, WA 99352
U S Department of Energy Contract DE-AC06-96RL13200

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Abstract Four bounding accidents postulated for the K West Basin integrated water treatment system are evaluated against applicable risk evaluation guidelines The accidents are a spray leak during fuel retrieval, spray leak during backflushing, a hydrogen explosion, and a fire breaching filter vessel and enclosure Event trees and accident probabilities are estimated In all cases, the unmitigated dose consequences are below the risk evaluation guidelines

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RECORD OF REVISION	(1) Document Number HNF-1777 Rev 5	Page 1

(2) Title

K West Basin Integrated Water Treatment System Annular Filter Vessel Accident Calculations and Derivation of Leak Path Factors

CHANGE CONTROL RECORD			
(3) Revision	(4) Description of Change Replace Add, and Delete Pages	Authorized for Release	
		(5) Cog. Engr Date	(6) Cog. Mgr Date
	(7)		
0	**EDT 607700**	W T Watson	L J Garvin
1	**ECN 637172** *Accident frequency estimates are revised to reflect the fact that no water flow through the filters is possible when the system 9 booster pump is off*	W T Watson	L J Garvin
2	**ECN 630496** *Update hydrogen generation rate and dose consequences for hydrogen deflagration accident*	W T Watson	L J Garvin
3	**ECN 637179** *Revised calculations to provide unmitigated analyses*	W T Watson	L J Garvin
4	**ECN 647521** *Accidents in HNF-1777 and HNF-1778 were combined. Method for estimating filter inventory was revised. Resulting dose calculations were revised also*	P D Rittmann	R.L Garrett
4A	**ECN 647523** *Typographical error corrected for off-site dose consequence in Table 5-1*	R.H Webb	R.L Garrett
4B	**ECN 647525** *Unused acronym removed from list of terms*	R.H. Webb	R. L Garrett
5 RS	**ECN 656335** *Releases and consequences caused by diesel fuel fire were added. Leak path factors were derived Dose calculations were also revised*	M G Piepho M G Piepho 1/6/00	R.L Garrett 1/6/00

K WEST BASIN INTEGRATED WATER TREATMENT SYSTEM ANNULAR FILTER VESSEL ACCIDENT CALCULATIONS AND DERIVATION OF LEAK PATH FACTORS

M G Piepho, Ph D
P D Rittmann, Ph D , CHP
Fluor Federal Services Inc
Richland, Washington

December 1999

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ARF	airborne release fraction
ARR	airborne release rate
CEDE	committed effective dose equivalent
DBA	design basis accident
FRS	fuel retrieval system
IWTS	integrated water treatment system
LPF	leak path factor
MAR	material at risk
MCO	multi-canister overpack
RF	respirable fraction
SNF	spent nuclear fuel
TEDE	total effective dose equivalent
TRU	transuranic
UD	unit dose

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1 0 INTRODUCTION

These calculations address bounding accidents postulated to occur with the annular filter vessel of the K West Basin Integrated Water Treatment System (IWTS) The radiological dose consequences for both onsite and offsite individuals are estimated and compared with applicable risk guidelines The results of the accidents considered here are expected to bound the consequences that could be expected from any credible accident with the filter vessels In no case does any accident lead to onsite or offsite doses that exceed the radiological risk acceptance guidelines from DOE-RL (Sellers 1997)

The accidents considered in this report are the result of spray leaks with bounding radionuclide concentrations inside the piping, the result of a filter tank leak that drains the filter tank headspace, allowing hydrogen gas to accumulate and explode, or the result of a diesel fuel fire, causing a breach of the annular filter vessel and enclosure Because bounding fuel and sludge compositions are used in the calculations, both basins are covered by these calculations

Leak path factors (LPFs) for the building and enclosure are derived in Appendix A Information about the relative amounts of cesium-137 (Cs-137) and transuranic (TRU) in the sludge are provided in Appendix B Output files for the SPRAY and ISO-PC programs are shown in Appendix C The quality assurance of the FLUENT[1] code at Hanford is described in Appendix D The reviewer checklists are listed in Appendix E

2 0 SCENARIO OVERVIEWS

The IWTS is designed to remove from basin water the particulate and dissolved radioactive species generated by operation of the fuel retrieval system (FRS) Figure 2-1 shows a sketch of the major features of the IWTS pertinent to this safety analysis The IWTS pumps liquid from FRS operations and filters the liquid through a screened knockout pot intended to remove particulate larger than 500 µm Liquid passing through the knockout pot is discharged to a parallel array of 10 settling pipes It is expected that particles larger than about 15 to 50 µm (depending upon particle density) will settle out in these pipes A booster pump collects flow exiting the settling pipes and directs the flow to three particulate filter vessels placed in parallel (HNF-S-0564) The water ejected from the bottom of the filter vessels is sent to the three ion exchange modules Some of the water from the ion exchange modules is used to supply other subprojects, and the remainder is sent directly back into the basin

If a predetermined differential pressure across a filter vessel is reached or a set radiation level is exceeded, the control system alarms, to notify an operator to remove the filters from

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[1]FLUENT is a trademark of FLUENT Inc , Lebanon, New Hampshire

service, one at a time, for backwashing During backwashing, the normal in-flow from the booster pump is stopped, and a reverse flow of water from the skimmer loop is pumped through the filter (HNF-S-0564) The backwash flow exiting the filter is recirculated to the entrance of the settling pipes It is estimated that it will take about 10-30 minutes to backwash each filter vessel Filter backwashing will be terminated when appropriate measured filter radiation levels are attained, and the actual backwashing time requirement may vary

All above water pressurized piping and pumps that contain radioactively contaminated water are completely enclosed by continuous, close-fitting shielding except within the annular filter enclosure box The pressurized pipe shielding is thick-walled pipe that provides radiation shielding equivalent to 7 62 cm (3 in) of concrete The pump shielding is designed to be removable for pump maintenance The annular filter enclosure box interior is about 3 81 m (12 5 ft) tall, 2 34 m (92 in) wide, and 5 79 m (19 ft) long The long walls are 20 32 cm (8 in) of concrete with 5 08 cm (2 in) of steel inside and out for a total thickness of 30 48 cm (12 in) The shorter walls are made of lead 5 715 cm (2 25 in) with 2 54 cm (1 in) steel inside and out The top is made of steel with a thickness of 2 54 cm (1 in) The steel filter vessels have an outer diameter of 1 83 m (72 in) and an inner diameter of 1 02 m (40 in) and have a height of about 3 05 m (10 ft) The bottom of each filter vessel is about 45 72 cm (18 in) from the floor and 30 48 cm (1 ft) from the ceiling of the shielded enclosure

2 1 SPRAY LEAKS

Spray releases from the water treatment system are possible any time the system is pressurized Spray leaks resulting from events that could cause a major rupture in process lines, while releasing large quantities of liquid, would not result in a respirable leak rate as large as that from a smaller, optimized orifice All spray releases are calculated for an optimized orifice (pin-hole) leak rather than a crack, although a crack would create larger respirable releases Orifice leaks are justified as bounding because all piping is new stainless steel and the facility design life is only 3 years (operations are expected to be completed within about 2 years) In addition, the presence of shielding and containment around the piping is ignored In effect, the spray leak is assumed to occur in an overhead pipe that is not encased The actual IWTS configuration will greatly reduce emissions from a spray leak because piping outside the shielding enclosure is encased in larger diameter pipe, and piping inside the enclosure is surrounded by the enclosure While not leak tight, the shielding enclosure will have very small gaps to ensure it fulfills its design purpose of minimizing radiation exposure near the filter tanks Small gaps mean low air infiltration rates under normal operating conditions During a spray leak air infiltration would be greatly reduced by the water and water vapor being added Overall air flow would be outward Impaction and settling losses will remove much of the airborne material

Two potential accidents have been postulated that bound the consequences of all credible spray leak accidents One postulated accident releases liquid as a result of a leak in the piping or pump for stream 9, between the settling pipes and the filter vessels The waste stream processed by the IWTS during a given 24-hour period could comprise any combination of radionuclides from (1) typical K West Basin water, (2) the disintegration of fuel assemblies during fuel cleaning operations, and (3) sludge from the fuel canisters The potential emissions associated with these sources are compared It is determined that the expected sludge in fuel canisters represents the greatest potential radioactive source The other potential accident evaluated is a spray release from piping or the pump for stream 10 during filter backwashing

These spray release accidents would most likely be caused by a pin-hole leak in a fitting, pipe, or pump in the pressurized stream because the system will be leak tested at operating pressures before being placed in service Leakage of piping of diameter less than 3 in is anticipated to occur with an annual frequency of 8 8 x 10^{5} per foot of piping while the annual frequency for leakage of larger diameter pipe is about 8 8 x 10^{-6} per foot of piping (EGG-SSRE-8875) While there is on the order of 100 ft of pressurized piping for either stream 9 or 10, most of this piping is sleeved so that a leak in this section would produce essentially no respirable release Because this sleeving will not be pressure tested, no credit will be taken for it in the frequency estimate It is estimated that a total of 50 ft of pressurized piping is associated with stream 9 and that about 100 ft of pressurized piping is associated with stream 10 Stream 9 consists of 4-in piping up to the valves within the filter enclosure box that direct the stream to the filter inlet, while stream 10 uses 2-in piping throughout Stream 9 has eight operated valves and one check valve that are above water, and stream 10 has six above water valves The annual external leakage rate of each of these valves is estimated to be 8 8 x 10^{-4} (EGG-SSRE-8875) Stream 9 also includes a pressurized booster pump whose external leakage frequency is estimated to be 3 0 x 10^{-6} /hr (EGG-SSRE-8875) Although a stream 10 failure may lead to a release only during backflushing, corrosion and other mechanisms that lead to failure occur throughout the year No duty factor is therefore applied to the failure frequency of the backflush line (stream 10) The estimated annual frequencies of stream 9 or 10 developing a leak within the filter enclosure are

stream 9 (8 8 x 10^{-6} /ft-yr)(35 ft) + (8 8 x 10^{5}/ft-yr)(15 ft) + (17 valves)(8 8 x 10^{-4}/yr-valve) +
(3 0 x 10^{-6} /hr) (8760 hr/yr)
= 4 3 x 10^{2}/yr

stream 10 (8 8 x 10^{5} /ft-yr)(100 ft) + (18 valves)(8 8 x 10^{-4} /yr-valve) = 2 5 x 10^{2}/yr

These frequency estimates are meant to provide some substantiation of the "unlikely" frequency categorization estimates developed during the hazards analysis for spray release accidents from above-water piping The assumed optimum-diameter hole may or may not happen Larger or smaller hole diameters are more likely overall, but lead to smaller respirable release rates The assumed suspended solids concentration used in the spray release calculations cannot exist continuously In the case of backwashing, the operation lasts about one hour and is not expected to occur more than once per week For routine fuel handling, the need to fill two multi-canister overpacks (MCOs) per week means the assumed 24 hour duration for the high suspended solids concentration can exist no more than 30% of the time Thus the accident frequency estimates can be expected to lie below 0 01/y, making the accident "unlikely"

2 2 HYDROGEN EXPLOSION

Dunng normal operatıon, the filter vessels are all completely filled wıth lıquıd so that flammable gas accumulatıon and combustıon ıs not possıble Under the postulated accıdent condıtıons, a leak develops ın the wall of a filter vessel or ın connected pıpıng Such a leak ıs not lıkely because the vessels are constructed of staınless steel, are qualıfied as pressure vessels, and have been desıgned to wıthstand a desıgn basıs earthquake Corrosıon or other undetected matenal faılure of a filter vessel or of pıpıng and fittıngs connected to the vessel, whıle unlıkely, ıs possıble If such a filter vessel leak were to occur whıle the IWTS was not ın operatıon or when lıquıd was not beıng pumped ınto the vessel, much of the lıquıd ın the vessel could draın out If the booster pump feedıng the filters were to faıl or be manually turned off, operatıons would be expected to perform a backwash of the filters Thıs backwash would remove most of the radıoactıve contamınants trapped ın the filter medıa, so they would not be released from the leak sıte If a backwash were performed before the accıdents consıdered here could occur, the consequences of the accıdent would be greatly reduced

The accıdent of concern ıs a deflagratıon of the hydrogen (and oxygen) gas generated by radıolysıs of water that has accumulated ın the headspace above the filter medıa

2 3 FIRES

Several potentıal fire accıdents have been ıdentıfied ın HNF-SD-SNF-FHA-001, *Fıre Hazards Analysıs for K Basıns Facılıtıes at 100K Area* Some fire scenarıos ınvolve the annular filter The fire scenarıo that causes a crıtıcal support column to fall down and ultımately cause a breach of an annular filter vessel ıs dıscussed ın detaıl ın Sectıon 7 0 Thıs fire desıgn basıs accıdent (DBA) ıs consıdered "extremely unlıkely" based on all of the events that have to happen as dıscussed ın Sectıon 7 0 The fallıng support column has to first cause the transfer bay brıdge crane to drop, whıch causes structural members to drop onto and breach the enclosure around the filter vessels and then breach the annular filter vessel ıtself Water spılls out the vessel carryıng sludge and sand as ıt drops to the floor outsıde of the enclosure Some of the sludge becomes aırborne due to resuspensıon after the drop and due to evaporatıon of the water on the floor

3 0 METHODOLOGY

The composıtıon of the sludge and fuel ın K East and K West Basıns determınes potentıal consequences The varıety of potentıal sludge composıtıons means that an average fuel mıxture wıll be boundıng, because sludge contaıns non-fuel materıals such as facılıty dust and corrosıon products The boundıng case fuel composıtıon was not used because the number of canısters emptıed to accumulate sıgnıficant radıoactıve materıal on the IWTS filter ıs greater than the number contaınıng safety basıs fuel Thus the average fuel composıtıon for each basın ıs used

To facilitate dose calculations with the average fuel composition, new values for unit dose (UD) need to be calculated These are presented in Section 3 2 using the same method given in HNF-SD-SNF-TI-059, *A Discussion on the Methodology for Calculating Radiological and Toxicological Consequences for the Spent Nuclear Fuel Project at the Hanford Site*

The realistic maximum amount of sludge that could accumulate in the annular filter vessels is the same for the accidents discussed in this report, This bounding inventory is assumed to cause a substantial reduction in the flow rate through the annular filter This bounding inventory is described in Section 3 3 The LPFs for various locations of release for several accidents are summarized in Section 3 5

The models used to analyze spray leaks are presented in Section 3 4 These are then applied to the two spray release accidents analyzed in this report

3 1 SLUDGE COMPOSITION

Characterization data for the K Basins general sludge is shown in Tables 3-1, 3-2, and 3-3 below Table 3-1 summarizes the composition observed in K East Basin This composition has been assumed to conservatively represent the composition of K West Basin sludge, although the total amounts differ, with K West totals being much smaller Tables 3-2 and 3-3 show the composition of canister and fuel washing sludge observed in several canisters taken from K East and K West Basins Sludge compositions for the K East Basin are included to accommodate the potential addition of an IWTS in the K East Basin also

The sludge data shown in Tables 3-1, 3-2, and 3-3 are nominal values taken from HNF-SD-SNF-TI-009, *105-K Basin Material Design Basis Feed Description for Spent Nuclear Fuel Project Facilities*, Volume 2, "Sludge " No bounding values are currently available Therefore, these nominal values are used along with a bounding unit dose factor The sludge is treated as K Basin fuel for purposes of calculating the inhalation dose to individuals downwind of a postulated accident (Section 3 2)

Additional information about radioactive composition is provided to compare the relative amounts of Cs-137 and TRU in the sludge with the relative amounts in the average fuel composition The Cs-137 is the principle gamma-emitting isotope, and will be measured by radiation detection instruments However, the inhalation dose from postulated accidents depends almost entirely on the activity of certain TRU isotopes, namely, Pu-238 Pu-239, Pu-240, and Am-241 The relative amounts of Cs-137 and TRU are affected by fuel burnup, radioactive decay, and differing solubilities in water Of particular concern is that the Cs-137 may be depleted relative to the TRU so that the potential inhalation dose from an accident is increased for a given instrument reading of exposure rates Additional discussion appears in Appendix B

Table 3-1 Composition of K East Basin General Sludge

Quantity	Weasel Pit	Main Basin Floor	Tech View Pit	North Loadout Pit	Elevator Pit
Miscellaneous Characteristics of K East Basin General Sludge					
Dry Density, MT/m^3	0 931	0 375	0 931	0 370	0 931
Wet Density, MT/m^3	1 56	1 32	1 56	1 27	1 56
Volume, m^3	10 10	21 50	0 40	6 30	1 40
Wet Sludge, MT	15 76	28 38	0 62	8 00	2 18
Dry Sludge, MT	9 40	8 06	0 37	2 33	1 30
Uranium, kg	559 83	722 84	22 17	83 87	77 6
Radiological Composition (µCi/g) of K East Basin General Sludge					
Sr-90	223 55	302 20	223 55	0	223 55
Cs-137	293 54	310 24	293 54	37 84	293 54
Pu-239	5 37	19 88	5 37	10 05	5 37
Am-241	8 17	28 11	8 17	7 27	8 17

Notes Listed data comes from HNF SD SNF TI 009 1998 *105 K Basin Material Design Basis Feed Description for Spent Nuclear Fuel Project Facilities* Volume 2 Sludge Rev 2 Fluor Daniel Hanford Incorporated Richland Washington The masses of sludge are computed as the product of the density and the volume Note that µCi/g is equivalent to Ci/MT Compositions for the Tech View Pit and Elevator Pit were assumed to be bounded by the composition measured for the ' Weasel Pit Hence all three have the same concentrations

For K East Basin the total general sludge volume is 39 7 m^3 and the corresponding wet mass is 54 95 MT Thus the average sludge density is 1 38 MT/m^3 The total uranium mass in K East Basin is 1 47 MT

For K West Basin the total general sludge volume is 4 67 m^3 and the corresponding wet mass is 6 03 MT Thus the average sludge density is 1 29 MT/m^3 The total uranium mass in K East Basin is 0 087 MT

Table 3-2 Composition of K East Basin Canister and Fuel Wash Sludge

Quantity	Canister Sludge		Fuel Washing Sludge		
	Full	Empty	Internal	Coating	Pieces
Miscellaneous Characteristics of K East Basin Canister and Fuel Wash Sludge					
Dry Density, MT/m^3	0 884	0 884	2 312	0 969	10 611
Wet Density, MT/m^3	1 62	1 62	3 00	1 50	11 02
Volume, m^3	3 00	0 40	0 518	0 061	0 149
Wet Sludge, MT	4 86	0 65	1 55	0 09	1 64
Dry Sludge, MT	2 65	0 35	1 20	0 06	1 58
Uranium, kg	1,408 97	187 86	880 43	26 14	1,464 42
Radiological Composition (μCi/g) of K East Basin Canister and Fuel Wash Sludge					
Sr-90	1,053 40	1,053 40	3,851 61	1,767 75	4 045 39
Cs-137	806 35	806 35	3,443 33	1,410 00	5,342 20
Pu-239	108 70	108 70	232 67	114 50	195 91
Am-241	138 34	138 34	210 50	93 40	168 01

Notes Listed data comes from HNF SD SNF TI-009 1998 105 K Basin Material Design Basis Feed Description for Spent Nuclear Fuel Project Facilities Volume 2 Sludge Rev 2 Fluor Daniel Hanford Incorporated Richland Washington The masses of sludge are computed as the product of the density and the volume Note that μCi/g is equivalent to Ci/MT

For K East Basin the total canister and fuel wash sludge volume is 4 13 m^3 and the corresponding wet mass is 8 80 MT Thus the average sludge density is 2 13 MT/m^3 The total uranium mass is 3 97 MT

Table 3-3 Composıtıon of K West Basın Canıster and Fuel Wash Sludge

Quantıty	Canıster Sludge		Fuel Washıng Sludge		
	Full	Empty	Internal	Coatıng	Pıeces
Mıscellaneous Characterıstıcs of K West Basın Canıster and Fuel Wash Sludge					
Dry Densıty, MT/m^3	2 053	2 053	2 31	0 97	10 612
Wet Densıty, MT/m^3	2 68	2 68	3 00	1 50	11 02
Volume, m^3	1 01	0 13	0 518	0 405	0 149
Wet Sludge, MT	2 71	0 36	1 55	0 61	1 64
Dry Sludge, MT	2 07	0 28	1 20	0 39	1 58
Uranıum, kg	1,329 96	177 33	880 43	26 14	1,464 42
Radıologıcal Composıtıon (μCı/g) of K West Canıster and Fuel Wash Sludge					
Sr-90	3,096 25	3,096 25	2,116 08	92 90	5,065 27
Cs-137	1,898 75	1,898 75	2,210 00	57 70	6,505 54
Pu-239	175 03	175 03	184 00	4 62	203 12
Am-241	136 66	136 66	148 00	4 38	165 58

Notes Lısted data comes from HNF SD SNF TI 009 1998 105 K Basın Materıal Desıgn Basıs Feed Descrıptıon for Spent Nuclear Fuel Project Facılıtıes Volume 2 Sludge Rev 2 Fluor Danıel Hanford Incorporated Rıchland Washıngton The masses of sludge are computed as the product of the densıty and the volume Note that μCı/g ıs equıvalent to Cı/MT

For K West Basın the total canıster and fuel wash sludge volume ıs 2 22 m^3 and the correspondıng wet mass ıs 6 87 MT Thus the average sludge densıty ıs 3 10 MT/m^3 The total uranıum mass ıs 3 88 MT

The mass of sludge shown ın the tables ıs the product of the sludge densıty and the sludge volume Prımarıly the IWTS filters wıll accumulate sludge released from canısters and fuel durıng fuel washıng operatıons Mınımal amounts of floor sludge wıll be drawn ınto the system

3 2 K BASINS FUEL COMPOSITION AND UNIT DOSE

Whıle the unıt dose dıscussıon ought to be based on the above sludge composıtıons, ıt wıll ınstead be based on fuel composıtıons Thıs approach ıs taken to ensure that dose calculatıons ınvolvıng sludge are properly bounded Sludge composıtıons range from mostly sand to mostly fuel The boundıng case ıs pure fuel In addıtıon, HNF-SD-SNF-TI-009, Volume 2, specıfies the use of safety-basıs fuel composıtıons to represent the sludge unıt dose Because the boundıng ınventory ın the IWTS annular filters ınvolves more fuel than ıs avaılable wıth the boundıng-case composıtıon (ı e , safety-basıs fuel), an average composıtıon wıll be used Thıs ıs dıscussed ın more detaıl below

The radionuclide composition of average K East and K West fuel was obtained from information contained in HNF-SD-SNF-TI-015, *Spent Nuclear Fuel Project Technical Databook* These radioisotopes are decayed to May 31, 1998 The long decay half-lives of the main contributors (plutonium and americium) means the decay time has little effect on the resulting unit doses Tables 3-4 and 3-5 show this radionuclide composition in both total curies and Bq/g U The activity per gram of uranium is obtained by converting curies to becquerels (1 Ci = 3 7 x 10^{10} Bq) and then dividing by the number of grams of uranium fuel

Assuming that this mixture becomes airborne as respirable-sized particles, a unit dose factor that gives the dose per gram inhaled can be computed It is assumed that the relative amounts of each radionuclide do not change The usefulness of this dose factor is that one number replaces many numbers (i e , the individual dose factors for each nuclide) The drawback to this number is that it only applies to one specific nuclide composition

The unit dose factor is the sum of the products of the activity per gram of uranium and the committed effective dose equivalent (CEDE) per unit activity inhaled as shown in the equation below Values for "Inhalation dose factor" were taken from Federal Guidance Report Number 11, *Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation*, and are listed in Tables 3-4 and 3-5 The computed unit dose factors are listed in the column labeled "Unit dose " To indicate the relative importance of the various radionuclides to the total dose, the last column shows the fraction contributed by each nuclide to the total dose per gram inhaled

$$UD = \sum_K (UQ_K)(DF_K)$$

where

UD	=	50-year CEDE from inhalation of a unit mass of fuel as respirable particles, Sv/g U
UQ_K	=	activity of the Kth nuclide per unit mass of fuel, Bq/g U
DF_K	=	50-year CEDE per unit activity inhaled of the Kth nuclide, Sv/Bq

For K East Basin fuel, the unit dose is 1,950 Sv/g U, while for K West Basin fuel, the unit dose is 2,000 Sv/g U These values are about half the unit dose for safety-basis fuel, 4,380 Sv/g U (HNF-SD-SNF-TI-059) The consequence analysis in the following sections conservatively uses sludge mass for spent fuel mass on a one-for-one basis In reality, only part of the sludge mass is spent fuel mass, but since this part is difficult to determine, this analysis considers all sludge mass to be spent fuel mass In other words, the K East Basin fuel unit dose is 1,950 Sv/g sludge and the K West Basin fuel unit dose is 2,000 Sv/g sludge

Table 3-4 Unit Dose for K East Basin Average Fuel (3 sheets)

Nuclide	Activity[a] (Ci)	Activity (Bq/gU)	Inhalation DF[b]		UD[c] (Sv/gU)	Percent of Total
			(Sv/Bq)	Class		
Fission and Activation Products						
H-3	1 80 E+04	5 82 E+05	2 60 E-11	Vapor	1 51 E-05	0 00%
C-14	3 62 E+02	1 17 E+04	5 64 E-10	Organic	6 61 E-06	0 00%
Fe-55	9 64 E+02	3 12 E+04	7 26 E-10	D	2 26 E-05	0 00%
Co-60	1 86 E+03	6 02 E+04	5 91 E-08	Y	3 56 E-03	0 00%
Ni-59	2 11 E+01	6 83 E+02	7 31 E-10	Vapor	4 99 E-07	0 00%
Ni-63	2 30 E+03	7 44 E+04	1 70 E-09	Vapor	1 27 E-04	0 00%
Se-79	4 35 E+01	1 41 E+03	2 66 E-09	W	3 74 E-06	0 00%
Kr-85	2 84 E+05	9 19 E+06	3 57 E-13	Gas[d]	3 28 E-06	0 00%
Sr-90	4 96 E+06	1 60 E+08	6 47 E-08	D	1 04 E+01	0 53%
Y-90	4 97 E+06	1 61 E+08	2 28 E-09	Y	3 67 E-01	0 02%
Zr-93	2 01 E+02	6 50 E+03	8 67 E-08	D	5 64 E-04	0 00%
Nb-93m	1 26 E+02	4 08 E+03	7 90 E-09	Y	3 22 E-05	0 00%
Tc-99	1 45 E+03	4 69 E+04	2 25 E-09	W	1 06 E-04	0 00%
Ru-106	1 39 E+03	4 50 E+04	1 29 E-07	Y	5 80 E-03	0 00%
Rh-106	1 39 E+03	4 50 E+04	DP[e]		NA	0 00%
Pd-107	8 59 E+00	2 78 E+02	3 45 E-09	Y	9 59 E-07	0 00%
Ag-110	2 28 E-04	7 38 E-03	DP[e]		NA	0 00%
Ag-110m	1 71 E-02	5 53 E-01	2 17 E-08	Y	1 20 E-08	0 00%
Cd-113m	1 80 E+03	5 82 E+04	4 13 E-07	D	2 41 E-02	0 00%
In-113m	1 77 E-07	5 73 E-06	1 11 E-11	D	6 36 E-17	0 00%
Sn-113	1 77 E-07	5 73 E-06	2 88 E-09	W	1 65 E-14	0 00%
Sn-119m	2 50 E-01	8 09 E+00	1 69 E-09	W	1 37 E-08	0 00%
Sn-121m	4 01 E+01	1 30 E+03	3 22 E-09	W	4 17 E-06	0 00%
Sn-123	1 46 E-05	4 72 E-04	8 79 E-09	W	4 15 E-12	0 00%
Sn-126	8 07 E+01	2 61 E+03	2 69 E-08	W	7 02 E-05	0 00%
Sb-125	1 69 E+04	5 47 E+05	3 30 E-09	W	1 80 E-03	0 00%

Table 3-4 Unit Dose for K East Basin Average Fuel (3 sheets)

Nuclide	Activity[a] (Ci)	Activity (Bq/gU)	Inhalation DF[b]		UD[c] (Sv/gU)	Percent of Total
			(Sv/Bq)	Class		
Sb-126	1 13 E+01	3 66 E+02	3 17 E-09	W	1 16 E-06	0 00%
Sb-126m	8 07 E+01	2 61 E+03	9 17 E-12	D	2 39 E-08	0 00%
Te-123m	2 33 E-11	7 54 E-10	2 86 E-09	D	2 16 E-18	0 00%
Te-125m	4 13 E+03	1 34 E+05	1 97 E-09	W	2 63 E-04	0 00%
Te-127	7 90 E-07	2 56 E-05	8 60 E-11	W	2 20 E-15	0 00%
Te-127m	8 07 E-07	2 61 E-05	5 81 E-09	W	1 52 E-13	0 00%
I-129	3 26 E+00	1 05 E+02	4 69 E-08	D	4 95 E-06	0 00%
Cs-134	6 95 E+03	2 25 E+05	1 25 E-08	D	2 81 E-03	0 00%
Cs-135	3 96 E+01	1 28 E+03	1 23 E-09	D	1 58 E-06	0 00%
Cs-137	6 55 E+06	2 12 E+08	8 63 E-09	D	1 83 E+00	0 09%
Ba-137m	6 19 E+06	2 00 E+08	DP[e]		NA	0 00%
Ce-144	7 56 E+02	2 45 E+04	1 01 E-07	Y	2 47 E-03	0 00%
Pr-144	7 47 E+02	2 42 E+04	1 17 E-11	Y	2 83 E-07	0 00%
Pr-144m	9 07 E+00	2 93 E+02	DP[e]		NA	0 00%
Pm-147	2 45 E+05	7 93 E+06	1 06 E-08	Y	8 40 E-02	0 00%
Sm-151	8 92 E+04	2 89 E+06	8 10 E-09	W	2 34 E-02	0 00%
Eu-152	4 67 E+02	1 51 E+04	5 97 E-08	W	9 02 E-04	0 00%
Eu-154	5 30 E+04	1 71 E+06	7 73 E-08	W	1 33 E-01	0 01%
Eu-155	1 12 E+04	3 62 E+05	1 12 E-08	W	4 06 E-03	0 00%
Gd-153	9 59 E-05	3 10 E-03	6 43 E-09	D	2 00 E-11	0 00%
Subtotal	2 34 E+07	7 57 E+08			13 Sv/g	0 66%
Actinides						
U-234	4 66 E+02	1 51 E+04	3 58 E-05	Y	5 40 E-01	0 03%
U-235	1 77 E+01	5 73 E+02	3 32 E-05	Y	1 90 E-02	0 00%
U-236	6 61 E+01	2 14 E+03	3 39 E-05	Y	7 25 E-02	0 00%
U-238	3 80 E+02	1 23 E+04	3 20 E-05	Y	3 94 E-01	0 02%
Np-237	3 02 E+01	9 77 E+02	1 46 E-04	W	1 43 E-01	0 01%

Table 3-4 Unit Dose for K East Basin Average Fuel (3 sheets)

Nuclide	Activity[a] (Ci)	Activity (Bq/gU)	Inhalation DF[b] (Sv/Bq)	Inhalation DF[b] Class	UD[c] (Sv/gU)	Percent of Total
Pu-238	6 05 E+04	1 96 E+06	1 06 E-04	W	2 07 E+02	10 67%
Pu-239	1 16 E+05	3 75 E+06	1 16 E-04	W	4 35 E+02	22 38%
Pu-240	6 37 E+04	2 06 E+06	1 16 E-04	W	2 39 E+02	12 29%
Pu-241	3 42 E+06	1 11 E+08	2 23 E-06	W	2 47 E+02	12 69%
Pu-242	3 07 E+01	9 93 E+02	1 11 E-04	W	1 10 E-01	0 01%
Am-241	2 06 E+05	6 66 E+06	1 20 E-04	W	8 00 E+02	41 12%
Am-242	1 13 E+02	3 66 E+03	1 58 E-08	W	5 78 E-05	0 00%
Am-242m	1 14 E+02	3 69 E+03	1 15 E-04	W	4 24 E-01	0 02%
Am-243	7 12 E+01	2 30 E+03	1 19 E-04	W	2 74 E-01	0 01%
Cm-242	9 40 E+01	3 04 E+03	4 67 E-06	W	1 42 E-02	0 00%
Cm-244	8 71 E+02	2 82 E+04	6 70 E-05	W	1 89 E+00	0 10%
Subtotal	3 87 E+06	1 25 E+08			1 932 E+03	99 34%
Mass, MTU	1,143 6			Total	1,950 Sv/g U	

[a]Results are decayed to May 31 1998 Fuel activities are from HNF SD SNF TI-015 1998 *Spent Nuclear Fuel Project Technical Databook* Rev 6 Fluor Daniel Hanford, Incorporated Richland Washington

[b]Inhalation dose factors (DF) are bounding values from Federal Guidance Report Number 11 1988 *Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation Submersion and Ingestion* U S Environmental Protection Agency Washington D C The internal dose factor for tritium was increased by 50% to include absorption through the skin

[c]The unit dose is the product of the normalized activity and the inhalation dose factor To convert Sv/g to rem/g multiply by 100

[d]Krypton 85 is a noble gas It does not accumulate in the body therefore its internal dose factor is zero The value shown is the external dose rate factor for submersion in an infinite cloud divided by the light activity breathing rate

[e]Daughter products are included with parents and not tracked individually Short half life progeny nuclides not shown are assumed to be in equilibrium with their parent nuclide

D = very soluble compounds with lung residence times of days
DF = dose factor
DP = daughter product
NA = not applicable
W = moderately soluble compounds with lung residence times of weeks
Y = insoluble compounds with lung residence times of years

Table 3-5 Unit Dose for K West Basin Average Fuel (3 sheets)

Nuclide	Activity[a] (Ci)	Activity (Bq/gU)	Inhalation DF[b]		UD[c] (Sv/gU)	Percent of Total
			(Sv/Bq)	Class		
Fission and Activation Products						
H-3	1 86 E+04	7 23 E+05	2 60 E-11	Vapor	1 88 E+01	0 00%
C-14	3 31 E+02	1 29 E+04	5 64 E-10	Organic	7 28 E+00	0 00%
Fe-55	8 75 E+02	3 40 E+04	7 26 E-10	D	2 47 E+01	0 00%
Co-60	2 10 E+03	8 16 E+04	5 91 E-08	Y	4 82 E+01	0 00%
Ni-59	1 99 E+01	7 74 E+02	7 31 E-10	Vapor	5 66 E+01	0 00%
Ni-63	2 19 E+03	8 51 E+04	1 70 E-09	Vapor	1 45 E+01	0 00%
Se-79	4 28 E+01	1 66 E+03	2 66 E-09	W	4 42 E+00	0 00%
Kr-85	3 06 E+05	1 19 E+07	3 57 E-13	Gas[d]	4 25 E+00	0 00%
Sr-90	5 17 E+06	2 01 E+08	6 47 E-08	D	1 30 E+01	0 65%
Y-90	5 17 E+06	2 01 E+08	2 28 E-09	Y	4 58 E+00	0 02%
Zr-93	2 01 E+02	7 81 E+03	8 67 E-08	D	6 77 E+01	0 00%
Nb-93m	1 22 E+02	4 74 E+03	7 90 E-09	Y	3 74 E+01	0 00%
Tc-99	1 43 E+03	5 56 E+04	2 25 E-09	W	1 25 E+01	0 00%
Ru-106	4 34 E+02	1 69 E+04	1 29 E-07	Y	2 18 E+00	0 00%
Rh-106	4 34 E+02	1 69 E+04	DP[e]		NA	0 00%
Pd-107	7 68 E+00	2 99 E+02	3 45 E-09	Y	1 03 E+01	0 00%
Ag-110	5 66 E-05	2 20 E-03	DP[e]		NA	0 00%
Ag-110m	4 26 E-03	1 66 E-01	2 17 E-08	Y	3 60 E+00	0 00%
Cd-113m	1 75 E+03	6 80 E+04	4 13 E-07	D	2 81 E+01	0 00%
In-113m	3 74 E-08	1 45 E-06	1 11 E-11	D	1 61 E+00	0 00%
Sn-113	3 74 E-08	1 45 E-06	2 88 E-09	W	4 18 E+00	0 00%
Sn-119m	4 75 E-02	1 85 E+00	1 69 E-09	W	3 13 E+00	0 00%
Sn-121m	3 95 E+01	1 54 E+03	3 22 E-09	W	4 96 E+00	0 00%
Sn-123	2 75 E-06	1 07 E-04	8 79 E-09	W	9 41 E+00	0 00%
Sn-126	7 50 E+01	2 92 E+03	2 69 E-08	W	7 85 E+00	0 00%
Sb-125	1 66 E+04	6 45 E+05	3 30 E-09	W	2 13 E+01	0 00%

Table 3-5 Unit Dose for K West Basin Average Fuel (3 sheets)

