APPENDIX A

DEBRIS GENERATION AND DRYWELL TRANSPORT CALCULATIONS

1. Insulation Inventories and Break Locations

The estimates of insulation inventories made by the licensee are documented for Units 2 and 3 in Refs. A-1 and A-2, respectively. Additional discussion of Unit-3 debris sources is provided in Ref. A-3, and the methodology used in this reference for modeling debris generation and transport to the suppression pool is described in Ref. A-4. Initial calculations performed by the licensee based on original fiber inventories cited in the above references suggested that significant head loss might occur across the Emergency Core Cooling System (ECCS) suction strainers following a large loss-of-cooling accident (LOCA). It was recommended that fibrous insulation be removed or replaced with reflective metallic insulation (RMI) as operations permitted, and thus, current inventories are based largely on verbal amendments to the published tables of insulation location and volume.

An independent calculation was performed of the insulation-debris volume that might be transported from the drywell to the suppression pool in a postulated large LOCA. The results of this calculation depend on the accuracy of "as left" insulation inventories provided by the licensee. Inventory data, which are provided for nonmetallic insulation in Tables A-1 (Ref. A-1) and A-2 (Ref. A-2), were collected by visual inspection of each operating floor within the drywell. In many cases, additional linear length was added to piping segments to account for the presence of valves and fittings. Other engineering approximations used to quantify the insulation volumes within the drywell are itemized in Ref. A-2.

In general, RMI dominates the gross insulation inventory at the Dresden plants. Only one pipe was reported to have calcium-silicate (Cal-Sil) insulation.[1] All other isolated applications of nonmetallic insulation, such as on valves, wall penetrations, elbows, and short piping segments, use NUKON™ fiberglass. Also of note is the fact that Unit 3 contains no nonmetallic insulation below the level of the lowest grating at reference elevation 515 ft. (The lowest operating level is at 492.3 ft). Unit 2 contains 11 ft^3 of fiber in the basement area below the lowest grating.

The Unit 2 estimated fibrous-insulation inventory of 94.36 ft^3 reported in Table A-1 is slightly higher than the value of 90.6 ft^3 reported by the licensee (Attachment A-1) in their summary of data pertinent to Bulletin 96-03 (Ref. A-5). It should be noted that many additional fiber locations were found in the original inspection, but verbal assurance was given that much of this material had been removed or replaced with RMI. The discrepancy between the estimated Unit 2 inventory and the reported inventory may be a result of incomplete information regarding which locations had been changed. Fiber insulation replaced or removed between the time of the inspection and the present amounts to a 26% reduction from the previous inventory.

A total insulation inventory was not reported by the licensee for Unit 3, but a review of tabular data provided in calculation DRE96-0262 suggests that Unit 3 contains approximately 96.25 ft^3 of fibrous NUKON™ and 5.052 ft^3 of Cal-Sil. This is somewhat less Cal-Sil than the 8.24 ft^3 reported in Attachment A-1. With regard to location, fiber is scattered throughout the drywell of both units with no particular emphasis on specific systems or components.

[1]The recirculation-water clean-up line around the midplane of Unit 3 is encased in Cal-Sil.

Table A-1. Nonmetallic Insulation Inventories for Dresden Unit 2[1,2,3]

Operating Level	Process Component	Insulation Thickness	Outside Diameter / Description	Approx. Azimuth[4]	Length / Size	Calculated Volume
Basement						
	Inboard B pumps	2 in	28-in. suction pipe	270°	3 ft	3.90 ft^3
	LPCI lines[5]	2 in	16-in. pipe includes two 45° fittings	270°	9 ft	7.07 ft^3
					Subtotal =	10.97 ft^3
First Floor						
	B discharge riser	2 in	28-in. pipe	270°	5 ft	6.54 ft^3
	A and D MSIV drain line[6]	2 in	2-in. pipe	0°	3 ft	0.52 ft^3
	LPCI line off of A suction riser	2 in	Tee from 16-in. pipe to 28-in. riser	90°	1 ft each side	1.05 ft^3
	N2A riser	2 in	28-in. pipe	90°	7 ft	9.16 ft^3
	2C main steam	2 in	2pc on two 1-ft x 2-ft rectangular hanger plates	320°	8 ft^2	1.33 ft^3
	D MSIV main steam	2 in	1pc on one 1-ft x 2-ft rectangular hanger plate	5°	4 ft^2	0.67 ft^3
					Subtotal =	19.27 ft^3
Second Floor						
	2B main steam line	2 in	28-in. pipe	105°	3 ft	3.93 ft^3
	Shutdown cooling	2 in	18-in. pipe	15°	3 ft	2.62 ft^3
	Shutdown cooling	2 in	18-in. pipe	15°	1 ft	0.87 ft^3
	2A feedwater to 2A sparger	2 in	12-in. pipe	60°	3 ft	1.83 ft^3
	2B feedwater to 2D sparger	2 in	12-in. pipe	320°	3 ft	1.83 ft^3
	2C main steam from reactor to HP turbine	2 in	28-in. pipe	255°	3 ft	3.93 ft^3
	2B feedwater to 2C sparger	2 in	12-in. pipe	240°	2 ft	1.22 ft^3
	2A feedwater to 2B sparger	2 in	12-in. pipe	150°	3 ft	1.83 ft^3
					Subtotal =	18.06 ft^3
Third Floor						
	N19B nozzle	3 in	Core-spray piping penetration	180°	5 ft x 5 ft square	6.25 ft^3
	N19B nozzle	2 in	12-in. pipe	180°	2 ft	1.22 ft^3
	N4C nozzle	3 in	Feedwater pipe	230°	4 ft x 4 ft square	4.00 ft^3
	Nozzle feedwater piping	3 in	12-in. pipe	230°	3 ft	2.95 ft^3
	N9 nozzle	3 in		165°	3 ft x 3 ft square	2.25 ft^3
	N9 nozzle	2 in	2-in. pipe	165°	1 ft	0.175 ft^3
	N16B nozzle	3 in		225°	3 ft x 3 ft square	2.25 ft^3
	N16B nozzle	3 in	1-in. pipe wrapped twice	225°	3 ft	1.57 ft^3

Operating Level	Process Component	Insulation Thickness	Outside Diameter / Description	Approx. Azimuth[4]	Length / Size	Calculated Volume
	N4D nozzle	3 in		315°	3 ft x 6 ft rectangle	4.50 ft^3
	2A core-spray line	2 in	12” pipe	320°	two 90° elbows	1.83 ft^3
	N19A core-spray nozzle	3 in		20°	4’ x 4’ square	4.00 ft^3
	N19A core-spray nozzle	2 in	12” pipe	20°	3 ft	1.83 ft^3
	N16A feedwater nozzle	3 in		35°	2’ x 4’ rectangle	2.00 ft^3
	N16A nozzle	2 in	2” pipe wrapped twice	35°	3 ft	1.05 ft^3
	N4A nozzle	3 in		80°	2’ x 2’ square	1.00 ft^3
					Subtotal =	36.88 ft^3
Fourth Floor						
	N13A nozzle	2 in	2” pipe	75°	6 ft	1.05 ft^3
	N13B nozzle	2 in	2” pipe	225°	6 ft	1.05 ft^3
	HPCI nozzle penetration	3 in	12” pipe	90°	56 in	4.58 ft^3
	missing wall panel	3 in		225°	2.5’ x 4’ rectangle	2.50 ft^3
					Subtotal =	9.18 ft^3
					Total =	94.36 ft^3

[1]Many other insulated components were noted in the original inspection, but verbal assurance was given that they had already been replaced.
[2]Unit 2 inventories taken from licensee calculation DRE98-0056 (Ref. 1).
[3]Insulation type is NUKON™ fiberglass unless otherwise noted.
[4]Azimuth referenced clockwise from north where main steam lines penetrate the drywell.
[5]Due for replacement during the next outage.
[6]Located inside a drywell penetration.

Table A-2. Nonmetallic Insulation Inventories for Dresden Unit 3[1,2,3,4]

Process Component	Insulation Thickness	Outside Diameter / Description	Length/Size	x (in)	y (in)	z (in)	Calculated Volume
Miscellaneous:							
Instrument tap at penetration	1 in	1.05-in. pipe	10 ft	710	407	6953	0.229 ft^3
Vessel Face	2 in		10 ft^2	654	459	6852	1.667 ft^3
Feedwater Piping	2 in	12.75-in. pipe	1.5 ft	464	788	6540	0.834 ft^3
Penetration X-111A	2 in	16-in. pipe	3 ft	454	899	6468	2.094 ft^3
Vlv. 3-203-3A	2 in	10 ft^2		684	801	6507	1.667 ft^3
Reactor Recirculation	2 in	7 ft^2		571	377	6390	1.167 ft^3
RWCU	1.5 in	2.375-in. pipe with Cal-Sil	65 ft	75° - 180° azimuth		6300	5.052 ft^3
						Fiber SubTotal =	7.658 ft^3
						Cal-Sil Sub Total =	5.052 ft^3
Feedwater Lines:							
Nozzle N-4A	2 in	12.75-in. pipe	8 ft	716	635	6854	4.451 ft^3
Nozzle N-4B	2 in	12.75-in. pipe	8 ft	659	448	6846	4.451 ft^3
Nozzle N-4C	2 in	12.75-in. pipe	8 ft	456	497	6854	4.451 ft^3
Nozzle N-4D	2 in	12.75-in. pipe	8 ft	522	720	6860	4.451 ft^3
						Fiber Subtotal =	17.80 ft^3
Main Steam Relief Valves:							
Vlv. 3-203-4A	2 in	Valve	8 in. x 50 in.	705	780	6507	0.463 ft^3
Vlv. 3-203-4B	2 in	Valve	8 in. x 50 in.	769	716	6507	0.463 ft^3
Vlv. 3-203-4C	2 in	Valve	8 in. x 50 in.	798	759	6507	0.463 ft^3
Vlv. 3-203-4D	2 in	Valve	8 in. x 50 in.	842	609	6507	0.463 ft^3
Vlv. 3-203-4E	2 in	Valve	8 in. x 50 in.	370	751	6507	0.463 ft^3
Vlv. 3-203-4F	2 in	Valve	8 in. x 50 in.	393	774	6507	0.463 ft^3
Vlv. 3-203-4G	2 in	Valve	8 in. x 50 in.	429	738	6507	0.463 ft^3
Vlv. 3-203-4H	2 in	Valve	8 in. x 50 in.	450	759	6507	0.463 ft^3
Vlv. 3-203-3B				842	555	6507	3.65 ft^3
Vlv. 3-203-3C				334	591	6507	3.65 ft^3
Vlv. 3-203-3D				386	695	6507	3.65 ft^3
Vlv. 3-203-3E				842	698	6507	3.65 ft^3
						Fiber Subtotal =	18.30 ft^3
Vessel Level Indicators:							
Level Ind. 2				45° azimuth		6936	0.4775 ft^3
Level Ind. 4				235° azimuth		6936	0.4775 ft^3
Level Ind. 1				45° azimuth		6804	0.4775 ft^3
Level Ind. 3				235° azimuth		6804	0.4775 ft^3
						Fiber Subtotal =	1.91 ft^3

Process Component	Insulation Thickness	Outside Diameter / Description	Length/Size	x (in)	y (in)	z (in)	Calculated Volume
Main Steam Isolation Valve Drains:							
3-3007A-1 1/2”				0° azimuth		6180	3.36 ft^3
3-3007B-1 1/2”				0° azimuth		6180	3.36 ft^3
3-3007C-1 1/2”				0° azimuth		6180	3.36 ft^3
3-3007D-1 1/2”				0° azimuth		6180	3.36 ft^3
3-3007B-2”				0° azimuth		6180	3.36 ft^3
						Fiber Subtotal =	16.80 ft^3
Feed Water Check Valves:							
3-220-58A				517	918	6240	16.89 ft^3
3-220-58B				665	909	6222	16.89 ft^3
						Fiber Subtotal =	33.78 ft^3
						Fiber Total =	96.25 ft^3
						Cal-Sil Total =	5.052 ft^3

[1] Many other insulated components were noted in the original inspection, but verbal assurance was given that they had already been replaced.

[2] Unit-3 inventories taken from licensee calculation DRE96-0262 (Ref. A-2).

[3] Insulation type is NUKON™ fiberglass unless otherwise noted.

[4] Lateral coordinates are given in inches referenced from surveyed column markers; the reactor is located at $x = 588$ in., $y = 573$ in. Vertical coordinates in inches are the same as those used for Dresden plant drawings.