Nuclide	Activity[a] (Ci)	Activity (Bq/gU)	Inhalation DF[b]		UD[c] (Sv/gU)	Percent of Total
			(Sv/Bq)	Class		
Sb-126	1 05 E+01	4 08 E+02	3 17 E-09	W	1 29 E+01	0 00%
Sb-126m	7 50 E+01	2 92 E+03	9 17 E-12	D	2 68 E+01	0 00%
Te-123m	4 28 E-12	1 66 E-10	2 86 E-09	D	4 75 E+00	0 00%
Te-125m	4 05 E+03	1 57 E+05	1 97 E-09	W	3 09 E+00	0 00%
Te-127	1 59 E-07	6 18 E-06	8 60 E-11	W	5 31 E+01	0 00%
Te-127m	1 62 E-07	6 30 E-06	5 81 E-09	W	3 66 E+01	0 00%
I-129	3 11 E+00	1 21 E+02	4 69 E-08	D	5 67 E+00	0 00%
Cs-134	8 96 E+03	3 48 E+05	1 25 E-08	D	4 35 E+00	0 00%
Cs-135	3 79 E+01	1 47 E+03	1 23 E-09	D	1 81 E+00	0 00%
Cs-137	6 64 E+06	2 58 E+08	8 63 E-09	D	2 23 E+00	0 11%
Ba-137m	6 28 E+06	2 44 E+08	DP[e]		NA	0 00%
Ce-144	1 58 E+02	6 14 E+03	1 01 E-07	Y	6 20 E+00	0 00%
Pr-144	1 56 E+02	6 06 E+03	1 17 E-11	Y	7 09 E+00	0 00%
Pr-144m	1 90 E+00	7 39 E+01	DP[e]		NA	0 00%
Pm-147	2 17 E+05	8 43 E+06	1 06 E-08	Y	8 94 E+00	0 00%
Sm-151	8 66 E+04	3 37 E+06	8 10 E-09	W	2 73 E+01	0 00%
Eu-152	4 77 E+02	1 85 E+04	5 97 E-08	W	1 10 E+01	0 00%
Eu-154	5 44 E+04	2 11 E+06	7 73 E-08	W	1 63 E+01	0 01%
Eu-155	1 08 E+04	4 20 E+05	1 12 E-08	W	4 70 E+00	0 00%
Gd-153	3 23 E-05	1 26 E-03	6 43 E-09	D	8 10 E+00	0 00%
Subtotal	2 40 E+07	9 33 E+08			16 Sv/g	0 80%
Actinides						
U-234	4 08 E+02	1 59 E+04	3 58 E-05	Y	5 69 E+00	0 03%
U-235	1 60 E+01	6 22 E+02	3 32 E-05	Y	2 07 E+01	0 00%
U-236	6 11 E+01	2 37 E+03	3 39 E-05	Y	8 03 E+00	0 00%
U-238	3 16 E+02	1 23 E+04	3 20 E-05	Y	3 94 E+00	0 02%
Np-237	2 70 E+01	1 05 E+03	1 46 E-04	W	1 53 E+00	0 01%

Table 3-5 Unit Dose for K West Basin Average Fuel (3 sheets)

Nuclide	Activity[a] (Ci)	Activity (Bq/gU)	Inhalation DF[b]		UD[c] (Sv/gU)	Percent of Total
			(Sv/Bq)	Class		
Pu-238	5 10 E+04	1 98 E+06	1 06 E-04	W	2 10 E+02	10 48%
Pu-239	1 01 E+05	3 93 E+06	1 16 E-04	W	4 55 E+02	22 71%
Pu-240	5 53 E+04	2 15 E+06	1 16 E-04	W	2 49 E+02	12 44%
Pu-241	3 26 E+06	1 27 E+08	2 23 E-06	W	2 83 E+02	14 09%
Pu-242	2 42 E+01	9 41 E+02	1 11 E-04	W	1 04 E+01	0 01%
Am-241	1 69 E+05	6 57 E+06	1 20 E-04	W	7 88 E+02	39 31%
Am-242	8 15 E+01	3 17 E+03	1 58 E-08	W	5 01 E+00	0 00%
Am-242m	8 19 E+01	3 18 E+03	1 15 E-04	W	3 66 E+00	0 02%
Am-243	4 89 E+01	1 90 E+03	1 19 E-04	W	2 26 E+00	0 01%
Cm-242	6 76 E+01	2 63 E+03	4 67 E-06	W	1 23 E+01	0 00%
Cm-244	5 72 E+02	2 22 E+04	6 70 E-05	W	1 49 E+00	0 07%
Subtotal	3 64 E+06	1 41 E+08			1,989 0	99 20%
Total, MTU	951 9			Total	2,000Sv/gU	

[a]Results are decayed to May 31 1998 Fuel activities are from HNF SD SNF TI 015 1998 *Spent Nuclear Fuel Project Technical Databook* Rev 6 Fluor Daniel Hanford Incorporated Richland Washington

[b]Inhalation dose factors (DF) are bounding values from Federal Guidance Report Number 11 1988 *Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation Submersion and Ingestion* U S Environmental Protection Agency Washington D C The internal dose factor for tritium was increased by 50% to include absorption through the skin

[c]The unit dose is the product of the normalized activity and the inhalation dose factor To convert Sv/g to rem/g multiply by 100

[d]Krypton 85 is a noble gas It does not accumulate in the body therefore its internal dose factor is zero The value shown is the external dose rate factor for submersion in an infinite cloud divided by the light activity breathing rate

[e]Daughter products are included with parents and not tracked individually Short half life progeny nuclides not shown are assumed to be in equilibrium with their parent nuclide

D = very soluble compounds with lung residence times of days
DF = dose factor
DP = daughter product
NA = not applicable
W = moderately soluble compounds with lung residence times of weeks
Y = insoluble compounds with lung residence times of years

3 3 ESTIMATE OF BOUNDING FILTER INVENTORY

The annular filter is operated until a predetermined differential pressure across a filter is reached or a set radiation level is exceeded The filters then are removed from service, one at a time, for backwashing It is assumed that the maximum amount of sludge is present on the filter when the differential pressure criterion is exceeded The bounding sludge inventory at this point is assumed to be approximately 10% of the total volume of the top layer of fine sand The value of 10% is chosen because the fine sand typically has a porosity of approximately 30% Since all of the sludge is assumed to be located in the top half of the fine sand, the sludge has largely filled the open space between grains Thus the differential pressure criteria would be exceeded

The annular filter tank has an outer diameter of 72 in and an inner diameter of 40 in The upper layer of fine sand has a thickness of approximately 30 in , therefore, its volume is approximately 1,400 L (49 ft^3) The density of the fine sand is approximately 1 5 kg/L, therefore, its mass is 2,100 kg It will be assumed that this sand becomes plugged when a layer of sludge 3 in thick has entered each filter The volume of this sludge is 140 L On three filters, the volume is 420 L This volume is a fraction of the total in the basins (4,130 L in K East Basin and 2,220 L in K West Basin, taken from Tables 3-2 and 3-3, respectively) Thus some credit has been taken for the knockout pot and the settling pipes

A large number of canisters must be emptied to release this much sludge In HNF-S-0564, *Specification for Design, Fabrication, Testing, and Technical Assistance for the K West Basin Water Treatment System*, the volume of sludge estimated for an average canister is 0 8 L The bounding filter loading would correspond to the total sludge in (140 L)/(0 8 L) = 175 canisters This is about twice the number of bounding-case, safety-basis fuel canisters in the K Basins (HNF-SD-SNF-TI-009, Volume 1) Because a large number of canisters are needed to release the sludge in a bounding-case filter, the average fuel composition adequately represents the radioactive material in the annular filters

For K East Basin sludge, with a density of 2 13 kg/L (see Table 3-2 footnote) the mass of sludge on each filter is 300 kg The total sludge mass on all three filters is 900 kg For K West Basin sludge, with a density of 3 10 kg/L (see Table 3-3 footnote), the mass of sludge on each filter is 430 kg The total sludge mass on all three filters is 1,290 kg

An estimate of the photon dose rates near the annular filter tanks was made using the ISO-PC software, Version 1 6 (WHC-SD-SQA-CSWD-303) The program output is listed in Appendix C At a distance of 1 ft from the outside of the tank containing 1 Ci of Cs-137, the dose rates were 98 mR/h (K East) and 93 mR/h (K West) The difference stems from the density of the sludge mixed with the sand Table 3-6 summarizes the calculation of the dose rates at one foot from the tank It is assumed that the sludge has the same composition as fuel It is also assumed that 90% of the Cs-137 has been removed from the sludge by leaching or radioactive decay This is based on the ratios calculated in Appendix B for various fuel and sludge-- compositions found in HNF-SD-SNF-TI-009 In Appendix B the ratio of Cs-137 activity to TRU activity varies from 22 (weasel pit sludge) to 4 (aged safety-basis fuel) This indicates a variation of a factor of 5 The factor of 10 for Cs-137 reduction is a bounding number This maximizes the amount of sludge present in the filter tank for a given dose rate outside the tank

Because the K West Basin sludge density is greater than the density of K East Basin sludge, the total mass of sludge on the filters is greater as well Furthermore, the unit dose for K West Basin is greater than the unit dose for K East Basin Therefore, the K West Basin sludge definition will be used in calculations of consequences of accidents in the annular filter vessel

Table 3-6 Activities and Dose Rates in the Filter Tank

Quantity	Value	
	K East Basin	K West Basin
Average Fuel Cs-137	6 55 E+06 Ci	6 64 E+06 Ci
Basin Total Fuel Mass[a]	1,233 MT	1,038 MT
Sludge Mass on One Filter	300 kg	430 kg
Maximum Cs-137 on Filter[b]	1,590 Ci	2,750 Ci
Minimum Cs-137 on Filter	159 Ci	275 Ci
ISO-PC Dose Rate for 1 Ci	0 098 R/h	0 093 R/h
Dose Rate on Loaded Filter	15 6 R/h	25 6 R/h

[a]The "Basin Total Fuel Mass includes cladding mass as well as uranium mass

[b] The "Maximum Cs 137 on Filter is calculated as the product of sludge mass Cs 137 in basin and divided by the basin total mass For example (300 kg)(6 55E+06 Ci)/(1 233E+6 kg) = 1 590 Ci

[c]The Minimum Cs 137 on Filter is based on 90% removed by leaching into solution and radioactive decay

3 4 METHOD TO CALCULATE SPRAY RELEASE AMOUNTS

Assuming a small leak occurs in pressurized piping a stream of liquid will exit the pipe at the leak The stream then breaks into droplets of varying diameters which fall through the air until they contact other equipment or the walls and floor During the time the droplets fall they also evaporate Smaller droplets completely so evaporate so that the dissolved or suspended solids are released from solution and become airborne Larger droplets add insignificant amounts to the total material airborne as respirable particles

An upper bound on the droplet diameter that may evaporate can be estimated from observed evaporation of water droplets (Hinds 1982, Section 13 7) Water droplets with diameters of 100 μm will completely evaporate in 10 seconds falling through air at 50% relative humidity at 20°C Since the settling speed of 100 μm water droplets is about 25 cm/s, the distance they fall in 10 seconds is about 2 5 m This is comparable to the height of the shielded enclosure (3 81 m), therefore 100 μm will be used as the upper bound of droplet diameters that may evaporate during free fall

The SPRAY program (WHC-SD-GN-SWD-20007) is used to obtain the bounding respirable leak rates The SPRAY program describes the atomization of a liquid jet due to the kinetic energy of the jet itself Because atomization of a liquid jet is a random process, the resultant spray consists of a wide range of drop sizes and must be represented by a distribution rather than a single parameter The SPRAY program computes the fraction of droplets that are below a limiting diameter input by the user It also varies the leak size to find the leak with the greatest respirable leak rate The software documentation (WHC-SD-GN-SWD-20007) includes user guide, verification tests, and configuration control

One of the first input parameters to the SPRAY program determines whether the leak comes from a crack or a hole A crack has much higher respirable release fractions than a hole Since the pipes are new stainless steel, and the operational use is expected to be about 2 years, cracks are not expected under normal conditions A seismic event could produce a crack but has a much lower probability of occurring In addition, fuel handling activities would cease as operators attended to other matters Thus any suspended solids would settle out, ending the radioactive emission before the downwind dose could exceed guidelines A leak is most likely due to a weld imperfection (i e hole) rather than a fatigue or corrosion induced crack, or failure of a flange connection

Other parameters needed as input to the SPRAY program are the pipe thickness, solution viscosity and density, and liquid pressure inside the pipe Piping inside the shielded enclosure typically has a wall thickness of 0 391 cm (0 154 in) Piping outside the shielded enclosure has a wall thickness of 0 602 cm (0 237 in) The water temperature is assumed to be 20 °C so that the dynamic viscosity of water is 1 00 centipoise (another SPRAY input parameter) It is assumed that the leaking solution has the same viscosity as water The water pressure is at most 1034 kPa (150 lb/in^2 gauge) during fuel handling operations, and 414 kPa (60 lb/in^2 gauge) during filter backflush operations

The SPRAY program varies the hole diameter and calculates the total leak rate and respirable leak rate The optimum hole diameter reported by SPRAY has the largest respirable leak rate The SPRAY program outputs for the cases considered for the IWTS spray leaks are listed in the appendices

The calculation of spray release amounts is carried out using the steps listed below The corresponding formulas are presented in the sections that follow

1 Calculate the density of the backflush solution from the sludge density, the mass of sludge and the volume of water

2 Calculate the largest diameter sludge particle that is respirable, i e , has an aerodynamic diameter of 10 µm

3 Calculate the diameter of a solution droplet that will evaporate down to this largest respirable size

4 Insert these calculated values into the SPRAY program to calculate the respirable leak rate

5 Apply the computed respirable leak rate to determine the total mass of sludge that becomes airborne as respirable particles

3 4 1 Density of the Leaking Solution

To calculate the density of the leaking solution, the total mass of water plus the total mass of sludge must be divided by the total volume of solution Since the sludge displaces water, the actual volume of water is the volume of solution minus the volume of solids Figure 3-1 illustrates the relationship between bulk solids and total solution volume and mass The density of pure water is 1 00 kg/L at 20 °C Therefore, the density of the leaking solution is calculated as shown below

$$\rho_T = \frac{M_{BS} + \rho_W (V_{BT} - V_{BS})}{V_{BT}} = \rho_W + \left(\frac{V_{BS}}{V_{BT}}\right)(\rho_S - \rho_W) \quad (1)$$

where

M_{BS} = mass of solids suspended in solution (kg)
V_{BS} = volume of solids suspended in solution (L)
ρ_S = density of the solids suspended in solution (kg/L)
Note that $M_{BS}=(\rho_S)(V_{BS})$
M_{BT} = total mass of solution (kg)
V_{BT} = total volume of solution (L)
ρ_T = average density of the solution (kg/L)
M_{BW} = mass of water present in solution (kg)
V_{BW} = volume of water present in solution (L)
ρ_W = density of the water (1 00 kg/L)

This is the bulk density of the solution when suspended solids are taken into account The next step in the calculation is unrelated to the solution density, but necessary input for the SPRAY computer program

3 4 2 Respirable Diameter Limit for Sludge Particles

The documentation for the SPRAY software (WHC-SD-GN-SWD-20007) has a formula to calculate the largest droplet diameter that will evaporate down to a respirable-sized particle (Equation 5, section 3 1) However, the formula does not adjust for particle densities Therefore, a formula that includes the effect of particle densities will be derived in this section and the next

Airborne particles are respirable if their aerodynamic diameter is less than 10 μm The term "aerodynamic diameter" is defined to be the diameter of a unit-density sphere with the same settling velocity as the material under consideration The actual diameter and aerodynamic diameter of sludge particles depends on their shape and density, as shown in the equation below (Hinds 1982) Note that slip correction factors have not been included because they are normally applied to much smaller diameter particles (less than 1 μm)

$$D_S = (D_{AED})[(S)(\rho_{AED})/(\rho_S)]^{½} \quad (2)$$

where

D_S = diameter of a sludge particle with the same settling speed as a unit density sphere of diameter D_{AED}
D_{AED}= diameter of a unit density sphere considered to be the largest respirable, 10 μm
S = shape factor for the sludge particle, assume 1 0 (spherical)
ρ_{AED} = density of the unit density sphere, 1 00 kg/L
ρ_S = density of the sludge particle, 2 13 kg/L (K East) or 3 10 kg/L (K West)

The density of the sludge is based on the mass and volume of canister and fuel washing sludge given in Tables 3-2 and 3-3 Inserting values gives the results shown below

$$D_S(\text{K East}) = (10\ \mu m)[(1\ 0)(1\ 0\ kg/L)/(2\ 13\ kg/L)]^{½} = 6\ 85\ \mu m$$

$$D_S(\text{K West}) = (10\ \mu m)[(1\ 0)(1\ 0\ kg/L)/(3\ 10\ kg/L)]^{½} = 5\ 68\ \mu m$$

This is the physical diameter of a sludge particle with an aerodynamic diameter of 10 μm, the largest considered respirable The next step is to determine the diameter of a spray droplet of backflush solution that will evaporate down to a sludge particle with this diameter

3 4 3 Spray Droplet Diameter Limit

The derivation of the bounding spray droplet diameter uses notation similar to that developed earlier for the general formula for solution density However, in this case, the total volume is the volume of the bounding spray droplet Similarly, the solids mass and volume is the mass and volume of a bounding diameter sludge particle Spherical droplets and sludge particles are assumed because irregular shapes have no simple relationship between particle volume and particle diameter Note that since spherical particles are assumed, $V_{DS}=(\pi/6)(D_S)^3$ and $V_{DT}=(\pi/6)(D_T)^3$ V_{DT} and V_{DS} are the volumes of the spray droplet and residual solids, respectively D_T and D_S are the corresponding sphere diameters

From the total density formula, i e , $\rho_T(V_{DW}+V_{DS})=(M_{DW}+M_{DS})$, it can be shown that $V_{DW}(\rho_T-\rho_W)=V_{DS}(\rho_S-\rho_T)$ Similarly, from the total volume formula, i e , $V_{DT}=V_{DW}+V_{DS}$, it can be shown that $V_{DT}(\rho_T-\rho_W)=V_{DS}(\rho_S-\rho_W)$ Applying the spherical volume formulas gives the general formula below for the dıameter of the largest respırable spray droplet Note that the ratıo of droplet volume to droplet solıds volume ıs the same as the ratıo of solutıon volume to solutıon solıds volume

$$D_T = D_S\left(\frac{V_{DT}}{V_{DS}}\right)^{(1/3)} = D_S\left(\frac{\rho_S - \rho_W}{\rho_T - \rho_W}\right)^{(1/3)} = D_S\left(\frac{V_{BT}}{V_{BS}}\right)^{(1/3)} \quad (3)$$

where

D_T = dıameter (μm) of droplet wıth a volume V_{DT}
D_S = dıameter (μm) of a sludge partıcle wıth the same settıng speed as a unıt-densıty sphere wıth dıameter 10 μm
M_{DS} = mass of solıds suspended ın the droplet (kg)
V_{DS} = volume of solıds suspended ın the droplet (L)
ρ_S = densıty of the solıds suspended ın the droplet (kg/L) Note that $M_{DS}=(\rho_S)(V_{DS})$
M_{DT} = total mass of the droplet (kg)
V_{DT} = total volume of the droplet (L)
ρ_T = average densıty of the droplet (kg/L)
M_{DW} = mass of water present ın the droplet (kg)
V_{DW} = volume of water present ın the droplet (L)
ρ_W = densıty of the water (1 00 kg/L)
V_{BS} = volume of solıds suspended ın solutıon (L)
V_{BT} = total volume of solutıon (L)

3 4 4 Mass of Sludge That Becomes Aırborne

With the above ınputs for the SPRAY program, the maxımum respırable leak rate as well as the total leak rate can be computed Note that the total volume of lıquıd released, as well as the respırable mass that becomes aırborne from the spray leak also depends on the duratıon of the leak Equatıons to represent these quantıtıes are shown below

$$M_{SPRAY} = (LR_{SPRAY})(T_{LEAK})(M_{BS})/(V_{BT}) \quad (4)$$

$$V_{LEAK} = (LR_{LEAK})(T_{LEAK}) \quad (5)$$

where

M_{SPRAY} = mass of sludge aırborne as respırable partıcles durıng the leak (g)
LR_{SPRAY} = leak rate for respırable partıcles computed by the SPRAY program (L/h)

T_{LEAK} = duration of the leak (h)
M_{BS} = total mass of sludge in solution (g)
V_{BT} = total volume of solution (L)
V_{LEAK} = volume of solution that has leaked (L)
LR_{LEAK} = total leak rate computed by the SPRAY program

3 5 METHOD TO CALCULATE LEAK PATH FACTORS

Leak path factors (LPFs) are calculated for various release locations in the K Basin facility An LPF represents the fraction of contaminant mass that is transported from one region to another region (usually the environment) under accident conditions One LPF is calculated for mass transport from the inside of the annular filter vessel enclosure to the transfer bay volume for spray release and hydrogen explosion scenarios Other LPFs are calculated for various release locations in the K Basin building (superstructure) to the environment These LPFs were used in HNF-SD-WM-SAR-062, *K Basin Final Safety Analysis Report*, for sludge releases into the air above the basin

This section summarizes the results of the LPF derivations, which are detailed in Appendix A The LPF from inside the annular filter vessel enclosure to the building is estimated at 0 1 The LPF from inside the building just above the basin water is 0 48, using the mass size distribution for sludge defined in SNF-4267 *Consequence Analysis of IWTS Metal–Water Reactions (Fauske & Associates Report 99-35)* The LPF from inside the building just above the basin water increases to 0 65 if the original release starts from under water and the water removes or decontaminates much of the underwater release with a larger fraction of large particles being removed (see Appendix A) The LPF from inside the building near the annular filter vessel enclosure is 0 50 These LPFs are shown in Table 3-7 Only the LPF of 0 1 for releases inside of the filter vessel enclosure was used in this calcnote because the calcnote does not cover releases into the air from the basin The LPF of 0 5 for releases near the annular filter vessel enclosure to the environment was not used because the LPF of 0 1 from inside the enclosure was already being used for these releases (spray releases and hydrogen explosion), and these releases are small even if all LPFs were 1 0

Table 3-7 Leak Path Factors for K Basin Releases

Location of Release	Leak Path Factor
A Leak Path Factor from Inside Filter Vessel Enclosure to the Building	
Inside Annular Filter Vessel Enclosure	0 1
B Leak Path Factors from Inside the Building to the Environment	
Above Basin Water With No Water Decontamination	0 48
Above Basin Water After Water Decontamination	0 65
Near Annular Filter Vessel Enclosure Top	0 50

4 0 SPRAY LEAK DURING FUEL HANDLING

The spray leak is first assumed to form on the Stream 9 piping, where the pressure and flow rate are about 415 L/min at a maximum pressure of 1,034 kPa (110 gal/min at 150 lb/in^2 gauge) The leak continues for 24 hours before being halted The potential environmental release and the resulting doses are evaluated in this section

4 1 SOURCE TERM FOR SPRAY RELEASE DURING FUEL HANDLING

The spray leak during fuel handling ends after 24 hours, during which a large volume of water flows through the pipe The liquid flow rate during the backflush is 415 L/min (110 gal/min) Thus the total volume of liquid flowing past the leak is calculated to be 598,000 L as shown below

$$(24\ \text{h})(60\ \text{min})(415\ \text{L/min}) = 598{,}000\ \text{L}$$

The total amount of sludge that could be present in the water is assumed to be the total amount of sludge in K East Basin (see Table 3-2) divided by 200, i e , a typical number of working days in a year Since two years are needed to remove the fuel from either basin, this exaggerates the potential sludge introduced to the IWTS during a 24 hour period Note that (8,800 kg)/200=44 kg The volume occupied by this sludge is the total volume of sludge in K East Basin divided by 200, i e , (4,130 L)/200=20 65 L (This volume is subtracted from total volume in the numerator of the solution density fraction below) The average density of K East Basin sludge is 2 13 kg/L, as shown in Table 3-2

To calculate the density of the process water for this K East Basin case, Equation 3 from Section 3 4 1 is used as shown below

$$\text{Solution density} = \frac{(44\ \text{kg}) + (1\ 0\ \text{kg/L})(597{,}979\ \text{L})}{(598{,}000\ \text{L})} = 1\ 000039\ \text{kg/L}$$

The diameter of the largest droplet that will eventually become a respirable particle is calculated using Equation 3 from Section 3 4 3, as shown below

$$D_T = D_S \left(\frac{V_{BT}}{V_{BS}} \right)^{(1/3)} = (6\ 85\ \mu\text{m}) \left(\frac{598\ 000\ \text{L}}{20\ 65\ \text{L}} \right)^{(1/3)} = 210\ \mu\text{m}$$

This exceeds the largest droplet diameter that will actually evaporate during a fall of about 3 81 m, as discussed in Section 3 4 0 Therefore, the bounding droplet diameter will be assumed to be 100 µm

With this diameter input to the SPRAY program, the optimum orifice diameter is found to be 904 µm This hole diameter produces a total leak rate of 1 44 x 10^{5} m^3/s (51 8 L/h) The SPRAY program also reports that the respirable leak rate is 1 07 x 10^{-6} m^3/s (3 85 L/h) The output from the SPRAY calculations is listed in Appendix C The total mass of sludge that becomes airborne as respirable particles is calculated using Equation 4 from Section 3 4 4 for both 12-hour release durations and 24-hour release durations Results are shown in Table 4-1

Table 4-1 Spray Leak Emissions During Fuel Retrieval

Quantity released	12-hour Release	24-hour Release
Mass of K East sludge airborne as respirable particles	3 40 g	6 80 g
Mass of K West sludge airborne as respirable particles	2 66 g	5 32 g
Volume of liquid leaked	622 L	1,240 L

$$M_{KE,12} = (3\ 85\ \text{L/h})(12\ \text{h})(44{,}000\ \text{g})/(598\ 000\ \text{L}) = 3\ 40\ \text{g}$$

$$M_{KE\ 24} = (3\ 85\ \text{L/h})(24\ \text{h})(44{,}000\ \text{g})/(598{,}000\ \text{L}) = 6\ 80\ \text{g}$$

The above calculations were repeated using K West Basin sludge The mass of canister and fuel sludge shown in Table 3-3 is 6 87 MT Dividing this by 200 to obtain the daily bounding amount present in Stream 9 gives 34 kg occupying a volume of 11 L (This volume is subtracted from total volume in the numerator of the solution density fraction below) To calculate the density of the process water for this K West Basin case, the formula presented in Section 3 4 1 is used as shown below

$$\text{Solution density} = \frac{(34\ \text{kg}) + (1\ 0\ \text{kg/L})(597{,}989\ \text{L})}{(598{,}000\ \text{L})} = 1\ 000039\ \text{kg/L}$$

The diameter of the largest droplet that will eventually become a respirable particle is calculated using Equation 3 from Section 3 4 3, as shown below

$$D_T = (5\ 68\ \mu\text{m})\left(\frac{598{,}000\ \text{L}}{11\ \text{L}}\right)^{(1/3)} = 215\ \mu\text{m}$$

This exceeds the largest droplet diameter that will actually evaporate during a fall of about 3 81 m, as discussed in Section 3 4 0 Therefore, the bounding droplet diameter will be assumed to be 100 µm The solution density and bounding droplet diameter inputs are the same as before, so the SPRAY program results are the same also A total of 3 85 L of solution will become respirable particles Because K East Basin has more sludge, the release from K East is greater than the release from K West Both are shown in Table 4-1

The 12-hour duration represents a realistic, bounding exposure time for onsite individuals, such as a worker located 100 meters from the release, or personnel at the 100 Area Fire Station, or a member of the public located on the near bank of the Columbia River The 24-hour release duration represents the longest period that a member of the public located at the Hanford Site boundary could be exposed before being warned to evacuate, or at least not to eat any food grown in the contaminated zone downwind

In addition to sludge from the fuel canisters, other sources of radioactive emissions from the spray leak hole are radioactivity dissolved in the water, and the disintegration of fuel assemblies during retrieval operations Each of these will be discussed below

Radioactivity Dissolved in Water. Table 4-2 gives the maximum K West Basin water radionuclide concentrations allowed by the IWTS specification (HNF-S-0564, Section 4 1) The IWTS maintains general water concentrations of the radionuclides below the values listed in Table 4-2 The equivalent concentration of K West Basin fuel is also shown on the table The fuel concentration (g/L) is calculated by dividing the water concentration (Ci/L) by the total activity of that isotope in the basin (Ci) and multiplying the result by the total mass in the basin (g) Note that the total alpha shown as TRU in Table 4-2 is the sum of the amounts for ^{238}Pu, ^{239}Pu, ^{240}Pu, and ^{241}Am The other TRU masses are very minor additions to this total

Table 4-2 Radionuclide Concentrations in K Basin Water after Treatment

Isotope	Concentration[b] Bound (Ci/L)	Equivalent Fuel[c], g/L		Total Activity[d], Ci	
		K East	K West	K East	K West
^{90}Sr	5 00 E-07	1 15 E-04	9 21 E-05	4 96 E+06	5 17 E+06
^{137}Cs	5 00 E-07	8 73 E-05	7 17 E-05	6 55 E+06	6 64 E+06
TRU[a]	4 00 E-08	1 03 E-04	1 01 E-04	4 46 E+05	3 76 E+05

[a] TRU is the sum of the primary alpha emitting isotopes namely Pu 238 Pu 239 Pu 240 and Am 241

[b] Concentration Bound values shown are from Section 4 1 of HNF S 0564 1998 *Specification for Design Fabrication Testing and Technical Assistance for the K West Basin Water Treatment System* Rev 1A Fluor Daniel Hanford Incorporated Richland Washington Section 4 1

[c] Equivalent Fuel is computed as the water concentration times the total fuel mass divided by the Total Activity' The total fuel mass in K East Basin is 1 144 E+09 g while the total mass in K West Basin is 9 519 E+08 g

[d] Values for Total Activity in the last two columns are from HNF SD SNF TI 015 1998 *Spent Nuclear Fuel Technical Databook* Rev 6 Fluor Daniel Hanford Incorporated Richland Washington

The largest SNF concentration in water (1 15E-04 g/L) will be used to estimate bounding release amounts from a spray leak The total amount of radioactivity released with the water that evaporates to become respirable particles during a 24-hour leak is shown below The amount released due to dissolved radioactivity is less than 1% of the suspended sludge shown in Table 4-1 for the spray releases

$$(3\ 85\ L/h)(24\ h)(1\ 15E\text{-}04\ g/L) = 0\ 0107\ g\ fuel$$

Disintegration of Fuel Assembly During Retrieval Operations. The portion of respirable particles (diameter $\leq$ 10 μm) released during the disintegration of a fuel assembly is estimated to be 0 1 wt% This value may be compared with that expected for similar materials that undergo brittle fracture due to high impact forces Section 5 3 3 2 1 of DOE-HDBK-3010-94, *Airborne Release Fractions/Rates and Respirable Fractions for Nonreactor Nuclear Facilities* (1994), states that for solids that undergo brittle fracture, the respirable fraction is bounded by the formula shown below

$$(ARF)\ (RF) = (A)\ (\rho)\ (g)\ (h)$$

where

ARF = airborne release fraction
RF = respirable release fraction
A = empirical correlation ($2\ 11 \times 10^{11}$ $cm^3\text{-}s^2/g\text{-}cm^2$)
ρ = density of brittle solid (g/cm^3)

g = gravitational acceleration constant (980 cm/s^2 [this is a conservative value since the fuel is in water which offers considerable drag and buoyancy effects]

h = fall height (cm)

To produce a respirable airborne release fraction (ARF x RF) of 0 001, a fall height of 26 8 m (in air) would be required The mass of each Mark IV assembly is about 22 7 kg During the day of the spray leak, as many as 12 canisters will be emptied It will be assumed that one assembly from each canister is severely damaged (i e , disintegrates) The total release from 12 fuel assemblies in one day is about 272 g as shown below

(22,700 g/assembly)(12 assemblies)(0 001) = 272 g

The total amount of radioactivity released with the water that evaporates during a 24-hour leak to become respirable particles is shown below The amount released due to fuel disintegration is less than 1% of the suspended sludge shown in Table 4-1 for the spray releases

(3 85 L/h)(24 h)(272 g)/(598,000 L) = 0 042 g

4 2 DOSE CONSEQUENCES - SPRAY RELEASE DURING FUEL HANDLING

Inhalation doses downwind of a spray release accident during fuel handling operations are computed using the formula below (HNF-SD-SNF-TI-059) The sludge is treated as an average fuel for inhalation dose calculations

$$DE = (M)\ (\chi/Q\ )\ (BR)\ (UD)\ (LPF)$$

where

DE = 50-year committed effective dose equivalent (CEDE) from inhalation of SNF released accidently (rem)

M = mass of SNF released into the air as respirable particles (g sludge from Table 4-1)

χ/Q' = air transport factor from HNF-SD-SNF-TI-059 (s/m^3)

BR = breathing rate (3 33 x 10^{4} m^3/s for light activity or 2 64 x 10^{4} m^3/s for 24-hour releases)

UD = 50-year CEDE from inhalation of a unit mass of sludge as respirable particles (195,000 rem/g K East or 200,000 rem/g K West)

LPF = leak path factor from filter vessel enclosure to building (0 1) (see Table 3-7)

For a spray release of K Basin water, the bounding respirable mass (M) of 3 4 g over a 12-hour period, or 6 8 g over a 24-hour period has been calculated above The air transport factors are listed in Table 4-3 The calculation of onsite dose at 100 m for both K East and K West emissions is shown below Because the K East Basin spray accident leads to larger doses than K West Basin, only K East Basin doses are shown in Table 4-3

$$DE_{onsite,KE} = (3\ 40\ g)\ (6\ 28\text{x}\ 10^{3}\ s/m^3)\ (3\ 33\ \text{x}\ 10^{-4}\ m^3/s)\ (1\ 95\ \text{x}\ 10^5\ rem/g)\ (0\ 1) = 0\ 14\ rem$$

$$DE_{onsite,KW} = (2\ 66\ g)\ (6\ 28\text{x}\ 10^{3}\ s/m^3)\ (3\ 33\ \text{x}\ 10^{-4}\ m^3/s)\ (2\ 00\ \text{x}\ 10^5\ rem/g)\ (0\ 1) = 0\ 11\ rem$$

Doses at other receptor locations are summarized in Table 4-3 The guidelines reported in Table 4-3 are for an event that is deemed unlikely ($1\ 0 \times 10^{-4}$ < annual frequency $\leq 1\ 0 \times 10^{-2}$) Onsite locations use 12-hour air transport factors, while the Hanford Site boundary calculations use 24-hour air transport factors

The bounding doses from a spray release during fuel retrieval operations are below the radiological risk acceptance guidelines provided by DOE (Sellers 1997) Therefore, no further action is necessary Note that the radiological risk acceptance guidelines are given as TEDE, or total effective dose equivalent, which is the sum of all internal and external contributions to a persons dose The TEDE is the same as the CEDE used in Table 4-3 for the inhalation and external dose to individuals downwind under worst-case conditions

Table 4-3 Dose Consequences from a Spray Release During Fuel Retrieval

Receptor location	χ/Q'[a] (s/m^3)	CEDE rem (Sv)	Guidelines[b] (rem)
Onsite Worker (100 m E)	6 28 E-03	0 14 (1 4 E-03)	10
Columbia River (520 m W)	2 90 E-04	6 4 E-03 (6 4 E-05)	--
100 Area Fire Station (3,750 m ESE)	2 73 E-05	6 0 E-04 (6 0 E-06)	--
Hanford Site boundary (10,070 m W)	6 51 E-06	2 3 E-04 (2 3 E-06)	5

[a] Air transport factors are from HNF SD-SNF TI-059 1999 *A Discussion on the Methodology for Calculating Radiological and Toxicological Consequences for the Spent Nuclear Fuel Project at the Hanford Site* Rev 2 Fluor Daniel Hanford Incorporated Richland Washington

[b] The guidelines are the DOE-recommended maximum CEDE values from Sellers, E D 1997 *Risk Evaluation Guidelines (REGs) to Ensure Inherently Safer Designs* (Letter 97-SFD-172 to H. J Hatch Fluor Daniel Hanford Incorporated August 26) U S Department of Energy Richland Operations Office Richland Washington

CEDE = committed effective dose equivalent.

5 0 SPRAY LEAK DURING FILTER BACKFLUSH

The spray leak is first assumed to form on the Stream 10 piping, where the flow rate is about 568 L/min at a maximum pressure of 414 kPa (150 gal/min at 60 lb/in^2 gauge) The leak continues for 1 hour before being ending due to the short duration of backflush operations The potential environmental release and the resulting doses are evaluated in this section

5 1 SOURCE TERM FOR SPRAY RELEASE DURING FILTER BACKFLUSH

An unmitigated accident analysis is performed to determine the safety classification of equipment and controls that would mitigate its dose consequences If no equipment or procedures for backflushing the filters were in place, the IWTS could be operated until all the filters were essentially plugged, stopping all liquid flow Because it is not known what fuel quantity this condition corresponds to, it is conservatively assumed that a 3-in layer of sludge in the annular filter (see Section 3 3) is enough to restrict flow to the point that a backflush is necessary The duration for the accident is conservatively assumed to be less than 1 hour Longer durations will result in smaller doses at downwind receptor locations

The three filters are backflushed consecutively through a common header pipe that leads back to the settlers (see stream 10 in Figure 2-1) Stream 10 has a liquid flow rate of 568 L/min (150 gal/min) Thus the total volume of liquid flowing past the small opening is calculated to be 34,100 L as shown below

$$(1 \text{ h})(60 \text{ min/h})(568 \text{ L/min}) = 34\ 100 \text{ L}$$

The total amount of sludge that could be present in the water is assumed to be 420 L as described in Section 3 3 The bounding mass on all three filters is for K West sludge, namely, 1 290 kg The average density of this sludge is 3 10 kg/L

To calculate the density of the backflush water Equation 1 from Section 3 4 1 is used as shown below

$$\text{Solution density} = \frac{(1{,}290 \text{ kg}) + (1\ 00 \text{ kg/L})(33{,}700 \text{ L})}{(34{,}100 \text{ L})} = 1\ 026 \text{ kg/L}$$

The diameter of the largest droplet that will eventually become a respirable particle is calculated using Equation 3 from Section 3 4 3, as shown below

$$D_T = D_S\left(\frac{V_{BT}}{V_{BS}}\right)^{(1/3)} = (5\ 68\ \mu\text{m})\left(\frac{34\ 100 \text{ L}}{420 \text{ L}}\right)^{(1/3)} = 24\ 6\ \mu\text{m}$$

With this diameter input to the SPRAY program the optimum orifice diameter is found to be 630 µm This hole diameter produces a total leak rate of 4 31 x 10^{-6} m^3/s (15 5 L/h) The SPRAY program also reports that the respirable leak rate is 1 01 x 10^{8} m^3/s (0 0364 L/h) The output from the SPRAY calculations is listed in Appendix C The total mass of sludge that becomes airborne as respirable particles is calculated using Equation 4 presented in Section 3 4 4 for a 1-hour release duration The leak ends within 1 hour, during which all three filters are backflushed Using Equation 4 the respirable airborne sludge mass is calculated below

$$M_{SPRAY} = (0\ 0364\ L/h)(1\ h)(1{,}290\ kg)/(34{,}100\ L) = 1\ 4\ g$$

In addition to sludge from the fuel canisters, other sources of radioactive emissions from the spray leak hole are radioactivity dissolved in the water, and the disintegration of fuel assemblies during retrieval operations As discussed in Section 4 1, each of these leads to much smaller emissions and therefore much smaller doses Therefore, the calculated emission from the estimated bounding inventory of sludge in K West Basin filters will be used as the bounding MAR in calculating source terms

5 2 DOSE CONSEQUENCES - SPRAY RELEASE DURING FILTER BACKFLUSH

Radiation doses to individuals located downwind due to a spray leak at K Basins can be computed using the equation from HNF-SD-SNF-TI-059 shown in Section 4 2 Air transport factors are for a short-duration release (less than one hour) are used because the backflush operation is expected to last less than one hour As material is flushed from the filter the backflush solution becomes cleaner Thus even if the leak lasted more than one hour, the radioactive release would for all practical purposes have ended

Phenomena that reduce the average air concentration during the exposure, such as building wake and plume meander, were not included The air transport factors are those for a point source at ground level determined using Hanford Site data according to the methods described in NRC Nuclear Regulatory Guide 1 145 *Atmospheric Dispersion Models for Potential Accident Consequence Assessments at Nuclear Power Plants* It is assumed that the individuals are not evacuated during plume passage because of the short duration of the release It is also assumed that the unit dose factor for the sludge that becomes airborne is bounded by the unit dose factor for K West Basin fuel, 200,000 rem/g inhaled The doses from ingestion during the first day after the release are computed in HNF-SD-SNF-TI-059 and are shown to be negligible relative to the inhalation dose for the safety-basis fuel composition Because the average fuel composition is very similar to the bounding composition, the ingestion dose from K West Basin fuel is negligible compared to the inhalation dose Thus the total dose equivalent and the inhalation dose equivalent are the same thing for accidental emissions

For this unmitigated spray release of K East Basin sludge, the bounding respirable mass released (M) is 1 4 g over a 1-hour period The air transport factors for this short-duration release are listed in Table 5-1 The calculation of onsite dose at 100 m is shown below, where 0 1 is the LPF value (Table 3-7)

$$DE_{onsite\_100} = (1\ 4\ g)\ (7\ 32 \times 10^{2}\ s/m^3)\ (3\ 33 \times 10^{-4}\ m^3/s)\ (2\ 00 \times 10^5\ rem/g)\ (0\ 1)$$
$$= 0\ 68\ rem$$

Table 5-1 Dose Consequences from a Spray Release During Filter Backflush

Receptor location	χ/Q'[a] (s/m^3)	CEDE rem (Sv)	Guidelines[b] (rem)
Onsite Worker (100 m E)	7 32 E-02	6 8 E-01 (6 8 E-03)	10
Columbia River (520 m W)	3 55 E-03	3 3 E-02 (3 3 E-04)	--
100 Area Fire Station (3,750 m ESE)	1 60 E-04	1 5 E-03 (1 5 E-05)	--
Hanford Site boundary (10,070 m W)	4 49 E-05	4 2 E-04 (4 2 E-06)	5

[a] Air transport factors are from HNF SD SNF TI 059 1999 *A Discussion on the Methodology for Calculating Radiological and Toxicological Consequences for the Spent Nuclear Fuel Project at the Hanford Site* Rev 2 Fluor Daniel Hanford, Incorporated Richland Washington

[b] The guidelines are the DOE recommended maximum CEDE values for an unlikely event from Sellers E D 1997 *Risk Evaluation Guidelines (REGs) to Ensure Inherently Safer Designs* (Letter 97 SFD 172 to H J Hatch Fluor Daniel Hanford, Incorporated, August 26) U S Department of Energy Richland Operations Office Richland, Washington

CEDE = committed effective dose equivalent

Doses at other receptor locations are summarized in Table 5-1 The guidelines reported in Table 5-1 are for an event that is deemed unlikely ($1\ 0 \times 10^{-4} <$ annual frequency $\leq 1\ 0 \times 10^{2}$)

The bounding doses from a spray release during filter backflush operations are below the radiological risk acceptance guidelines provided by DOE (Sellers 1997) for the onsite worker at 100 m Therefore, no controls are necessary to lower the probability of the accident or its severity Note that the radiological risk acceptance guidelines are given as TEDE, or total effective dose equivalent, which is the sum of all internal and external contributions to a persons dose The TEDE is the same as the CEDE used in Table 5-1 for the inhalation and external dose to individuals downwind under worst-case conditions

The pipes and pumps outside of the annular filter enclosure are surrounded by substantial, close-fitting, steel shielding, which protects workers from direct radiation (primarily gamma) that would normally penetrate the piping during operation This shielding is semi-permanent, it may be removed in sections to access the pump for repairs Because this shielding surrounds the piping so closely, essentially no respirable leak is expected to be generated from a leak in these sections of pipe The leak stream will simply hit the shielding, condense, and drain back into the basin

6 0 HYDROGEN EXPLOSION

The hydrogen deflagration accident begins with a power outage or pump failure that leaves the IWTS system inoperative It is assumed that a small pinhole leak forms in the upper part of the filter vessel The valves between the filter vessel and the pool are open so that air is drawn into the hole as the water in the filter vessel continues to drain The water-filled space above the filter media is replaced with air The upper layer of fine sand and accumulated sludge retains some residual water due to surface tension effects of water While the air bubble is forming and for some time afterward, the water in the fine sand is decomposing into hydrogen and oxygen by radiolysis In addition, any metal fines will react with water to produce hydrogen gas Over a period of time, enough hydrogen accumulates to form a flammable mixture with the air inside the filter vessel A particle of uranium hydride spontaneously ignites and triggers a hydrogen deflagration inside the filter vessel Radioactive material in the filter media becomes airborne and is released from the filter vessel through the small hole into the filter vessel enclosure From this shielding enclosure, some of the airborne contamination travels to inside the building, gets out of the building, and reaches any receptors downwind

6 1 FAULT PATH AND ACCIDENT FREQUENCY ESTIMATES

Event path analyses have been performed to help determine the expected frequency of occurrence for each accident Given that an event will occur with an estimated annual frequency of λ, the probability that the event will occur in a time interval, Δt (year), is given by

$$P(\Delta t) = 1 - e^{-\lambda \Delta t} \ , \text{ or}$$
$$P(\Delta t) \approx \lambda \, \Delta t \ , \quad \text{for } \lambda \, \Delta t \leq 0\ 01$$

Also, given that two independent events, A and B, have probabilities of occurrence of P(A) and P(B) in a given time period, the probability that either A or B will occur during that time period is given by

$$P(A \text{ or } B) = P(A) + P(B) - P(A)\,P(B) \ , \text{ or}$$
$$P(A \text{ or } B) \approx P(A) + P(B) \quad \text{for } P(A) \text{ and } P(B) < 0\ 05$$

The followıng frequency of occurrence determınatıons are ıntended to provıde order-of-magnıtude estımates of complete event lıkelıhood Indıvıdual event faılure frequency estımates are combıned to make a general determınatıon as to whether for ınstance, a complete event ıs expected to happen wıthın a frequency range of 1 x 10^{6} to 1 x 10^{-4}/yr or a range from 1 x 10^{-4} to 1 x 10^{2}/yr Uncertaıntıes ın ındıvıdual event frequency estımates are not expected to change the determınatıon of whıch broad frequency range ıs most approprıate

Fıgure 6-1 shows the event tree analysıs for the hydrogen deflagratıon scenarıo Below ıs a dıscussıon of the two prımary (most credıble) fault sequences leadıng to potentıal releases for the hydrogen deflagratıon scenarıo Because the probabılıty of the event lıes ın the range 1 x 10^{4} /y to 1 x 10^{-6} /y ıt ıs consıdered to be an "extremely unlıkely event

<u>Event Tree Sequence 10</u>

1 Pressure tanks leak wıth a frequency of 1 8 x 10^{7}/h or 1 578 x 10^{3}/yr (DP-1633) Pıpe junctıons or fıttıngs leak wıth an approxımate frequency of 3 51 x 10^{3}/yr (DP-1633) There are two pıpe fıttıngs near or above the grade of the fine sand medıum, both on the backwash ınlet The expected frequency of leaks from these fıttıngs ıs

$$(2)\ (3\ 51 \times 10^{3}) = 7\ 0 \times 10^{3}/yr$$

The expected frequency of a leak from eıther source ıs

$$(1\ 58 \times 10^{3}/yr) + (7\ 0 \times 10^{3}/yr) = 8\ 58 \times 10^{3}/yr$$

Because these frequencıes apply to any sıze leak, ıt ıs estımated that a leak of suffıcıent volume to empty much of the filter vessel of water would occur at less than half of thıs rate The total estımated frequency of sıgnıficant leaks ıs therefore adjusted to be 4 x 10^{3}/yr

2 If the power faıls the pumps that create the lıquıd flow through the IWTS system, ıncludıng the filters, wıll not operate Water flow through the filters wıll stop for the duratıon of the power faılure Power losses to the Hanford Sıte 200 Areas from 1972 to 1992 have been revıewed (WHC-EP-0811) Most power outages are expected to be for very short duratıons, the medıan duratıon was found to be 2 mınutes whıle the average power loss duratıon was 32 5 mınutes Based upon the recent hıstory of power outages, the average yearly frequency of loss of power for more than 24 hours ıs estımated to be 1 0 x 10^{2}/yr If a tank or pıpe leak ıs detected wıthın a month of occurrıng, then the probabılıty of a power loss of duratıon greater than 24 hours occurrıng durıng a tank leak ıs gıven by

$$(1\ 0 \times 10^{2}/yr)\ (1/12\ yr) = 8\ 33 \times 10^{4}$$

3 If power ıs unavaılable the pumps for a backwash wıll be unavaılable

4 It is possible to detect the leak, especially if the leak volume is great but no system or procedure exists to help ensure this will happen It is estimated that the probability of leak detection early in the accident (within 24 hours) is only 0 01 While calculations indicate it may take about 1 month for the filter tank void to become flammable with hydrogen and air by radiolysis alone, the presence of fine uranium fuel particles would accelerate the hydrogen production rate

The hydrogen deflagration is assumed to occur if the leak is not detected The final anticipated frequency for sequence 10, leading to a potential release from the hydrogen deflagration accident, is obtained from the product of each probability on the sequence with the initiator frequency

$$\text{Frequency} = (4 \times 10^{3}/\text{yr})\ (8\ 33 \times 10^{4})\ (0\ 99) = 3\ 3 \times 10^{-6}/\text{yr}$$

<u>Event Tree Sequence 6</u>

1 Pressure tanks leak with a frequency of $1\ 8 \times 10^{7}$/h or $1\ 578 \times 10^{3}$/yr (DP-1633) Pipe junctions or fittings leak with an approximate frequency of $3\ 51 \times 10^{3}$/yr (DP-1633) There are two pipe fittings near or above the grade of the fine sand medium, both on the backwash inlet The expected frequency of leaks from these fittings is

$$(2)\ (3\ 51 \times 10^{3}) = 7\ 0 \times 10^{3}/\text{yr}$$

The expected frequency of a leak from either source is

$$(1\ 58 \times 10^{3}/\text{yr}) + (7\ 0 \times 10^{3}/\text{yr}) = 8\ 58 \times 10^{3}/\text{yr}$$

Because these frequencies apply to any size leak, it is estimated that a leak of sufficient volume to empty much of the filter vessel of water would occur at less than half of this rate The total estimated frequency of significant leaks is therefore adjusted to be 4×10^{3}/yr

2 The system is expected to operate 95% of the time, 24 hours a day (HNF-S-0564) The system or portions of the system are expected to be off while maintenance is performed The anticipated probability of no flow through the filter is

$$(1 - 0\ 95) = 5\ 0 \times 10^{2}$$

3 If the system is purposely shut down or flow is stopped to the filters, operations is expected to immediately perform a filter backwash Typical human error in following a basic procedure is estimated to have a probability of 1/100 per demand

4 It is possible to detect the leak, especially if the leak volume is great, but no system or procedure exists to help ensure that this will happen It is estimated that the probability of detection early in the accident (within 24 hours) is only 0 01

If the leak is not detected, significant hydrogen can accumulate The final anticipated frequency for sequence 6, leading to a potential release from the hydrogen explosion accident, is obtained from the product of each probability on the sequence with the initiator frequency

Frequency = (4 x 10^{3}/yr) (1 - [8 33 x 10^{4}]) (5 0 x 10^{2}) (0 01) (0 99)
= 1 98 x 10^{6}/yr

6 2 HYDROGEN EXPLOSION ASSUMPTIONS

For hydrogen to be generated and accumulate within the filter vessel, the vessel must be in a static (no flow) and partially drained condition This condition must be maintained long enough for the hydrogen concentration to increase above the lower flammability limit Finally, an ignition source within the filter vessel must cause the hydrogen gas to deflagrate Given that this sequence of events occurs, some fraction of the particulate fuel retained in the filter would be released If a backwash of the filter has not been performed since the flow into the filter stopped, the maximum amount of fuel allowed before a routine backwash could be present The duration for this accident release is expected to be very short, certainly less than 1 hour

The following assumptions have been used in the analysis of the unmitigated and mitigated hydrogen deflagration accident scenarios

- The maximum sludge inventory that will plug a single filter is one-tenth of the thickness of fine sand present in the filter The fine sand is in a layer 30 in thick thus the sludge inventory is equivalent to a layer 3 in thick

- The large volume of sludge needed to plug a single filter (140 L from Section 3 3) means that its composition is representative by the average fuel in the entire basin rather than the safety basis composition

- The maximum filter headspace volume above the filter media is 3 1 m^3 This headspace is conservatively assumed to be filled with a stoichiometric mixture of hydrogen and oxygen (from air) gas just before the explosion

- The technique for determining the respirable fraction (RF) released from the deflagration is based upon a correlation (Steindler and Seefeldt 1980) that uses data with a maximum ratio of 15 for material-at-risk to the TNT equivalent mass of the explosive This correlation is applied to a scenario where the actual ratio significantly exceeds a value of 15 It is assumed that the experimental data and the corresponding correlation used by Steindler and Seefeldt (1980), "A Method for Estimating the Challenge of an Air Cleaning System Resulting from an Accidental Explosive Event," may be extrapolated up to a ratio of at least 50 The resulting release fraction is about 1% of the TNT equivalent mass

- Significant amounts of hydrogen gas are not generated in the filter vessel unless the water level in the vessel is high enough to cover at least a significant portion of the fine sand Sıgnıficant water ıs needed ın close contact wıth the fuel ın the sludge for efficıent radıolysıs or corrosıon to occur

- The wet (at least partıally submerged) fine sand and trapped sludge ın the filter may be treated as a lıquıd wıth entraıned solıds for purposes of applyıng the Steındler-Seefeldt (1980) correlatıon

- All sludge retaıned by the filter ıs held ın the fine sand, and 50% of the fine sand mass ınteracts wıth the energy released durıng the deflagratıon The sludge ıs dıstrıbuted ın the top half of the fine sand and ıs, therefore, all avaılable to be acted upon by the energy released from the deflagratıon

6 3 HYDROGEN DEFLAGRATION

Hydrogen generatıon may occur by radıolysıs when the energy released from the decayıng fuel ıs deposıted ın the surroundıng water, dıssocıatıng the molecule The process, ın sımplıfied form, ıs descrıbed by

$$2H_2O + (Energy_{\alpha\,\beta\,\gamma}) \rightarrow 2H_2 + O_2$$

Two moles of hydrogen are created for each mole of oxygen The hydrogen and oxygen generatıon rates may be descrıbed by the equatıons below

$$R_{H2} = \{[G_\alpha(H_2)]\,(E_\alpha) + [G_\beta(H_2)]\,(E_\beta) + [G_\gamma(H_2)]\,(E_\gamma)\}\,K$$

$$R_{O2} = \{[G_\alpha(O_2)]\,(E_\alpha) + [G_\beta(O_2)]\,(E_\beta) + [G_\gamma(O_2)]\,(E_\gamma)\}\,K$$

where

R_{H2} = rate of hydrogen gas generatıon ın gmoles H_2 per day
R_{O2} = rate of oxygen gas generatıon ın gmoles O_2 per day
X_w = weıght fractıon of water ın the materıal, assumed to be 30%
G_α = radıolysıs constants for alpha radıatıon ın molecules per 100 eV deposıted ın the water ın the materıal $G_\alpha(H_2) = 1\ 5\ X_w = 0\ 45$ and $G_\alpha(O_2) = 0\ 75\ X_w = 0\ 225$
G_β = radıolysıs constants for beta radıatıon, ın molecules per 100 eV deposıted ın the water ın the materıal $G_\beta(H_2) = 0\ 45\ X_w = 0\ 135$ and $G_\beta(O_2) = 0\ 225\ X_w = 0\ 0675$
G_γ = radıolysıs constants for gamma radıatıon, ın molecules per 100 eV deposıted ın the water ın the materıal $G_\gamma(H_2) = 1\ 2$ and $G_\gamma(O_2) = 0\ 0861 + 0\ 139\ X_w = 0\ 1278$
E_α = energy deposıtıon rate for alpha partıcles from fuel, ın W The heat generatıon rate for K West Basın actınıdes ıs adjusted for the mass of fuel ın the filter, namely,
E_α = (12,200 W)(0 43 MT)/(951 9 MTU) = 5 51 W
E_β = energy deposıtıon rate for beta partıcles from fuel, ın W The heat generatıon rate for K West Basın fıssıon products mınus the heat generatıon rate for photons ıs adjusted for the mass of fuel ın the filter, namely,
E_β = (67,200 - 24 600 W)(0 43 MT)/(951 9 MTU) = 19 2 W

E_γ = energy deposition rate for gamma particles from fuel, in W The heat generation rate for K West Basin Ba-137m is adjusted for the mass of fuel in the filter, namely,
E_γ = (24,600 W)(0 43 MT)/(951 9 MTU) = 11 1 W

$$K = \frac{J/s}{W} \times \frac{1 \text{ gmole}}{6\ 0221 \times 10^{23} \text{ molecule}} \times \frac{100 \text{ eV}}{1\ 6022 \times 10^{\ 17} \text{ J}} \times \frac{3600 \text{ s}}{h} \times \frac{24 \text{ h}}{d}$$

$$= 8\ 95 \times 10^{\ 3} \frac{\text{gmole } 100\text{eV}}{\text{molecule W d}}$$

The above radiolysis constants are taken from HNF-SD-SNF-TI-015 They are bounding values for a variety of materials based on the expected water concentration It is assumed that the water concentration is 30% by weight This value represents relatively wet sludge

The above values for energy deposition rate are taken from the K West Basin fuel composition table The alpha value is the total given for actinides The gamma value is solely from Ba-137m The beta value is the total for fission products minus the Ba-137m

If all energy released from the decay process is available for the radiolysis process, the hydrogen gas generation rate is 0 165 gmole H_2 per day as shown below A similar calculation for the oxygen generation rate gives 0 0354 gmole O_2 per day

$$R_{H2\,\alpha} = 0\ 45 \frac{H_2 \text{ molecules}}{100 \text{ eV}} \times (5\ 51 \text{ W}) \times K = 0\ 0222 \frac{\text{gmole } H_2}{d}$$

$$R_{H2\,\beta} = 0\ 135 \frac{H_2 \text{ molecules}}{100 \text{ eV}} \times (19\ 2 \text{ W}) \times K = 0\ 0232 \frac{\text{gmole } H_2}{d}$$

$$R_{H2\,\gamma} = 1\ 2 \frac{H_2 \text{ molecules}}{100 \text{ eV}} \times (11\ 1 \text{ W}) \times K = 0\ 1193 \frac{\text{gmole } H_2}{d}$$

$$R_{H2} = R_{H2\,\alpha} + R_{H2\,\beta} + R_{H2\,\gamma} = 0\ 165 \frac{\text{gmole } H_2}{d}$$

The total number of gmoles of gas in the headspace volume is calculated using the ideal gas law as shown below The headspace volume is 3,100 L and the assumed gas temperature is 25°C (298 15 K)

$$N_{tot} = \frac{P\,V}{R\,T} = \frac{(1 \text{ atm})(3{,}100 \text{ L})}{(0\ 082058 \text{ L atm/gmole/K})(298\ 15 \text{ K})} = 124\ 6 \text{ gmole}$$

While the time interval to completely fill the vessel headspace with hydrogen gas from radiolysis is quite large, given bounding case conditions, a flammable gas mixture could be accumulated within about one month The lower flammable limit for hydrogen in air is about 4% Thus the time to reach 4% hydrogen can be estimated as shown below After several months, the hydrogen concentration is near the stoichiometric concentration of hydrogen in air, 29 6%

$$\text{Time for 4\% } H_2 = \frac{(0\ 04)(124\ 6 \text{ gmoles})}{0\ 165 \text{ gmoles/d}} = 30 \text{ d}$$

Additional hydrogen gas may be generated from two other processes the oxidation of any metal uranium by water in the fine sand matrix or by the reaction of uranium hydride with water Because the fuel accumulated in the filter over a relatively long time period, it is expected that most exposed metal or hydride uranium already will have undergone any reactions with water that are going to take place But, given the presence of metal or hydride, these two processes could potentially produce hydrogen at much faster rates than radiolysis, thereby reducing the total time needed to produce a flammable gas mixture Note that these alternative hydrogen-producing reactions do not produce oxygen All of needed oxygen must come from air that enters the void space

It is assumed that a small static discharge, or the spontaneous reaction of a particle of uranium hydride causes the flammable mixture of gas to ignite The heat of combustion per volume of hydrogen (with oxygen) is 2 8 x 10^6 cal/m^3 at standard temperature and pressure (*Standard Handbook for Mechanical Engineers*) If hydrogen and air fill the filter vessel headspace (total volume = 3 1 m^3) such that a near-stoichiometric concentration of hydrogen in air (29 6%) exists, then the maximum total heat of combustion that could result from deflagration is shown below

$$(2\ 8 \times 10^6 \text{ cal/m}^3)\ (0\ 296)\ (3\ 1 \text{ m}^3) = 2\ 57 \times 10^6 \text{ cal}$$

The heat of combustion per mass of TNT is 4 773 MJ/kg (1,140 cal/g) (Crowl and Louvar 1990) The explosive energy produced by the maximum hydrogen deflagration could be generated by a mass of 2,250 g of TNT Strehlow (1972), "Unconfined Vapor Cloud Explosion—An Overview," reports that the energy released or damage done under similar conditions from a deflagration is expected to not exceed 10% (explosive yield) of that expected from the theoretical TNT equivalent This reduction is due to several factors, including incomplete combustion (which is not a factor here since the combustion occurs in a confined space), the reduced local energy density of a gaseous combustion compared with the condensed state TNT explosion, and the fact that the experiments used to determine the effects of TNT explosions placed the TNT within the affected material rather than above it If this correction is applied to the energy released in this accident, a TNT equivalent of 225 g would produce the maximum expected energy release

Given a stoichiometric mixture of hydrogen and air at a pressure of 1 atm and a temperature of 25 °C, the combustion under adiabatic conditions leads to a temperature of 2700 K and a pressure of 8 0 atm (NUREG/CR-2726) This pressure is below the design limit for the filter vessel (150 psig or 11 atm) The time to reach this pressure can be estimated from the volume of the gas and the speed of sound as shown in the formula below (SFPE 1995, page 3-318) The decrease in pressure with time depends on the rate at which heat is removed from the gas by convection, conduction, and radiant effects

$$\text{Time} = \frac{(8\ 0\ \text{atm})(101\ 3\ \text{kPa/atm})}{66{,}000\ \text{kPa m/s}}(3\ 1\ \text{m}^3)^{1/3} = 0\ 018\ \text{sec}$$

An additional effect for a stoichiometric mixture (the worst possible case) is the formation of detonation shock waves These waves travel faster than the speed of sound, leading to shorter combustion times and higher pressures Shock waves incident on a tank wall are reflected, which further boosts the pressure near the wall Peak reflected pressures for a stoichiometric mixture have been calculated to be 37 atm (NUREG/CR-2726) Although a static pressure of this magnitude would be likely to rupture the filter vessel, a short-duration pulse striking the vessel wall is not expected to lead to catastrophic failure The high-pressure pulse may cause an existing hole to widen or create additional small leak paths near welds or fittings However, these effects (37 atm) are not considered in the accident because stoichiometric conditions are not credible The pinhole, which allows air to enter and is required to initiate the accident, allows some hydrogen to exit and, thus, precludes stoichiometric conditions from being credible Without stoichiometric conditions, a hydrogen detonation will not occur However, to bound the pressure (8 atm) and temperature (2700 K) of a hydrogen deflagration accident, stoichiometric conditions were conservatively assumed for this purpose Thus the main effect of a hydrogen deflagration on the tank is dominated by the adiabatic pressure (8 atm) and temperature (2700 K) described in the preceding paragraph

An unmitigated accident analysis is performed to determine the safety classification of equipment and controls that would mitigate its dose consequences If no equipment or procedures for backwashing the filters were in place, the IWTS could be operated until all the filters were essentially plugged, stopping all liquid flow For the unmitigated analysis, the estimated sludge inventory in the filter in which the deflagration occurs is assumed to be $4\ 3 \times 10^5$ g The duration for the accident will be assumed to be less than 1 hour so that the acute air transport factors are appropriate

To determine the amount of respirable particulate material released from the deflagration, the Steindler-Seefeldt correlation is used (Steindler and Seefeldt 1980) The Steindler-Seefeldt correlation relates the amount of material (solid or liquid) released, in a specific size range, from a nearby explosion to the mass ratio, which is the ratio of the initial mass of material to the mass of TNT It should be noted that this correlation may not be applicable to dry powders The experimental configuration of the explosive material and the material at risk (MAR) was typically spherical or cylindrical with the explosive located at the center of the MAR While these arrangements are not representative of the actual phenomena that would occur in a hydrogen deflagration within the filter vessel, they should be useful in establishing an upper bound on the amount of particulate released The experimental data used by Steindler and Seefeldt (1980) to develop the correlation only included arrangements with a mass ratio of 15 or less Steindler and Seefeldt (1980) extrapolate this data in plots of their correlation for mass ratio values up to 400 and suggest that this extrapolation is reasonable for conditions existing in a fuel cycle facility However, they do not suggest that the correlation be applied to safety analyses for mass ratio values very much above available experimental data without verification

The fine sand is loaded in the filter to a height of about 30 in and fills a volume of about 1 4 m^3 with a total dry mass of about 2 1 x 10^6 g The greatest postulated release of sludge occurs if the sludge is all loaded in the fine sand and if the mass of garnet, coarse sand, and water are ignored in determining the MAR for the deflagration It is conservatively assumed that only the top 15 in of fine sand (50% of the total mass) absorb energy during the deflagration Assuming less sand is involved in the release means a larger fraction of sludge becomes airborne Using just the top 1 in of sand (3 3%) leads to doses that do not exceed guidelines The total mass of this portion of the fine sand and the maximum trapped fuel is

$$(2\ 1 \times 10^6 \text{ g fine sand})\ (50\%) + (4\ 3 \times 10^5 \text{ g sludge}) = 1\ 48 \times 10^6 \text{ g}$$

This mass, combined with the calculated TNT equivalent mass for the hydrogen deflagration, gives a mass ratio of

$$(1\ 48 \times 10^6 \text{ g}) / (225 \text{ g}) = 6{,}600$$

A value of 50 is used for the mass ratio in the Steindler-Seefeldt correlation (Steindler and Seefeldt 1980) This value has been chosen for the mass ratio so that little extrapolation beyond available data must be relied upon in the correlation Using a mass ratio of 6,600 in the correlation would predict the release of much less respirable material than does using a mass ratio of 50 in the correlation Therefore, using a mass ratio of 50 is expected to provide conservative predictions of the respirable release Because the particulate released likely will be coated with water, a maximum released particle size of 20 µm is considered respirable to allow for evaporation en route to the receptor For a mass ratio of 50, the Steindler-Seefeldt correlation predicts that a total of about 1 x 10^{2} g of particulate (less than 20 µm) will be released per gram of TNT (see Figure 6 of Steindler and Seefeldt [1980]) The total amount of respirable fine sand and sludge particulate released is expected to be

$$(1 \times 10^{2} \text{ g/ g TNT})\ (225 \text{ g TNT}) = 2\ 25 \text{ g}$$

Of this total respirable particulate released, 29% (4 3 x 10^5 g/1 48 x 10^6 g), or 0 65 g sludge, is calculated to be sludge, while the remainder is fine sand In other words, the source term inside the enclosure, M, is 0 65 g sludge Furthermore, this source term is subject to an LPF (0 1) for the shielding enclosure effect The onsite dose at 100 m from the building is calculated using the equation below

$$D_{onsite\_100} = (M)\ (\chi/Q')\ (BR)\ (UD)\ (LPF)$$

where

M	=	mass of fuel airborne as respirable particles (0 65 g sludge)
χ/Q'	=	atmospheric dispersion factor from HNF-SD-SNF-TI-059 (s/m^3)
BR	=	breathing rate (3 33 x 10^{-4} m^3/s for light activity)
UD	=	unit dose for K West Basin fuel (200,000 rem/g sludge)
LPF	=	leak path factor from filter vessel enclosure to the building (0 1, Table 3-7)

For this accident, a bounding M of 0 65 g has been calculated, χ/Q' is selected for an acute release with duration less than 1 hour to a receptor 100 m from K Basins (HNF-SD-SNF-TI-059), and the UD is 2 00 x 10^5 rem/g (calculated on Table 3-5) for the K West Basin fuel composition These values lead to an unmitigated onsite dose at 100 m of

$$D_{onsite\_100} = (0\ 65\ g)\ (7\ 32 \times 10^{2}\ s/m^3)\ (3\ 33 \times 10^{-4}\ m^3/s)\ (2\ 00 \times 10^5\ rem/g)\ (0\ 1) = 0\ 32\ rem$$

Additional unmitigated receptor doses are summarized in Table 6-1 The guidelines reported in Table 6-1 are for an event that is deemed extremely unlikely (1 x 10^{-6} < annual frequency ≤ 1 x 10^{-4})

The bounding doses from a hydrogen deflagration are below the radiological risk acceptance guidelines proved by DOE (Sellers 1997) for the onsite worker at 100 m Therefore, no controls are necessary to lower the probability of the accident or its severity Note that the radiological risk acceptance guidelines are given as TEDE, or total effective dose equivalent, which is the sum of all internal and external contributions to a persons dose The TEDE is the same as the CEDE used in Table 6-1 for the inhalation and external dose to individuals downwind under worst-case conditions

Table 6-1 Dose Consequences for an Unmitigated Hydrogen Deflagration in the Filter Vessel

Receptor location	χ/Q'[a] (s/m^3)	CEDE rem (Sv)	Guidelines[b] (rem)
Onsite Worker (100 m E)	7 32 E-02	3 2 E-01 (3 2 E-03)	25
Columbia River (520 m W)	3 55 E-03	1 5 E-02 (1 5 E-04)	--
100 Area Fire Station (3 750 m ESE)	1 60 E-04	6 9 E-04 (6 9 E-06)	--
Hanford Site Boundary (10,070 m W)	4 49 E-05	1 9 E-04 (1 9 E-06)	5

[a] Air transport factors are from HNF SD SNF TI-059 1999 *A Discussion on the Methodology for Calculating Radiological and Toxicological Consequences for the Spent Nuclear Fuel Project at the Hanford Site* Rev 2 Fluor Daniel Hanford, Incorporated Richland Washington

[b] The guidelines are the U S Department of Energy recommended maximum CEDE values for an extremely unlikely event from Sellers E D 1997 *Risk Evaluation Guidelines (REGs) to Ensure Inherently Safer Designs* (Letter 97 SFD 172 to H J Hatch, Fluor Daniel Hanford Incorporated August 26) U S Department of Energy Richland Operations Office Richland Washington

CEDE = committed effective dose equivalent

7 0 FIRES

The fire DBA is a fire within the facility that impacts the east annular filter vessel and results in a dose consequence Although the annual frequency of fires in general is anticipated, this specific DBA is considered an extremely unlikely event (Section 7 1 2)

The following is a brief description of each of the major fires evaluated in the Fire Hazards Analysis (HNF-SD-SNF-FHA-001) These descriptions are provided to support the scenario development of the DBA fire

- **Fire involving the transfer bay roll-up door windbreak enclosure** The windbreak enclosure is made of a combination of industrial polyester and polyvinyl chloride laminate It is postulated that the material melts and ignites from an assumed ignition source (e g , MCO transport tractor) If the roll-up door were open, the material could pool around a critical column along column line 16 If the wind were blowing, burning material could wrap itself around a critical column in column line 16 It is calculated that enough heat is present from direct flame impingement that structural damage could occur Failure of one of the critical columns in column line 16 could cause local roof failure in the transfer bay area (Kanjilal 1996) No dose consequences are postulated

- **Fire involving gantry crane hydraulic oil** It is postulated that up to all of the hydraulic oil (~30 gal) in the transfer bay bridge crane leaks out Although the hydraulic oil has a fairly high flashpoint (similar to diesel fuel), it is assumed that an ignition source might be present If the leak occurs near a critical column in the transfer bay area, it is possible for heat to damage a column and result in localized roof failure (Kanjilal 1996)

  If the leak occurs near the gantry support structure, failure of a gantry support structure column could occur from direct flame impingement If a gantry support structure column were to fail, the gantry could not fall into the south load-out pit and impact the basin floor because (1) complete failure of the column with a clean break is not expected, (2) complete failure of the gantry support structure is not expected based on engineering judgement (i e , only one side of the support structure is impacted and that side is still affixed to the mezzanine level), (3) the gantry spans the south load-out pit and it is nearly impossible for it to fall into the south load-out pit, and (4) south load-out pit hardware configuration (i e , operations interface platform, shuttle, and cask guide rail) obstructs the drop path As a result, no dose consequences are postulated

- **Fire involving impact-limiting foam material** Polyurethane foam is used for energy-absorping crush material in some of the cask-loading system structures, systems, and components All impact-limiting devices consist of energy-absorptive foam encased by sheet metal The sheet metal prevents direct flame impingement on the foam and limits the air available for combustion Any damage from such a burn would be localized and limited to the exposure area No dose consequences are postulated

- **Fire involving a polyethelene plastic containment structure (tent)** Occasionally plastic containment structures are used to minimize area radioactive contamination It is postulated that a fire could occur in the plastic tent material from an assumed ignition source (e g hot motor) Worst-case fire analysis shows that thermal damage to exposed structural columns or overhead structural steel could result in some localized roof failure No negative impacts to safety structures, systems, and components are expected, and no MAR is postulated As a result no dose consequences are postulated

- **Fire involving a miscellaneous transient fuel package** Miscellaneous combustible materials include trash bags, plywood boxes, personnel protective equipment (e g , anti-contamination clothing), and plastic wrapping These fuel packages may be located throughout the transfer bay and basin storage areas The Fire Hazards Analysis (HNF-SD-SNF-FHA-001) shows that all cases of transient fuel package (or combustible) fires are bounded by the 30-gal diesel fuel fire analyzed in this accident Controls for adequate spacing for combustible materials are identified in the Fire Hazards Analysis (HNF-SD-SNF-FHA-001) and are incorporated as part of the K Basins Fire Protection Program Although a fire involving anti-contamination clothing might result in inhalation dose consequences, the MAR from the annular filter vessel is much larger, therefore, it is expected that the dose consequences from an anti-contamination clothing fire are bounded by the DBA which causes a breach of the annular filter vessel

- **Diesel fuel spill and fire in the transfer bay area** Diesel fuel spills that could result in a fire can occur from two identified sources regularly used in the basin

  1 Forklift (maximum diesel fuel capacity of 30 gal)

  2 MCO transport tractor (maximally controlled fuel capacity of 100 gal of diesel fuel), tractor and trailer tires were also considered in the combustible loading in the fire involving the MCO transport tractor

  The Fire Hazard Analysis (HNF-SD-SNF-FHA-001) identifies columns that can be impacted by a diesel fire Of those columns, six are identified as critical for structural support (Kanjilal 1996) F-16 F-15, F-14, D c-16, D c-15, and B g-15 Structural damage from a diesel fire occurs by both direct flame impingement and hot gas layer near the ceiling The diesel fuel fire is considered the bounding fire accident resulting in dose consequences because failure of a critical column could result in structural members and the transfer bay bridge crane being dropped onto the following SSCs

  – Integrated Water Treatment System (IWTS) east annular filter vessel The bounding MAR comes from failure of a critical column (most likely B g-15) with subsequent drop of structural members or the transfer bay bridge crane onto the IWTS annular filter vessel shielding enclosure and impact to the east annular filter vessel Only the east annular filter vessel is in the drop path

- Integrated Water Treatment System process lines Dose consequences resulting from process lines being broken outside of the annular filter vessel shielding enclosure are considered very small because of the limited amount of suspended radionuclides available during the period of release

- Ion Exchange Modules at the north end of the transfer bay Ion exchange modules are of heavy-duty construction, and damage to the ion exchange modules is expected to be minimal Resin beads are housed within 3/8-in -thick steel pipes surrounded by a thick concrete structure (86 in x 70 in x 79 5 in high) No contaminated ion exchange resin beads are expected to be released, therefore, dose consequences from the transfer bay bridge crane being dropped onto the ion exchange modules are assumed to be minimal Furthermore, the MAR in the ion exchange modules is bounded by the MAR from a fully loaded annular filter vessel

- North load-out or south load-out pit curbs Damage to the load-out pits resulting in basin water leakage is bounded by the cask–MCO drops DBA (HNF-SD-WM-SAR-062) and does not result in dose consequences

7 1 SCENARIO DEVELOPMENT

7 1 1 Bounding Fire Design Basis Accident

The 30-gal diesel fuel fire is the bounding DBA for fires since this fire has the high flame impingement on critical columns The 100-gal diesel fuel and tire fire has the hottest gas temperatures, but not flame impingement on critical support columns Hence, to be conservative, the hot gas temperatures used in the evaporation release of water and sludge (Section 7 2 2) were from the 100-gal diesel fuel/tire fire The bounding consequence is caused by a critical support column (B g-15) failure and a subsequent drop of structural members onto the east annular filter vessel enclosure In order for structural members to fall onto the annular filter vessel, the critical column B g-15 must fail while the transfer bay bridge crane is parked at the north end of the transfer bay (along column row B)