The licensee specifically excluded the volume of foam insulation present in the drywells of each unit from debris generation using the rationale that it would float and could not contribute to blockage of the ECCS suction strainers. The licensee reports approximately 6.2 ft^3 of foam for Unit 3; no estimate was available for Unit 2.

Both units also contain approximately 13.9 ft^3 of asbestos in each pipe penetration through the containment vessel. A break within the penetration could eject this material and damage insulation present inside the drywell. This scenario was not considered in the debris-generation analysis because (1) large-LOCA breaks in the penetrations are unlikely, (2) it is difficult to estimate the directed zone of influence that would vent from the penetration, and (3) other break locations can lead to higher fibrous debris generation. Asbestos was not considered as a debris source in this analysis because other break locations in the drywell cannot severely affect insulation within the penetrations.

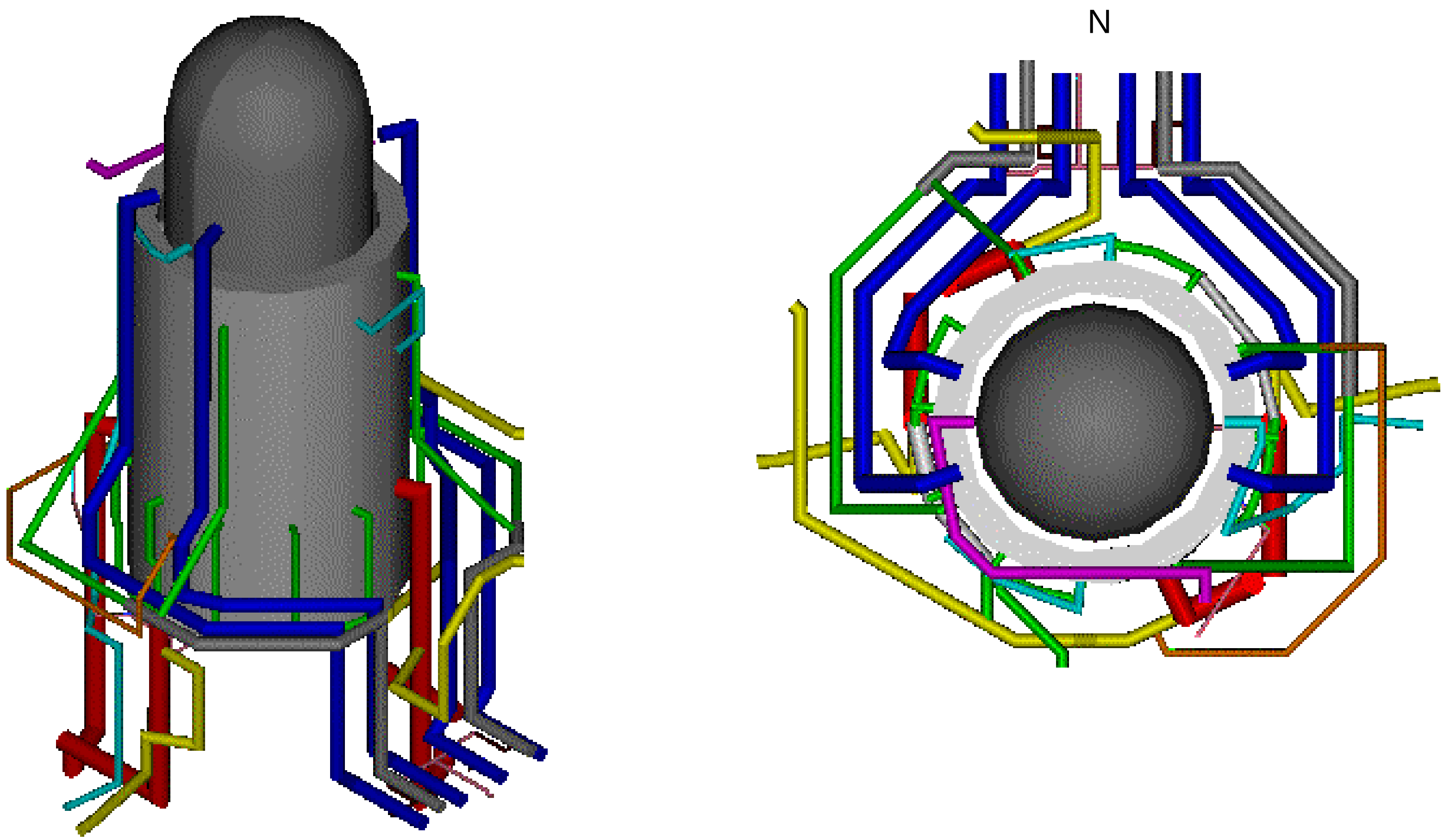
Large inventories of insulation are also present in the reactor cavities and in the bioshield penetrations of both Dresden units. Break scenarios near the reactor were not considered here because, in addition to the three issues listed above, there is no direct transport pathway out of the reactor cavity to the suppression pool.

For Unit 3, the licensee provided a three-dimensional AutoCAD™ model of all insulated pipes and components (Ref. A-2); it is assumed that Unit 2 shares the same physical arrangement. Figure A-1 illustrates the configuration of insulated structures present inside the drywell. This model helps greatly to visualize regions of piping congestion for the purpose of selecting a bounding-scenario break location. Physical boundaries provided by the containment vessel are overlaid on internal structures in Fig. A-2 to serve as a visual reference of size. The lower containment sphere is 66 ft in diameter.

One product of the AutoCAD™ model that is of particular interest to this study is a table of weld locations that were considered as potential break locations. Locations for welds in 28-in.-o.d. pipes are reproduced in Table A-3. Because of the large destruction zones for 28-in. pipe breaks relative to the size of the drywell and the diverse locations of 28-in. lines, welds in smaller pipes were not examined for this assessment.

2. Licensee Debris Generation and Transport Calculation

Given the insulation inventory for Unit 3, the licensee used the PIPES program (Ref. A-6) to model the volume of debris generated and transported during a large LOCA. This utility represents insulation volumes such as pipe casings and valve blankets by a number of line segments and spatial points. The insulation volumes then are mapped into a spherical zone of influence (ZOI) of appropriate size for the destruction pressure of the insulation type to determine the amount of debris generated. Simple transport factors then are applied to the debris volume that depend on the location of the insulation above and below the lowest grating in the drywell to determine the amount that reaches the suppression pool. A table of weld locations in pipes greater that 12 in. in diameter was evaluated to determine the worst-case debris volume. The most conservative debris volume then was reported as the basis for suppression-pool transport.



(a) (b)

Fig. A-1. Insulated piping systems and components in the drywell of Dresden Unit 3. The highest piping congestion, and hence the highest insulation density, occurs at the lower right of panel (a) where main steam lines penetrate the containment. Azimuths are referenced in degrees east of north as labeled in panel (b).

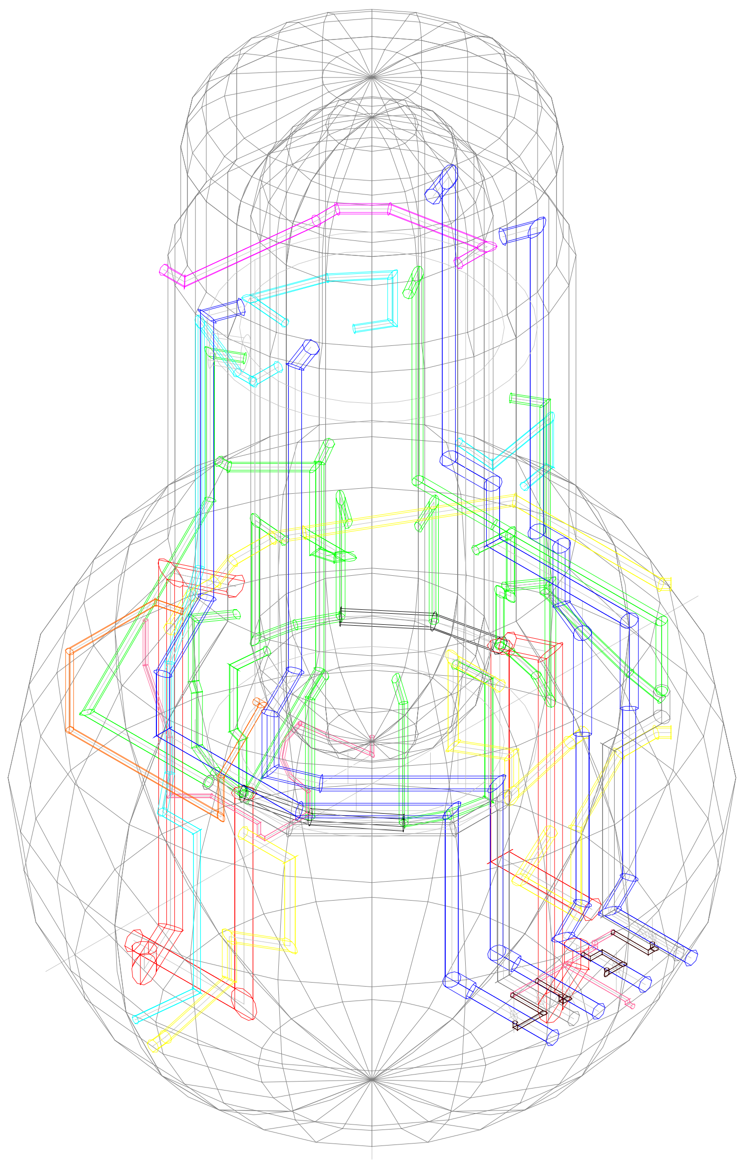


Fig. A-2. Wire frame image of Dresden Unit 3 piping systems that shows relative size and location of the drywell.

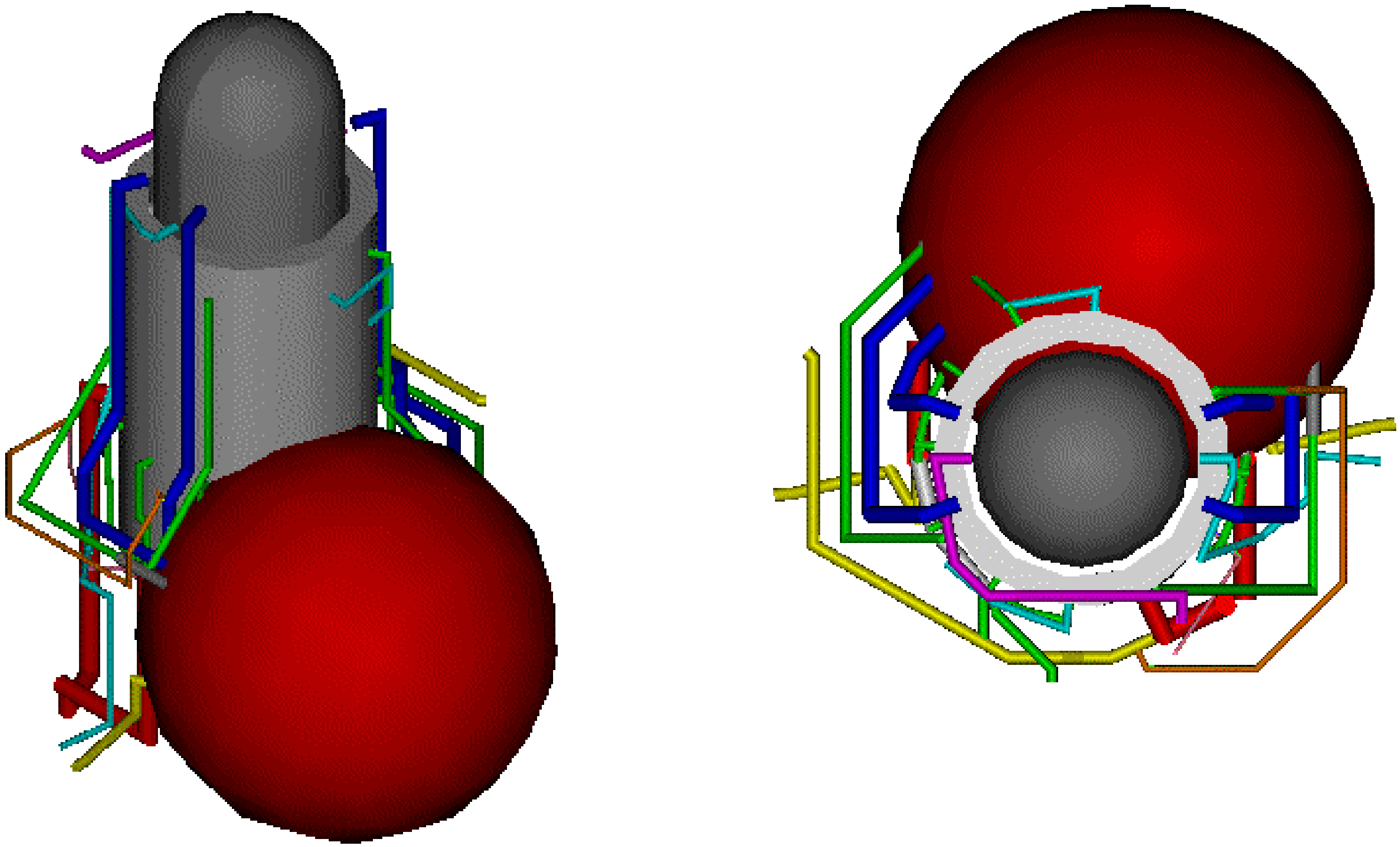
Table A-3. Weld Locations in 28-in.-o.d. Piping[1,2]
(Independent estimates of maximum debris generated from these locations in Unit 3 are also given. See Sec. A3).