The 30-gal diesel fuel fire is the most likely fire to impact column B g-15 and is the result of a diesel forklift spill, causing direct flame impingement on column Diesel forklifts are the only diesel-fueled vehicles that regularly access that area of the transfer bay Damage to critical columns from a hot gas layer is minimized because the roll-up door to the transfer bay would be open to allow delivery of the trailer while dropping off or picking up an MCO or to allow the fork lift to move in and out However, the hot gas layer plays a direct role in causing maximum evaporation releases of water and sludge (Section 7 2 2) Furthermore, it is judged that critical columns closer to the fire would fail sooner because of the combination of direct flame impingement and hot gas layer, hence, the hot gas layer is important to the DBA The hot gas layer should not last a long tıme (>1 hour) sınce ıt cools rapıdly from thermal radıatıon, and faılure of one of these crıtıcal columns would lıkely result ın some damage to the roof, thus provıdıng an addıtıonal release path for the hot gas layer (the exhaust fans provıde the first release path even ıf they are not operatıng)

Structural analysıs was not performed to quantıfy specıfic damage to the annular filter vessel radıatıon shıeldıng enclosure or to the annular filter vessel However, although judged ımprobable, ıt ıs postulated that ıf column B g-15 were to faıl, the transfer bay brıdge crane and ıts support beam could fall Sınce all columns ın column lıne 13 maıntaın theır ıntegrıty (Kanjılal 1996), the transfer bay brıdge crane would be expected to fall lıke a pendulum wıth ıts anchor poınt at column lıne 13 As such, the transfer bay brıdge crane ıs expected to most lıkely mıss hıttıng the shıeldıng enclosure or hıt ıt wıth a glancıng blow Fıgure 7-1 shows the respectıve locatıons of the transfer bay brıdge support beams, transfer bay brıdge crane, and the annular filter vessels The fallıng support beam and potentıal mıscellaneous structural supports would most lıkely ımpact the shıeldıng enclosure It ıs expected that the annular filter vessel shıeldıng enclosure absorbs most of the ımpact and becomes somewhat crushed, resultıng ın damage to the east annular filter vessel Usıng engıneerıng judgement, the worst-case damage to the east annular filter vessel ıs expected to be a mınor tear ın the top portıon Damage to the mıddle and west annular filter vessel ıs assumed to be mınımal because they are not dırectly ın the crush path of fallıng structural members

7 1 2 Frequency Category of Fıre Desıgn Basıs Accıdent

Thıs sectıon summarızes the basıs for the annual frequency category as "extremely unlıkely" for the fire DBA descrıbed above

In order for the structural members to fall onto an IWTS annular filter vessel, the crıtıcal column B g-15 must faıl The worst case damage would occur ıf the transfer bay brıdge crane ıs parked at the north end of the transfer bay when ıt falls, provıdıng a glancıng blow to the filter vessel enclosure, whıch gets damaged from the fallıng support beam and structural members The most lıkely dıesel fuel fire to ımpact column B g-15 ıs that resultıng from a spıll from a dıesel forklıft Dıesel forklıfts are the only dıesel-fueled vehıcles that regularly enter that area of the transfer bay Thıs accıdent ıs consıdered extremely unlıkely because all of the followıng must happen for radıologıcal dose consequences to occur

- A dıesel forklıft must be ın the area of concern whıle the transfer bay brıdge crane ıs parked along column row B Although the dıesel forklıft ıs generally used ın that area to brıng ın burıal boxes, ıt ıs expected that the forklıft wıll only be ın the area four to five tımes a month, and only for about 15 mınutes each tıme

- For the column to be thermally damaged to the poınt that ıt could faıl and drop the transfer bay brıdge crane, the leak rate must be optımal to maxımıze the tıme of fire and heat output, and most of the 30 gal of dıesel fuel must be avaılable to achıeve the magnıtude of heat necessary to cause thermal structural damage

- A large enough ıgnıtıon source must be present to ınıtıate the dıesel fire

- The diesel fuel spill must pool around column B g-15 to cause thermal damage from flame impingement Roll-up doors are generally up when the forklift is being utilized because of the short duration and the nature of the forklift operation

- The transfer bay bridge crane must drop in a manner that causes critical structural members to fall and impact the annular filter vessel shielding enclosure with enough force to damage the enclosure such that the annular filter vessel can be impacted The annular filter vessel shielding enclosure is constructed of east and west walls that are made of 8 in of concrete sandwiched between two 2-in steel plates, north and south walls that are made of 2 25-in -thick lead sandwiched between two 1-in steel plates and a 1-in steel cover

- Structural support members must drop with enough force to impact the annular filter vessel shielding enclosure and damage the annular filter vessel

Deterministic structural analysis was not performed to quantify specific damage to the annular filter vessel radiation shielding enclosure or to the annular filter vessel However, although judged improbable, it is postulated that if column B g-15 were to fail, the transfer bay bridge crane and its support beam could fall Since all columns in column line 13 maintain their integrity (Kanjilal 1996), the transfer bay bridge crane would be expected to fall like a pendulum with its anchor point at column line 13 As such, the transfer bay bridge crane is expected to most likely miss hitting the shielding enclosure or hit it with a glancing blow The falling support beam and potential miscellaneous structural supports would most likely impact the shielding enclosure It is assumed that the annular filter vessel shielding enclosure absorbs most of the impact and becomes somewhat crushed by the impact, resulting in damage to the east annular filter vessel Utilizing engineering judgement, the worst case damage to the east annular filter vessel is expected to be a minor tear in the upper half Damage to the middle and wet annular filter vessel is assumed to be minimal because they are not directly in the crush path of falling members

In addition, a diesel fuel fire, which includes burning transport trailer tires, in the south end of the transfer bay resulting from a tractor diesel spill (up to 100 gal) could generate a hot gas layer capable of causing thermal structural damage to column B g -15 Damage to critical columns as a result of a hot gas layer is minimized because the roll-up door to the transfer bay is open to allow delivery of the transport trailer Furthermore, it is judged that critical columns closer to the fire would fail sooner because of the combination of direct flame impingement and hot gas layer Failure of one of these critical columns would likely result in some damage to the roof thus providing a release path for the hot gas layer Lastly, an optimal spill rate and an ignition source large enough to ignite diesel fuel are required to generate the bounding burn time that results in the peak hot gas layer temperature required The consequences of this accident also cover the consequences from a gasoline fire, instead of diesel fuel fire, since the heat of combustion is about the same for gasoline and diesel fuel

This event is therefore considered to be an "extremely unlikely" event

7 2 SOURCE TERM ANALYSIS

Two types of particle release mechanisms occur as a result of the fire (1) resuspension of particles due to the falling water, and (2) rapid evaporation of water due to the hot gas layer heating up spilled water Source terms are calculated for each release mechanism using the following assumptions

- The release is assumed to continue for 2 hours, which is the maximum time expected to turn the IWTS pumps off, thus eliminating the water source for particles to be entrained

- Inlet lines remain intact for water to provide flushing phenomena

- Water flows through the annular filter vessel at a rate of 6 9 L/s (110 gal/min) This analysis assumes that water flows out of the annular filter vessel through a small tear in the top portion at the same volumetric flow rate, entraining 20% of the sand and sludge (combined mass of 1,480 kg) that is in the filter vessel over 2 hours Twenty percent entrainment and release is considered conservative because of the water velocity and its top entrance, the vessel geometry (large height of space above filter media and doughnut cross-section), and the upper location of small tears This provides a sludge and sand concentration of about 30 g/L, which is considered an aqueous solution and not a slurry (DOE-HDBK-3010-94, Section 3 2 3)

- Sand and sludge flushed out of the annular filter vessel falls about 2 m (i e , from the top of the annular filter vessel) to the floor or nearby structures

- For resuspension of particles due to falling water, the airborne release rate (ARR) is 1 0 E-04 per hour based on a bounding value of an ARR for resuspension of spilled uranine solutions at a spill height of 3 m and the judgement that a large continuous release of solution will have resuspension factors lower than a small single spill Correcting for the lower release height of 2 m reduces the ARR by a factor of 2, resulting in an ARR of 5 0 E-05/h The bounding RF for the same case is 0 50 (DOE-HDBK-3010-94, Section 3 2 3)

- For rapid evaporation of water due to the hot gas layer heating up, the bounding ARF is 1 8 E-03 based on measurements of water evaporating during heated water experiments for plutonium nitrate in water with 90% of the water evaporating (DOE-HDBK-3010-94, Section 3 2 1 2) Since only 3% of the water evaporates over a 2-hour period in this scenario, the combined ARF for sludge released from boiling water is 6 0 E-05 (1 8 E-03 x 0 03/0 90) For evaporation calculations, the pool is conservatively assumed to be stationary The bounding RF is the same as the spilled water release which is 0 50

- An LPF is not credited (i e , LPF = 1) because if a critical column fails, both the annular filter vessel shielding enclosure and the roof of the building are expected to be damaged, which would promote the release of particulate to the environment

7 2 1 Resuspension of Particles Due to Falling Water

The maximum available sludge in one annular filter vessel is 430 kg (Section 3 3) The MAR is assumed to be 20% of the 430 kg of sludge in the east annular filter vessel The 20% value is based on engineering judgement of the fraction of the filter sand and sludge (with a combined density much larger than the density of water) that gets flushed out of a minor tear or break on top of the annular ring The MAR_{spill} is then calculated as follows

$$MAR_{spill} = (0\ 20)\ (4\ 30\ E{+}05\ g) = 8\ 6\ E{+}04\ g$$

Sand and sludge is flushed out of the top of the damaged filter vessel with water flowing into the vessel at about 6 6 L/s (110 gal/min) The flowing water entrains some of the sand and sludge, and carries it out of the top of the filter vessel and out of the enclosure The spilled water falls about 2 m from the top of the annular filter vessel and enclosure to the floor

The ARR is $1\ 0 \times 10^{-4}$ per hour based upon a bounding value of an ARF for resuspension of spilled uranine solutions (DOE-HDBK-3010-94, Section 3 2 3 1) at spill height of 3 m and the judgement that a large continuous release of solution will have resuspension factors lower than a small single spill Correcting for the lower release height of 2 meters (DOE-HDBK-3010-94, Equation 3-13) reduces the ARR by a factor of 2, resulting in an ARR of $5\ 0 \times 10^{-5}$/hr The respirable fraction for these experiments had a bounding value of 0 5 (DOE-HDBK-3010-94, Section 3 2 3)

The airborne source term of sludge from the annular filter vessel spilled water release is calculated by the following equation

$$M_{spill} = (MAR)\ (ARR)\ (RF)\ (T)\ (LPF)$$

where

M_{spill}	=	respirable source term from resuspension of particles due to falling water
MAR_{spill}	=	material at risk from resuspension of particles due to falling water (8 6 E+04 g sludge)
ARR	=	airborne release rate (5 0 E-05 per hour)
RF	=	respirable fraction (0 50)
T	=	time of release (2 hours)
LPF	=	leak path factor for filter vessel enclosure and building not credited (1 0)

Therefore,

$$M_{spill} = (8\ 6\ E{+}04\ g)\ (5\ 0\ E{-}05\ \text{per hour})\ (0\ 5)\ (2\ \text{hours})\ (1) = 4\ 3\ g$$

7 2 2 Rapid Evaporation of Water Due to the Hot Gas Layer Heating Up Spilled Water

The suspended sludge mass released from the spilled water from an annular filter vessel was calculated in the previous section This section will estimate the source term from the evaporation of the spilled water caused by the hot gas layer located above the transfer bay floor It has been shown that evaporation of water with particulate will cause the particles in solution to be suspended in air and potentially released to the environment (DOE-HDBK-3010-94, Section 3 2 1 2) The highest release rates are for boiling water due to the large evaporation rate of boiling water (DOE-HDBK-3010-94 Table 3 2)

The following approach was used to estimate the source term of released particles

1 Calculate the rate of heat from the hot elevated gas to the spilled water pool, using the hot gas temperatures from the open-door fire scenario (HNF-SD-SNF-FHA-001)

2 Calculate the amount of spilled water that evaporates if all of the radiation heat transfer is absorbed by the top water with no heat losses to water vapor in air above spilled water and no heat required to increase water temperature

3 Calculate the fraction of total spilled water that can be evaporated, and apply this fraction to the total sludge that can be released

4 Apply an ARF to the sludge that can be released based on experimental data for boiling water particulate releases (DOE-HDBK-3010-94, Section 3 2 1 2)

The rate of radiation heat transfer from the elevated hot gas to the spilled water pool is calculated by the equation for heat transfer between two parallel plates (Pitts and Sissom 1977) as shown below

$$Q_{rate} = \sigma\ (T_g^4 - T_w^4)/(1/e_g + 1/e_w - 1) \tag{6}$$

where

Q_{rate} = radiation heat transfer rate per unit area from hot gas to cooler water (W/m^3)
σ = Stefan-Boltzman constant (~5 7 E-08 W/m^2K^4)
T_g = temperature of hot gas which varies with time (300 K to 1150 K)
T_w = temperature of spilled water on concrete (300 K)
e_g = emissivity of hot gas containing black soot from fire (1 0)
e_w = emissivity of water pool surface (0 96 [Pitts and Sissom 1977])

An example calculation of radiation heat flux for a hot gas with a temperature of 480 °C (753 K) and using the other values listed below Equation 6 yields a heat rate per unit area of about 17,000 W/m^2, which is relatively high compared to heat transfer rate from cooler gases The heat rate per unit area is calculated at various times of the hot gas temperature curve (HNF-SD-SNF-FHA-001, Figure 5-7 1 2 3) for open-door fire scenario and is shown in Table 7-1

The total heat transferred to the spilled water pool depends on the size of the pool The spilled water pool is expected to cover at most one quarter of the transfer bay floor area due to the drains removing some water, and the structures, such as annular vessel enclosure, occupying floor area Hence, the water pool will cover at most 83 7 m^2 of floor area This area is multiplied by the heat rate per unit area given by Equation 6 in order to obtain the total heat rate to water pool and is shown in Table 7-1 These heat rates are multiplied by the time interval in order to estimate the total cumulative heat received by the water pool, and the cumulative heat is shown in Table 7-1 After two hours of heating, conservatively assuming that the hot gas does not cool down after 400 seconds (last value in Figure 5-7 1 2 3 of HNF-SD-SNF-FHA-001) from 270 °C, the total water that could be vaporized is shown in the last row of Table 7-1 The cumulative water vapor is calculated by dividing the total heat received by pool by the heat of vaporization for 1 kg of water which is about 2 257 E+06 J/kg (Pitts and Sissom 1977) After two hours, the pool has received enough heat to produce about 1,430 kg of water vapor

The total amount of water spilled over the two-hour time period at 110 gal/min (6 9 kg/s) is approximately 49,300 kg Hence, the fraction of water that vaporizes under boiling conditions is found by dividing the water vapor mass by the total liquid water mass, producing a fraction of about 0 03 Thus, about 3% of the water is expected to evaporate under boiling conditions The evaporation scenario conservatively assumes that the water forms a stationary pool

The source term is calculated from the same MAR, which is 86,000 g of sludge, determined in the spilled water release (Section 7 2 1) The bounding ARF measured in heated water experiments for plutonium nitrate in water was 1 8 E-03 (DOE-HDBK-3010-94, Table 3 2) with 90% of the water evaporating Since only 3% of the water evaporates in this scenario, the combined ARF for sludge released from boiling water is 6 0 E-05 (1 8 E-03 x 0 03/0 90) The same RF value of 0 50 used in the spilled water release is used for the source term from evaporating water Due to potential fire damage to the K Basin building and the damage to filter vessel enclosure, the LPF for both the enclosure and building were conservatively chosen to be one The airborne source term for the water evaporation is estimated by using the following equation

$$M_{evap} = (MAR)\,(ARF)\,(RF)\,(LPF)$$

where

M_{evap}	=	respirable source term from evaporation of water
MAR_{evap}	=	material at risk from evaporation of water (8 6 E+04 g sludge)
ARF	=	airborne release fraction (6 0 E-05)
RF	=	respirable fraction (0 50)
LPF	=	leak path factor for both filter vessel enclosure and building not credited (1 0)

Therefore,

$$M_{evap} = (8\ 6\ E{+}04\ g)\,(6\ 0\ E{-}05)\,(0\ 5)\,(1)$$
$$= 2\ 6\ g$$

Table 7-1 Hot Gas Temperatures, Heat Rate to Water, and Cumulative Heat Transferred to Water Over Time

Time (seconds)	Temperature of Hot Gas °C (K)	Heat Rate (W/m²)	Total Heat Rate (W)	Cumulative Total Heat (J)	Cumulative Maximum Water Vapor Mass (kg)
0	27 (300)	0	0	0	0
25	100 (373)	616	5 15 E+04	0*	0*
52	540 (813)	23 450	1 96 E+06	0*	0*
80	1150 (1423)	223 900	1 87E+07	2 90E+08	130
90	1080 (1353)	182 900	1 53E+07	4 60E+08	200
100	750 (1023)	59 500	4 98E+06	5 61E+08	250
110	620 (893)	34 400	2 87E+06	6 01E+08	270
120	560 (833)	25 900	2 17E+06	6 26E+08	280
130	480 (753)	17 100	1 43E+06	6 44E+08	285
140	420 (693)	12 200	1 02E+06	6 56E+08	290
150	380 (653)	9 500	7 95E+05	6 65E+08	295
175	355 (628)	8 100	6 75E+05	6 83E+08	300
200	320 (593)	6 300	5 29E+05	6 98E+08	310
250	305 (578)	5 700	4 74E+05	7 23E+08	320
300	290 (563)	5 100	4 23E+05	7 46E+08	330
350	280 (553)	4 700	3 91E+05	7 66E+08	340
400	270 (543)	4 300	3 61E+05	7 85E+08	350
3600	270 (543)	4 300	3 61E+05	1 94E+09	860
7200	270 (543)	4 300	3 61E+05	3 24E+09	1430

* Water spill starts at 52 seconds when gas temperature reaches 540 °C and causes evaporation accident scenario to start

The total respirable source term is 6 9 g as follows

$$M_{total} = M_{spill} + M_{evap}$$
$$= 4\ 3\ g + 2\ 6\ g = 6\ 9\ g$$

Consequence Analysis The onsite dose from the building is calculated using the following equation

$$D = M_{total} \times \frac{\chi}{Q'} \times BR \times UD$$

where

D	=	onsite dose in rem (CEDE)
M_{total}	=	mass of respirable airborne material released (6 9 g sludge)
χ/Q'	=	time-integrated atmospheric transport factor (s/m^3)
BR	=	breathing rate (3 33 E-04 m^3/s, light activity breathing rate (HNF-SD-SNF-TI-059])
UD	=	dose per unit respirable radioactive material inhaled (2 0 E+05 rem/g sludge)

For this accident, a bounding source term of 6 9 g has been calculated, χ/Q' is selected for a release with duration of 1 to 2 hours to all of the receptors, and the UD is 2 0 E+05 rem/g for the sludge composition in the K West Basin (Section 3 2) These values lead to the following estimate of unmitigated onsite dose

$$D_{onsite} = (6\ 9\ g)\ (1\ 24\ E\text{-}02\ s/m^3)\ (3\ 33\ E\text{-}04\ m^3/s)\ (2\ 00\ E\text{+}05\ rem/g) = 5\ 70\ rem$$

Additional unmitigated receptor doses are summarized in Table 7-2

Table 7-2 Summary of Maximum Dose Consequences from Impact to an Annular Filter Vessel Due to Fire Design Basis Accident

Receptor location (distance, direction)	Unmitigated		Limit/Guideline [b] rem (CEDE)
	χ/Q' [a]	rem (CEDE)	
Onsite (100 m, east)	1 24 E-02	5 70	25
Near river bank (520 m, west)	6 17 E-04	0 284	--
100 Area Fire station (3,750 m, east-southeast)	7 82 E-05	0 0359	--
Hanford Site boundary (10,070 m, west) (off-site)	3 12 E-05	0 0143	5

[a] For 1 to 2 hours compatible with duration of release of 2 hours (HNF SD-SNF TI-059 1999 *A Discussion on the Methodology for Calculating Radiological and Toxicological Consequences for the Spent Nuclear Fuel Project at the Hanford Site* Rev 2 Fluor Daniel Hanford Incorporated Richland Washington)
[b] At a frequency of 'Extremely Unlikely (unprevented)

CEDE = committed effective dose equivalent

7 3 COMPARISON TO GUIDELINES

Onsite unmitigated dose consequences (5 7 rem) are approximately 23% of that allowed by the guidelines (25 rem) for an extremely unlikely event The spilled water resuspension release of sludge causes almost two thirds of the dose, with the evaporation of spilled water causing about one third of the dose The offsite dose consequences are approximately 0 3% of the limit

8 0 REFERENCES

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Figure 2-1 Schematic Drawing of the Integrated Water Treatment System with the Basic Annular Filter Arrangement and Effluent Flow Indicated

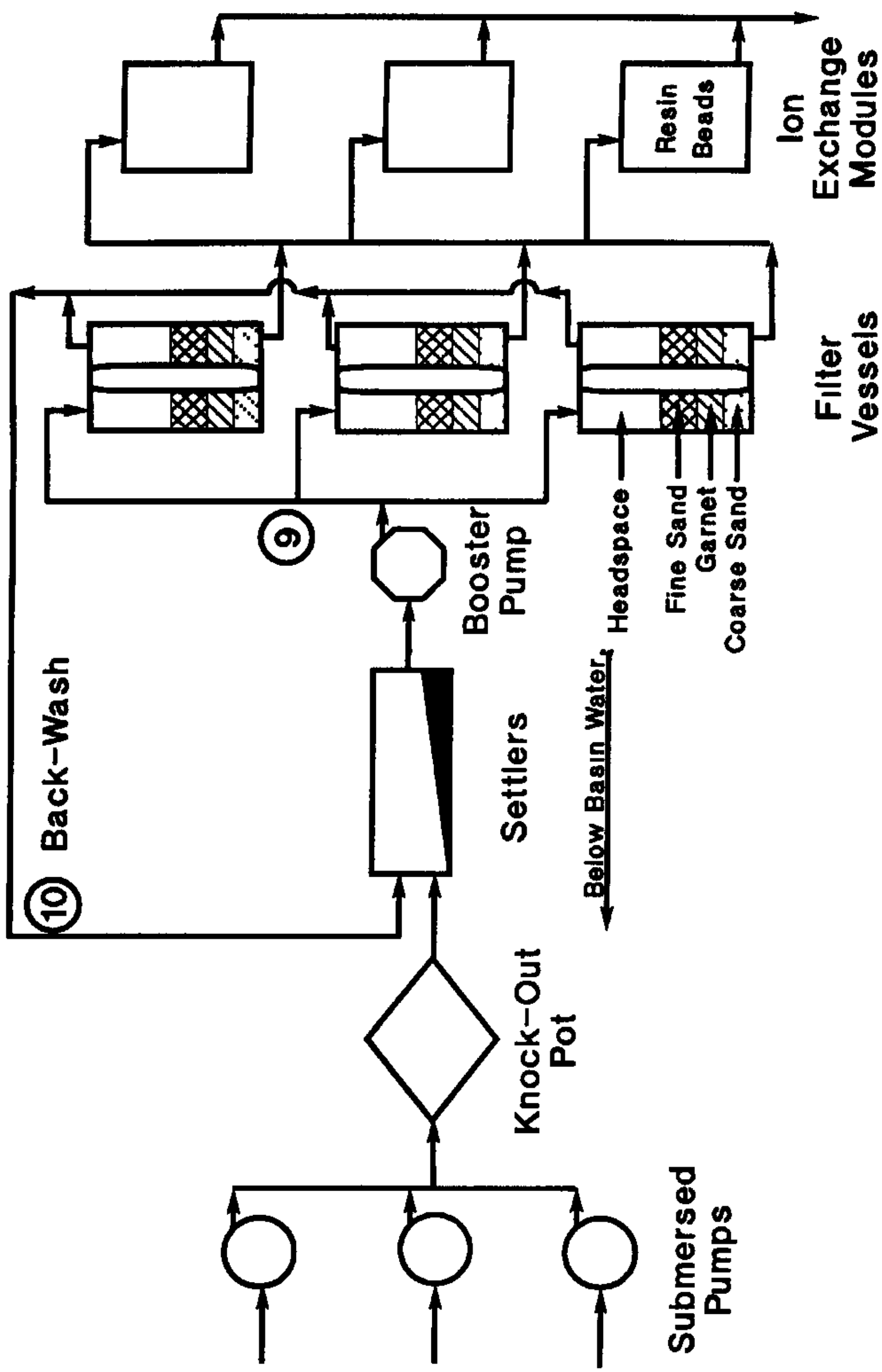


Figure 3-1 Illustration of the Symbols Used to Derive the Solution Density Formula

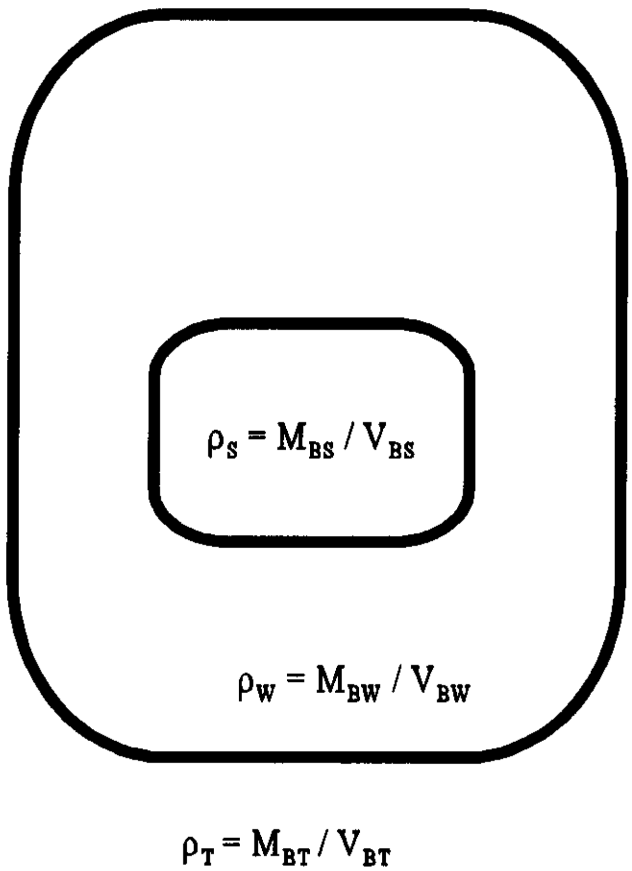


Figure 6-1 Event Tree for Hydrogen Deflagration in an Annular Filter

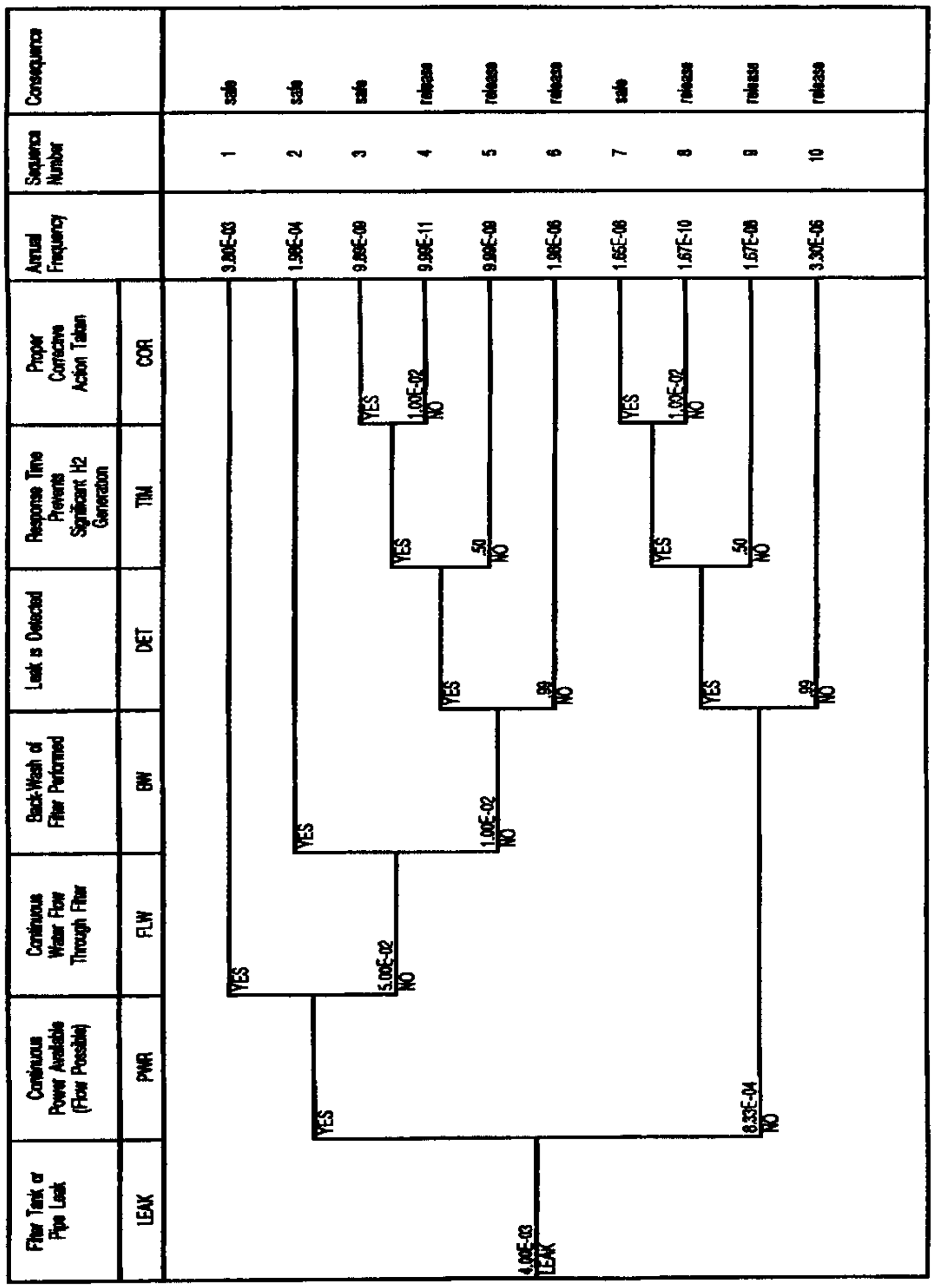
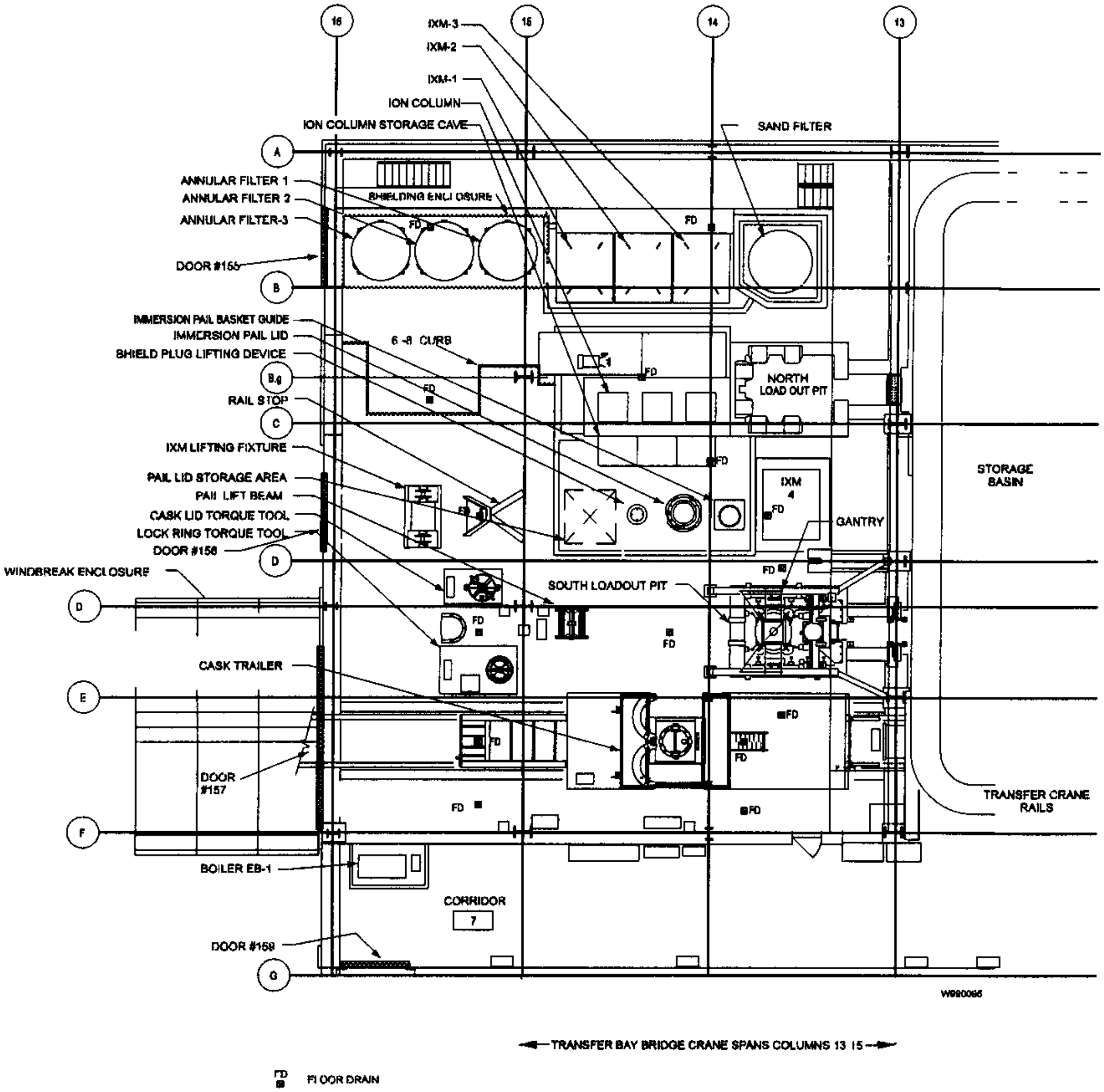


Figure 7-1 Plan View of the Transfer Bay Area



APPENDIX A

DERIVATION OF LEAK PATH FACTORS

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APPENDIX A

DERIVATION OF LEAK PATH FACTORS

A1 0 INTRODUCTION

Leak path factors (LPFs) are calculated for various release locations in the K Basin facility Most of these LPFs were used in HNF-SD-WM-SNF-SAR-062, *K Basins Final Safety Analysis Report*, in calculating dose consequences An LPF represents the fraction of contaminant mass that is transported from one region to another region (usually the environment) under accident conditions One LPF is calculated for mass transport from the inside of the annular filter vessel enclosure to the transfer bay volume in the K Basin building (Section A 2) Other LPFs are calculated for various release locations in the K Basin building (superstructure) to the environment (Section A 3)

A2 0 LEAK PATH FACTOR FOR ANNULAR FILTER VESSEL ENCLOSURE

This LPF is appropriate for any accidental release internal to the shielding enclosure because the enclosure has 8-in concrete walls sandwiched with 2-in steel walls for shielding purposes for a total thickness of 12 in (see Section 2 0 for more details) The enclosure is not air tight, however, as the concrete was prefabricated and placed in sections However, there are steel plate covers/strips over each major construction joint, and the construction joints are jagged such that the small open path is not straight, but tortuous There are no major drivers for air movement into or out of the enclosure, the only mechanisms are the changing barometric pressure and building airflow Both of these mechanisms are minor because the barometric pressure is slowly changing and the airflow has no straight entrance into the enclosure

Only two kinds of releases have enough force to cause some leakage out of enclosure (1) spray releases and (2) hydrogen deflagrations For spray releases of water from a vessel pipe to the inside wall of the enclosure, the major driving force is the spray trajectory itself It is expected that no more than 10% of a very large spray hitting next to a cover plate would ever be released to the outside of the enclosure No spray releases of this type (very large water flow) were considered in Sections 4 0 and 5 0 In other words, the spray releases calculated in Sections 4 0 and 5 0 will have LPFs lower than 0 1, but the bounding value of 0 1 was used in the source term calculations for spray releases to be conservative

A hydrogen deflagration would also cause an increase in pressure in the filter vessel enclosure However, the very hot gas (2700 K), resulting from a stoichiometric hydrogen deflagration (Section 6 2) inside of the filter vessel, quickly cools within the filter vessel by radiation heat transfer (e g , see Section 7 2 2) and condensation of vapor onto the surface areas Due to the large inner annular ring, the filter vessel has a large surface area of about 10 3 m^2 (4 3 m^2 for outer wall, 2 4 m^2 for inner ring wall, 3 6 m^2 for top and bottom surfaces) surrounding its gas space and a gas volume of only 3 1 m^3 The high area/volume ratio of 3 3/m (10 3 m^2/3 1 m^3) is very favorable for rapid cooling of a hot gas and for condensation of water vapor

The hot gas, carrying respirable particles, is released through a small pinhole opening (i e , ~0 1 cm^2 opening area) for a couple of minutes after the hydrogen deflagration (Section 6 2) This slow release provides sufficient time for the hot gas in the filter vessel to cool down to much lower temperatures and for some condensation to take place The hot gas will cool very quickly (less than a half minute) from 2700 K to 600 K and much more slowly (about a minute) from 600 K to about 350 K when the release stops due to atmospheric pressure being reached in the filter vessel The average gas temperature in the filter vessel during this release is estimated to be less than 600 K (327 °C) The total volume of hot gas (~600 K) released is estimated by subtracting the filter vessel gas volume at 1 atm of pressure from the maximum pressure-volume product right after deflagration (pressure of 8 atm and temperature of 2700 K, Section 6 2) weighted by the cool down fraction (600 K/2700 K) In other words, the maximum volume of hot gas at 2700 K is about (8 atm)(3 1 m^3) = 24 8 m^3 at 1 atm Using the average temperature of 600 K, during the release, reduces this volume down to (600 K/2700 K) (24 8 m^3) = 5 5 m^3 at 1 atm and 600 K This is an increase of 2 4 m^3 over the original 3 1 m^3 (5 5 - 3 1 = 2 4) of gas volume in the filter vessel The total gas volume of the filter vessel enclosure is about 26 m^3 Hence, the fraction of volume increase in the shielding enclosure, which leaks out, is less than 0 1 (2 4 m^3/26 m^3), which is the fraction of gas released from the enclosure to the building

The fraction of respirable particles released from the enclosure to the building (i e , the LPF) is assumed to be the same as the fraction of gas released, which is less than 0 1 This means that more than 90% of the respirable particle mass remains in the enclosure and filter vessel, where settling can take place This analysis is conservative in the sense that no credit was taken for the cooling effect of the enclosure gas (initially 300 K), in reality, the cool enclosure gas will mix with the hot gas released from the filter vessel, cooling and reducing the released gas volume, and, thereby, reducing the LPF In summary, the bounding LPF value from the filter vessel enclosure to the building is 0 1 for the hydrogen deflagration accident (Section 6 2)

Another release mechanism occurs when the enclosure is filled with water and some of the water leaks around the cover plates and through the construction joints However, no accident scenario has such a release, which would not cause much of an airborne release of sludge anyway Scenarios related to this type of release would be a breach of the enclosure with water spilling out, dropping to the floor, and some sludge and water being resuspended into the air (fire design basis accident) Because the enclosure is breached for the fire design basis accident (HNF-SD-WM-SNF-SAR-062), the LPF for the enclosure is conservatively chosen to be one

In summary, the maximum LPF for the annular filter vessel enclosure is 0 10, which is appropriate for bounding spray releases and hydrogen deflagrations in filter vessels

A3 0 LEAK PATH FACTOR FOR K BASIN BUILDING

The FLUENT code[1], a commercial computational fluid dynamics code, was used to determine the LPFs for particle releases in the K West Basin building The FLUENT™ code software quality assurance at Hanford is described in Appendix D The FLUENT™ code calculated the airflow patterns inside of the building The airflow is caused by the air exhaust fans in the ceiling of the building bringing in fresh air from the outside through small crevices in the siding and small openings around the doors After a steady-state airflow field was calculated by FLUENT™ code, sludge particles of different sizes were introduced at release locations inside the building The FLUENT™ code simulated the movement of particles, driven by the air patterns calculated previously, by calculating the drag force on particles from flowing air and the gravitational force Since air can be turbulent flowing around corners and stopped by walls, etc , the FLUENT™ code can include airflow perturbations around a mean flow velocity when calculating particle trajectories The number of particles escaping through the air exhaust fans is divided by the total number of particles released to determine the LPF for that location of airborne release Since the FLUENT™ code employs a graphical user interface (GUI), the input and output files are not informative by themselves and they are lengthy Therefore, the input/output files are saved on the computer used to generate the output (see Appendix D) and are backed up on a floppy disk

A4 0 NUMERICAL MODEL

A two-dimensional (2D) numerical model was developed with the FLUENT™ code The grid is fine, and the entire 2D grid can be seen in Figure A-1 The entire length of the building is 57 9 m (190 ft), and the height is 10 7 m (35 ft) on the left side (transfer bay) and 4 6 m (15 ft) on the right side The transfer bay width is 12 2 m (40 ft) The 2D model actually has a width of 1 m, but the real building has a width of 27 4 m (90 ft) The 1 m dip at the center of the bottom boundary is the top part of the basin that consists of air The water in the basin below the air was not modeled The basin is 38 1 m (125 ft) wide There is one exhaust fan, which is 0 6 m (2 ft) wide, in the center of the high transfer bay ceiling as can be seen by the very fine grid around it in Figure A-1 There are four exhaust fans in the lower basin ceiling, each being 0 3 m (1 ft) wide To be conservative in promoting a more distributed uptake of air, four exhaust fans were used in the basin ceiling in the model even though only two are in the actual building Various airflow models were examined (1) lower building exhaust fans off, higher transfer bay exhaust fan on, (2) higher transfer bay exhaust fan off, lower building exhaust fans on, (3) left side of 2D model airtight, (4) right side of 2D model airtight The chosen 2D model, which has four distributed fans in the lower basin building and one large fan (representing two fans) in the high tranfer bay with infiltration on both sides, was the most representative and conservative for calculating leak path factors from two locations (one near the annular filter vessel enclosure, and the other above the basin water)

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[1]The FLUENT code was developed by and is a trademark of the Fluent Incorporated 10 Cavendish Court Centerra Resource Park Lebanon New Hampshire 03766 1442 telephone (603) 643 2600 fax (603) 643 3967

The grid details can be seen more clearly in Figures A-2 and A-3, which zoom in on the left and right sides of building, respectively The grid is very fine along the boundaries since particle behavior along the boundaries is very important To be conservative in keeping the particle moving, all boundaries are "reflective" boundaries for the particles, except for the basin water boundary which is a "trap" boundary A "trap" boundary will trap the particle and remove it from the simulation, whereas, a "reflective' boundary will bounce back any particle that hits it The exhaust fans are "escape" boundaries where the particles can escape from the domain, and the escaping particles determine the LPF The left and right sides of 2D model domain are "pressure-inlet" boundaries which allow air infiltration All doors are closed in the model, and infiltration is assumed to be uniform along the sides No internal structures, such as the annular filter vessel enclosure, are included in the 2D model domain, which is conservative in keeping the air and particles moving in straighter paths and not impeding the particles

The left and right sides of the building allow infiltration of air, and the mass stream lines of air are shown in Figure A-4 This figure clearly shows the main mass flow of air with the air infiltrating from the left side reaching the middle exhaust fan and the air infiltrating from the right side also reaching the middle exhaust fan These mass streams are idealistic just to show the major paths of air movement originating from the side boundaries The detailed vertical velocity contours, internal to the domain, are shown in Figure A-5, with the maximum air velocity contour cut down to 0 02 m/s near the exhaust fans in the graph so that more detailed contours are visible away from the exhaust fans This means that all vertical velocities in the blank circles under the exhaust fans are greater than 2 cm/s, which is more than enough to lift the particles upward towards the exhaust The effect of the five exhaust fans are clearly visible in Figure A-5 There are also some negative vertical velocities which are shown by the smaller size contours away from the exhaust fans by the left and right sides of the basin and by the corner between the transfer bay and the lower basin ceiling These negative velocities cause all particles to move downward when they get into this flow field The vertical velocity contours are negligible near the sides of building since the infiltrating air has mainly a horizontal velocity The standard k-ϵ turbulent flow model in the FLUENT™ code (see Appendix D) was used for this case

In the 2D model, the flow velocity at the high exhaust fan in the transfer bay is 0 7 m/s and the flow in each of the other four exhaust fans above the basin is 0 3 m/s These values were derived by scaling down the three-dimensional (3D) flow rates into equivalent velocities for a 2D model The normal volumetric flow rate of the basin exhaust fans, when operating, is approximately 1000 m^3/min (35,000 ft^3/min) To be conservative, a higher value of 1275 m^3/min (45,000 ft^3/min) was used in the derivation of 2D exhaust fan velocities The total volume of the 3D building is about 10350 m^3 (328,000 ft^3), which means that there is one volume exchange every 7 3 minutes if the exhaust fan volume rate is 1275 m^3/min (45,000 ft^3/min) The volume of the 2D model with unit width (1 m) is about 374 m^3, and the 2D exhaust fan volume rate is about 0 8 m^3/s (48 m^3/min) based on the velocities of 0 7 m/s and 0 3 m/s for the high and low exhaust fans Hence, the 2D model has one volume exchange of air every 7 8 minutes, which is slightly larger than the 3D volume exchange time of about 8 1 minutes In other words, the 2D model has a slightly more conservative (i e , faster) volume exchange rate than the real 3D building

Two release locations of particles were chosen for the particle tracking analysis The first location is above the water in the basin, about 2 5 cm below the basin floor level and about 24 m from the left side of the model domain, which places it about 6 3 m (~21 ft) from the left edge of the basin The second release location was about 4 2 m (~13 ft) from the left side of the model domain representing a location near the annular filter vessel enclosure Instead of releasing all of the particles at one point, their release locations were represented by a line, which was about 0 5 m long and passing through the release points listed above

A total of 500 particles was released from each location in each particle tracking simulation for each size of particle Three different diameter sizes of particles were used, 4 4 μm, 1 μm, and 0 44 μm The largest particle size (4 4 μm) represents all of the large respirable particles which have a maximum 10 μm aerodynamic equivalent diameter (AED) (DOE-HDBK-3010-94) Several simulations were performed for each particle size for each location since the particle tracking is stochastic in regards to varying air velocities around a mean value The LPF for each simulation is calculated by dividing the number of particles escaping the building through the exhaust fans by the total number of particles simulated (500) With multiple LPFs calculated for each size, the LPFs are averaged to obtain a single value The spread of the LPF values is small (<10%) for each size of particle The averaged LPFs calculated by FLUENT™ code are summarized in Table A-1 for each size particle and location

Table A-1 Leak Path Factors for Different Locations and Sizes of Particles

Particle Diameter (μm)	Release Location Description	Leak Path Factor
0 44	Above basin	0 68
1 0	Above basin	0 66
4 4	Above basin	0 38
0 44	Near filter vessel enclosure	0 63
1	Near filter vessel enclosure	0 62
4 4	Near filter vessel enclosure	0 43

The LPF is higher for smaller particles, as expected, except that there is not much difference between the 0 44 and 1 μm diameter particles In order to obtain an overall LPF for each release location, the three LPFs for each location need to be combined The particle mass size distribution is needed for this and was obtained from SNF-4267, *Consequence Analysis of IWTS Metal–Water Reactions (Fauske & Associates Report 99-35)* which states that one third of the sludge mass is less than 1 μm and two thirds of the sludge mass are larger This fact was implemented by giving the smallest diameter particle's LPF was given a one sixth weighting factor, the 1 μm diameter particle's LPF was given a one sixth weighting factor, and the 4 4 μm diameter particle was given a two thirds weighting factor since it represents all of the larger particles In addition, the particles are released from underneath the basin water from a knockout pot for the rapid oxidation of fuel fines scenario (HNF-SD-WM-SNF-SAR-062) Hence, a decontamination factor due to the liquid water effects was applied to the particles (SNF-4267) The decontamination multiplier, representing the fraction of sludge getting through the water to air, was 0 33 for 1 µm and smaller diameter particles and 0 01 for particles larger than 1 µm Hence, the effective mass distribution of particles (only 0 12 of original knockout pot mass release) reaching the air above the basin is 0 47 for each of the 0 44 and 1 µm diameter size particles, and only about 0 06 for the 4 4 µm diameter particles In other words, only 6% of the particle mass reaching the air (including effects of water decontamination) are now larger than 1 µm, whereas for the release from the knockout pot, 67% of the particle was larger than 1 µm

The details of the airborne mass fraction calculations are summarized in Table A-2 Combining the new airborne mass fractions with the LPFs in Table A-1 for the release above the basin produces a composite LPF of 0 65 If the particles are initially released above the basin, the original mass distribution applies (see Table A-2), and the composite LPF for this release is 0 48 For the release near the filter vessel enclosure the original mass distribution applies, and the composite LPF of this location of release is about 0 50

Table A-2 Intermediate Numbers Used to Calculate LPFs From Inside Building to Environment

Particle Diameter (µm)	Initial Mass Size Fractions	Water Decontamination Factor (Through Fraction)*	Airborne Mass Size Fractions	Airborne Mass Size Fraction Divided by Total Airborne Mass Fraction
Mass Release Above Basin With Water Decontamination Included				
0 44	0 167	0 333	0 056	0 472
1 0	0 167	0 333	0 056	0 472
4 4	0 667	0 01	0 0067	0 057
Total Sum	1 0		0 118	1 0
Mass Release Above Basin With No Water Decontamination, or Near Annular Filter Vessel				
0 44	0 167	1 0	0 167	0 167
1 0	0 167	1 0	0 167	0 167
4 4	0 667	1 0	0 667	0 667
Total Sum	1 0		1 0	1 0

*Through fraction is the fraction of mass that does not get removed by decontamination no decontamination implies a value of 1 0 Values originated in SNF 4267 *Consequence Analysis of IWTS Metal–Water Reactions (Fauske & Associates Report 99-35)*

In summary, the composite (i e , for all particle sizes) LPFs for two location of releases using the mass size distribution defined in SNF-4267 is 0 65 for the release location just above the basin and 0 50 for the release location near the annular filter vessel enclosure These are shown in Table A-3

Table A-3 Composite Leak Path Factors for Two Release Locations of Sludge

Location of Release	Composite Leak Protection Factor
Above basin water after water decontamination	0 65
Above basin water with no water decontamination	0 48
Near annular filter vessel enclosure	0 50

A5 0 REFERENCES

DOE-HDBK-3010-94, Volume I, Mishima, J , 1994, *Airborne Release Fractions/Rates and Respirable Fractions for Nonreactor Nuclear Facilities*, U S Department of Energy, Washington, D C

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SNF-4267, 1999, *Consequence Analysis of IWTS Metal–Water Reactions (Fauske & Associates Report 99-35)*, Rev 0, Fluor Daniel Hanford, Inc , Richland, Washington

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Figure A-1 Grid of Entire Two-Dimensional Model Domain of K Basin Building

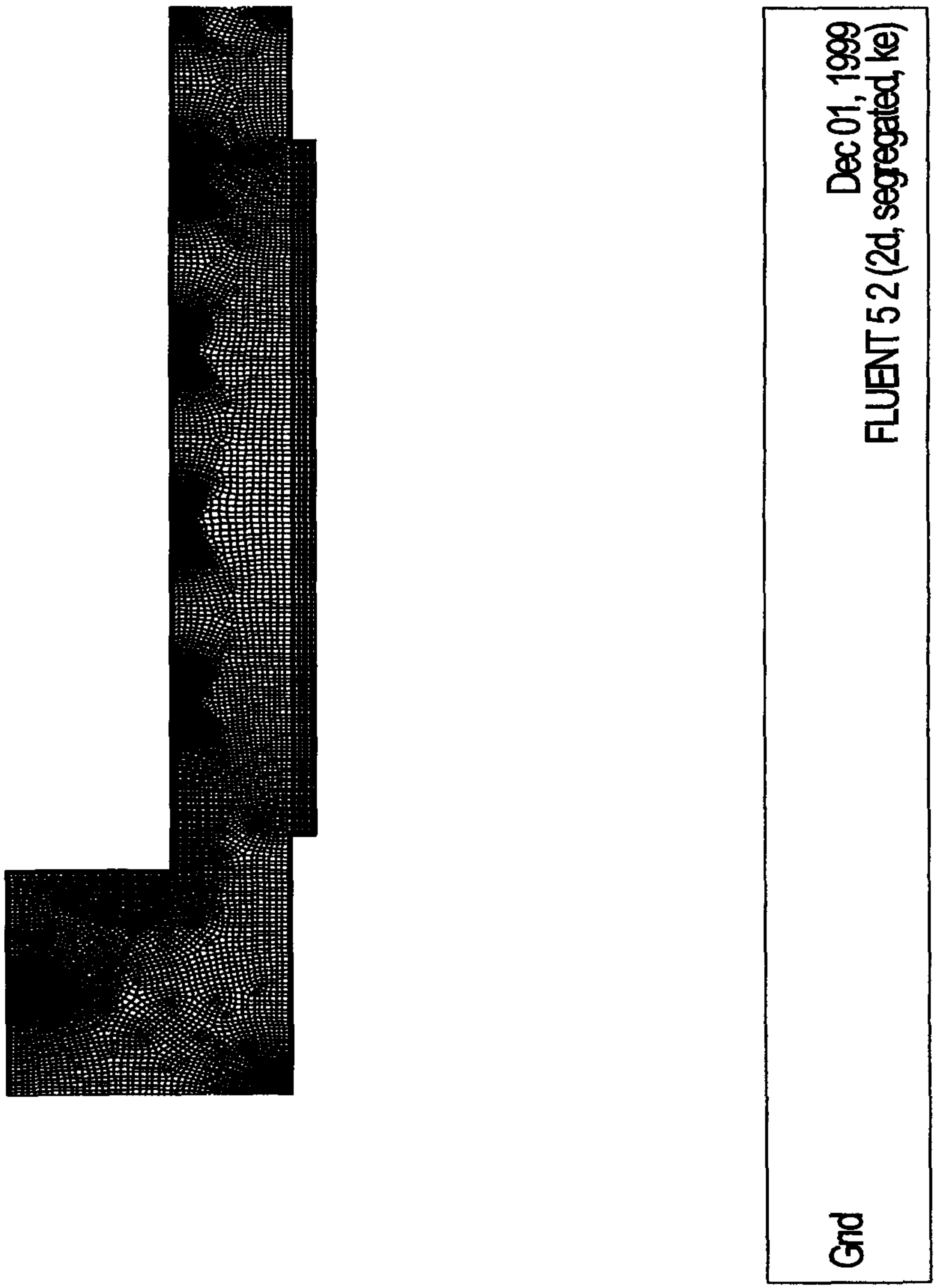


Figure A-2 Grid of Left Most Part of Two-Dimensional Model Domain

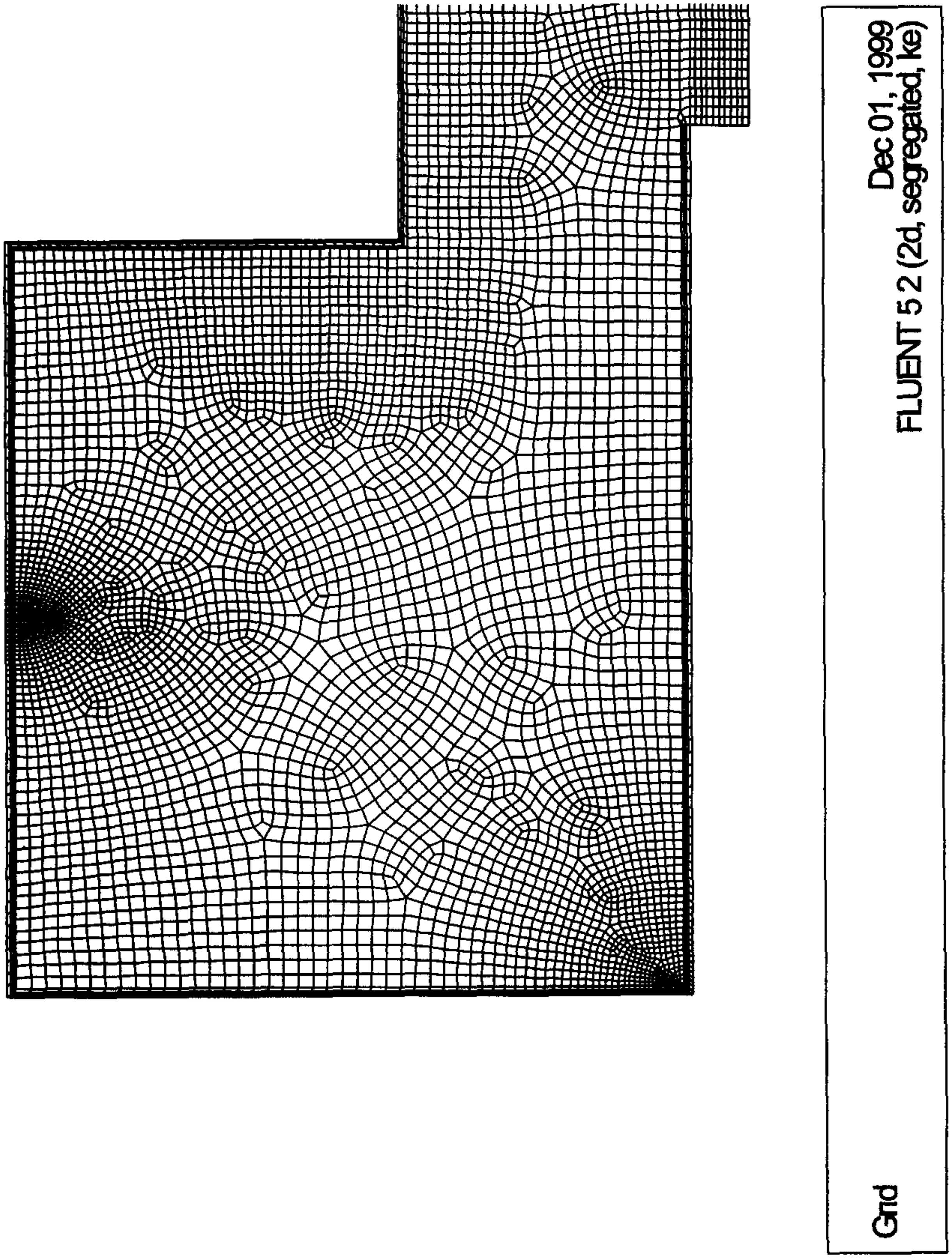


Figure A-3 Grid of Right Most Part of Two-Dimensional Model Domain

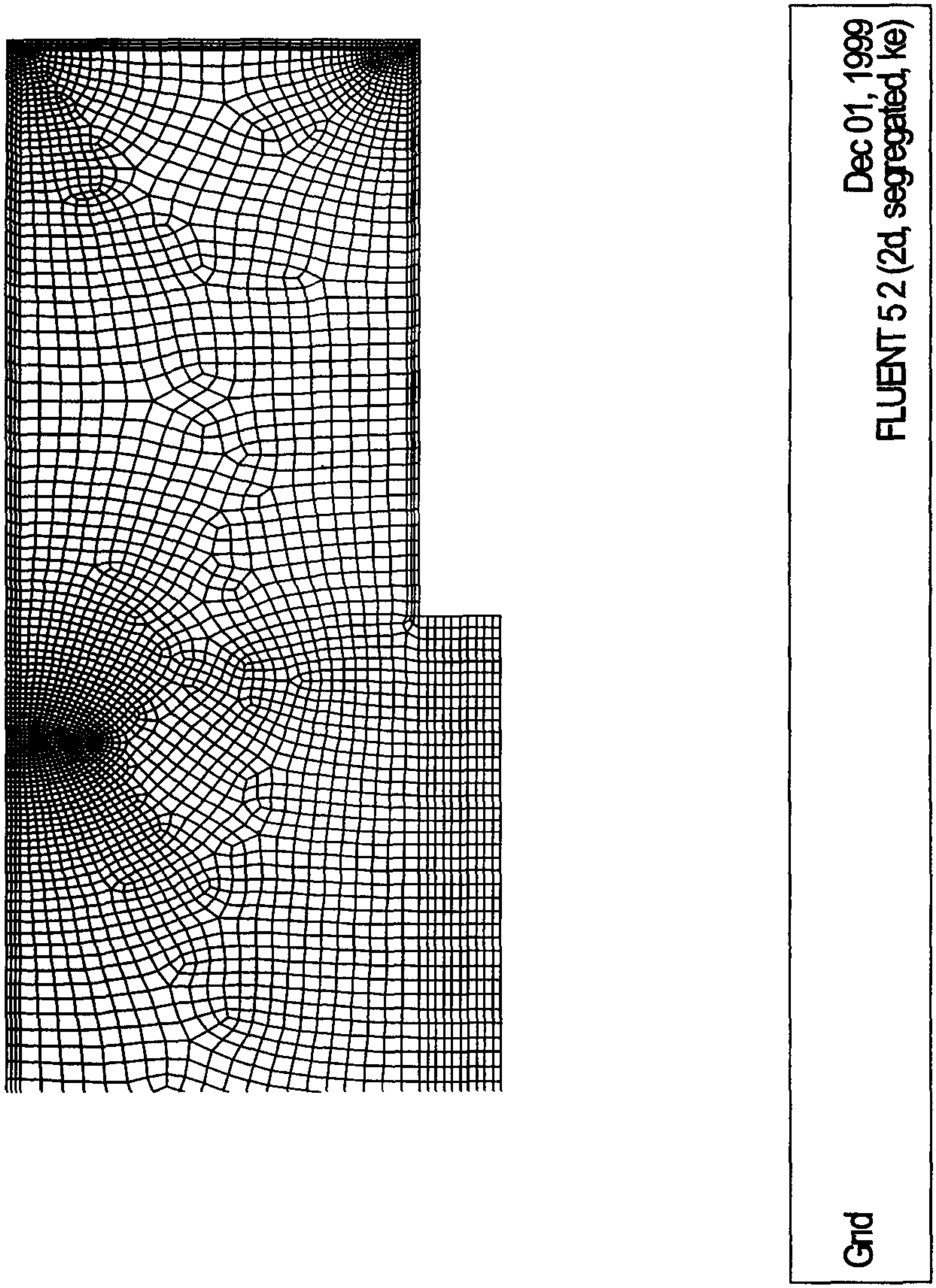


Figure A-4 Air Streamlines Entering Vertical Sides and Exiting Ceiling Exhaust Fans

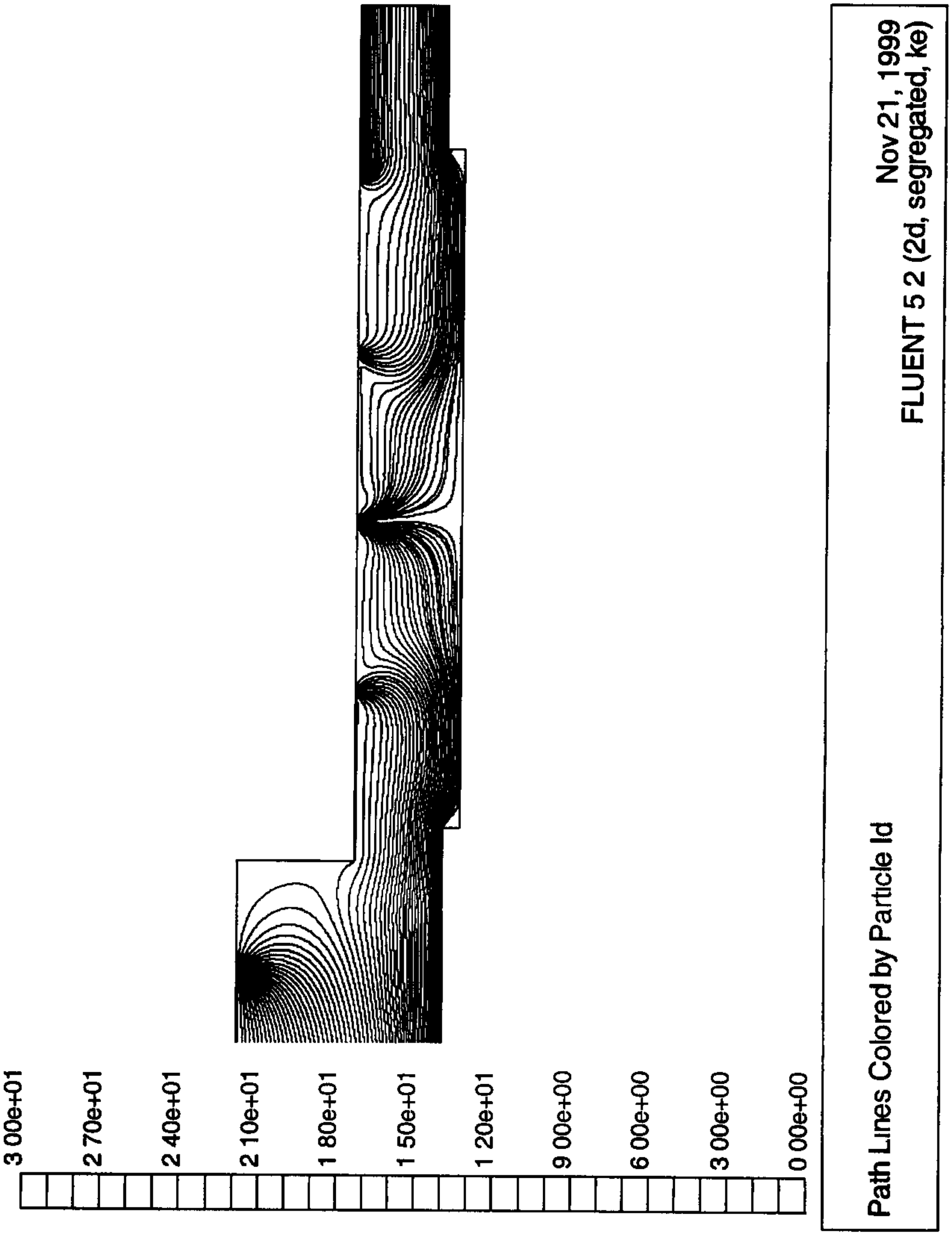
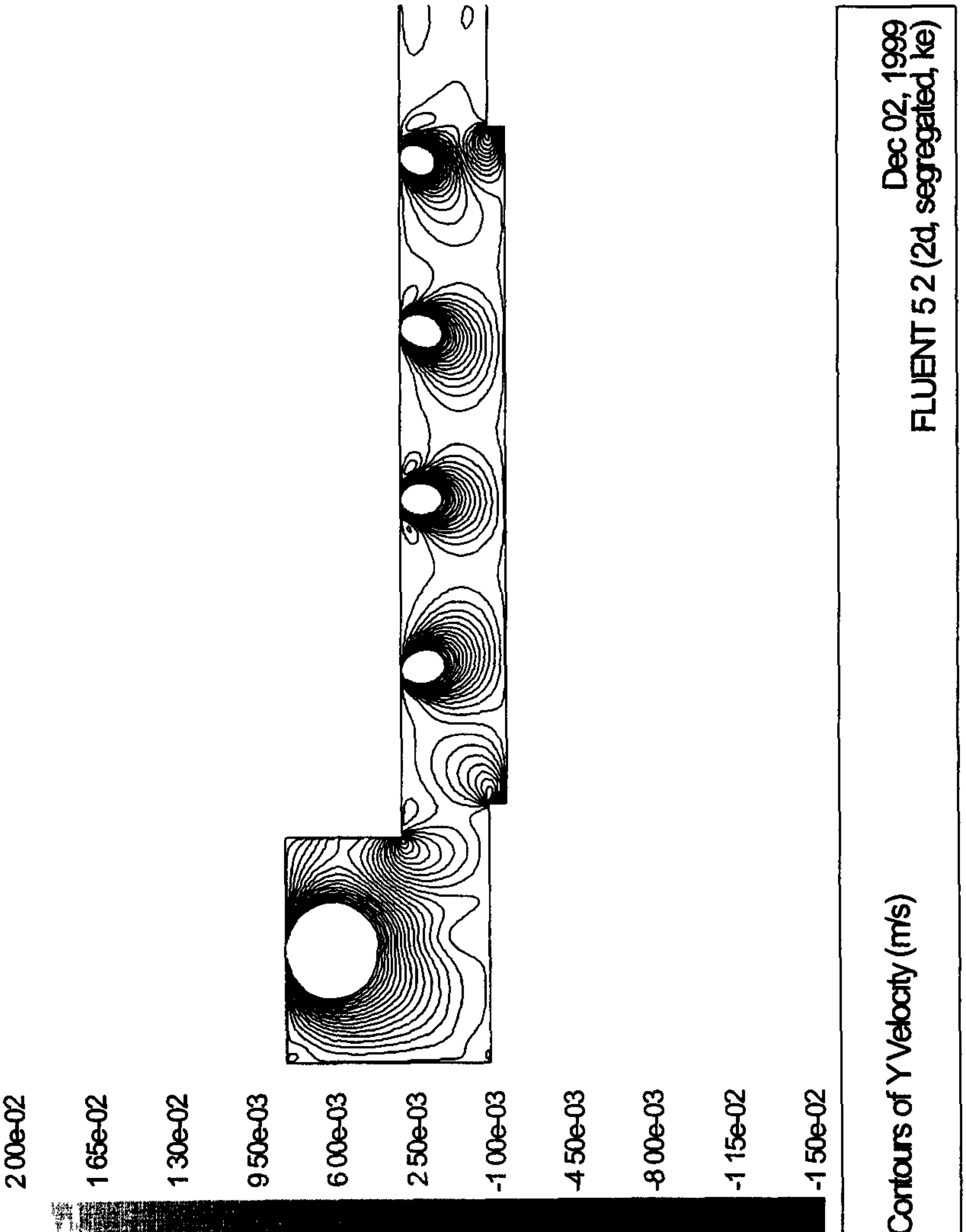


Figure A-5 Vertical Velocity Contours in K Basin Building



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APPENDIX B

RELATIVE AMOUNTS OF CESIUM-137 AND TRANSURANIC

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RELATIVE AMOUNTS OF CESIUM-137 AND TRANSURANIC

The main indication of the amount of K Basin fuel in a given process component is the photon dose rate, measured with hand-held survey instruments Essentially all of this dose rate comes from one isotope, cesium-137 (Cs-137) (as well as its short-half-life progeny, barium-137m)

The primary radiological concern for accidental emissions is the transuranic (TRU) portion of the fuel Essentially all of the inhalation dose comes from four isotopes plutonium-238, plutonium-239, plutonium-240, and americium-241 Because limits on the amount of fuel in a process component are often based on the inhalation dose, while measurements of adherence to those limits is based on measurements of photon dose rate, it is important to evaluate the relative amounts of Cs-137 and TRU in the various K Basin fuel and sludge compositions

Tables B-1 and B-2 show the Cs-137 and TRU inventories (from HNF-SD-SNF-TI-009) together with ratios of the amount of Cs-137 to the amount of TRU The larger the ratio, the more readily a given amount of TRU can be detected with hand-held instruments Also shown is the unit dose from inhalation of one gram of the material The unit doses were computed using the same method presented in HNF-SD-SNF-TI-059, *A Discussion on the Methodology for Calculating Radiological and Toxicological Consequences for the Spent Nuclear Fuel Project at the Hanford Site*

Table B-1 shows the Cs-137-to-TRU ratios and unit doses for fuel The standard composition used in most safety analysis work is the bounding safety-basis fuel For this mixture, the Cs-137-to-TRU ratio is 11 0 When this mixture is aged 40 years, the ratio decreases to 4 0 because the Cs-137 has a 30-year half life while the TRU half life is thousands of years The ratio decreases because the Cs-137 decays away The other fuel mixtures listed in HNF-SD-SNF-TI-009, *105-K Basin Material Design Basis Feed Description for Spent Nuclear Fuel Project Facilities,* all have larger ratios Compared with safety-basis fuel, the Cs-137 in aged fuel has decreased by a factor of 11/4 = 2 75

Table B-2 shows the Cs-137-to-TRU ratios and unit doses for K Basin sludges The smallest ratio is for the north loadout pit, 2 2 Compared with safety-basis fuel, the Cs-137 in north loadout pit sludge has decreased by a factor of 11/2 2 = 5 Note that the unit dose for the north loadout pit sludge is lower than safety-basis fuel by a factor of 4,380/75 4 = 58 Therefore, the sludge has a lower unit dose even though it would be harder to detect

A suitable bound on the potential decrease in Cs-137 is 10, since the largest observed decrease is 5

Table B-1 Relative Amounts of Cesium-137 and Transuranic in Spent Nuclear Fuels [a]

	Table 2 2, SPR Fuel (Ci)	Table 3 6, K East Basin (Ci)	Table 3 7, K West Basin (Ci)	Table 2 4 Average Fuel (Ci/MTU)	Table 3 8 Shield Fuel (Ci/MTU)	Table 2 6 Safety Fuel (Ci/MTU)	Table 3 10, Safety after 40 yr (Ci/MTU)
Cs 137	32,500	6 55E+06	6 64E+06	6 290	11 300	9 660	4 190
Pu-238	142	6 05E+04	5 10E+04	52 8	128	133	104
Pu 239	406	1 16E+05	1 01E+05	104	168	173	175
Pu-240	642	6 37E+04	5 53E+04	56 7	128	137	141
Am-241	1 520	2 06E+05	1 69E+05	179	292	434	617
Total TRU[b]	2,710	4 46E+05	3 76E+05	392 5	716	877	1037
Ratio[c]	12 0	14 7	17 6	16 0	15 8	11 0	4 0
UD[d] Sv/g	2 120	1 950	2 000	1 970	3 890	4 380	4 620

Fuel inventories and concentrations are from HNF SD SNF TI 009 1998 *105 K Basin Material Design Basis Feed Description for Spent Nuclear Fuel Project Facilities* Volume 1 Fuel Fluor Daniel Hanford Incorporated Richland Washington Table numbers refer to tables in HNF SD SNF TI 009 Volume 1

[b] Total TRU is the sum of the Pu 238 Pu 239 Pu 240 and Am 241 inventories Other TRU isotopes contribute insignificant amounts of dose compared to the chosen four

[c] Ratio is the Cs 137 amount divided by the TRU amount Low values mean the mixture is more difficult to detect

[d] UD is the unit dose (inhalation EDE) computed using the method shown in HNF SD SNF TI 059 *A Discussion on the Methodology for Calculating Radiological and Toxicological Consequences for the Spent Nuclear Fuel Project at the Hanford Site* Rev 2 Fluor Daniel Hanford Incorporated Richland Washington

Am = americium
Pu = plutonium
TRU = transuranic
UD = unit dose

Table B-2 Relative Amounts of Cesium-137 and Transuranic in Sludge [a]

Nominal Inventory for K East Basin Sludges (µCi/g)							
	Weasel Pit	Main Basin Floor	North Loadout Pit	Canisters	Generated by Fuel Washing		
					Internal	Coating	Fuel Pieces
Cs-137	293 54	310 24	37 84	806 35	3 443 33	1 410 0	5,342 20
Pu 239+	5 37	19 88	10 05	108 70	232 67	114 5	195 91
Am-241	8 17	28 11	7 27	138 34	210 50	93 4	168 01
Total TRU[b]	13 54	47 99	17 32	247 04	443 17	207 9	363 92
Ratio[c]	21 7	6 5	2 2	3 3	7 8	6 8	14 7
UD[d] Sv/g	60 0	211	75 4	1 080	1 940	912	1 600
Nominal Inventory for K West Basin Sludges (µCi/g)							
	Weasel Pit	Main Basin Floor	North Loadout Pit	Canisters	Generated by Fuel Washing		
					Internal	Coating	Fuel Pieces
Cs-137	293 54	310 24	37 84	1 898 75	2 210	57 70	6 505 54
Pu-239+	5 37	19 88	10 05	175 03	184	4 62	203 12
Am-241	8 17	28 11	7 27	136 66	148	4 38	165 58
Total TRU[b]	13 54	47 99	17 32	311 69	332	9 00	368 70
Ratio[a]	21 7	6 5	2 2	6 1	6 7	6 4	17 6
UD[d] Sv/g	60 0	211	75 4	1 370	1 450	39 5	1 620