Line	Sequential Weld #	Coordinates (reference inches) x	y	z	Max. Debris (ft^3) Generated from this Location
3-0201A-28"	1	785	430	6108	9.8
	2	785	465	6108	13.2
	3	785	530	6108	14.5
	4	785	573	6207	17.6
	5	785	573	6308	16.1
	6	785	573	6364	18.3
3-0202A-28"	7	737	385	6056	18.5
	8	687	362	6105	10.4
	9	687	362	6169	11.7
	10	687	362	6409	11.1
	11	659	420	6530	10.1
	12	655	430	6530	9.6
3-0201B-28"	13	391	715	6108	16.1
	14	391	680	6108	16.4
	15	391	615	6108	16.0
	16	391	573	6194	16.4
	17	391	573	6304	19.1
	18	391	573	6368	17.9
3-0202B-28"	19	450	737	6055	16.1
	20	501	760	6191	17.5
	21	501	760	6256	20.1
	22	501	760	6417	21.7
	23	518	722	6529	20.8
	24	522	715	6529	22.4

[1]Weld location 21 was identified by the licensee as producing and transporting the maximum volume of 18.4 ft^3 of fiber to the sump screen.
[2]Coordinates are provided on the pipe centerlines. In this system, the center of the reactor core is at $x = 588$ in. and $y = 573$ in.

RMI is used on almost all piping systems and components at Dresden. Rather than reporting a total volume and estimating debris generation and transport, it is assumed in the licensee analysis (and in LANL independent review) that a saturation bed of shredded RMI will build up on the suction strainers.

Except for one pipe in Unit 3 that is wrapped in calcium silicate, all nonmetallic insulation present in the Dresden drywells is fibrous NUKON™. Unjacketed NUKON™ has a destruction pressure of 10 psia, which leads to a spherical ZOI with radius $R_{ZOI}\{ft\} = 10.4D\{ft\}$ where D is the diameter of the broken pipe (Ref. A-7). For the 28-in.-diam pipe welds examined in this review, $R_{ZOI} = 24.2$ ft. Figure A-3 shows the volume affected by a 48-ft-diam spherical ZOI.



(a) (b)

Fig. A-3. A 48.5-ft-diam, 10-psia, spherical ZOI generated from a double-ended guillotine break of a 28-in.-diam pipe encompasses almost half of the Dresden drywell.

Destruction pressures specific to calcium silicate are not available, so the entire volume of the one calcium-silicate-wrapped pipe was included in all break scenarios for Unit 3. In part, this assumption was rationalized by assuming that calcium silicate will erode or dissolve in the downwash of containment sprays. (No experimental evidence currently exists to support or refute this conservative assumption.) Similarly, a drywell transport factor of 1.0 was used to force all of the calcium silicate into the suppression pool. This approach is conservative because, even though the ZOI is very large, the recirculation-water clean-up line in question wraps around 105° of the drywell. Calcium silicate is thought to degrade to a particulate form that may exacerbate strainer head loss when fibrous material is also present in the suppression pool.

Figure A-4 shows the basic dimensions of the two Dresden drywells. Semicontiguous floor gratings are present at elevations 515 ft, 537 ft, 562 ft, and 576 ft. The downcomer orifices sit just above the basement floor at an elevation of 503 ft. The cylindrical bioshield wall and reactor vessel occupy a large portion of the upper drywell. They would certainly provide shadowing to some insulation from the pressure jet in a real LOCA; however, no credit was given for this in estimates of debris generation. Drywell transport factors for fibers were applied in accordance to the recommendations of Ref. A-7; i.e., 0.28 for debris generated above the lowest grating and 0.78 for debris generated below the lowest grating.

The licensee provided debris volume and transport estimates for two scenarios: (1) a large-pipe break somewhere in the drywell volume and (2) a large-pipe break within the drywell penetration (flued head). A break within a containment penetration ejects the resident asbestos and damages some amount of peripheral fiber and metallic insulation. They estimated the damaged volume at 100% asbestos (~13.9 ft^3), 1.93 ft^3 of fiber, and 0 ft^3 of calcium silicate for Unit 2 and, 2.67 ft^3 of fiber and 8.24 ft^3 of calcium silicate for Unit 3. They also cite drywell transport factors for asbestos of 0.24 for material generated above the grating and 0.54 for material generated below the grating. Neither the damaged volume from a directed jet nor the asbestos transport factors can be verified easily, so the LANL review only considers the free-volume break scenario, which generates approximately 18.5 ft^3 of fiber debris.

A third scenario was examined by the licensee (Ref. A-3) that consists of a break within the bioshield wall. The ZOI was assumed to encompass all insulation inside the wall and all insulation within penetrations. A very large volume of shredded RMI and 1.43 ft^3 of NUKON were assumed, but no transport path is available out of the reactor cavity to the suppression pool. As a result LANL independent analysis does not examine this scenario.

For estimate debris value the licensee stated to have applied debris-generation Methods 2 and 3 described in Ref. 7. It appears that Method 2 was applied to free-volume breaks and Method 3 was applied to breaks within containment penetrations. For Unit 2, the volume of insulation within the ZOI was estimated crudely using two overlapping vertical regions with heights roughly equal to the ZOI diameter. (One zone extends from the basement up to the third level, and one zone extends from the first floor up to the fourth level). All of the insulation within each region was added, and the appropriate drywell transport factor was applied depending on target location. Results for the more conservative case were reported.

Conservative assumptions used by the licensee for the free-volume break scenario include (1) no shielding of target insulation by intervening structures, (2) no pipe restraint at the break location so that maximum separation and offsets apply, and (3) no credit taken for special jackets and bands that are present on some insulation blankets (treated as unjacketed material).

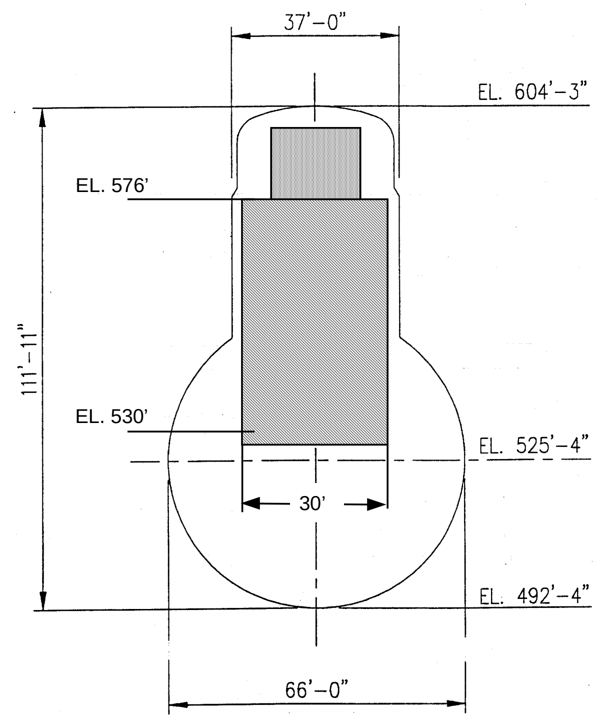


Fig. A-4 Rough dimensions and elevations for the Dresden drywell. The biological shield and reactor vessel fill most of the upper containment volume.

3. Independent Estimate of Debris Generation and Transport

To verify the amount of transported debris estimated by the licensee, an automated sampling scheme was developed to superimpose spherical ZOIs on the insulation inventories provided in Tables A-1 and A-2. Applications of fiber insulation in the plants are spaced randomly throughout the drywell on short pipe segments, valves, and penetrations, so it seemed reasonable to treat these volumes as point targets that could be affected by a large-LOCA break. The single pipe in Unit 3 using Cal-Sil insulation is too long for the point approximation to be valid, but, because some segment of this pipe would be affected by a break at any location, the entire volume of Cal-Sil was transported to the suppression pool for added conservatism. Large volumes of RMI also would be damaged by a break at any location; therefore, it was assumed for head-loss calculations that a saturation bed of shredded foil would eventually accumulate on the suction strainers.

Exact spatial locations and orientations were not available for the Unit 2 insulation volumes reported by the licensee. Instead, rough elevations were given based on the operating level, and rough azimuthal angles were given based on the location around the drywell. For this investigation, the vertical and radial coordinates of each point insulation target were sampled randomly between appropriate floor elevations and from the centerline to the outer wall of the drywell. Random locations that fell within the volume of the bioshield or the reactor vessel were discarded so that realistic placements could be obtained. Although complete coordinates were available for Unit 3 insulation volumes, the radial and vertical information was discarded so that sampling could be performed consistent with the approach used for Unit 2.

A simple computer program called BWRDEBRIS (Attachment A-2) was developed in the MATLAB macro language (Ref. A-8) to sample the target insulation locations and to map spherical ZOIs within the drywell. Figures A-5 through A-7 show the capabilities of the tool for visualizing target-insulation locations (small yellow objects) with respect to the drywell (large yellow objects) for a spherical ZOI (large blue objects) centered at a given break location (magenta object). Operating floors are shown in red, and insulation targets enveloped by the ZOI are shown as small blue objects. This tool was found to be very helpful for identifying potential regions of high insulation density.

For a given break location, each random insulation configuration leads to a different estimate of transported debris. After several thousand configurations have been evaluated (in approximately 10 min of computer time), one obtains a distribution of debris volume that might be transported similar to that shown in Fig. A-8. The range of debris volume transported to the suppression pool is shown on the *x* axis, and the numbers of samples observed with estimated volumes in each histogram bin are shown on the *y* axis. For this example, the maximum transported debris volume was 19.8 ft^3. Recall that the variation in transported volume shown in this figure is solely the result of the uncertainty regarding the actual location of the insulation with respect to the ZOI. Many other factors of uncertainty have been addressed by the conservative choice of transport factors, zero sheltering, etc.

A distribution of transported debris volume based on 1000 insulation configurations was generated for each weld location listed in Table A-3 for 28-in.-diam pipes. The maximum volume observed for each weld is listed in the table for Unit-3 insulation inventories. Weld location #24 in pipe 3-0202B-28" showed the highest transported fiber volume of 22.4 ft^3, which is significantly higher than the 18.4 ft^3 reported by the licensee. Their estimate was based on one plant-specific insulation configuration, so it is not surprising that a random configuration might artificially group more insulation into the ZOI. Most distributions of transported debris generated in this analysis had a mode (maximum probability) of between 18 and 19 ft^3 independent of break location, which indicates that the spherical ZOI is large with respect to the drywell. Similar results were obtained using Unit-2 insulation inventories.

4. Recommendations

Independent verification confirms transported fibrous debris volumes in the range of 18.5 to 19 ft^3, consistent with the licensee estimates of 18.26 and 18.4 ft^3 for Units 2 and 3, respectively. Estimates 20% higher were obtained from artificial target locations, but there is no compelling reason to suspect such high insulation density within the drywell.

LANL believes that the licensee needs to update and document the current estimate of insulation types and volumes present in the drywells of Dresden Units 2 and 3. The recent practice of removing and replacing fibrous NUKON undoubtedly improves plant safety with respect to strainer head loss in a postulated LOCA, but it leaves some ambiguity about the quantitative basis for that improvement. The current configuration could be documented by revising an existing reference that describes a known inventory in the past to include dates of completion on work orders performed to modify specific applications of insulation. Both the plant analysis and this independent review have given credit for low inventories of fiber that currently are substantiated by anecdote only.