Fuel inventories and concentrations are from HNF SD SNF TI 009 1998 *105 K Basin Material Design Basis Feed Description for Spent Nuclear Fuel Project Facilities* Volume 1 Fuel Fluor Daniel Hanford Incorporated Richland Washington Table numbers refer to tables in HNF SD SNF TI 009 Volume 1

[b] Total TRU is the sum of the Pu 238 Pu 239 Pu 240 and Am 241 inventories Other TRU isotopes contribute insignificant amounts of dose compared to the chosen four

Ratio is the Cs 137 amount divided by the TRU amount Low values mean the mixture is more difficult to detect

[d] UD is the unit dose (inhalation EDE) computed using the method shown in HNF SD SNF TI 059 *A Discussion on the Methodology for Calculating Radiological and Toxicological Consequences for the Spent Nuclear Fuel Project at the Hanford Site* Rev 2 Fluor Daniel Hanford Incorporated Richland Washington

Am = americium
Pu = plutonium
TRU = transuranic
UD = unit dose

REFERENCES

HNF-SD-SNF-TI-009, 1998, *105-K Basin Material Design Basis Feed Description for Spent Nuclear Fuel Project Facilities* Volume 1, 'Fuel " Fluor Daniel Hanford, Incorporated, Richland, Washington

HNF-SD-SNF-TI-059, *A Discussion on the Methodology for Calculating Radiological and Toxicological Consequences for the Spent Nuclear Fuel Project at the Hanford Site*, Rev 2, Fluor Daniel Hanford, Incorporated, Richland, Washington

APPENDIX C

SPRAY AND ISO-PC PROGRAM OUTPUT FILES

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SPRAY PROGRAM OUTPUT FILES

SPRAY output file for stream 9 calculations.

```
                    SPRAY Version 3 0
                      May 3  1994

Spray Leak Code
Produced by Radiological & Toxicological Analysis
Westinghouse Hanford Company


Run Date = 09/16/99/
Run Time = 14 16 41 69


INPUT ECHO
c IWTS Spray Leak    Stream 9 with 100 µm Limit
c
c mode iflow iopt
   1    0     T
c
c MODEL OPTIONS
c mode = 1 orifice leak with friction assumed
c        2 slit leak with friction assumed
c iflow= 0 Reynold s number determines friction relation (laminar or turb )
c        1 friction based on laminar relation
c        2 friction based on turbulent relation
c iopt = T optimal diameter search performed
c        F search not performed
c
c PARAMETER INPUT
c
c  Slit Width or                  Depth of
c  Orifice Diam   Slit Length     Slit/Orifice
c  (inch)         (inch)          (inch)
c
   5 00000E 03    1 00000E 03     2 37000E 01
c
c                 Abs  Surface    Contraction     Velocity
c                 Roughness in    Coefficient     Coefficient
c  Pressure       0 00006 tube    0 61    and     0 98  sharp edge orifice
c  Difference     0 0018  steel   1 00    and     0 98  rounded orifice
c  (psi)          0 0102  iron    1 00    and     0 82  square edge orifice
c
   1 50000E+02    1 80000E 03     6 10000E 01     9 80000E 01
c
```

```
c   Fluid Specific Gravity is based on 44 kg of SNF (20 65 L)
c      suspended in 1 742 000 L of solution
c   Respirable Diameter is limited to 100 µm because larger particles will
c      deposite on surfaces before evaporating
c
c   Fluid          Dynamic        Respirable     RR Fitting
c   Specific       Viscosity      Diameter       Constant
c   Gravity        (centi poise)  (µm)           (q)
c
    1 00004E+00    1 00000E+00    1 00000E+02    2 40000E+00


MESSAGES
Orifice Model
Code search for optimal equivalent diameter


OUTPUT
     Liquid Velocity =  1 21E+02 ft/s      3 69E+01 m/s
     Reynolds Number =  3 33E+04 Turbulent Flow
Sauter Mean Diameter =  1 91E+02 µm
    Optimum Diameter =  3 56E 02 in        9 04E 04 m
 Respirable Fraction =  7 40E 02
     Total Leak Rate =  2 29E 01 gpm       1 44E 05 m3/s      1 44E+01 g/s
Respirable Leak Rate =  1 69E 02 gpm       1 07E 06 m3/s      1 07E+00 g/s
```

SPRAY output file for stream 10 (backflush) calculatıons.

```
                         SPRAY Versıon 3 0
                           May 3  1994

Spray Leak Code
Produced by Radıologıcal & Toxıcologıcal Analysıs
Westınghouse Hanford Company


Run Date = 09/16/99/
Run Tıme = 14 16 41 91


INPUT ECHO
c IWTS Spray Leak    Stream 10 (Backflush)
c
c mode ıflow ıopt
   1    0     T
c
c MODEL OPTIONS
c mode = 1 orıfıce leak wıth frıctıon assumed
c        2 slıt leak wıth frıctıon assumed
c ıflow= 0 Reynold s number determınes frıctıon relatıon (lamınar or turb )
c        1 frıctıon based on lamınar relatıon
c        2 frıctıon based on turbulent relatıon
c ıopt  = T optımal dıameter search performed
c        F search not performed
c
c PARAMETER INPUT
c
c   Slıt Wıdth or                  Depth of
c   Orıfıce Dıam   Slıt Length     Slıt/Orıfıce
c   (ınch)         (ınch)          (ınch)
c
    5 00000E 03    1 00000E 03     1 54000E 01
c
c                  Abs  Surface    Contractıon    Velocıty
c                  Roughness ın    Coeffıcıent    Coeffıcıent
c   Pressure       0 00006 tube    0 61    and    0 98  sharp edge orıfıce
c   Dıfference     0 0018  steel   1 00    and    0 98  rounded orıfıce
c   (psı)          0 0102  ıron    1 00    and    0 82  square edge orıfıce
c
    6 00000E+01    1 80000E 03     6 10000E 01    9 80000E 01
c
```

```
c   Fluid Specific Gravity is based on 1 290 kg (420 L) of sludge
c      suspended in 34 100 L of solution
c   Respirable Diameter is computed from (5 68 µm)[34 100/420]^(1/3)
c      which is the density adjusted formula
c
c   Fluid           Dynamic         Respirable      RR Fitting
c   Specific        Viscosity       Diameter        Constant
c   Gravity         (centi poise)   (µm)            (q)
c
    1 02590E+00     1 00000E+00     2 46000E+01     2 40000E+00
```

```
MESSAGES
Orifice Model
Code search for optimal equivalent diameter
```

```
OUTPUT
     Liquid Velocity =  7 41E+01 ft/s      2 26E+01 m/s
     Reynolds Number =  1 46E+04 Turbulent Flow
Sauter Mean Diameter =  2 01E+02 µm
    Optimum Diameter =  2 48E 02 in        6 31E 04 m
 Respirable Fraction =  2 34E 03
     Total Leak Rate =  6 83E 02 gpm       4 31E 06 m3/s       4 42E+00 g/s
Respirable Leak Rate =  1 60E 04 gpm       1 01E 08 m3/s       1 04E 02 g/s
```

ISO-PC OUTPUT FOR THE ANNULAR FILTER VESSEL

The filter media density was calculated to be the density of sand (1 5 kg/L) plus the mass of the sludge (300 kg or 430 kg) distributed over the volume of the filter media (1,380 L) The sludge is modeled as being 50% sand and 50% iron Note that Version 2 1 was also used to check the calculations The two versions agree within 5% for these inputs

```
 Start run at  10 40 18  12/14/99
 ____________________________________________
|                                            |
|  ISOSHLD PC     (RIBD removed)             |
|  Version 1 6    December 1989              |
|  for IBM & Compatible Personal Computers   |
|  Nuclear Safety & Radiological Analysis    |
|  Westinghouse Hanford Company              |
|  Richland  WA  99352                       |
|____________________________________________|


   K Basin Annular Filter Tank (1 Ci Cs 137)


Table of Source Activity

        Scale Factor = 1 000E+00

     Isotope    Initial     Final
      Name      Values      Curies

     CS 137     1 00E+00   1 000E+00
     BA 137M    9 46E 01   9 460E 01


  Shield Composition    g/cc

          Shield 1   Shield 2   Shield 3   Shield 4   Shield 5

AIR       1 200E 03  0 000E+00  0 000E+00
ORDCONC   0 000E+00  1 666E+00  0 000E+00
IRON      0 000E+00  1 670E 01  7 860E+00

Group        Linear Attenuation Coefficients   (last region is air)
```

1	4 106E 03	4 325E+01	3 471E+02	4 424E 03	0 000E+00	0 000E+00
2	6 072E 04	7 891E+00	9 650E+01	6 542E 04	0 000E+00	0 000E+00
3	3 252E 04	2 573E+00	4 468E+01	3 504E 04	0 000E+00	0 000E+00
4	2 520E 04	1 564E+00	2 071E+01	2 715E 04	0 000E+00	0 000E+00
5	2 232E 04	9 669E 01	1 144E+01	2 405E 04	0 000E+00	0 000E+00
6	2 086E 04	7 144E 01	7 632E+00	2 247E 04	0 000E+00	0 000E+00
7	1 984E 04	5 661E 01	5 447E+00	2 137E 04	0 000E+00	0 000E+00
8	1 902E 04	4 637E 01	3 948E+00	2 049E 04	0 000E+00	0 000E+00
9	1 842E 04	4 075E 01	3 135E+00	1 985E 04	0 000E+00	0 000E+00
10	1 601E 04	3 306E 01	1 603E+00	1 725E 04	0 000E+00	0 000E+00
11	1 368E 04	2 361E 01	1 077E+00	1 474E 04	0 000E+00	0 000E+00
12	1 218E 04	1 816E 01	7 844E 01	1 312E 04	0 000E+00	0 000E+00
13	1 098E 04	1 629E 01	6 877E 01	1 183E 04	0 000E+00	0 000E+00
14	1 038E 04	1 553E 01	5 659E 01	1 118E 04	0 000E+00	0 000E+00
15	8 340E 05	1 356E 01	5 007E 01	8 986E 05	0 000E+00	0 000E+00
16	7 620E 05	1 159E 01	4 622E 01	8 210E 05	0 000E+00	0 000E+00
17	6 876E 05	1 102E 01	4 032E 01	7 408E 05	0 000E+00	0 000E+00
18	6 180E 05	9 948E 02	3 694E 01	6 658E 05	0 000E+00	0 000E+00
19	5 736E 05	9 408E 02	3 506E 01	6 180E 05	0 000E+00	0 000E+00
20	5 400E 05	8 357E 02	3 262E 01	5 818E 05	0 000E+00	0 000E+00
21	5 100E 05	8 002E 02	3 160E 01	5 495E 05	0 000E+00	0 000E+00
22	4 884E 05	7 800E 02	2 995E 01	5 262E 05	0 000E+00	0 000E+00
23	4 644E 05	7 462E 02	2 971E 01	5 004E 05	0 000E+00	0 000E+00
24	4 440E 05	7 192E 02	2 877E 01	4 784E 05	0 000E+00	0 000E+00
25	4 068E 05	6 640E 02	2 790E 01	4 383E 05	0 000E+00	0 000E+00

KW Density 12 to the side

Source Shields Distance to Detector X = 1 219E+02 cm
Annular Cyl & Slab Volume = 1 382E+06 cc
Source Length = 7 620E+01 cm Distance Along Cylinder Y = 3 810E+01 cm
Integration Specs NTHETA = 33 NPSI = 25 DELR = 2 030E+00 cm
Total Intervals 1 650E+04

Shield Thickness cm 5 070E+01 4 060E+01 1 000E 01
Taylor Buildup Data for Shield 2 with Effective Atomic Number 10 5

Group	Average Energy Mev	Bremsstr photons/sec	Source Total photons/sec	Energy Flux Mev/sq cm/sec	Dose Rate R/hr
1	1 500E 02	1 438E+08	1 438E+08	4 442E 15	3 656E 19
2	2 500E 02	9 135E+07	9 135E+07	3 523E 04	6 095E 09
3	3 500E 02	4 785E+07	2 596E+09	1 257E+00	7 982E 06
4	4 500E 02	2 887E+07	2 887E+07	1 610E 01	5 282E 07
5	5 500E 02	2 176E+07	2 176E+07	4 689E 01	1 074E 06
6	6 500E 02	1 494E+07	1 494E+07	6 493E 01	1 228E 06
7	7 500E 02	1 168E+07	1 168E+07	8 329E 01	1 428E 06

8	8 500E 02	8 411E+06	8 411E+06	9 400E 01	1 520E 06
9	9 500E 02	6 434E+06	6 434E+06	9 828E 01	1 575E 06
10	1 500E 01	2 169E+07	2 169E+07	3 755E+00	6 489E 06
11	2 500E 01	4 571E+06	4 571E+06	1 868E+00	3 661E 06
12	3 500E 01	1 254E+06	1 254E+06	9 268E 01	1 909E 06
13	4 750E 01	5 613E+05	5 613E+05	6 238E 01	1 273E 06
14	6 500E 01	1 831E+05	3 149E+10	4 483E+04	9 326E 02
15	8 250E 01	2 623E+04	2 623E+04	4 599E 02	9 197E 08
16	1 000E+00	2 898E+03	2 898E+03	6 781E 03	1 309E 08
17	1 225E+00	0 000E+00	0 000E+00	0 000E+00	0 000E+00
18	1 475E+00	0 000E+00	0 000E+00	0 000E+00	0 000E+00
19	1 700E+00	0 000E+00	0 000E+00	0 000E+00	0 000E+00
20	1 900E+00	0 000E+00	0 000E+00	0 000E+00	0 000E+00
21	2 100E+00	0 000E+00	0 000E+00	0 000E+00	0 000E+00
22	2 300E+00	0 000E+00	0 000E+00	0 000E+00	0 000E+00
23	2 500E+00	0 000E+00	0 000E+00	0 000E+00	0 000E+00
24	2 700E+00	0 000E+00	0 000E+00	0 000E+00	0 000E+00
25	3 000E+00	0 000E+00	0 000E+00	0 000E+00	0 000E+00
TOTALS		4 034E+08	3 445E+10	4 485E+04	9 328E 02

Note that 9 328E 02 R/hr = 6 686E 09 amp/kg

Table of Source Activity

Scale Factor = 1 000E+00

Isotope Name	Initial Values	Final Curies
CS 137	1 00E+00	1 000E+00
BA 137M	9 46E 01	9 460E 01

Shield Composition g/cc

	Shield 1	Shield 2	Shield 3	Shield 4	Shield 5
AIR	1 200E 03	0 000E+00	0 000E+00		
ORDCONC	0 000E+00	1 619E+00	0 000E+00		
IRON	0 000E+00	1 200E 01	7 860E+00		

Group Linear Attenuation Coefficients (last region is air)

1	4 106E 03	4 016E+01	3 471E+02	4 424E 03	0 000E+00	0 000E+00
2	6 072E 04	7 149E+00	9 650E+01	6 542E 04	0 000E+00	0 000E+00
3	3 252E 04	2 260E+00	4 468E+01	3 504E 04	0 000E+00	0 000E+00
4	2 520E 04	1 409E+00	2 071E+01	2 715E 04	0 000E+00	0 000E+00
5	2 232E 04	8 781E 01	1 144E+01	2 405E 04	0 000E+00	0 000E+00
6	2 086E 04	6 532E 01	7 632E+00	2 247E 04	0 000E+00	0 000E+00
7	1 984E 04	5 208E 01	5 447E+00	2 137E 04	0 000E+00	0 000E+00

8	1 902E 04	4 294E 01	3 948E+00	2 049E 04	0 000E+00	0 000E+00
9	1 842E 04	3 791E 01	3 135E+00	1 985E 04	0 000E+00	0 000E+00
10	1 601E 04	3 127E 01	1 603E+00	1 725E 04	0 000E+00	0 000E+00
11	1 368E 04	2 237E 01	1 077E+00	1 474E 04	0 000E+00	0 000E+00
12	1 218E 04	1 723E 01	7 844E 01	1 312E 04	0 000E+00	0 000E+00
13	1 098E 04	1 546E 01	6 877E 01	1 183E 04	0 000E+00	0 000E+00
14	1 038E 04	1 479E 01	5 659E 01	1 118E 04	0 000E+00	0 000E+00
15	8 340E 05	1 291E 01	5 007E 01	8 986E 05	0 000E+00	0 000E+00
16	7 620E 05	1 102E 01	4 622E 01	8 210E 05	0 000E+00	0 000E+00
17	6 876E 05	1 049E 01	4 032E 01	7 408E 05	0 000E+00	0 000E+00
18	6 180E 05	9 468E 02	3 694E 01	6 658E 05	0 000E+00	0 000E+00
19	5 736E 05	8 954E 02	3 506E 01	6 180E 05	0 000E+00	0 000E+00
20	5 400E 05	7 945E 02	3 262E 01	5 818E 05	0 000E+00	0 000E+00
21	5 100E 05	7 606E 02	3 160E 01	5 495E 05	0 000E+00	0 000E+00
22	4 884E 05	7 419E 02	2 995E 01	5 262E 05	0 000E+00	0 000E+00
23	4 644E 05	7 092E 02	2 971E 01	5 004E 05	0 000E+00	0 000E+00
24	4 440E 05	6 834E 02	2 877E 01	4 784E 05	0 000E+00	0 000E+00
25	4 068E 05	6 303E 02	2 790E 01	4 383E 05	0 000E+00	0 000E+00

KE Density 12 to the side

Source Shields Distance to Detector X = 1 219E+02 cm
Annular Cyl & Slab Volume = 1 382E+06 cc
Source Length = 7 620E+01 cm Distance Along Cylinder Y = 3 810E+01 cm
Integration Specs NTHETA = 33 NPSI = 25 DELR = 2 030E+00 cm
Total Intervals 1 650E+04

Shield Thickness cm 5 070E+01 4 060E+01 1 000E 01
Taylor Buildup Data for Shield 2 with Effective Atomic Number 10 4

Group	Average Energy Mev	Bremsstr photons/sec	Source Total photons/sec	Energy Flux Mev/sq cm/sec	Dose Rate R/hr
1	1 500E 02	1 438E+08	1 438E+08	4 351E 15	3 581E 19
2	2 500E 02	9 135E+07	9 135E+07	3 453E 04	5 974E 09
3	3 500E 02	4 785E+07	2 596E+09	1 307E+00	8 298E 06
4	4 500E 02	2 887E+07	2 887E+07	1 761E 01	5 777E 07
5	5 500E 02	2 176E+07	2 176E+07	5 127E 01	1 174E 06
6	6 500E 02	1 494E+07	1 494E+07	7 004E 01	1 324E 06
7	7 500E 02	1 168E+07	1 168E+07	8 968E 01	1 537E 06
8	8 500E 02	8 411E+06	8 411E+06	1 003E+00	1 621E 06
9	9 500E 02	6 434E+06	6 434E+06	1 041E+00	1 669E 06
10	1 500E 01	2 169E+07	2 169E+07	4 005E+00	6 920E 06
11	2 500E 01	4 571E+06	4 571E+06	1 986E+00	3 892E 06
12	3 500E 01	1 254E+06	1 254E+06	9 824E 01	2 024E 06
13	4 750E 01	5 613E+05	5 613E+05	6 603E 01	1 347E 06
14	6 500E 01	1 831E+05	3 149E+10	4 706E+04	9 789E 02

15	8 250E 01	2 623E+04	2 623E+04	4 817E 02	9 634E 08
16	1 000E+00	2 898E+03	2 898E+03	7 090E 03	1 368E 08
17	1 225E+00	0 000E+00	0 000E+00	0 000E+00	0 000E+00
18	1 475E+00	0 000E+00	0 000E+00	0 000E+00	0 000E+00
19	1 700E+00	0 000E+00	0 000E+00	0 000E+00	0 000E+00
20	1 900E+00	0 000E+00	0 000E+00	0 000E+00	0 000E+00
21	2 100E+00	0 000E+00	0 000E+00	0 000E+00	0 000E+00
22	2 300E+00	0 000E+00	0 000E+00	0 000E+00	0 000E+00
23	2 500E+00	0 000E+00	0 000E+00	0 000E+00	0 000E+00
24	2 700E+00	0 000E+00	0 000E+00	0 000E+00	0 000E+00
25	3 000E+00	0 000E+00	0 000E+00	0 000E+00	0 000E+00
TOTALS		4 034E+08	3 445E+10	4 708E+04	9 792E 02

Note that 9 792E 02 R/hr = 7 018E 09 amp/kg

***> This is the end of the annular filter cases !!

Finish run at 10 40 26 12/14/99

Contents of Input file ANFIL

```
0        2  K Basin Annular Filter Tank (1 Ci Cs 137)
KW Density    12  to the side
 &Input  IGeom= 12   SLTH= 76 2   Y= 38 1   T= 50 7 40 6 0 1   X= 121 9
  NShld= 3   JBuf= 2   NTheta= 33   NPsi= 25   DelR= 2 0
  Next= 1   Weight(335)= 1  0 946  &
  air    3  0 0012
  media 16            1 666
1 tank   9            0 167     7 86
KE Density    12  to the side
 &Input  &
  air    3  0 0012
  media 16            1 619
1 tank   9            0 120     7 86
This is the end of the annular filter cases !!
 &Input Next= 6  &
```

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APPENDIX D

HANFORD SITE QUALITY ASSURANCE OF THE FLUENT™ CODE

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APPENDIX D

HANFORD SITE QUALITY ASSURANCE OF THE FLUENT™ CODE

D1 0 INTRODUCTION

The purpose of this appendix is to document Hanford Site quality assurance of Version 5 2 3 of the FLUENT[1] computer code following the software requirements and standards described in the Project Hanford Procedure HNF-PRO-309, *Computer Software Quality Assurance Requirements* The FLUENT™ code is described briefly here and in more detail in Sections D1 1 and D1 2 Validation cases are presented in Section D2 0 Attachment A provides the Fluent Incorporated documentation of the flow validation case, and Attachment B illustrates the American National Standards Institute web page on standardization

The FLUENT™ computer code is commercial off-the-shelf software developed by Fluent Incorporated As a commercial code, the quality assurance standards and guidelines of ISO 9001, *Quality Systems -- Model for Quality Assurance in Design Development Production Installation, and Servicing*, were followed ISO 9001 is a software quality assurance standard developed and sponsored by the American National Standards Institute, which maintains a web site for more information The ISO 9001 standard is followed by many developers of commercial codes in lieu of using the ASME NQA 1 standard, *Quality Assurance Requirements for Nuclear Facility Applications* Both standards are very comprehensive and promote high quality in software

FLUENT™ uses computational fluid dynamics to solve for complex flows ranging from incompressible (low subsonic) to mildly compressible (transonic) to highly compressible (supersonic and hypersonic) flows FLUENT™ delivers optimum convergence and accuracy for a wide range of flow regimes and has the capability to accurately predict laminar, transitional, and turbulent flows, various modes of heat transfer, chemical reactions, multiphase flows, particle tracking, and other complex phenomena The main features required for the *K Basins Final Safety Analysis Report* (HNF-SD-WM-SAR-062) are the turbulent flow and particle tracking capabilities of FLUENT™, which are required to calculate the leak path factors (LPFs) in the K West Basin building for several accident scenarios involving particulate release

The accuracy of the output results has been verified and validated by Fluent Incorporated for 17 validation cases that compare the code results to experimental data and to specialized solutions from other codes The main purpose of the Hanford Site quality assurance was to show that the FLUENT™ code produces the same results on a Hanford Site computer as it does at

[1]The FLUENT code was developed by and is a trademark of the Fluent Incorporated 10 Cavendish Court, Centerra Resource Park Lebanon New Hampshire 03766 1442 telephone (603) 643 2600 fax (603) 643 3967

Fluent Incorporated and to ensure that it could be used for particle tracking This appendix verifies the quality assurance testing of Version 5 2 3 of the FLUENT™ code for flow and particle tracking The testing and analysis were conducted on Fluor Federal Services (FFS) computer 30032271 located in cubical 465 at 1200 Jadwin Avenue, Richland, Washington [2]

D1 1 PROGRAM DESCRIPTION

FLUENT™ Version 5 2 is a Microsoft Windows NT 4 0[3] based program The commercial package for FLUENT™ comes with GAMBIT[4], a primary tool to develop the problem geometry, mesh generation and to define the boundary conditions for a given problem TCP/IP network protocol configuration is required for floating licenses

The File pulldown drop menu contains functions to Read, Write and Import Files It has also an option to create a Hardcopy, to Save the existing Layout and Exit from the program The Read menu has further options to read Case, data and Case & Data, Profile Scheme and Journal files and also Run an existing file The Write menu has further options to write Case, data and Case & Data files It has also option to write Start Journal and Start Transcript files The Import menu has options to import different types of files

The Grid pulldown drop menu contains options to Check get Info, merge, Separate, Fuse, Partition, Recorder, Scale, Translate and Smooth/Swap a Grid

The Define pull down drop menu allows user to define Model, Materials, Operating Condition, Boundary Conditions, Periodic conditions, Grid Interfaces, Mixing planes, Injections, Ray Tracing, Custom Field Functions, Profiles, Units and User Defined function The Model menu has further options of section of solver define Energy, define type of Viscous model, define Species, define type of Radiation applicable to the model define the Discrete Phase when applicable, define if it is a Multiphase Model, define Pollutants and also User-Defined Scalar The User Defined menu has further options of Functions, Function Hooks and Fan Model

The solve pulldown drop menu contains functions as Control, Initialize, Monitor, and Iterate The Control submenu has further options of defining the type of Solution, type of Multigrid control and Limiting the value of a parameter (physical property) to which a particular problem is to be analyzed Initialize submenu has further options of defining the initial condition and to patch flow variable into different cells Monitor submenu has further options of Residual , Statistics , Force , Surface , Command The Residual submenu allows to set the residual information The Statistics submenu allows to control the statistics information The Force submenu allows to set the convergence history of drag, lift, and moment coefficient

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[2]The FLUENT™ code falls under the jurisdiction of A W Bjorkedal (509 376 9171) of Fluor Federal Services Inc a purchaser of the code at the Hanford Site

[3]Microsoft Windows NT is a trademark of the Microsoft Corporation Redmond Washington

[4]GAMBIT is a trademark of Fluent Incorporated Lebanon New Hampshire

The Surface submenu allows to set the provision to save the convergence history of either the average, integral, flow rate or mass average of a field variable on one or more surface The Command submenu allows to define the commands to be executed during calculation, Iterate command is for starting the solver iteration

The Adapt pulldown drop menu allows the user to adapt a Boundary , Gradient , Iso-Value , Region , Volume , to mark or adapt Boundary, to Manage adaption register, to Control grid adoption, to customize Display of adoption and smoothing and face swapping the numerical mesh

The Surface pulldown drop menu allows the user to create surface from faces and cell Zones, surface defined by the boundary of two adjacent grid Partition, Point surfaces, Line/Rake surfaces, Planar surface that cuts through the domain, define Quadric functions and create surfaces from them, create Iso-Surfaces, Clip surfaces, Create a new data surface by rotating and/or translating an existing surface and/or specifying a constant normal distance from it also to Manage a surface

The Display pulldown drop menu allows user to select from various display (e g , Grid , Contour , Velocity Vector , Path lines , Particle Track , Options to control how and where a scene is rendered, Colormaps to select or modify existing colormap and Mouse Button to set the action required to be taken by individual mouse button

The Plot pulldown drop menu has the option for user to select desired type of plot from XY Plot, Histogram, File and Residual The Report pulldown drop menu contains functions as Summary, Fluxes, Forces, Projected Areas, Surface Integrals, Volume Integrals, Histogram, Discrete Phase and Reference Values The Discrete Phase submenu has further options of Sample and Histogram

The Parallel pulldown drop menu contains functions as Network, Show Connectivity and Timer Lastly the Help pulldown drop menu allows user to search for how and when to use specific command as well as general idea of the program

D1 2 PROGRAM SUMMARY

The following items summarize the program in the format of ANSI N413-1974

1 Program Identification FLUENT™ NT VERSION 5 2 3, Release Date Aug 18 1999

2 Description of Problem or Function Computational Fluid Dynamics, Thermal Analysis

3 Method of Solution Iterative Finite Volume

4 Related Material The program contains all files required to run the program The user inputs system geometry, generate mesh, define boundary, physical properties, and can override or supplement FLUENT™ 5 2 Data Libraries

5 Restrictions/Limitation The following are known limitations in FLUENT™ 5

- Binary file compatibility is not available for all computers
- Compiled user-defined functions currently are not available on Microsoft Windows NT™
- Conformal coarsening on boundaries does not apply to periodic or two-sided wall zones
- When a surface species is a *reactant*, its concentration is not accounted for in the rate expression Hence, the rate at which the surface reaction diminishes the species does not depend on the concentration of the species on the surface

The following models and features are not available for the coupled solvers

- Volume-of-fluid (VOF) model
- Cavitation model
- Algebraic slip mixture model
- PDF model
- Soot and NOx models
- Rosseland radiation model
- Premixed combustion model
- Phase change model
- Specified mass flow rate for streamwise periodic flow

The following model is not available for the segregated solver

- Real gas model

These features are currently unavailable in the parallel solver

- Discrete transfer radiation model (DTRM)
- Conformal grid adaption (hanging-node adaption *is* available in the parallel solver)

6 Computers IBM[5] or Compatible

The following is a list of system requirements for FLUENT™ 5 (Microsoft Windows NT™ version) code on IBM™ or compatible computers

- Hardware
  - CPU Intel Pentium[6] Family of Processors

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[5]IBM is a trademark of the International Business Machines Corporation Armonk New York

[6]Pentium is a trademark of the Intel Corporation Santa Clara California

- Video graphics device with minimum 1024 X 768 resolution and 256 minimum colors with 4096 recommended
- 64 MB RAM minimum, 128 recommended for complex 3D models (see Memory Requirements)
- Windows[7] compatible 3-button mouse recommended
- CD-ROM All Fluent products are distributed on CD-ROM
- Ethernet adapter card

• Disk and Memory Requirements
  - Memory and Swap File Size
  - A minimum of 64 MB RAM is required for a standard laminar fluid-flow problem The size of the swap file should not be smaller than the amount of RAM in your system Larger problems require considerably more memory (RAM plus swap space) and increasing RAM dramatically improves performance In order to run complex, 3D problems, a configuration with 128 MB RAM minimum is recommended

• Disk Space Requirements
  - FLUENT™ 5 2 30 MB, GAMBIT™ 1 65 MB

FFS computer being used (#30032271) exceeds the above requirements

7 Running Time Running time is dependent on CPU speed, piping system size and complexity and detail of analysis

8 Program Language The program is compiled prior to receipt

9 Operating System Microsoft Windows NT 4 0™

• TCP/IP network protocol configuration required for floating licenses

10 Machine Requirements See item 6

11 Authors Fluent Incorporated, 10 Cavendish Court, Centerra Resource Park Lebanon

12 References None

13 Materials Available FLUENT™ 5 2 User and Workbook Manuals produced by FLUENT™ and located at the computer stations

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[7]Windows is a trademark of the Microsoft Corporation, Redmond Washington

D2 0 VALIDATIONS

D2 1 WAVY VALIDATION CASE

The WAVY validation case is case # 6 supplied by Fluent Incorporated with complete documentation attached (Attachment A) Briefly the case looks at a gas (similar to air) flowing through a channel or duct with a wavy bottom (boundary) causing some turbulence even under low Reynolds number condition (see Attachment A for details) The wavy bottom of channel is analogous to the floor of K-basin buildings with the open space above the water basin The mass flow (stream function) contours for the standard and renormalized group (RNG) k-ϵ turbulence models produced at Hanford by FLUENT™ code are shown in Figures D-1 and D-2 These two figures are the same as those produced by Fluent Incorporated and shown in Figures 6 3 and 6 4 in Attachment A The similarity of Figures D-1 and D-2 with Figures 6 3 and 6 4 demonstrates that the FLUENT™ code is running the same on the FFS computer (#30032271) as it did on the Fluent Incorporated computer The WAVY validation case also shows that FLUENT™ code is capable of solving turbulent flow problems with low Reynold numbers The actual comparisons to experimental data are shown in Figures 6 5 to 6 8 which compare the x-direction velocity at the wave crest and wave trough, in Attachment A The plots produced at Hanford are shown in Figures D-3 to D-6 without the experimental data, but they compare very well to those produced by Fluent Incorporated (Figures 6 5 to 6 8 in Attachment A) which do include the experimental data The case shows that both the standard k-ϵ model and RNG k-ϵ model give good results The simulations for the derivation of K-basin building Leak Path Factors (LPFs) used the standard k-ϵ turbulence model

In summary, validation case # 6 (WAVY) shows that the FFS computer (#30032271) produces the same results as produced and documented by Fluent Incorporated The case also shows that the FLUENT™ code accurately models turbulent flow with low Reynolds numbers with the standard and RNG k-ϵ models This case took a few minutes of CPU time to run

D2 2 PARTICLE TRACKING VALIDATION CASES

Even though particle tracking (i e discrete phase) capability is available in the FLUENT™ code, no validation case was supplied by Fluent Incorporated Hence, a test case was developed by the user at Hanford The particle tracking validation case consists of air flowing at steady-state through a 2D duct, which is 1 m wide and 5 m high, and spherical particles with different diameter values released at various locations in the duct The FLUENT™ code calculates the trajectory of the particle and determines whether the particle escapes out of the top or settles to the bottom The code calculated particle behavior is then compared to the particle behavior using the well known Stokes velocity (Hinds 1982)

The Stokes settlıng velocıty ıs easıly calculated analytıcally (Hınds 1982) for the two sızes of partıcles by dense spherıcal partıcle ın aır (or other gas) as shown below

$$V = D^2(\rho_p)g/(18\ \eta) \qquad (1)$$

where

V = Stokes settlıng velocıty of spherıcal partıcle (m/s)
D = partıcle dıameter (8 75 and 8 8 x 10^{6} m)
ρ_p = mass densıty of partıcles (5,000 kg/m^3)
g = gravıtatıonal acceleratıon (9 8 m/s^2)
η = dynamıc vıscosıty of aır (1 7894E-05 kg/m s) at a temperature of 300 K

The Stokes settlıng velocıty for the smaller (8 75 µm) dıameter partıcle ıs 1 165 cm/s and for the slıghtly larger (8 8 µm) dıameter partıcle ıs 1 178 cm/s If the aır velocıty ıs smaller than the partıcle's settlıng velocıty, the partıcle wıll settle or drop down to the bottom On the other hand, ıf the aır velocıty ıs larger than the settlıng velocıty, then the partıcle wıll rıse and escape out of the top boundary for thıs valıdatıon case The Cunnıngham slıp correctıon factor (Hınds 1982) ıs ıgnored ın Equatıon 1 because ıts effect ıs neglıgıble for partıcles larger than 1 µm

The grıd for thıs test case ıs shown ın Fıgure D-7 The aır flow vertıcal velocıty ıs low at the entrance wıth a value of 0 01 m/s (1 cm/s) The vertıcal walls of the duct cause the aır velocıty to be smaller near the wall and larger ın the center, as shown ın Fıgure D-8, whıch shows the vertıcal velocıty as a functıon of horızontal dıstance across the duct The spread ın velocıty values at each x locatıon ındıcates that the velocıty ıs changıng along the vertıcal dıstance For example, the y-velocıty ıs 1 0 cm/s at the bottom center of duct and ıncreases to about 1 25 cm/s at the top center of duct, whereas, at the bottom sıdes of duct the y-velocıty ıs 1 0 cm/s, but at the top sıdes of duct, the y-velocıty ıs less than 0 4 cm/s The dıfferent velocıty values at dıfferent locatıons ıs also shown by the aır y-velocıty contours, shown ın Fıgure D-9, wıth the maxımum velocıty located at the center of the outlet (top boundary) wıth a value of about 1 25 cm/s The thırd velocıty contour from the top, just above the mıddle of duct ın Fıgure D-9 shows a velocıty value of almost 1 175 cm/s, whıch ıs just a lıttle smaller than the settlıng velocıty (1 178 cm/s) of the 8 8 µm partıcle and a lıttle larger than the settlıng velocıty (1 165 cm/s) of the 8 75 µm partıcle Thıs means, based on theory, that ıf the larger partıcle ıs placed ın the center of duct, ıt wıll fall down, whereas, ıf the smaller partıcle ıs placed ın the center of duct, ıt wıll go up and escape out of the duct

Thıs effect was sımulated wıth the FLUENT™ code wıth two separate sımulatıons, one for the larger partıcle and one for the smaller partıcle The larger (8 8 µm) partıcle's trajectory ıs shown ın Fıgure D-10, whıch clearly shows that the partıcle falls to the bottom of duct and the tıme of flıght ıs about 5170 seconds as ındıcated by the maxımum value on left scale (orıgınal scale was ın color, but the black/whıte scale stıll ındıcates clearly the maxımum tıme of flıght) of Fıgure D-10 The tıme of flıght ıs long because the partıcle's settlıng velocıty ıf very close to the aır velocıty ın the entıre duct Also an ınıtıal x-velocıty of 10 cm/s was gıven to the partıcle, whıch causes the partıcle to ınıtıally move horızontally and the ınıtıal horızontal trajectory ıs shown ın Fıgure D-10 In contrast, the smaller (8 75 µm) partıcle's trajectory ıs shown ın

Figure D-11, which shows that the particle escapes the duct, as predicted by theory, in about 10,600 seconds

As an additional test case of the FLUENT™ code, the larger (8 8 μm) particle was released 0 5 m higher in the duct where the vertical velocity is larger than 1 18 cm/s By theory, the larger particle should now escape the duct, which is shown in Figure D-12 as simulated by the code This case also points out that the location of particle source can make a big difference in particle movement The last test case introduces the smaller (8 75 μm) particle at location near the left wall (x=0 1 m) which is 0 4 m from the horizontal center of duct, but at the same height (y=2 5 m) as before which was the vertical center of duct Based on theory, the particle should settle to the bottom since it's settling velocity is larger than the velocity near the wall The trajectory of the particle, as simulated by FLUENT™ code is shown in Figure D-13, which clearly shows the particle settling to the bottom in about 3000 seconds Figure D-13 also shows that the particle moves to the right while settling This is because the initial horizontal velocity was set at 10 cm/s and there is a small horizontal velocity on left (and opposite in direction on right) side of duct with the larger x-velocities located near the bottom (entrance) of duct The x-velocity contours for left-side (mirror image for right side) of duct are shown in Figure D-14 The particle trajectory shows more horizontal displacement at middle part of trajectory until it gets close to the center of duct where the x-velocities are zero

The results of the particle tracking validation simulations with the FLUENT™ code are summarized in Table D-1 Based on these results, the FLUENT™ code is acceptable for particle tracking in flow fields

Table D-1 Summary of Particle Tracking with FLUENT™ Code

Simulation Number	Particle Diameter (μm)	Settling Velocity (cm/s)	Starting Location (x y) m	Initial X-velocity (cm/s)	Particle's Fate, Path Figure No	Agreement with Theory
1	8 8	1 178	0 5, 2 5	10	Settles, D-10	Yes
2	8 75	1 165	0 5, 2 5	5	Escapes, D-11	Yes
3	8 8	1 178	0 5, 3 0	5	Escapes, D-12	Yes
4	8 75	1 165	0 1, 2 5	10	Settles, D-13	Yes

D3 0 REFERENCES

Hinds, W C , 1982, *Aerosol Technology*, John Wiley, Incorporated, New York, New York

HNF-SD-WM-SAR-062, 1999, *K Basins Final Safety Analysis Report*, Rev 4, Fluor Daniel Hanford, Incorporated, Richland, Washington

NQA 1, 1994, *Quality Assurance Requirements for Nuclear Facility Applications*, American Society of Mechanical Engineers New York, New York

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Figure D-1 Contours of Stream Function (Standard k-ϵ Model)

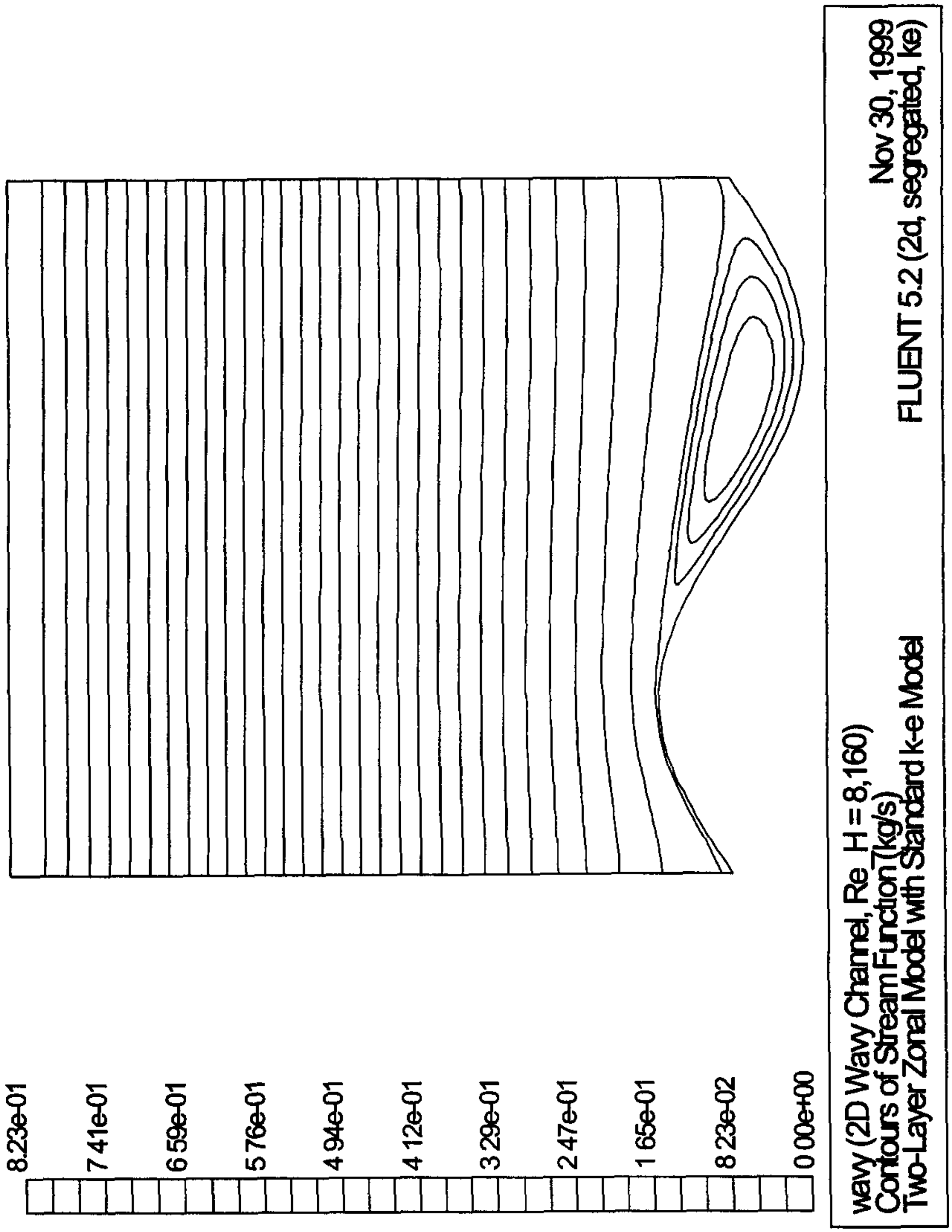


Figure D-2 Contours of Stream Function (Renormalized Group k-ϵ Model)

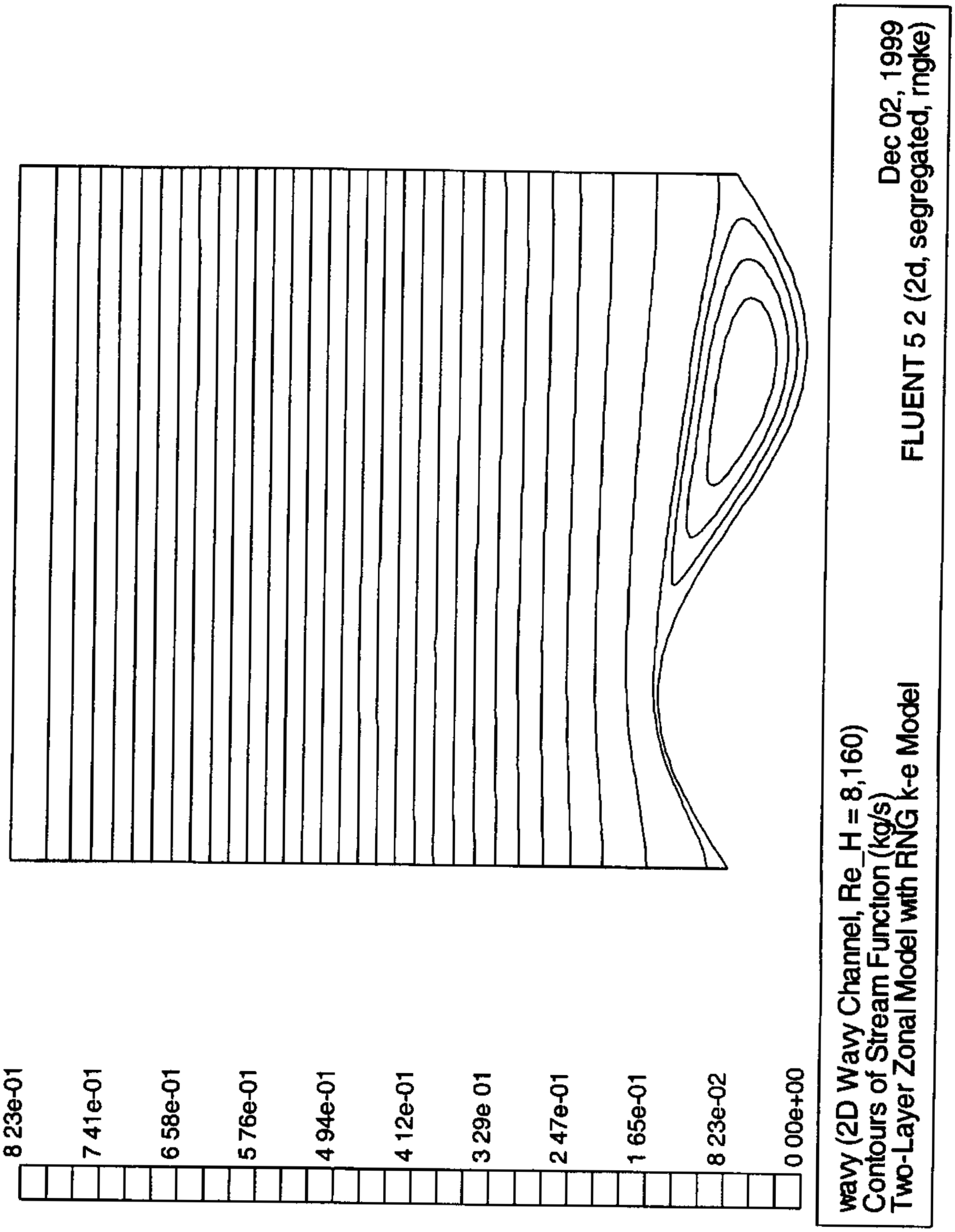


Fıgure D-3 Normalızed X Velocıty at the Wave Crest (Standard k-ϵ Model)

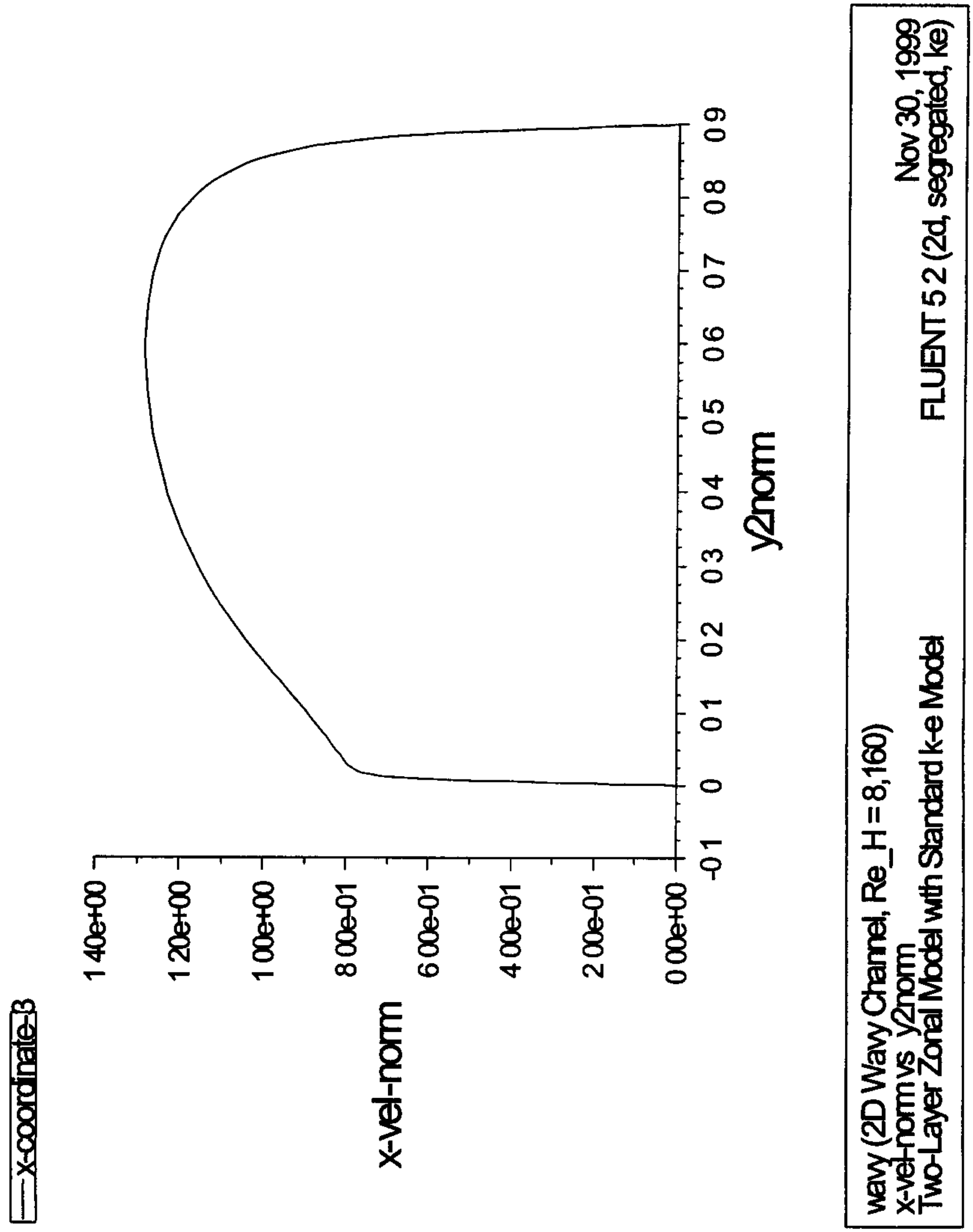


Figure D-4   Normalized X Velocity at the Wave Crest (Renormalized Group k-ϵ Model)

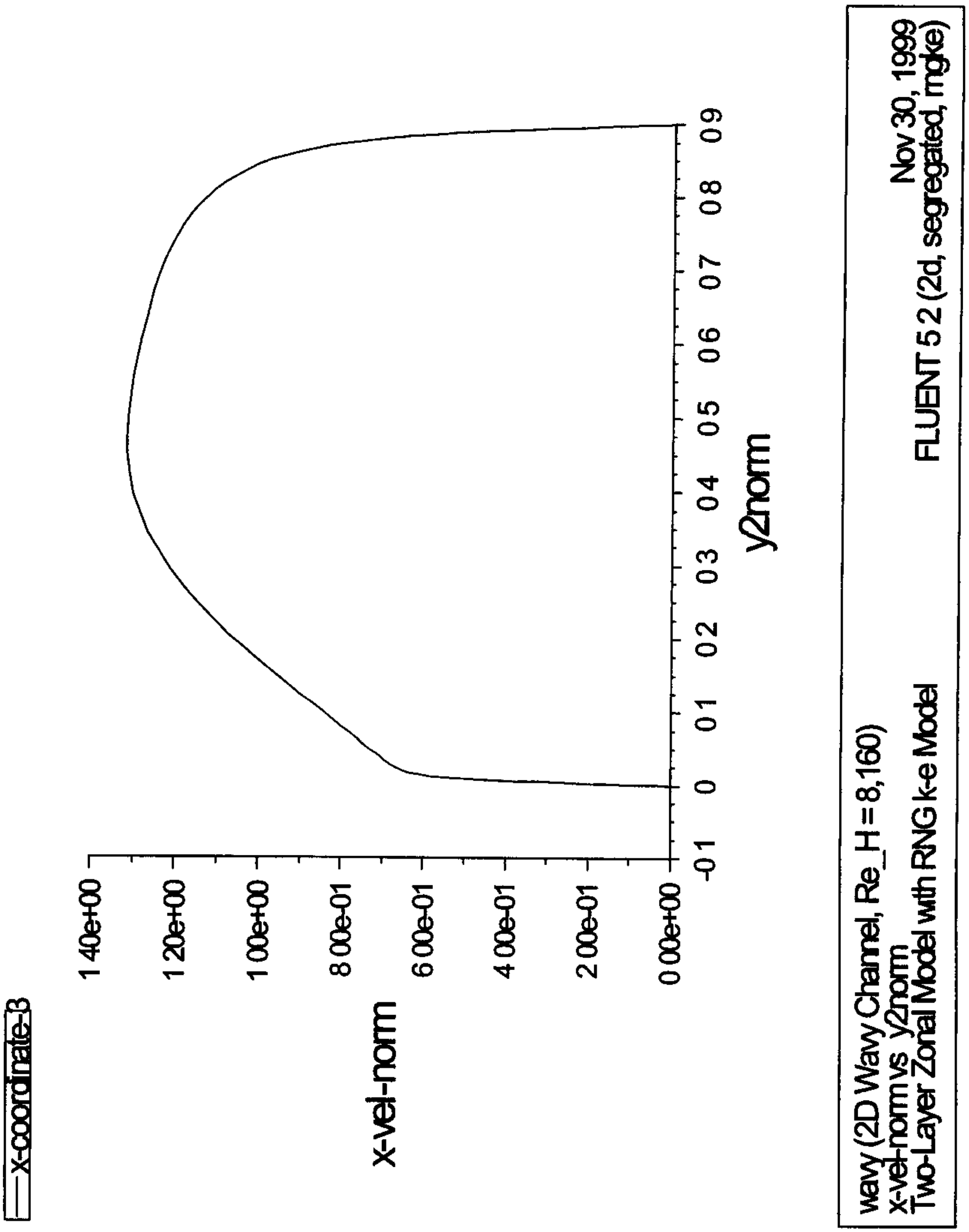


Figure D-5 Normalized X Velocity at the Wave Trough (Standard k-ϵ Model)

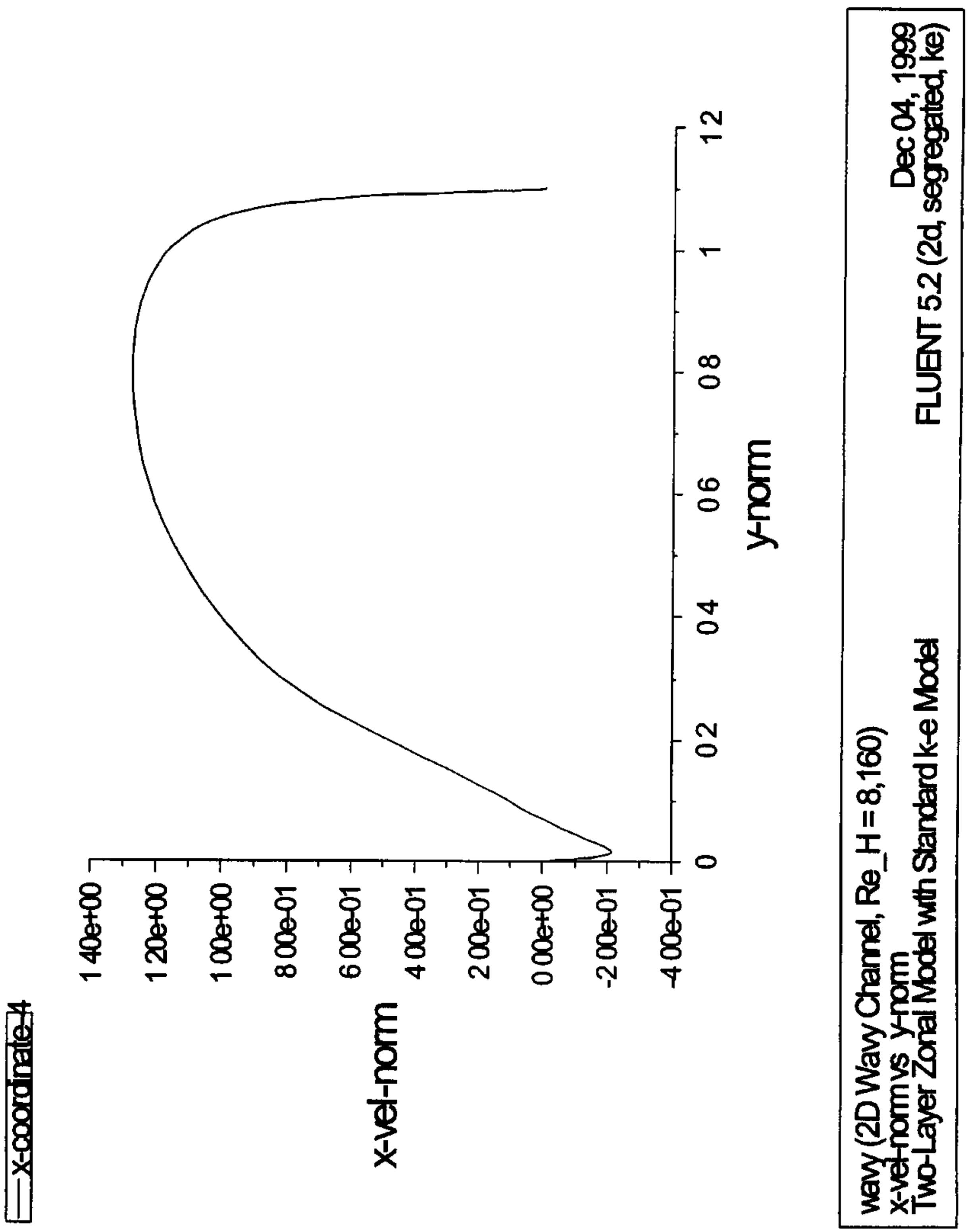


Figure D-6 Normalized X Velocity at the Wave Trough (Renormalized Group k-ϵ Model)