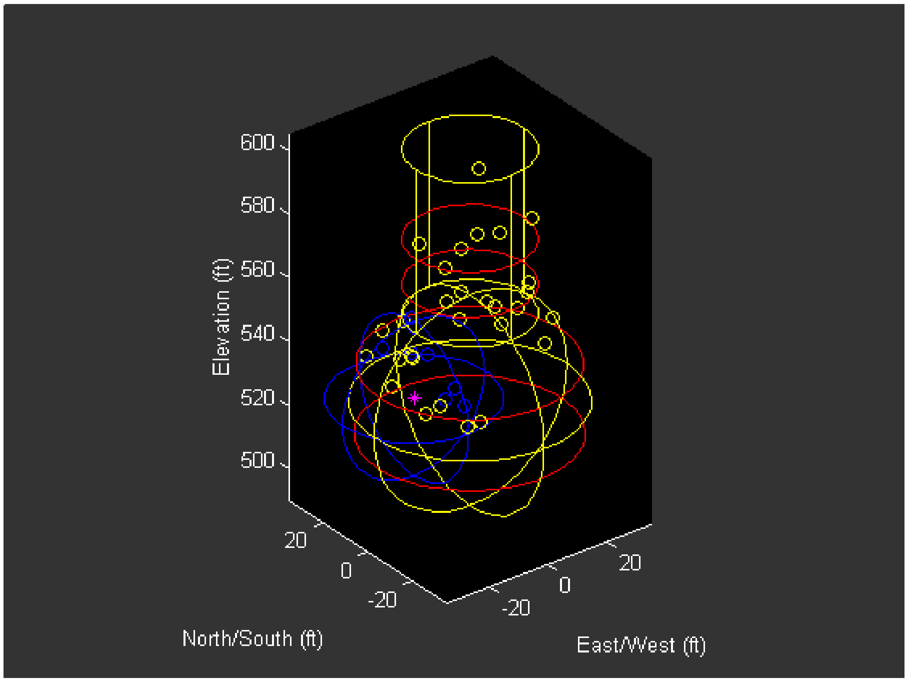


Fig. A-5. Perspective of randomly located point insulation sources (small yellow) relative to the drywell containment structure (large yellow), the floor grating (red), and the spherical ZOI (magenta/blue) for a 28-in. pipe break.

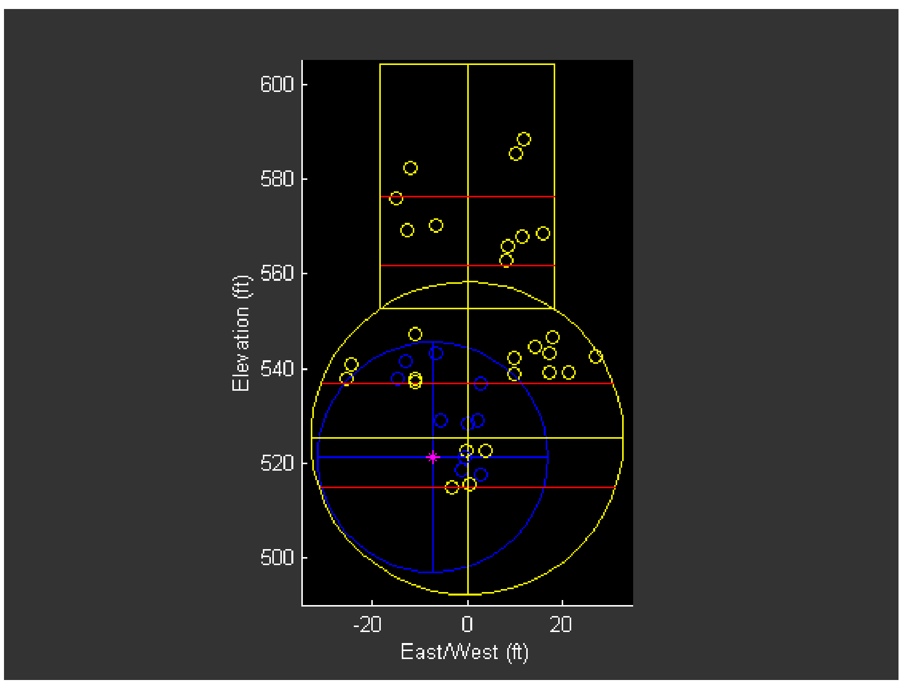


Fig. A-6. Side view of randomly located point insulation sources (small yellow) relative to the drywell containment structure (large yellow), the floor grating (red), and the spherical ZOI (magenta/blue) for a 28-in. pipe break.

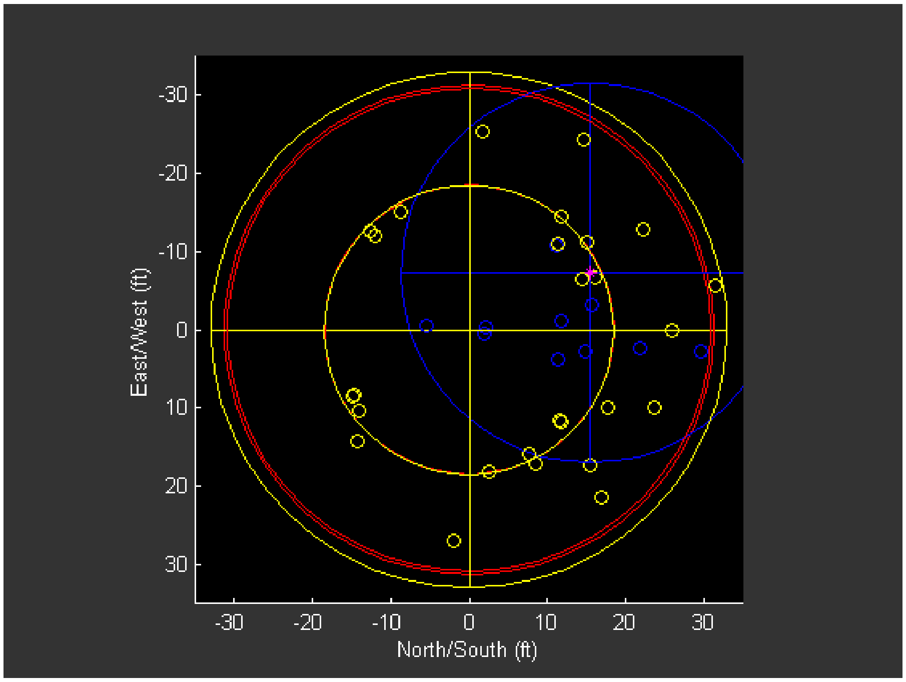


Fig. A-7. Top view of randomly located point insulation sources (small yellow) relative to the drywell containment structure (large yellow), the floor grating (red), and the spherical ZOI (magenta/blue) for a 28-in. pipe break.

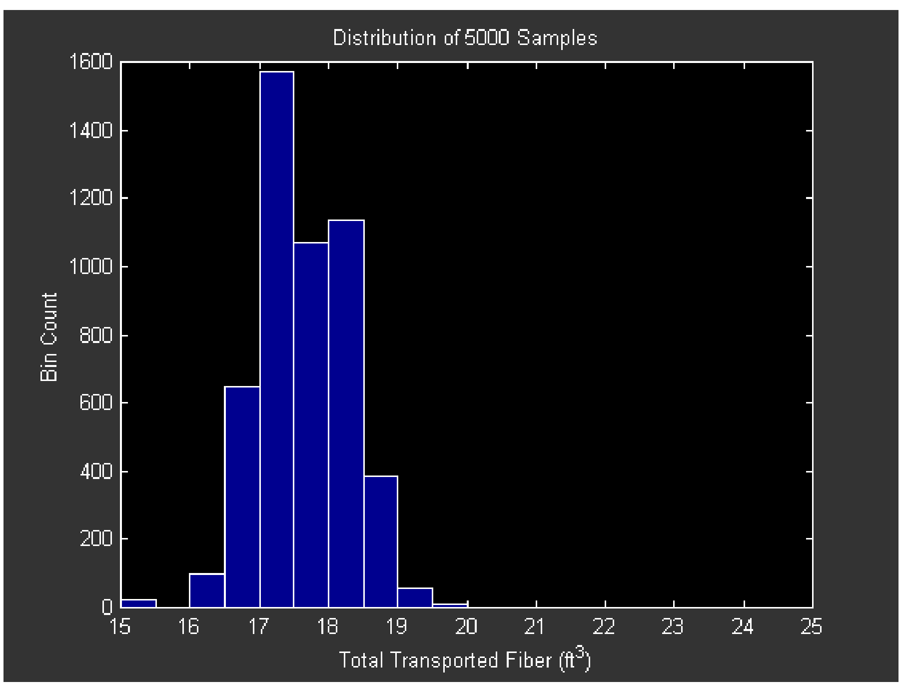


Fig. A-8. A simple counting distribution of total fiber transported to the suppression pool for 5000 trials of point insulation sources randomly located relative to a 28-in. pipe break at weld location 3-0202B-28". The maximum transported volume in this sample is 19.8 ft^3.

References

A-1. Calculation DRE98-0056, “Unit-2 Sources of Fibrous Debris,” R.1, Attachment C, pp. C15 – C16.

A-2. Calculation DRE96-0262, “Dresden Unit-3 Three-Dimensional AutoCAD Release-13 Model of the Insulated Pipes Inside the Drywell,” Exhibit C, NEP-12-02, Rev. 4, January 21, 1997.

A-3. Calculation DRE97-0154, “Unit-3 Estimation of Debris Sources.”

A-4. Calculation DRE99-0018, “Methodology for Debris Generation and Transportation.”

A-5. NRC Bulletin 96-03, “Potential Plugging of Emergency Core Cooling Suction Strainers by Debris in Boiling-Water Reactors,”.

A-6. PIPES, Innovative Technology Solutions, Albuquerque, New Mexico.

A-7. BWROG, “Utility Resolution Guidance for ECCS Suction Strainer Blockage,” NEDO-32686 (November 20, 1996).

A-8. “MATLAB: The Language of Technical Computing,” Ver 5.3, The Math Works, Inc., Natick, MA (1998).

Attachment A-1

Data Submitted by Licensee

Appendix-A **Plant Familiarization**

1. General Plant Data

Plant Name: Dresden
Containment Type: Mark I
Vendor for Strainer: Performance Contracting Inc. (PCI)
Vendor for DH Analysis: PCI for clean strainer, DE&S / ITS for debris
Vendor for Loads Analysis: DE&S

2. Inventory of Major Insulations

	Unit 2		Unit 3	
Fibrous	90.6 cubic feet	Total in drywell, DRE98-0056, Attachment A, As Left	-	Total not tabluated
	18.26 cubic feet	Total on strainers, DRE98-0056, Page 25	18.4 cubic feet	Total on strainers, DRE97-0154 Page 45
Particulate	None	NDIT SEC-DR-98-049	8.24 cubic feet	Calcium Silicate, DRE97-0154, Page 45
RMI	N / A	Saturation Bed, DRE98-0018, Page 29	N / A	Saturation Bed, DRE98-0018, Page 29
Other				
Armaflex Foam	-	Not tabulated	6.2 cubic feet	NDIT SEC-DR-96-091
Asbestos	13.9 cubic feet	Maximum volume in any one penetration, DR0055.F10.001, Page 10	13.9 cubic feet	Maximum volume in any one penetration, DR0055.F10.001, Page 11

3. Debris Generation Model Used in the Analysis

	Unit 2		Unit 3	
Method #1 -- All Debris In the Containment (NEDO Section 3.2.1.2.3)	N / A		N / A	
Method #2	Yes	DRE98-0056, page 7, Section 2.2, used large areas within the drywell	Yes	DRE97-0154, Page 40, Section 6.4
Method #3	Yes	Flued heads, DRE98-0056, Page 11, Section 2.6	Yes	DRE97-0154, Page 7, Section 2.3, Flued Heads, Page 10, Section 2.6
Method #4 -- Not reviewed by Staff	-		-	

4. Drywell Transport Factors Used in the Analysis

	Unit 2		Unit 3	
Transport Factor is assumed equal to 1	No		No	
Used URG Transport Factors	Yes	URG R/0, Page 83, DRE98-0056, Page 18, Section 6.1.3 and Attachment A	Yes	URG R/0, Page 83, DRE97-0154, Page 26, Calcium Silicate = 1.0
Plant Specific Calculations	Yes	Asbestos: 0.24 / 0.54 (combined destruction, transportation and settlement) DRE98-0056, Page 18, ITS/CECO-98-01, Page 26	Yes	Asbestos: 0.24 / 0.54 (combined destruction, transportation and settlement), DRE97-0154, Page 26, ITS/CECO-98-01, Page 25

5. Suppression Pool Transport Factors Used in the Analysis

	Unit 2		Unit 3	
Transport Factor is assumed equal to 1	No		No	
Used NUREG/CR-6224 Type Calculations	Yes		Yes	
Plant Specific Calculations	Yes	Asbestos, 10% settles in pool, ITS/CECO-98-01, Page 17, Section 6.1 (included in factor)	Yes	Asbestos, 10% settles in pool ITS/CECO-98-01, Page 17, Section 6.1 (included in factor)

6. Sources of Other Debris (Miscellaneous Debris)

	Unit 2		Unit 3	
Other Fibrous	-	Asbestos - see above responses	-	Asbestos - see above responses
Paint	170 lbs (for Case	85 lbs of qualified coatings within ZOI (URG Page 58), 85 lbs of unqualified coatings in drywell, DRE98-0018, Page 25	170 lbs (for Case	Same
Rust	50 lbs	URG Page 57, DRE98-0018, Page 25	lbs	Same
Sand/Concrete	N / A	URG Page 59, Section 3.2.2.2.2.1.2 - Included in dust and dirt	-	Same
Dirt and Dust	150 lbs	URG Page 53, DRE98-0018, Page 25	-	Same
Sludge	370 lbs	Actual, DRE98-0018, Page 25	-	Same
Other (e.g., FOAM)	N / A		N / A	

7. Head Loss Estimation

	Unit 2		Unit 3	
Vendor Correlation and Analysis Used	Yes	1.97 ft loss @ 10,000 gpm/strainer per PCI Report # PCI-NPD-CE01, R/2, Page 12, Table 3, 1.28 ft @ 8050 gpm and 1.03 ft @ 7250 gpm, DRE98-0018 Page 30, Section	-	Same
Vendor LTR Enclosed	N / A		N / A	
Vendor LTR Previously Reviewed by Staff	N / A		N / A	
Vendor tested Exact Strainers with Insulation	N / A		N / A	
Plant Specific Analysis (e.g., URG Correlations)	Yes	DRE98-0018, Page 7, Section 2.0, Fiber per NUREG/CR-6224 using Blockage 2.5R and HLOSS	-	Same

8. NPSH Calculations and Comparison with GL 97-04

	Unit 2		Unit 3	
Operator Throttling of ECCS Assumed	Yes		-	Same

Time at which throttled	10 minutes	NDIT # SEC-DR-97-0160, DRE98-0018, Page 11	10 minutes	NDIT # SEC-DR-97-0160, DRE97-0156, Page 9
Flow and Temp after Throttling used in Calcs.	29000 gpm 152 °F	NDIT # SEC-DR-97-0160, DRE98-0018, Page 11	29000 gpm 152 °F	NDIT # SEC-DR-97-0160, DRE97-0156, Page 9
Maximum Pool Temperature	172 °F	NDIT # SEC-DR-97-0160, DRE98-0018, Page 11	172 °F	NDIT # SEC-DR-97-0160, DRE97-0156, Page 9
Assumed Containment Overpressure	9.5 psi	(maximum) See UFSAR Page 6.3-79, Section 6.3.3.4.3.4	9.5 psi	(maximum) See UFSAR Page 6.3-79, Section 6.3.3.4.3.4
Staff reviewed the NPSH Calculation	Yes		Yes	
Reference No:	-	letter from J. Stang to I. Johnson, 4/30/97, Ammendment #157	-	letter from J. Stang to I. Johnson, 4/30/97, Ammendment #152
Date of Approval:	-	4/30/1997	-	4/30/1997

9. Suppression Pool Cleanliness Program (SPCP)

SPCP Part of Maintenance Rule (10 CFR 50.65) Program	Yes	PM ID # 0000134165, 122841, DTS 1600-36	Yes	PM ID # 0000134367, 122840, DTS 1600-36
SPCP Addressed NRCB 95-02	-	Not by name, but PM ID # 0000134165, 122841, DTS 1600-36 address cleanliness.	-	Not by name, but PM ID # 0000134367, 122840, DTS 1600-36 address cleanliness.

10. Codes and Standards (Comparison with Licensing Basis/UFSAR)

Quality Assurance Requirements				
10 CFR Appendix-B	-	PCI strainer documentation package, Tab #2 Standard Quality Articles, NEC-01-6070, Section I, 1.1 Vectra Proposal # 596-463, Page 15, Section 3.7	-	Same
ASME Certificate Required	-	Not a pressure retaining component, so ASME does not apply	-	Same
Materials				
Conform to ASTM Specifications	-	PCI strainer documentation package, Tab #2	-	Same
Certified Material Test Reports are Provided	-	PCI strainer documentation package, Tab #5	-	Same
Design/Fabrication	-	PCI strainer documentation package, Tab #4, DE&S letter VD0300-31, Attachment 1, Section 4.0	-	Same
Qualified ASME Section III, Subsection NC	N / A		N / A	
Qualified ASME Section III, Class 2	N / A		N / A	
Other ( )	N / A		N / A	
Welding				
Qualified to ASME Section IX	Yes	DE&S Specification DS-ECCS-DR-01, page 10, Section 3.5.2	Yes	DE&S Specification DS-ECCS-DR-01, page 10, Section 3.5.2
Other ( )	N / A		N / A	
NDE per ASME Section III				
Critical welds examined by liquid penetrant	-	PCI strainer documentation package, Tab #4	-	Same
All Other Welds Visually Examined	Yes		-	Same
Other ( )	N / A		N / A	

Appendix-B Head Loss Estimate Calculations

1. Destruction Pressures Used

Insulation Type				
Transco RMI	N / A	Saturation Bed per DRE98-0018, Section 6.5.2	-	Same
Cal-Sil with Al Jacket	N / A		0 psi	DRE97-0154, Page 26, Table 5
K-Wool	N / A		N / A	
Temp-Mat with ss wire retainer	N / A		N / A	
Knaupf	N / A		N / A	
Jacketed Nukon	SER	DRE99-0018, Page 17, DRE98-0056, Page 7	10 psi	DRE97-0154, Page A3, DRE99-0018, Page 17
Unjacketed Nukon	SER	DRE99-0018, Page 17, DRE98-0056, Page 7	10 psi	DRE97-0154, Page A3, DRE99-0018, Page 17
Koolphen-K	N / A		N / A	
MIRROR from Diamond	SER	DRE99-0018, Page 17, DRE98-0056, Page 7	4 psi	DRE97-0154, Page A3, DRE99-0018, Page 17
Min-K	N / A		N / A	

Other:	0 psi	All asbestos within a flued head is assumed to be ejected for any break within the flued heads	0 psi	All asbestos within a flued head is assumed to be ejected for any break within the flued heads

2. Area of the Zone of Influence Used (or Equivalent L/D for Sphere)

Insulation Type				
Transco RMI	27.9 feet	DRE99-0018, Page19	-	Not tabulated in DRE97-0154, but calculation follows URG (DRE97-0154, Page 7, Section 2.2)
Cal-Sil with Al Jacket	N / A	(No CalSil in Unit 2)	infinite	DRE99-0018, Page19, DRE97-0154, Pages 23 & 45
K-Wool	N / A		N / A	
Temp-Mat	N / A		N / A	
Knaupf	N / A		N / A	
Jacketed Nukon	23 feet	DRE99-0018, Page19	-	Not tabulated in DRE97-0154, but calculation follows URG (DRE97-0154, Page 7, Section 2.2)
Unjacketed Nukon	23 feet	DRE99-0018, Page19	-	Not tabulated in DRE97-0154, but calculation follows URG (DRE97-0154, Page 7, Section 2.2)
Koolphen-K	N / A		N / A	
MIRROR RMI	27.9 feet	DRE99-0018, Page19	-	Not tabulated in DRE97-0154, but calculation follows URG (DRE97-0154, Page 7, Section 2.2)
Min-K	N / A		N / A	
Other:	N / A		N / A	

3 Volume of Debris Generated by the Break

Insulation Type				
Transco RMI	-	Saturation Bed	-	Saturation Bed
Cal-Sil with Al Jacket	N / A		8.24 cubic feet	DRE97-0154, Page 45
K-Wool	N / A		N / A	
Temp-Mat	N / A		N / A	
Knaupf	N / A		N / A	
Jacketed Nukon and Unjacketed Nukon	18.26 cubic feet 1.93 cubic feet	DRE98-0056, Page 25 <= 1.93 in pool from flued head break, DRE98-0056, Page 25	18.4 cubic feet 2.67 cubic feet	DRE97-0154, Page 45 <= 2.67 in pool from flued head break, DRE97-0154, Pages 42-44
Koolphen-K	N / A		N / A	
MIRROR RMI		Included in Transco		Included in Transco
Min-K	N / A		N / A	
Other:	N / A		N / A	

4. Drywell Debris Transport Fractions Used in the Analysis

Insulation Type				
Transco RMI	-	Saturation Bed, DRE98-0018, Page 30, Section 6.5.2	-	Saturation Bed, DRE98-0018, Page 30, Section 6.5.2
Cal-Sil with Al Jacket	N / A		1.0	DRE97-0154, Page 26, Table 5
K-Wool	N / A		N / A	
Temp-Mat	N / A		N / A	
Knaupf	N / A		N / A	
Jacketed Nukon and Unjacketed Nukon	0.28 above grating 0.78 below grating	DRE98-0056, Page 18, Table 1, DRE99-0018, Page 22, Table 4	0.28 above grating 0.78 below grating	DRE97-0154, Page 26, Table 5, DRE99-0018, Page 22, Table 4
Koolphen-K	N / A		N / A	
MIRROR RMI	-	See Transco	-	See Transco
Min-K	N / A		N / A	
Other:	0.24 above grating 0.54 below grating	Asbestos: DRE98-0056, Page 18, Table 1, DRE99-0018, Page 22, Table 4	0.24 above grating 0.54 below grating	Asbestos: DRE97-0154, Page 26, Table 5, DRE99-0018, Page 22, Table 4

5 Wetwell Debris Transport Fractions Used in the Analysis

Insulation Type				
Transco RMI	N / A	Combined destruction / transportation factors (both drywell and wetwell) were used - see issue 4 above	N / A	See Unit 2
Cal-Sil with Al Jacket	100 %	DRE98-0056, Page 18, Table 1, DRE99-0018, Page 22, Table 4	100 %	DRE97-0154, Page 26, Table 5, DRE99-0018, Page 22, Table 4
K-Wool	N / A		N / A	
Temp-Mat	N / A		N / A	
Knaupf	N / A		N / A	
Jacketed Nukon	100 %	DRE98-0056, Page 18, Table 1, DRE99-0018, Page 22, Table 4	100 %	DRE97-0154, Page 26, Table 5, DRE99-0018, Page 22, Table 4
Unjacketed Nukon	100 %	DRE98-0056, Page 18, Table 1, DRE99-0018, Page 22, Table 4	100 %	DRE97-0154, Page 26, Table 5, DRE99-0018, Page 22, Table 4
Koolphen-K	N / A		N / A	
MIRROR RMI	N / A	See Transco	N / A	See Transco
Min-K	N / A		N / A	
Other:	various based on settlement	DRE98-0018, Page 30, Table 6	various based on settlement	DRE98-0018, Page 30, Table 6

6. Net Insulation Debris on the Strainer

Insulation Type				
Transco RMI	N / A	Saturation Bed, DRE98-0018, Page 35, Table 3	N / A	Saturation Bed, DRE98-0018, Page 35, Table 3
Cal-Sil with Al Jacket	N / A		8.24 cubic feet	DRE97-0154, Page 45
K-Wool	N / A		N / A	
Temp-Mat	N / A		N / A	
Knaupf	N / A		N / A	
Jacketed Nukon	18.26 cubic feet	DRE98-0018, Page 25	18.4 cubic feet	DRE97-0156, Page 45
Unjacketed Nukon	-	included in above	-	included in above
Koolphen-K	N / A		N / A	
MIRROR RMI	N / A	Saturation Bed, DRE98-0018, Page 35, Table 3	N / A	Saturation Bed, DRE98-0018, Page 35, Table 3
Min-K	N / A		N / A	
Other:	N / A		N / A	