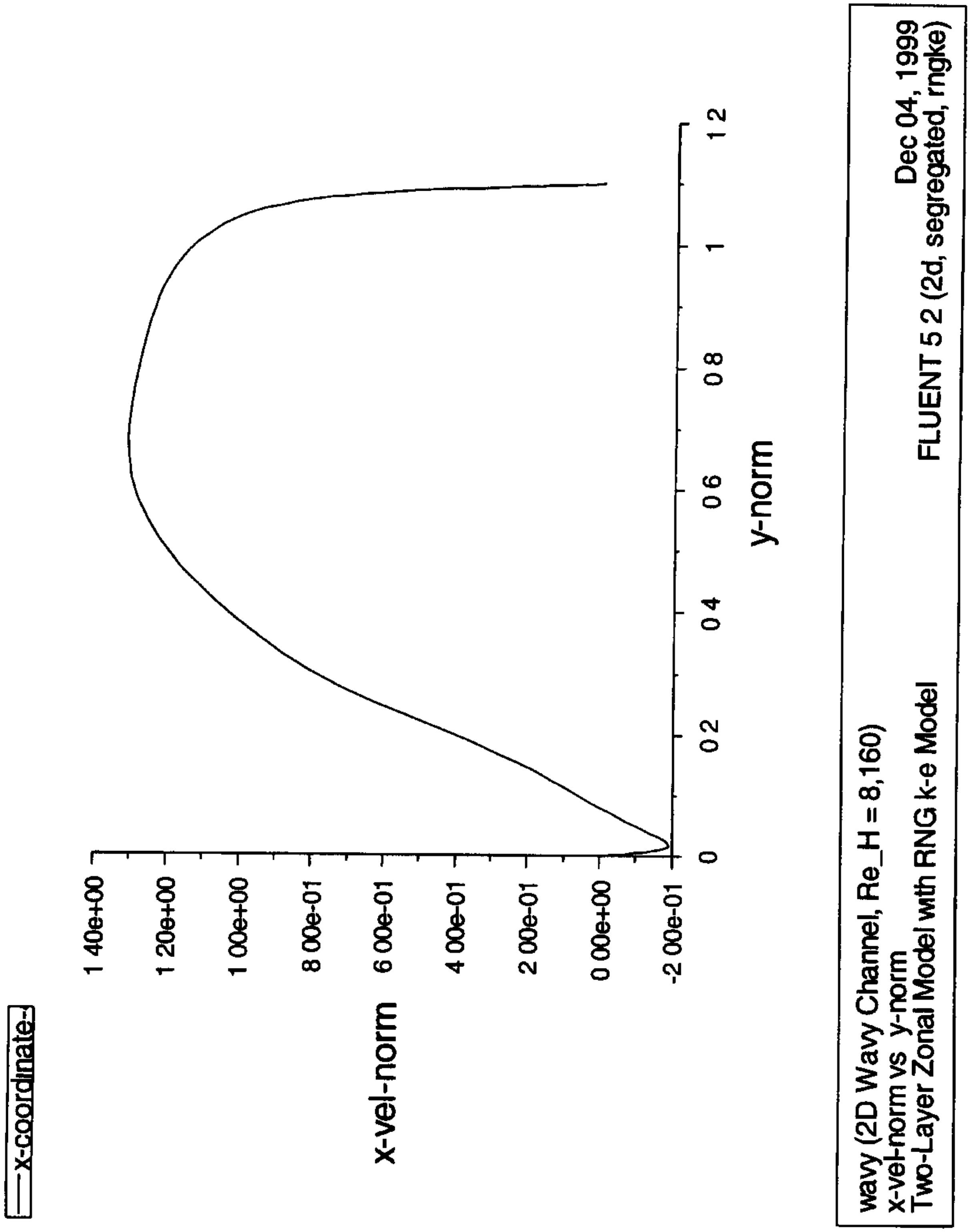


Figure D-7 FLUENT Grid Used for Particle Tracking Validation Case

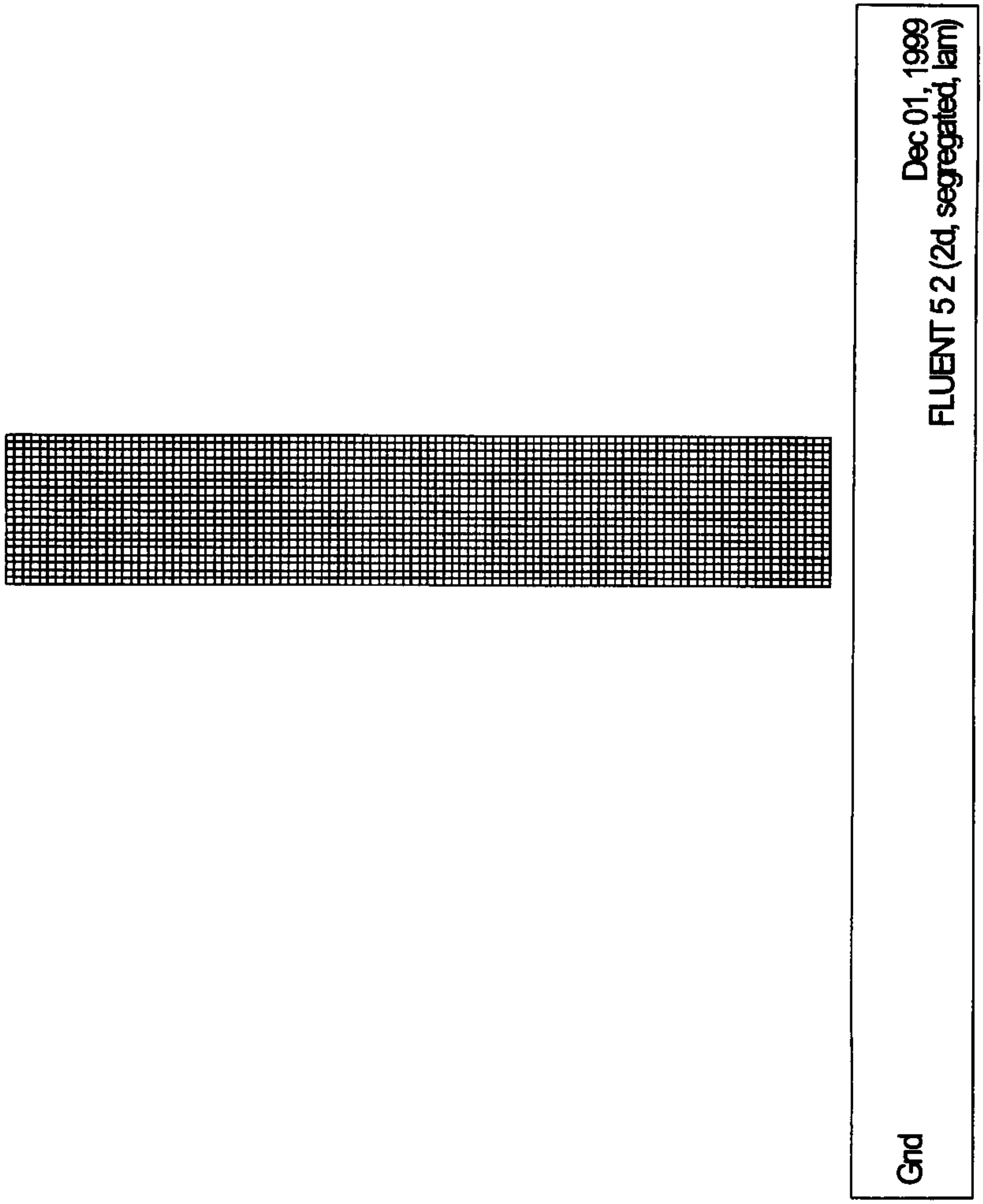


Figure D-8 Vertical Air Velocities Versus Horizontal Duct Position

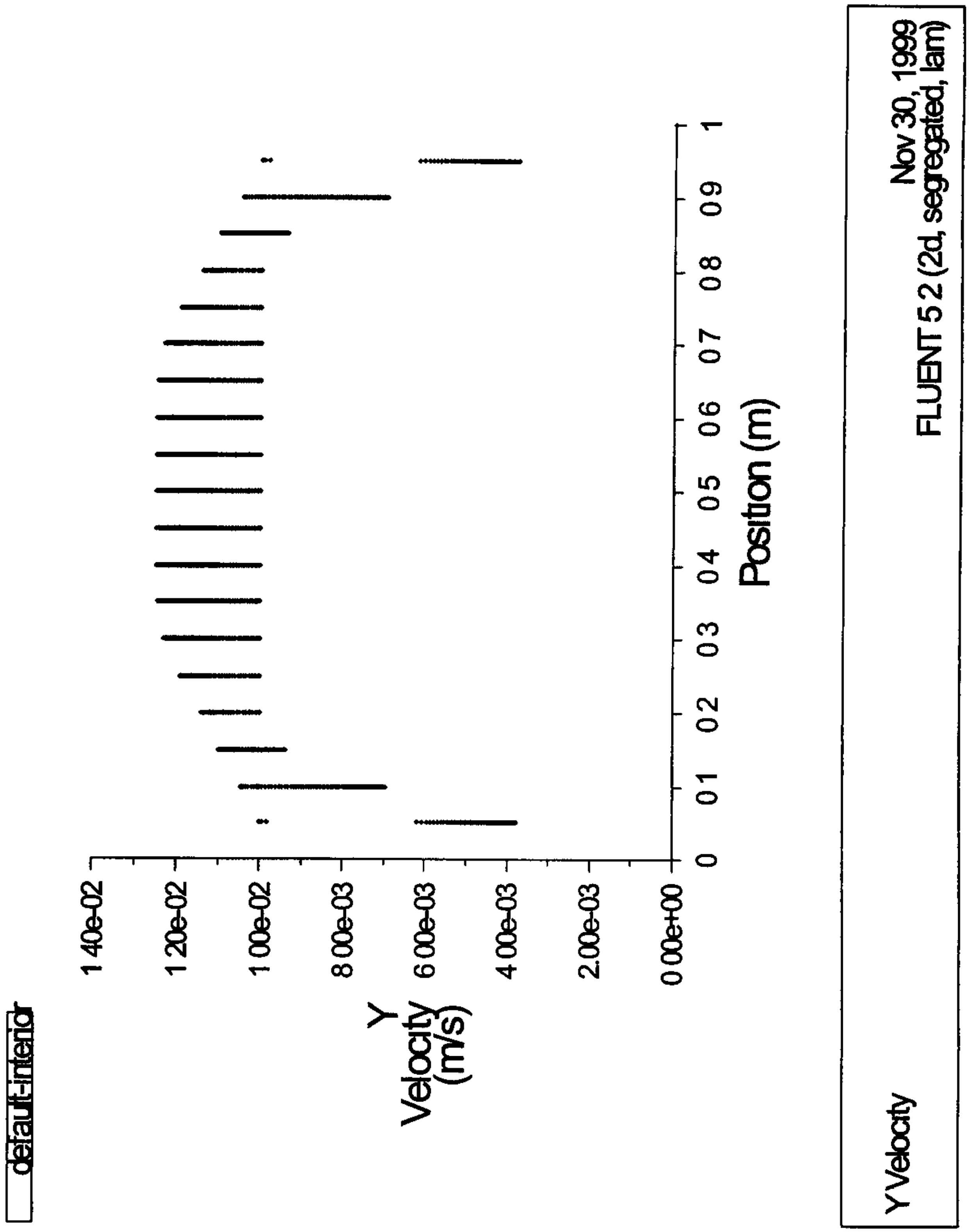


Figure D-9 Vertical Air Velocity Contours in Duct

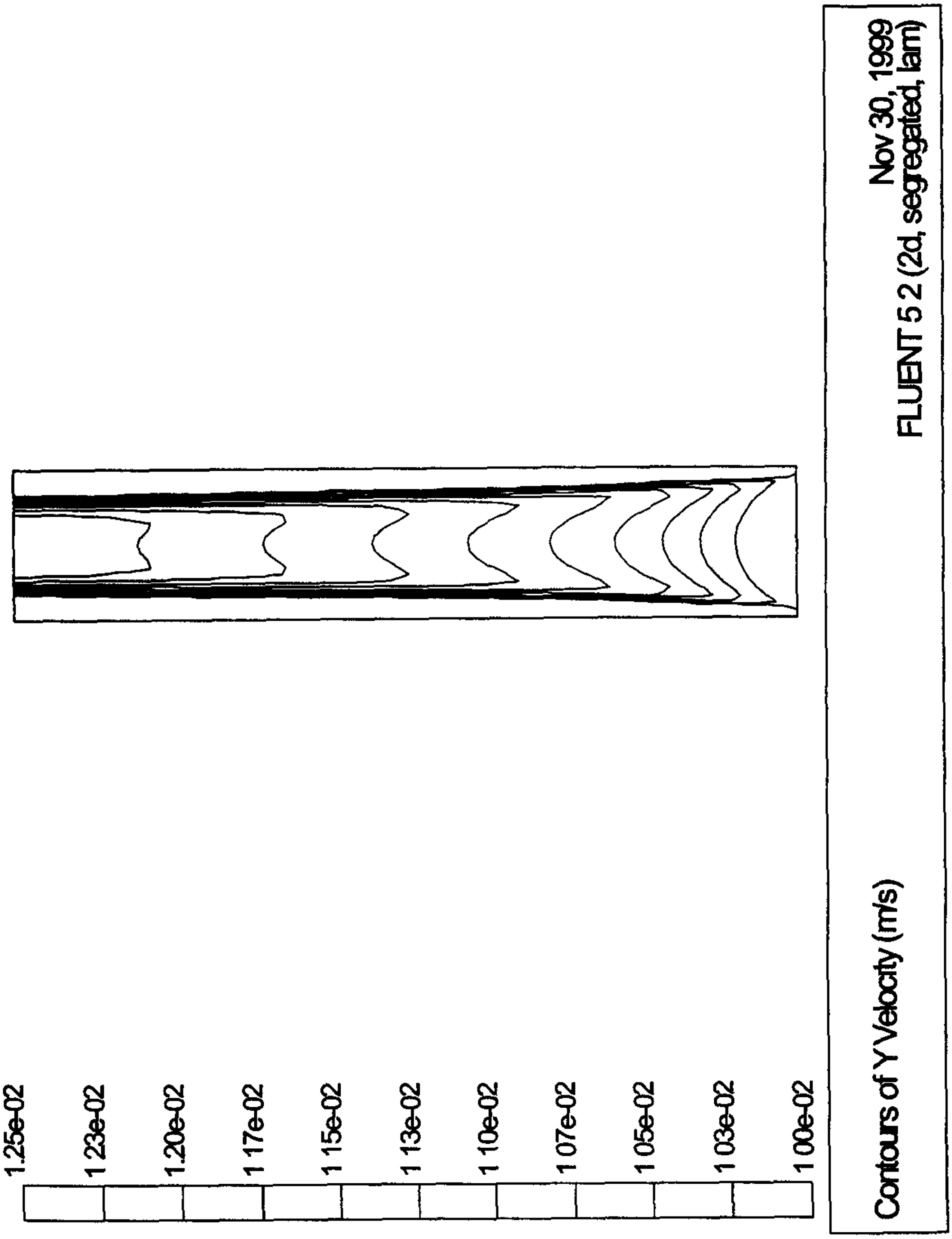


Figure D-10 Trajectory of Larger (8 8 μm) Particle Released in Duct Center

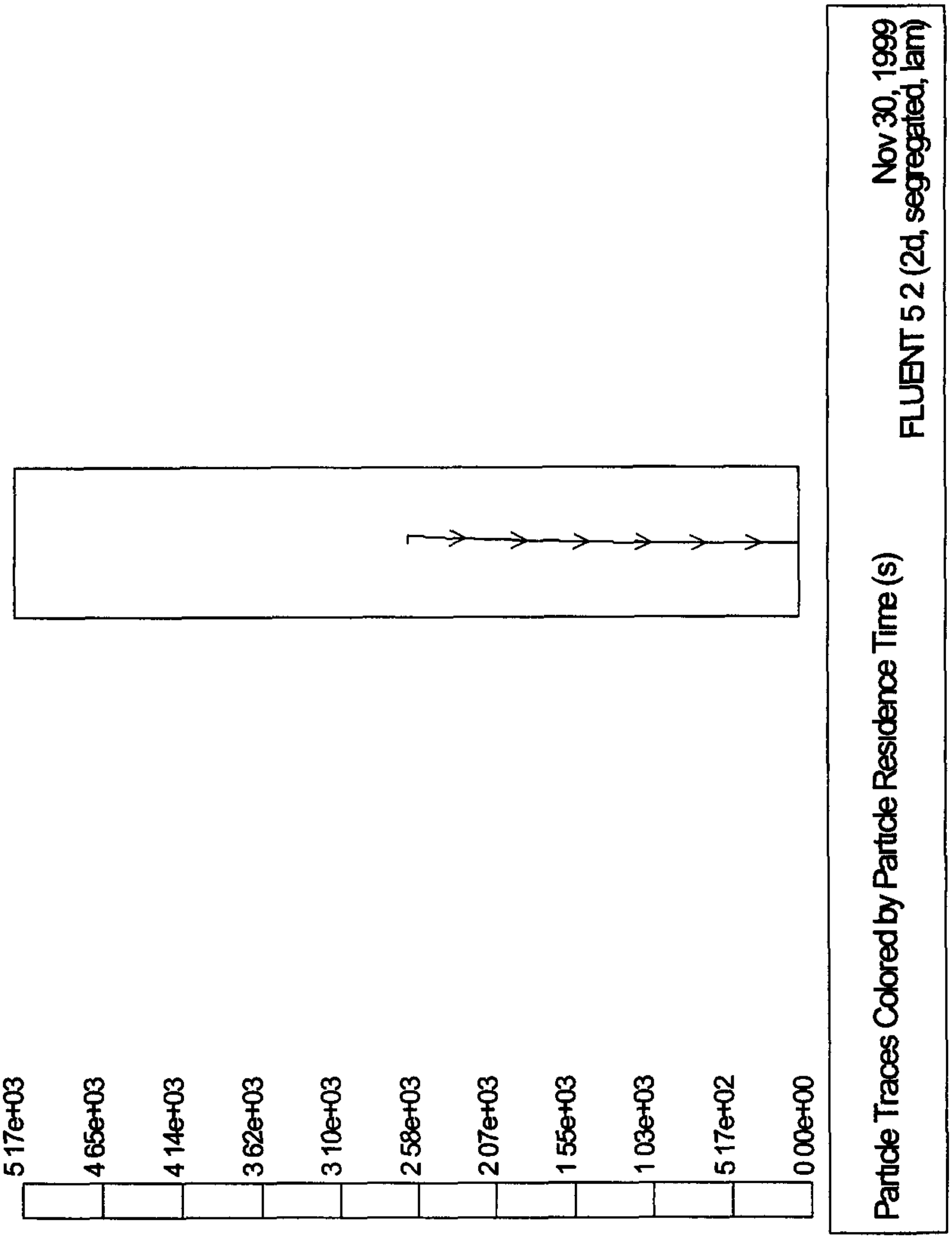


Figure D-11 Trajectory of Smaller (8 75 µm) Particle Released in Duct Center

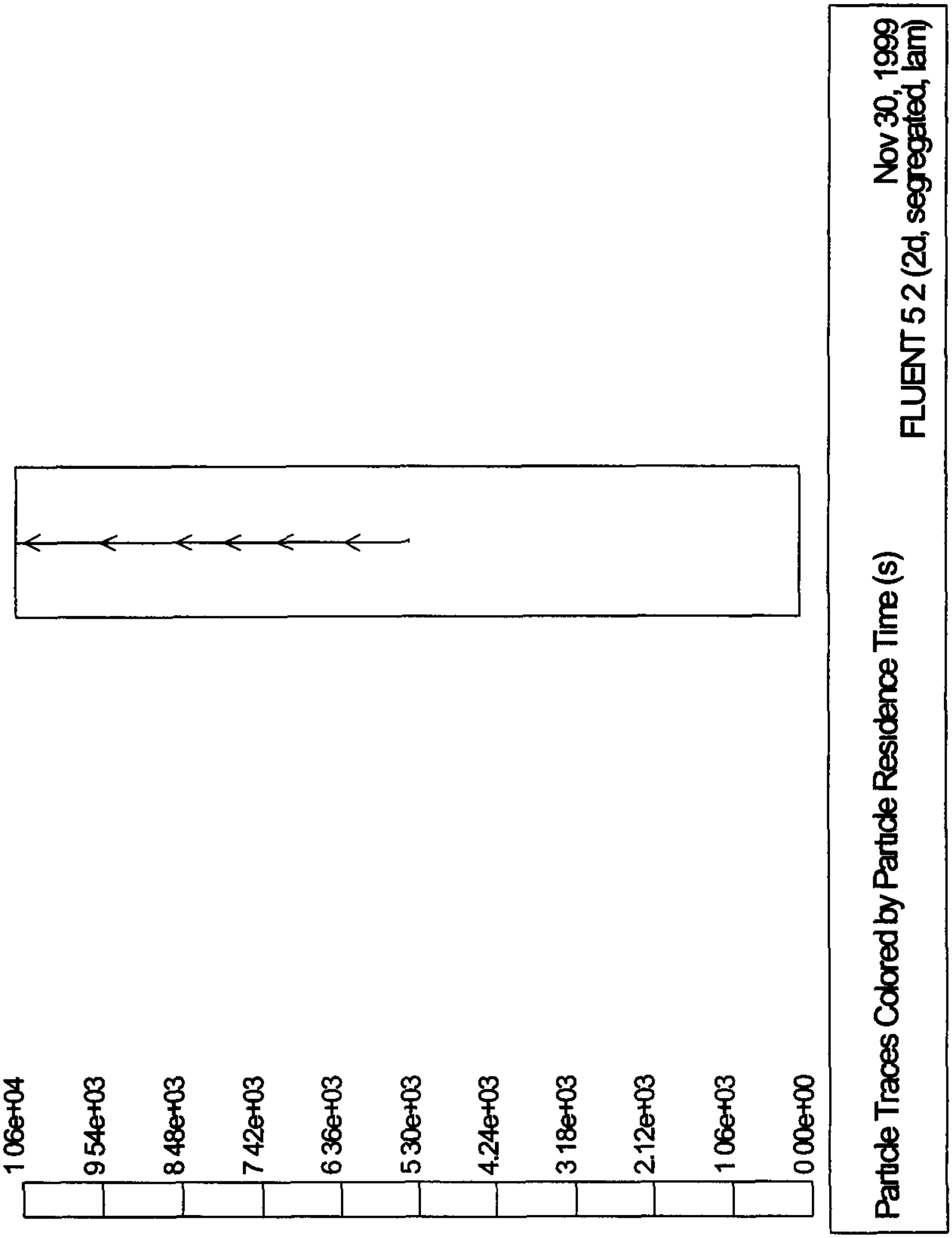


Figure D-12 Trajectory of Larger (8 8 μm) Particle Released Above Duct Center

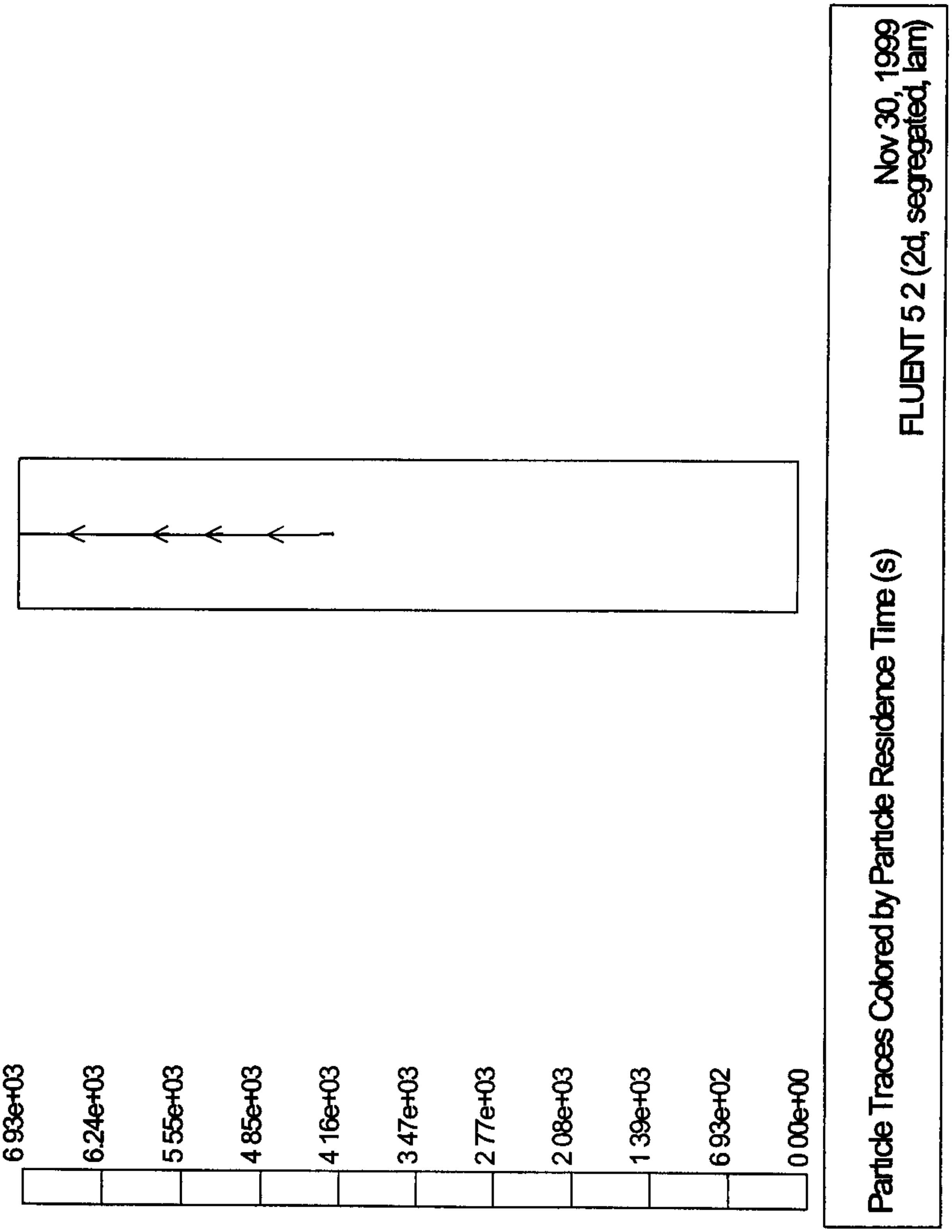


Figure D-13 Trajectory of Smaller (8 75 μm) Particle Released Near Wall

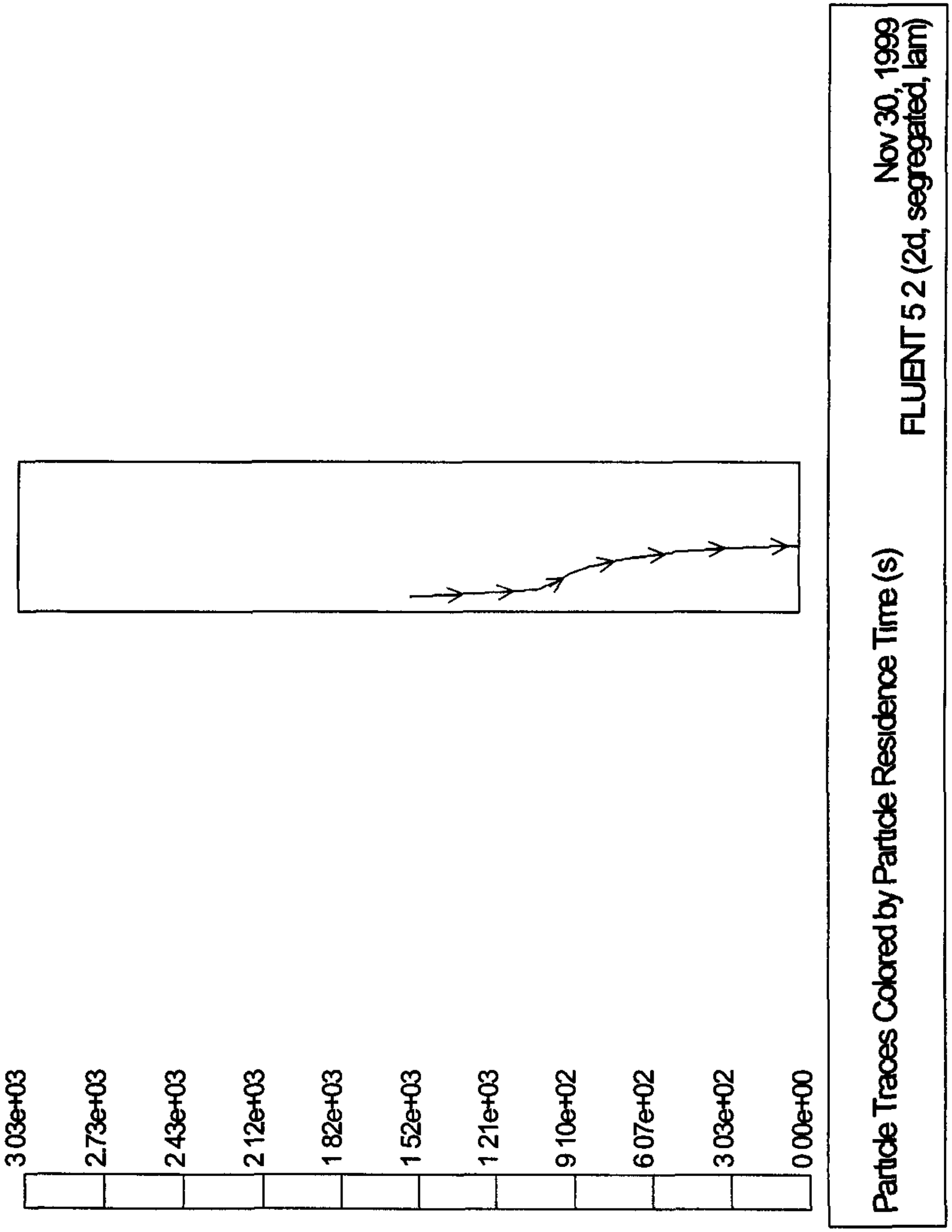
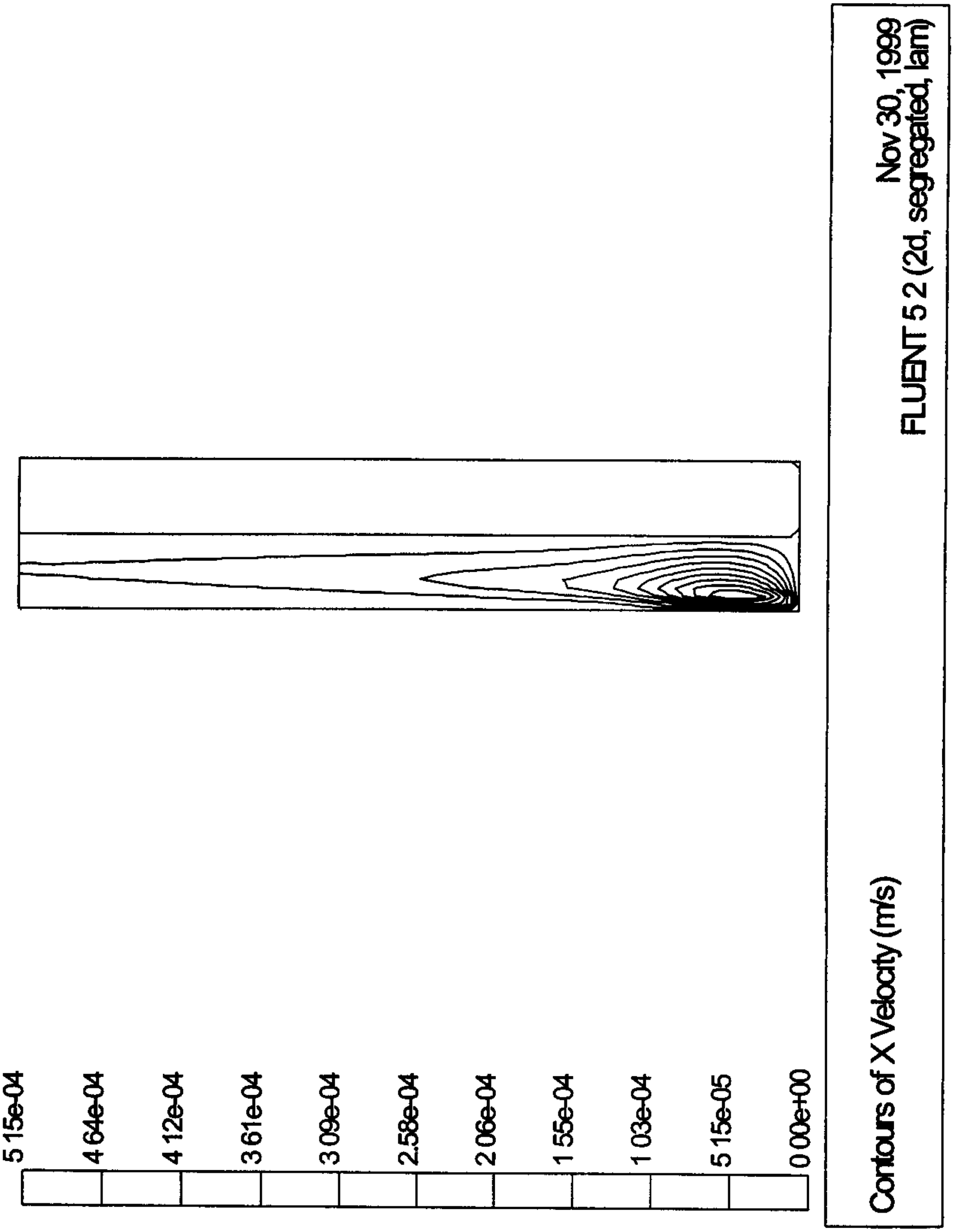


Figure D-14 Horizontal Velocity Contours on Left Side of Duct



ATTACHMENT A

VALIDATION CASE 6 FROM FLUENT INCORPORATED

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ATTACHMENT A

VALIDATION CASE 6 FROM FLUENT INCORPORATED

Validation 6. Periodic Flow in a Wavy Channel

6 1 Introduction

Periodic flows in wavy channels have many engineering applications, such as flows in heat exchangers Such flows often fall in the range of low-Reynolds number (< 10,000) turbulent flows and pose a challenge in the near-wall modeling of turbulence This case was found to be a good test to validate the prediction of low-Reynolds number turbulent flows Kuzan's experimental measurements [1] provide good benchmark data for this validation

6 2 Purpose

The purpose of this test is to compare the predictions of FLUENT's standard k-ε and RNG k-ε turbulence models, using the two layer zonal wall treatment, against the experimental results of Kuzan [1] for the u velocity profiles

6 3 Problem Description

The wavy bottom wall has a sinusoidal shape whose amplitude and wave length are 0 1 m and 1 0 m, respectively Since the flow is periodic, the computational domain can be chosen to cover only one period of the wavy channel, as shown in Figure 6 1 The length of the periodic domain is 1 m

6 3 1 Fluid Properties

The properties of the fluid are assumed to be constant The density is $\rho = 1$ kg/m^3, and the viscosity is $\mu = 1 \times 10^{-4}$ kg/m s

6 3 2 Flow Physics

The Reynolds number Re is based on the mean channel height, $D = (H+h)/2$, and the average fluid velocity at the mean channel height, $U = 0.816$ m/s

$$Re = \frac{\rho U D}{\mu} = 8,160 \qquad (6\ 1)$$

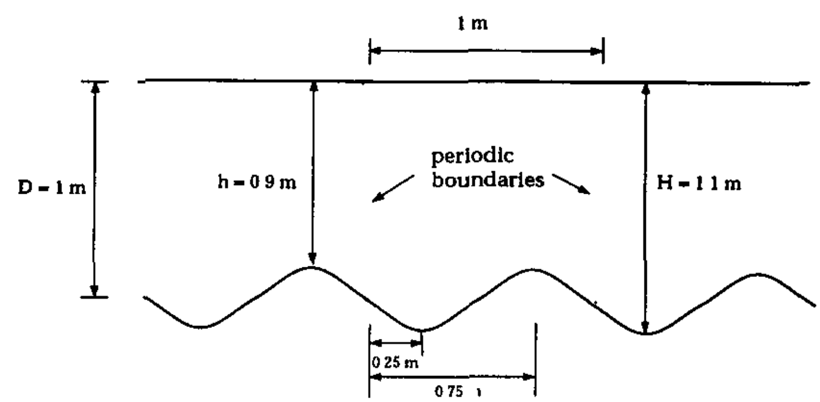

Figure 6 1 Problem Description

6 3 3 Boundary Conditions

Periodic boundary conditions were applied to the upstream and downstream boundaries of the domain The periodicity of the flow was specified using the mass flow rate of the fluid, $m = 0\ 816$ kg/s

6 4 Grid

An 81 × 91 quadrilateral mesh was generated Weighting factors were applied to concentrate the grid near the walls This grid is shown in Figure 6 2

6 5 Case Setup

The setup of the FLUENT case files was done using the mass flow rate periodic conditions and the constant fluid properties in Section 6 3

6 6 Calculation

Two cases were run The first run used the standard k ϵ turbulence model, and the second run used the RNG k-ϵ turbulence model In both cases the two-layer zonal model was chosen as the near-wall treatment because the Reynolds number is low ($Re = 8,160$)

6 7 Results

Figures 6 3 and 6 4 present the streamline contour plots obtained with the standard k-ϵ and RNG k ϵ models A large recirculation develops downstream

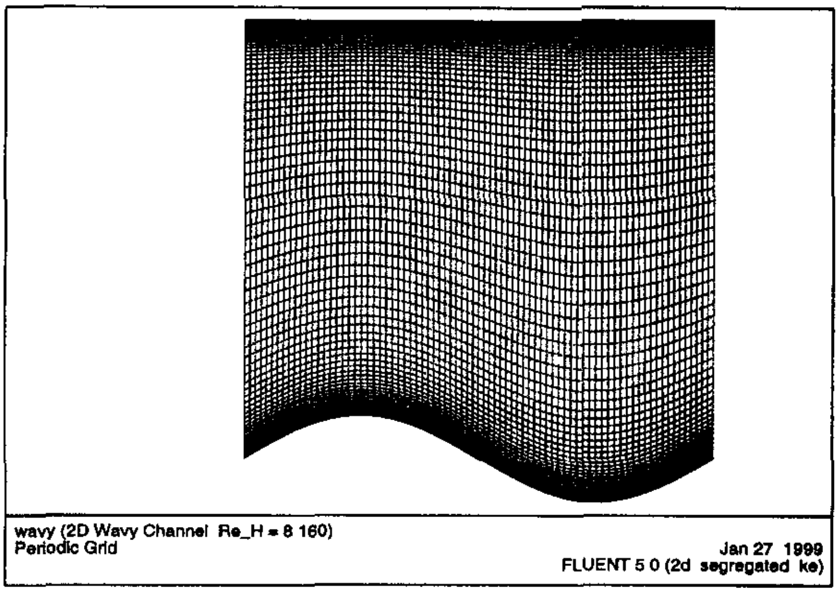

Figure 6 2 Grid

of the wave crest Far above the wave crest, streamlines are not perturbed

Figures 6 5–6 8 compare the u velocity profiles at the wave crest and at the wave trough with Kuzan's [1] experimental results for both the standard k-ε and the RNG k-ε models (The u velocity is normalized by the average fluid velocity at the mean channel height, $U = 0\ 816$ m/s)

The velocity profiles at the wave trough confirm that the flow reversal occurs in the wave hollow, thus creating a recirculation zone Near the top straight wall, velocity profiles remain attached to the wall The predictions are in very close agreement with the experimental data

6 8 Conclusion

The **FLUENT** near-wall treatment with the two-layer zonal turbulence model has been validated against the experimental data The test showed that both the standard k-ε model and the RNG k-ε model give good results

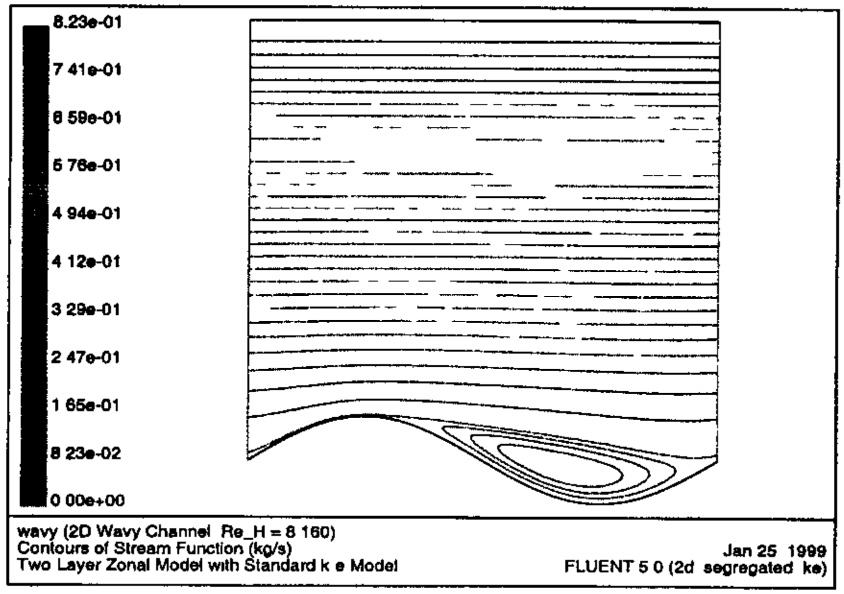

Figure 6 3 Contours of Stream Function (Standard k ε Model)

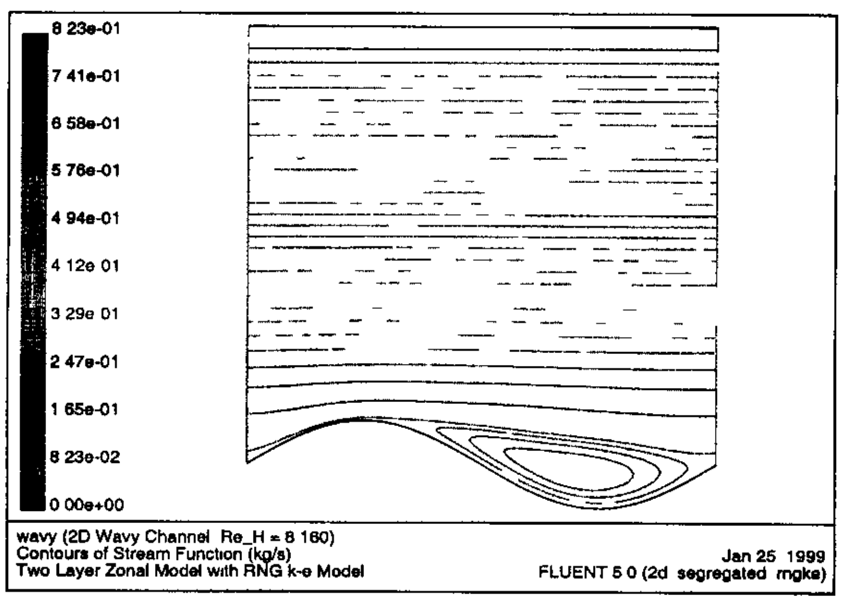

Figure 6 4 Contours of Stream Function (RNG k-ε Model)

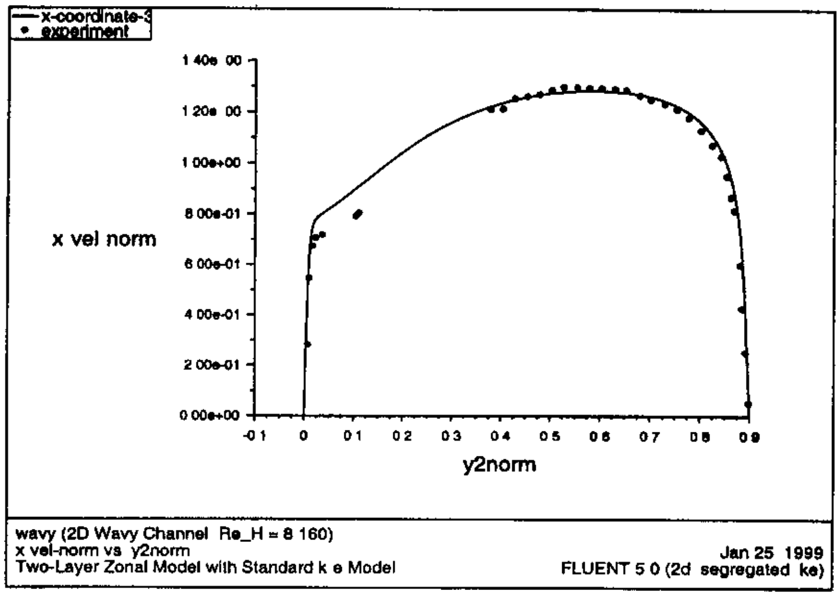

Figure 6 5 Normalized u Velocity at the Wave Crest (Standard k ε Model)

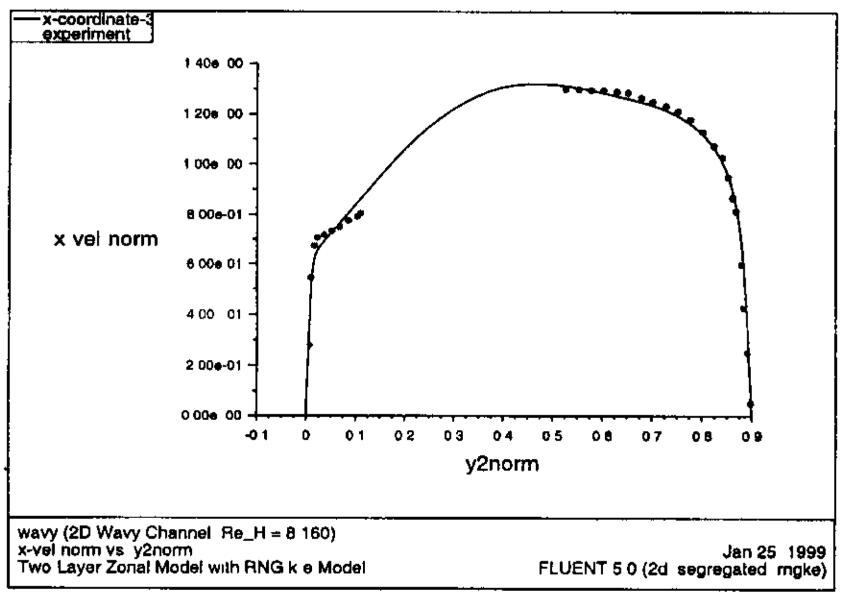

Figure 6 6 Normalized u Velocity at the Wave Crest (RNG k-ε Model)

Periodic Flow in a Wavy Channel

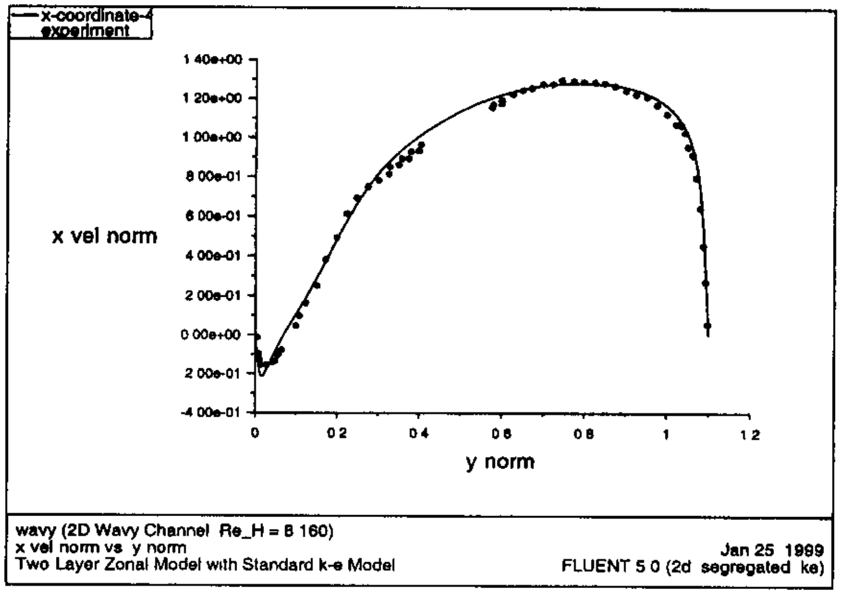

Figure 6 7 Normalized u Velocity at the Wave Trough (Standard k ε Model)

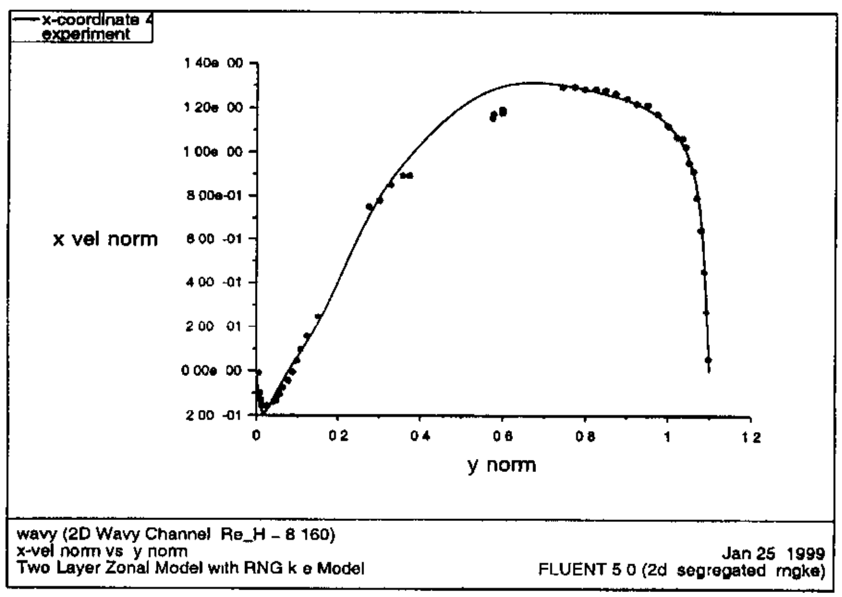

Figure 6 8 Normalized u Velocity at the Wave Trough (RNG k ε Model)

6 9 References

1 Kuzan, J D , *Velocity Measurements for Turbulent Separated and Near-Separated Flows Over Solid Waves*, Ph D thesis, Dept Chem Eng , Univ Illinois, Urbana, IL, 1986

6 10 Test Details

Test Date	November 18, 1998
Solver	FLUENT
Version	5 0
Platform	Sun Ultra
Case File(s)	wavy_std cas wavy_rng cas
Journal File(s)	wavy_r1 jou wavy_r2 jou
Data File(s)	wavy_std dat wavy_rng dat
Monitor File(s)	xvel_std mon xvel_rng mon
Experimental Data Files	crest exp trough exp

The files associated with this validation are arranged as follows The FLUENT case file(s) are in the top-level wavy directory FLUENT journal files to run the case(s) are in the subdirectory wavy/run The data files generated at Fluent Inc are stored in the wavy/run/out Fluent Inc subdirectory

If you wish to rerun this validation example automatically on your own platform, please follow these steps

1 Change directories to the wavy/run subdirectory

2 Create a subdirectory called out The journal files will save the data file from each run to this subdirectory (and not overwrite the data files supplied on your distribution CD ROM or tape, which are in the out Fluent Inc subdirectory) The journal file will not function unless this subdirectory exists

3 Start the 2D version of FLUENT

4 Read the journal file(s) (first for run 1, then run 2, etc)

The FLUENT journal file will

1 Read the case file

2 Adjust solution control parameters

3 Calculate

4 Write data and monitor file(s) to the out subdirectory

5 Quit from FLUENT

You may then restart FLUENT, read in the case and data files, examine the results, and compare them with the experimental profiles from the run/exp subdirectory as shown in this report

When carrying out any comparison bear in mind that minor differences in numerics from platform to platform are quite common Typically, such differences affect the residual and variable histories, but do not affect the final, converged result

ATTACHMENT B

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About ANSI

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Standardization A Management Tool for Building Success ▼

Helping to facilitate success

Consumer confidence through conformity assessment

A vital issue for business

The answer is ANSI

For our mutual good

The voice of America

Conformity assessment

What are the benefits to your business?

Value, integrity and service

Get involved today

Your involvement

Standardization A Management Tool for Building Success

Standards Up front on the world stage

As we move toward a global economy standardization issues continue to grow more complex In fact, standards are now absolutely critical to the survival and prosperity of companies marketing in multiple nations Products must function and be accepted in differing cultures value systems and environments What's more most goods are no longer produced in one community for use solely in that location and that affects us on the domestic front For example it is not unusual for products marketed in Europe to have been assembled in the U S from components made in Asia

As more international trade agreements are implemented domestic manufacturers will face growing competition from international concerns importing to the U S Standardization provides an international language to help shrink barriers to trade

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From a CEO standpoint we cannot be competitive if we do not develop the standards in such a way that we either have a leading edge or a competitive edge It is our intent and our hope to be able to generally license standards to broader markets thus adding to the accelerating technology that is molding our life

Ryal R Poppa Chairman and CEO Storage Technology Corp

When the ISO 9000 series of international quality standards was released in 1987 it represented the first attempt to link the world through one set of quality management systems standards The impact has been enormous By becoming an important criteria in selecting suppliers international standards like these have changed the face of world markets in the last few years Today additional implications confront the U S as we move forward with the implementation of the GATT and NAFTA agreements

That's why U S industry and government leaders have taken a second look at international standards and their implications for world trade Companies in every industry and of every size are realizing that they will have to be a part of the international standards scene if they are to survive (let alone thrive) There is a growing understanding that "either you help make the standards or play the game by your competitor's rules ' As a result more and more organizations are choosing to become proactively involved in standards development and implementation

Standards actually break down barriers to trade provide industry stability and encourage commerce

◆

APPENDIX E

PEER REVIEW CHECKLIST

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CHECKLIST FOR PEER REVIEW

Document Reviewed	HNF-1777, *K West Basin Integrated Water Treatment System Annular Filter Vessel Accident Calculations and Leak Path Factor Derivations*
Scope of Review	Appendixes A and D
Author	M G Piepho

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

ALOK K BISWAS *A K Biswas* 12/9/99

Reviewer (Printed Name and Signature) 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**

CHECKLIST FOR PEER REVIEW

Document Reviewed	HNF-1777 Revision 5, *K West Basin Integrated Water Treatment System Annular Filter Vessel Accident Calculations and Derivation of Leak Path Factors*
Scope of Review	Section 7, Appendices A, D
Author	M G Piepho

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

Paul Rittmann 12-27-99

Reviewer (Printed Name and Signature) 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

CHECKLIST FOR PEER REVIEW

Document Reviewed HNF-1777 Revision 5 *K West Basin Integrated Water Treatment System Annular Filter Vessel Accident Calculations and Derivation of Leak Path Factors*

Scope of Review All Sections and Appendices

Author M G Piepho P D Rittmann

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
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[✓]	[ ]	[ ]	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**

Steven H Peck Steven H Peck 1/4/2000

Reviewer (Printed Name and Signature) 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

[a] Models in Sections 3, 4 5 and 6 have not changed from Rev 4, New models in added Section 7 0 and Appendices A & D were reviewed elsewhere (see other checklists)

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