7. Miscellaneous Debris

Debris Type				
Other Fibrous	-	DRE98-0018, Page 25, Table 6.3	-	Same
Paint	-	DRE98-0018, Page 25, Table 6.3	-	Same
Rust	-	DRE98-0018, Page 25, Table 6.3	-	Same
Sand/Concrete	-	DRE99-0018, Page 10	-	Same
Dirt and Dust	-	DRE98-0018, Page 25, Table 6.3	-	Same
Sludge	-	DRE98-0018, Page 25, Table 6.3	-	Same
Other (FOAM)	N / A		-	DRE97-0154, Pag e25

8. ECCS Flow Rate and Design Details

Before Throttling				
Flow Rate (GPM)	32200 gpm	with break, NDIT # SEC-DR-97-160, w/o break, full flow design (total) = 29000, DRE97 0010, Page 9	-	Same
Pool Temperature (°F)	149 °F	NDIT # SEC-DR-97-160	-	Same
Wetwell Pressure (psia)	3.1 psig	(at 600 seconds) UFSAR Table 6.2-3	3.1 psig	(at 600 seconds) UFSAR Table 6.2-3
NPSH Margin	varies	See calculation DRE97-0012, Pages 12 & 13	-	Same

After Throttling (Time: 10 min)				
Flow Rate (GPM)	29000 gpm	total flow, NDIT # SEC-DR-97-160	-	Same
Pool Temperature (oF)	172 °F	NDIT # SEC-DR-97-160	-	Same
Wetwell Pressure (psia)	2.0-10.9 psig	UFSAR Table 6.2-3	2.0-10.9 psig	UFSAR Table 6.2-3

NPSH Margin	varies	See calculation DRE97-0010, Pages 9 & 10	-	Same

9. Strainer Flow Rates and Design Details

Previous Strainer Flow Rate Data				
Full Design	9700 gpm	See calculation DRE97-0010, Page 9, upper middle case, total flow/3	-	Same
Full Single Failure	10700 gpm	See calculation DRE97-0012, Page 12, middle case, total flow/3	-	Same
Throttle Single Failure	8000 gpm	See calculation DRE97-0010, Page 9, lower right case, total flow/3	-	Same
Throttle Design	6300 gpm	See calculation DRE97-0010, Page 9, upper right case, total flow/3	-	Same
Outer Diameter	18.3 inches	Calculation 64.313.1119, Page 1	-	Same
Active Length	9.97 inches	Calculation 64.313.1119, Page 1	-	Same
Flange Diameter	27.5 inches	outside diameter, PCI Drawing DRU2-ECCS-8005-1100, M-3230-12, Section B	27.5 inches	outside diameter, PCI Drawing DRU3-ECCS-8003-1100, M-3230-11
Plate Area	4.55 square feet	Calculation 64.313.1119, Page 1	-	Same
Clean Head Loss	5.8 feet	Calculation 64.313.1119, Page 3	-	Same

Replacement Strainer Flow Rate Data				
Full Design	9700 gpm	See calculation DRE97-0010, Page 9, upper middle case, total flow/3	-	Same
Full Single Failure	10700 gpm	See calculation DRE97-0012, Page 12, middle case, total flow/3	-	Same
Throttle Single Failure	8000 gpm	See calculation DRE97-0010, Page 9, lower right case, total flow/3	-	Same
Throttle Design	6300 gpm	See calculation DRE97-0010, Page 9, upper right case, total flow/3	-	Same
Outer Diameter	32.5 inches	PCI Drawing DRU2-ECCS-8005-1100	32.5 inches	PCI Drawing DRU3-ECCS-8003-1100
Active Length	54 inches	PCI Drawing DRU2-ECCS-8005-1100	54 inches	PCI Drawing DRU3-ECCS-8003-1100
Plate Area (Effective)	118 square feet	DRE98-0018, Page 23, Table 6.1	-	Same
Gap Volume	6 cubic feet	DRE98-0018, Page 23, Table 6.1	-	Same
Circumscribed Area	48 square feet	DRE98-0018, Page 23, Table 6.1	-	Same
Clean Head Loss	Varies	1.97 ft loss @ 10,000 gpm/strainer per PCI Report # PCI-NPD-CE01, R/2, Page 12, Table 3, 1.28 ft @ 8050 gpm and 1.03 ft @ 7250 gpm, DRE98-0018 Page 30, Section	-	Same
Basis for Clean DH	-	Equations based on testing, PCI Report # PCI NPD-CE01, Page 12, Table 3 and Page 3	-	Equations based on testing, PCI Report # PCI NPD-CE01, Page 12, Table 3 and Page 3

10. Strainer Head Loss Calculations

Unthrottled Flow (single failure or design case): For common header plants design flow may result in worse head loss.

Circumscribed Velocity	0.37 feet / second	Flow = 32,200 gpm, DRE98-0018, Pages 23 & 24	-	Same
Plate Velocity	0.15 feet / second	Flow = 32,200 gpm, DRE98-0018, Pages 23 & 24	-	Same
Temperature	67 °F	PCI Report # PCI-NPD-CE01, PCI Memo for record, 4/19/97, Summary of bare strainer head loss tests conducted at Fairbanks Morse, Table 1 & 2	-	Same
Mass of Fibrous Debris	7.6 lb	2.4 lb / cubic foot per DRE98-0018, Page 26	7.7 lb	2.4 lb / cubic foot per DRE98-0018, Page 26
Volume of Fibrous Debris	18.26 cubic feet	DRE98-0018, Page 25	18.4 cubic feet	DRE97-0156, Page 45
% Occupancy of Gap	76 %		77 %	
Area of Reflective Metallic	N / A	Saturation	N / A	Same
Kt	0.073 ft / sec (max)	DRE98-0018, Page 31	-	Same
Kh	N / A		N / A	
Mass of Corrosion Prod.	varies	DRE98-0018, Page 25, Table 6.3	-	Same
Correlation Head Loss	N / A	NUREG-6224 method used to determine head loss, so this is not applicable	N / A	NUREG-6224 method used to determine head loss, so this is not applicable

Bump-up Factors	N / A	NUREG-6224 method used to determine head loss, so this is not applicable	N / A	NUREG-6224 method used to determine head loss, so this is not applicable
Paint Chips	N / A	The head loss due to the individual components (other than MRI) was not determined independantly.	N / A	The head loss due to the individual components (other than MRI) was not determined independantly.
Rust	N / A	The head loss due to the individual components (other than MRI) was not determined independantly.	N / A	The head loss due to the individual components (other than MRI) was not determined independantly.
Sand	N / A	The head loss due to the individual components (other than MRI) was not determined independantly.	N / A	The head loss due to the individual components (other than MRI) was not determined independantly.
Dirt/Dust	N / A	The head loss due to the individual components (other than MRI) was not determined independantly.	N / A	The head loss due to the individual components (other than MRI) was not determined independantly.
Zinc	N / A	The head loss due to the individual components (other than MRI) was not determined independantly.	N / A	The head loss due to the individual components (other than MRI) was not determined independantly.
Calcium-Silicate	N / A	The head loss due to the individual components (other than MRI) was not determined independantly.	N / A	The head loss due to the individual components (other than MRI) was not determined independantly.
Net Debris Head Loss	4.48 feet	DRE98-0018, Page 35, Table 7	4.48 feet	DRE98-0018, Page 35, Table 7
Clean Head Loss	1.03 feet	PCI Report # PCI-NPD-CE01, Page 12, Table 3, DRE98-0018, Page 30, Section 6.5.1	1.03 feet	PCI Report # PCI-NPD-CE01, Page 12, Table 3, DRE98-0018, Page 30, Section 6.5.1
Total Head Loss	5.8 feet	Actual = 5.51 ft, use 5.8 ft for future changes	5.8 feet	Actual = 5.51 ft, use 5.8 ft for future changes
NPSH Margin Left	-	See UFSAR Page 6.3-78, Section 6.3.3.4.3.3	-	See UFSAR Page 6.3-78, Section 6.3.3.4.3.3
Throttled Flow:				
Circumscribed Velocity	0.34 feet / second	Circumscribed area = 48 sq ft, DRE98-0018, Page 23, Section 6.1.1, Flow = 29,000 gpm DRE98-0018, Page 24, Table 6.2	-	Same
Plate Velocity	0.14 feet / second	Total surface area = 118 sq ft , DRE98-0018, Page 23, Section 6.1.1, Flow = 29,000 gpm DRE98-0018, Page 24, Table 6.2	-	Same
Temperature	67 °F	PCI Report # PCI-NPD-CE01, PCI Memo for record, 4/19/97, Summary of bare strainer head loss tests conducted at Fairbanks Morse, Table 1 & 2	-	Same
Mass of Fibrous Debris	-	Same as unthrottled flow	-	Same as unthrottled flow
Volume of Fibrous Debris	-	Same as unthrottled flow	-	Same as unthrottled flow
% Occupancy of Gap	-	Same as unthrottled flow	-	Same as unthrottled flow
Area of Reflective Metallic	-	Same as unthrottled flow	-	Same as unthrottled flow
Kt	-	Same as unthrottled flow	-	Same as unthrottled flow
Kh	-	Same as unthrottled flow	-	Same as unthrottled flow
Mass of Corrosion Prod.	-	Same as unthrottled flow	-	Same as unthrottled flow
Correlation Head Loss	-	Same as unthrottled flow	-	Same as unthrottled flow
Bump-up Factors	-	Same as unthrottled flow	-	Same as unthrottled flow
Paint Chips	-	Same as unthrottled flow	-	Same as unthrottled flow
Rust	-	Same as unthrottled flow	-	Same as unthrottled flow
Sand	-	Same as unthrottled flow	-	Same as unthrottled flow
Dirt/Dust	-	Same as unthrottled flow	-	Same as unthrottled flow
Zinc	-	Same as unthrottled flow	-	Same as unthrottled flow
Calcium-Silicate	-	Same as unthrottled flow	-	Same as unthrottled flow
Net Debris Head Loss	-	Same as unthrottled flow	-	Same as unthrottled flow
Clean Head Loss	-	Same as unthrottled flow	-	Same as unthrottled flow
Total Head Loss	-	Same as unthrottled flow	-	Same as unthrottled flow
NPSH Margin Left	-	Same as unthrottled flow	-	Same as unthrottled flow

11. Overall Strainer Performance

Strainer Plate Area Increase	113.5 square feet	(each)	-	Same
Circumscribed Area Increase	43.5 square feet	(circumscribed - plate area) (each)	-	Same
Volume Increase	25.92 cubic feet 1.28 cubic feet 24.64 cubic feet	new strainer volume (each) old strainer volume (each) (each)	- - -	Same Same Same

Hole Dimension Change	none		-	Same
Volume of Gap	6 cubic feet	(each)	-	Same
DH Old (RG 1.82, Rev. 0 or 1)	5.8 feet	head loss across the original strainers, Calc 64.313.1119, Page 3	-	Same
DH New (RG 1.82, Rev. 2)	5.8 feet	from item 10 above	-	Same
Cont. Over Pres. Requirement	9.5 psi	(maximum) See UFSAR Page 6.3-79, Section 6.3.3.4.3.4	9.5 psi	(maximum) See UFSAR Page 6.3-79, Section 6.3.3.4.3.4

Appendix-C
Codes/Standards and Suppression Pool Cleanliness Program

1. Does the Strainer Design, Material Procurement and Manufacturing meet Codes and Standards in the following Disciplines

Quality Assurance Requirements				
10 CFR Appendix-B	-	See Appendix A, Item #10	-	
ASME Certificate Required	-	See Appendix A, Item #10	-	
Materials Conform to ASTM Specifications	-	See Appendix A, Item #10	-	
Certified Material Test Reports are Provided	-	See Appendix A, Item #10	-	
Design/Fabrication Qualified ASME Section III, Subsection NC	-	See Appendix A, Item #10	-	
Qualified ASME Section III, Class 2	-	See Appendix A, Item #10	-	
Other ( )	-	See Appendix A, Item #10	-	
Welding Qualified to ASME Section IX	-	See Appendix A, Item #10	-	
Other ( )	-	See Appendix A, Item #10	-	
NDE per ASME Section III Critical welds examined by liquid penetrant	-	See Appendix A, Item #10	-	
All Other Welds Visually Examined	-	See Appendix A, Item #10	-	
Other ( )	-	See Appendix A, Item #10	-	

2. Has the licensee incorporated its suppression pool cleanliness program into the scope of its maintenance rule (10CFR50.65) program

	Yes	ComEd's Maintenance Rule program is based on implementation of 10CFR 50.65, Regulatory Guide 1.160 and NUMARC 93-01. In establishing the Systems structures and components that are in the scope of the Rule, the guidelines established in paragraph (b) of 10 CFR 50.65 and NUMARC 93-01, Section 8 were used. Application of the guidelines results in Primary Containment and the ECCS being part of the scope of the Maintenance Rule. The Maintenance Rule requires that the effectiveness of the maintenance activities be monitored for all the systems, structures and components in the scope. The effectiveness of maintenance on these systems is monitored through the performance of the systems. The performance of these high safety significance systems and structures (ECCS and Primary Containment) is measured using availability and reliability criteria. One of the maintenance activities affecting the performance of the SSCs is cleanliness inspections. Should these surveillances determine that cleanliness acceptance criteria are not met, then a PIF	Yes	Same
If the answer to number 1 above is yes, then				
What goals have been established by the licensee for suppression pool cleanliness? Strainer cleanliness?		The surveillances performed have acceptance criteria. 10 CFR 50.65 requires goals be established for SSCs that do not have an adequate maintenance program. Currently, there are no goals established for these SSCs, since performance has been satisfactory. Satisfactory performance indicates an adequate maintenance program exists.	-	Same
How is the licensee monitoring its suppression pool/strainer cleanliness goals?	-	As described above, performance is adequate, therefore, no goals have been established.	-	Same

If monitoring is not required, what preventative maintenance is the licensee performing to ensure that the suppression pool and associated strainers can perform their intended safety function?	-	Surveillances exist to determine the functionality including ECCS performance tests and cleanliness inspections. In accordance with the technical specifications, the ECCS are tested at least quarterly to demonstrate operability. (All ECCS take suction off a common ring header; therefore, each ECCS operability test demonstrates operability of the suppression pool and strainers.) Additionally, the suppression pool structure and coating is surveilled every refueling outage under DTS 1600-11, "Primary Containment Structure General and Coating Inspections", and the strainers are surveilled each refueling outage under DTS 1600-36, "Emergency Core Cooling System (ECCS) Suction Strainer Inspection Criteria".	-	Same
What is the frequency of monitoring or preventative maintenance (as applicable to the licensee's program)?	-	The ECCS systems are tested at least quarterly to demonstrate operability. The suppression pool and suction strainers are surveilled each refueling outage.	-	Same
When was the last assessment of suppression pool performance/goals or preventative maintenance performed, and what were the licensee's findings?	-	ComEd's maintenance rule program requires a monthly review of the SSC performance against the performance criteria. These SSC's are not in (a)(1), therefore, the maintenance program was assessed to be adequate.	-	Same
What related industry experience was considered in the last assessment and what were the licensee's conclusions relative to applicability of this experience to their plant?	-	In accordance with 10CFR 50.65, industry experience is used when establishing goals for (a)(1) SSC, i.e. do not have an adequate maintenance program. Since the systems are not in (a)(1), no industry experience was specifically reviewed during the last monthly assessment. Additionally, ComEd has an OPEX program in place to review industry events and make improvements. ComEd has closely followed industry developments regarding suction strainer fouling and has made several improvements, including strainer replacement, based on these developments.	-	Same
What adjustments, if any, were made to the licensee's programs based on the last assessment?	-	No adjustments were necessary.	-	Same
Has the licensee considered the affect of its maintenance or monitoring activities on total availability of safety systems?	-	The performance criteria established for the systems in the scope of the rule have used the insights from the site's IPE. Additionally, maintenance activities are reviewed prior to their performance to determine the effect on core damage frequency or shutdown risk.	-	Same
Has the licensee taken steps to minimize unavailability of safety systems due to suppression pool/strainer monitoring or maintenance activities?	-	Thorough inspections are conducted during refueling outages to assure that the functions are available when required.	-	Same
When is the next assessment of performance/goals or preventative maintenance scheduled?	-	ComEd's maintenance rule program requires a monthly review of the SSC performance against the performance criteria. These SSC's are not in (a)(1), therefore, the maintenance program was assessed to be adequate.	-	Same
If the answer to number 1 above is no, what is the licensee's basis for not including the suppression pool and/or suction strainers in the scope of its maintenance rule activities? In addition, did the licensee establish a suppression pool cleanliness program as requested in NRC Bulletin 95-02?	N / A		N / A	
How is the licensee ensuring the operability of the ECCS relative to ensuring an adequately clean suppression pool and ECCS suction strainers? How is the licensee administratively controlling its suppression pool/strainer cleanliness program?	N / A N / A		N / A N / A	
What criteria has the licensee established for suppression pool and strainer cleanliness?	N / A		N / A	
What is the licensee's planned frequency for cleaning the suppression pool and strainers?	N / A		N / A	

Attachment A-2

Program Listing of DEBRIS Model

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% BWRDEBRIS randomly locates insulation targets within a BWR drywell         %
% and superimposes spherical zones of influence to determine the amount of   %
% debris generated in a postulated LOCA.  Each insulation target is assumed  %
% to be a point source that can be enveloped by the ZOI.                     %
%                                                                            %
% Insulation is placed at sampled locations between specified operating      %
% floors.  Drywell transport factors are then applied depending on location  %
% above or below the lowest grating to determine the amount of debris        %
% transported to the suppression pool.  For a given break location, many     %
% repeated trials can be run to generate a distribution of debris that       %
% could possibly be transported due to the unknown actual locations of the   %
% insulation targets.                                                        %
%                                                                            %
% All geometry is computed in units of feet referenced to the vertical core  %
% centerline.                                                                %
%                                                                            %
%                                                              bcl 3/30/99   %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% Housekeeping
clc;
clear all;
close('all');
whos;

% Input Data ...
%
   % General parameters
   Rzoi  = 24.27;  % Destruction radius (ft) for complete separation of 28" line
                   % Pdest = 10psi for NUKON
   above = 0.28;   % Transport factors for targets above and below lowest grating
   below = 0.78;
   iopt  = 1;      % 1 = randomize radius and polar angle of target locations
                   % 0 = use known (x, y, z) coordinates for targets
                   %     (???iopt=0 not yet functional???)
   ihist = 5000;   % Number of samples in histogram of transported debris
                   %   volume (set ihist=1 to skip histogram generation)
   vmin = 15.0;    % Minimum amount of transported debris expected (ft^3)
   vmax = 25.0;    % Maximum amount of transported debris expected (ft^3)
   nbin = 20;      % Number of bins in the interval vmax-vmin
   ibrk = 21;      % Weld location from sequential list

   % Containment geometry (ft)
   floors   = [492.33, 515, 537, 562, 576.17, 604.25];
   necktop  = 604.25;
   ballrad  = 33;
   ballctr  = 525.33;
   biorad   = 15;
   biomin   = 530;
   biomax   = 576.17;
   neckrad  = 18.5;
   neckbot  = ballctr + ballrad*cos(asin(neckrad/ballrad));

%   % Break location (in CAD reference coord ft)
%   %   (worst NUKON break reported for Unit 3)
%   xbrk = 41.75;
%   ybrk = 63.33;
%   zbrk = 521.33;

%   % Break location (in CAD reference coord ft)
%   %   (approx worst NUKON break for Unit 2)
%   %   (azimuth 180 deg CW from N)
```

```
%   xbrk = 49.0;   % lined up on center
%   ybrk = 31.25;  % half of containment radius
%   zbrk = 540;        % just above second floor level

%   % Break location (in CAD reference coord ft)
%   %    (manual estimate of worst case break location)
%   xbrk = 60;
%   ybrk = 33;
%   zbrk = 520;

   % Break location (28" weld locations for Unit 3 from Dresden Table)
   xbrk = [ 785, 785, 785, 785, 785, 785, 737, 687, 687, 687, ...
            659, 655, 391, 391, 391, 391, 391, 391, 450, 501, ...
            501, 501, 518, 522];
   ybrk = [ 430, 465, 530, 573, 573, 573, 385, 362, 362, 362, ...
            420, 430, 715, 680, 615, 573, 573, 573, 737, 760, ...
            760, 760, 722, 715];
   zbrk = [6108, 6108, 6108, 6207, 6308, 6364, 6056, 6105, 6169, 6409, ...
           6530, 6530, 6108, 6108, 6108, 6194, 6304, 6368, 6055, 6191, ...
           6256, 6417, 6529, 6529];
   xbrk = xbrk/12;   ybrk = ybrk/12;   zbrk = zbrk/12;

   % Assign final break location
   xbrk = xbrk(ibrk);
   ybrk = ybrk(ibrk);
   zbrk = zbrk(ibrk);

   % Distance to containment centerpoint from CAD origen
   xcont = 588/12;
   ycont = 573/12;

   % NUKON insulation data
   % (nkn# in ft^3, azm# in deg)

   % Unit 3 from Dresden table, (x,y,z) in inches and volumes in ft^3
   % Notes: Main Steam Drain locations are listed last
   %        Includes small amount (8ft^3) replaced after inventory was taken
   x = [710, 654, 716, 659, 456, 522, 705, 769, 798, 842, ...
        370, 393, 429, 450, 464, 454, 684, 571, 821, 695, ...
        624, 552, 681, 495, 681, 495, 842, 334, 386, 842, ...
        517, 665, 588, 612, 636, 564, 540];
   y = [407, 459, 635, 448, 497, 720, 780, 716, 759, 609, ...
        751, 774, 738, 759, 788, 899, 801, 377, 340, 898, ...
        913, 913, 666, 480, 666, 480, 555, 591, 695, 698, ...
        918, 909, 837, 837, 837, 837, 837];
   z = [6953, 6852, 6854, 6846, 6854, 6860, 6507, 6507, 6507, 6507, ...
        6507, 6507, 6507, 6507, 6540, 6468, 6507, 6390, 6459, 6210, ...
        6210, 6210, 6936, 6936, 6803, 6803, 6507, 6507, 6507, 6507, ...
        6240, 6222, 6228, 6228, 6228, 6228, 6228];
   nkn=[0.229, 1.667, 4.451, 4.451, 4.451, 4.451, 0.463, 0.463, 0.463, 0.463, ...
        0.463, 0.463, 0.463, 0.463, 0.834, 2.094, 1.667, 1.167, 1.129, 0.333, ...
        3.333, 3.333, 0.478, 0.478, 0.478, 0.478, 3.650, 3.650, 3.650, 3.650, ...
        16.89, 16.89, 3.360, 3.360, 3.360, 3.360, 3.360];

        % Convert to same format as Unit 2 data
        %    (azimuths defined clockwise from North=0)
        x = x/12;    y = y/12;    z = z/12;
        x = x-xcont; y = y-ycont;
        azm = pi/2 - atan2(y,x);
        azm = (360/2/pi)*azm; % radians to degree
        i = find(azm<0);
        azm(i) = azm(i)+360;
        if any(azm<0) | any(azm>360),
           fprintf('Problem with azimuth conversion')
           stop
        end%if
        i = find(z<=floors(2));
        azm0 = azm(i);    nkn0 = nkn(i);
        i = find(z>floors(2) & z<=floors(3));
        azm1 = azm(i);    nkn1 = nkn(i);
        i = find(z>floors(3) & z<=floors(4));
        azm2 = azm(i);    nkn2 = nkn(i);
        i = find(z>floors(4) & z<=floors(5));
        azm3 = azm(i);    nkn3 = nkn(i);
        i = find(z>floors(5));
        azm4 = azm(i);    nkn4 = nkn(i);
        if (length([azm0, azm1, azm2, azm3, azm4]) ~= length(z)),
           fprintf('Problem with data assignment to each floor')
           stop
        end%if
```

```
   % Unit 2 in azimuth (deg East of North) and volume ft^3
   %   Notes: From walk down inventory
   %          Conservative list includes 32.5ft^3 removed after walkdown
   %   azm4   = [  75,   225,   90, 225];
   %   nkn4   = [1.05,  1.05, 4.58, 2.5];
   %
   %   azm3   = [ 180,   180,  230,  230,  165,   165,  225,  225, 315,  320,  20,   20,
35,   35,  80];
   %   nkn3   = [6.25,  1.22,  4.0, 2.95, 2.25, 0.175, 2.25, 1.57, 4.5, 1.83, 4.0, 1.83,
2.0, 1.05, 1.0];
   %
   %   azm2   = [ 105,    75,   30,   15,   15,   60,  320, 285,  285,  255,  240,  150];
   %   nkn2   = [3.93,  2.62,  0.0, 2.62, 0.87, 1.83, 1.83, 1.4, 5.24, 3.93, 1.22, 1.83];
   %
   %   %azm2   = [ 105,    15,   15,   60,  320,  255,  240,  150];
   %   %nkn2   = [3.93,  2.62, 0.87, 1.83, 1.83, 3.93, 1.22, 1.83];
   %
   %   azm1   = [ 270,     0,     5,    0,    90,    90,   90,  320,    5,    0,    0,
265];
   %   nkn1   = [6.54, 13.96, 0.873, 0.52, 0.393, 0.654, 9.16, 1.33, 0.67, 0.79, 1.57,
6.0];
   %
   %   %azm1   = [ 270,     0,    90,    90,   90,  320,    5];
   %   %nkn1   = [6.54,  0.52, 0.393, 0.654, 9.16, 1.33, 0.67];
   %
   %   azm0   = [ 270,   270];
   %   nkn0   = [ 3.9,  7.07];

% Begin calculations ...

% Total insulation inventories
inven0 = sum(nkn0);
inven1 = sum(nkn1);
inven2 = sum(nkn2);
inven3 = sum(nkn3);
inven4 = sum(nkn4);
total  = inven0+inven1+inven2+inven3+inven4;
fprintf('NUKON inventories:\n')
fprintf('------------------------------------\n')
fprintf('insulation in basement     = %g\n',inven0)
fprintf('insulation in first level  = %g\n',inven1)
fprintf('insulation in second level = %g\n',inven2)
fprintf('insulation in third level  = %g\n',inven3)
fprintf('insulation in fourth level = %g\n',inven4)
fprintf('total insulation           = %g\n\n',total)

% Floor heights
nfloor = length(floors)-2;
hts    = floors(2:nfloor+2) - floors(1:nfloor+1);

% Convert azimuths from degrees to radians
fact = 2*pi/360;
azm0 = fact*azm0;
azm1 = fact*azm1;
azm2 = fact*azm2;
azm3 = fact*azm3;
azm4 = fact*azm4;

% Determine azimuth of break
xbrk = xbrk-xcont;
ybrk = ybrk-ycont;
abrk = pi/2 - atan2(ybrk,xbrk);
abrk = abrk/fact;
fprintf('Azimuth of Break:\n')
fprintf('--------------------------------------------------------\n')
fprintf('Azimuth of break location in CAD coordinates = %g\n\n',abrk)

% Compute outline of containment and ZOI
npts    = 50;
angles  = linspace(0,2*pi,npts);
%
zbal1   = ballctr*ones(1,npts);
xbal1   = ballrad*cos(angles);
ybal1   = ballrad*sin(angles);
xbal2   = zeros(1,npts);
ybal2   = ballrad*cos(angles);
zbal2   = ballrad*sin(angles) + ballctr;
ybal3   = zeros(1,npts);
xbal3   = ballrad*cos(angles);
```

```
zbal3   = ballrad*sin(angles) + ballctr;
%
neckbot = neckbot*ones(1,npts);
necktop = necktop*ones(1,npts);
neckx   = neckrad*cos(angles);
necky   = neckrad*sin(angles);
%
zzoi1   = zbrk*ones(1,npts);
xzoi1   = Rzoi*cos(angles) + xbrk;
yzoi1   = Rzoi*sin(angles) + ybrk;
xzoi2   = xbrk*ones(1,npts);
yzoi2   = Rzoi*cos(angles) + ybrk;
zzoi2   = Rzoi*sin(angles) + zbrk;
yzoi3   = ybrk*ones(1,npts);
xzoi3   = Rzoi*cos(angles) + xbrk;
zzoi3   = Rzoi*sin(angles) + zbrk;
%
xgrat = zeros(npts,nfloor);
ygrat = zeros(npts,nfloor);
zgrat = zeros(npts,nfloor);
agrat = acos( (ballctr-floors(2:3))/ballrad );
rgrat = ballrad*sin(agrat);
xgrat(:,1:2) = (rgrat'*sin(angles))';
ygrat(:,1:2) = (rgrat'*cos(angles))';
zgrat(:,1:2) = (floors(2:3)'*ones(1,npts))';
xgrat(:,3:4) = neckrad*sin(angles)'*ones(1,2);
ygrat(:,3:4) = neckrad*cos(angles)'*ones(1,2);
zgrat(:,3:4) = (floors(4:5)'*ones(1,npts))';
%
xnek1   = zeros(1,2);
ynek1   = neckrad*ones(1,2);
znek    = [neckbot(1), necktop(1)];
xnek2   = neckrad*ones(1,2);
ynek2   = zeros(1,2);
xnek3   = zeros(1,2);
ynek3   = -neckrad*ones(1,2);
xnek4   = -neckrad*ones(1,2);
ynek4   = zeros(1,2);

% Number of entries per level
n0 = length(azm0);
n1 = length(azm1);
n2 = length(azm2);
n3 = length(azm3);
n4 = length(azm4);

% Check consistency of input
if length(nkn0) ~= n0 | ...
   length(nkn1) ~= n1 | ...
   length(nkn2) ~= n2 | ...
   length(nkn3) ~= n3 | ...
   length(nkn4) ~= n4,
   fprintf('ERROR: problem with input entries')
   stop
end%if

% Index vectors
idx0 = zeros(1,n0);
idx1 = ones(1,n1);
idx2 = 2*ones(1,n2);
idx3 = 3*ones(1,n3);
idx4 = 4*ones(1,n4);

% Initialize flags and arrays
jopt = ihist>1;
icnt = 0;
debris = zeros(ihist,1);
del  = (vmax-vmin)/nbin;
dbin = vmin+del/2:del:vmax;

% Randomize targets and compile histogram
while icnt<ihist,
   icnt = icnt+1;

if iopt,                          % randomize target locations
%--------------------------------------------------------------
% Choose random locations of NUKON
%   (floors 2, 3 and 4 in neck, floors 0, 1, 2 in ball)
%   (all levels exclude bioshield volume for target placement)
z0 = []; z1 = []; z2 = []; z3 = []; z4 = [];
```

```
r0 = []; r1 = []; r2 = []; r3 = []; r4 = [];

% Cylindrical neck locations
z3 = floors(4) + rand(1,n3)*hts(4);
z4 = floors(5) + rand(1,n4)*hts(5);
r3 = sqrt(biorad^2 + (neckrad^2-biorad^2)*rand(1,n3) );
r4 = sqrt(biorad^2 + (neckrad^2-biorad^2)*rand(1,n4) );
if any(r3>neckrad) | any(r4>neckrad),
   fprintf('Problem with target radii in neck')
   stop
end%if

% Spherical ball locations for basement level
maxang = pi;
minang = acos( (floors(2)-ballctr)/ballrad );
angles = acos( cos(minang) - rand(1,n0)*(cos(minang) - cos(maxang)) );
minrad = (floors(2)-ballctr)./cos(angles);
maxrad = ones(1,n0)*ballrad;
radii  = (minrad.^(1/3) + rand(1,n0).*(maxrad.^(1/3) - minrad.^(1/3))).^(1/3);
if imag(radii) ~= 0,
   fprintf('Problem with basement radii')
   stop
end%if
if any(radii <= 0),
   fprintf('Problem with basement radii')
   stop
end%if
r0     = radii.*sin(angles);
z0     = ballctr + radii.*cos(angles);

% Spherical ball locations for first floor
topang = acos( (floors(3)-ballctr)/ballrad );
botang = acos( (floors(2)-ballctr)/ballrad );
minang = 0; maxang = pi; minrad = 0;
while length(z1) < n1,
   angle  = acos( cos(minang) - rand*(cos(minang) - cos(maxang)) );
   if angle<topang,
      maxrad = (floors(3)-ballctr)/cos(angle);
   elseif angle>botang,
      maxrad = (floors(2)-ballctr)/cos(angle);
   else
      maxrad=ballrad;
   end%else if
   radius = (rand*maxrad^3)^(1/3);
   if (imag(radius) ~= 0),
      fprintf('Problem with radius')
      stop
   end%if
   rad1 = radius*sin(angle);
   zee1 = ballctr + radius*cos(angle);
   i = length(z1);
   if (zee1<biomin),
      z1(i+1) = zee1;
      r1(i+1) = rad1;
   elseif (rad1 > biorad),
      z1(i+1) = zee1;
      r1(i+1) = rad1;
   end%if
end%while

% Spherical ball locations for second floor
%    (excludes a small region in neck on second floor)
topang = 0;
botang = acos( (floors(3)-ballctr)/ballrad );
minang = topang; maxang = botang; maxrad=ballrad;
while length(z2) < n2,
   angle  = acos( cos(minang) - rand*(cos(minang) - cos(maxang)) );
   minrad = (floors(3)-ballctr)/cos(angle);
   radius = (minrad^3 + rand*(maxrad^3 - minrad^3))^(1/3);
   if (imag(radius) ~= 0),
      fprintf('Problem with radius')
      stop
   end%if
   rad2 = radius*sin(angle);
   zee2 = ballctr + radius*cos(angle);
   i = length(z2);
   if (zee2<biomin),
      z2(i+1) = zee2;
      r2(i+1) = rad2;
   elseif (rad2 > biorad),
```

```
      z2(i+1) = zee2;
      r2(i+1) = rad2;
   end%if
end%while

% Combine insulation description vectors
radii = [r0, r1, r2, r3, r4];
azmth = [azm0, azm1, azm2, azm3, azm4];
z     = [z0, z1, z2, z3, z4];
nkn   = [nkn0, nkn1, nkn2, nkn3, nkn4];
idx   = [idx0, idx1, idx2, idx3, idx4];

% Convert to Cartesian coords
%   (note that CAD azimuth is rotated 90deg)
x = radii.*sin(azmth);
y = radii.*cos(azmth);
if any( abs(x) > ballrad ),
   fprintf('x-coord is wrong')
   stop
end%if
if any( abs(y) > ballrad ),
   fprintf('y-coord is wrong')
   stop
end%if
if any(z>floors(6)) | any(z<floors(1)),
   fprintf('z-coord is wrong')
   stop
end%if
%-----------------------------------------------
end%if                  % randomize target locations

% find insulation in ZOI
R   = sqrt( (x-xbrk).^2 + (y-ybrk).^2 + (z-zbrk).^2 );
in  = find(R <= Rzoi);

% compute volumes
NKNzoi = nkn(in);
IDXzoi = idx(in);
ilo  = find(IDXzoi == 0);
Vzoi = sum(NKNzoi);
Vlo  = sum(NKNzoi(ilo));
Vhi  = Vzoi - Vlo;
VThi = Vhi*above;
VTlo = Vlo*below;
debris(icnt) = VThi+VTlo;

end%while icnt<ihist

% print results
if ~jopt,
fprintf('Summary:\n')
fprintf('---------------------------------------------------\n')
fprintf('Number of point targets in ZOI                   = %g\n',length(in))
fprintf('Volume generated in ZOI ignoring bioshield       = %g\n',Vzoi)
fprintf('Volume transported from ZOI above lowest grating = %g\n',VThi)
fprintf('Volume transported from ZOI below lowest grating = %g\n',VTlo)
fprintf('Total volume transported from ZOI                = %g\n\n',VThi+VTlo)
end%if

% plot insulation points in 3-space
if ~jopt,
figure
axis('equal')
colordef black
axis([-35 35 -35 35 490 605])
xlabel('East/West (ft)')
ylabel('North/South (ft)')
zlabel('Elevation (ft)')
hold on
plot3(x,y,z,'yo')
plot3(x(in),y(in),z(in),'bo')
plot3(neckx,necky,necktop,'y')
plot3(neckx,necky,neckbot,'y')
plot3(xbal1,ybal1,zbal1,'y')
plot3(xbal2,ybal2,zbal2,'y')
plot3(xbal3,ybal3,zbal3,'y')
plot3(xbrk,ybrk,zbrk,'m*')
plot3(xzoi1,yzoi1,zzoi1,'b')
plot3(xzoi2,yzoi2,zzoi2,'b')
plot3(xzoi3,yzoi3,zzoi3,'b')
```

```
plot3(xgrat,ygrat,zgrat,'r')
plot3(xnek1,ynek1,znek,'y')
plot3(xnek2,ynek2,znek,'y')
plot3(xnek3,ynek3,znek,'y')
plot3(xnek4,ynek4,znek,'y')
hold off
end%if

% plot histogram of total transported debris
if jopt,
figure
hist(debris,dbin)
xlabel('Total Transported Fiber (ft^3)')
ylabel('Bin Count')
title(['Distribution of ' num2str(ihist) ' Samples'])
fprintf('\n\nMaximum Transported Debris Volume = %g\n',max(debris))
end%if
```