1 of 1

MARTIN MARIETTA

**PORTSMOUTH
GASEOUS
DIFFUSION
PLANT**

**EVALUATION OF COVERAGE OF ENRICHED
UF₆ CYLINDER STORAGE LOTS BY
EXISTING CRITICALITY ACCIDENT ALARMS**

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Battelle

March 1995

Battelle

... Putting Technology To Work

MARTIN MARIETTA UTILITY SERVICES, INC
UNDER CONTRACT WITH
THE UNITED STATES
ENRICHMENT CORPORATION

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CYLINDER STORAGE LOTS BY EXISTING
CRITICALITY ACCIDENT ALARMS**

March 1995

by

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Under Contract 426215

to

MARTIN MARIETTA UTILITY SERVICES, INC.

**PORTSMOUTH GASEOUS DIFFUSION PLANT
P.O. Box 628 Piketon, Ohio 45661**

Under Contract USECHQ-93-C-0001

to the

U.S. ENRICHMENT CORPORATION

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EVALUATION OF COVERAGE OF ENRICHED UF₆ CYLINDER STORAGE LOTS BY EXISTING CRITICALITY ACCIDENT ALARMS

Executive Summary

The Portsmouth Gaseous Diffusion Plant (PORTS) is leased from the U.S. Department of Energy (DOE) by the United States Enrichment Corporation (USEC), a government corporation formed in 1993. Under the auspices of this new corporation, PORTS is in transition from regulation by DOE to regulation by the Nuclear Regulatory Commission (NRC). One of the nuclear regulations to which the plant must adhere is 10 CFR Part 76.89, which requires that criticality alarm systems be provided for the site.

PORTS originally installed criticality accident alarm systems in all building for which nuclear criticality accidents were credible.¹ Currently, however, alarm systems are not installed in the enriched uranium hexafluoride (UF₆) cylinder storage lots.

This report analyzes and documents the extent to which enriched UF₆ cylinder storage lots at PORTS are covered by criticality detectors and alarms currently installed in adjacent buildings. Monte Carlo calculations are performed on simplified models of the cylinder storage lots and adjacent buildings. The storage lots modelled are X-745B, X-745C, X-745D, X-745E, and X-745F. The criticality detectors modelled are located in building X-343, the building X-344A/X-342A complex, and portions of building X-330 (see Figures 1 and 2). These criticality detectors are those located closest to the cylinder storage lots.

The results of this analysis indicate that the existing criticality detectors currently installed at PORTS are largely ineffective in detecting neutron radiation from criticality accidents in most of the cylinder storage lots at PORTS, except sometimes along portions of their peripheries.

Evaluation of Coverage of Enriched UF₆ Cylinder Storage Lots by Existing Criticality Accident Alarms

1.0 Introduction

The Portsmouth Gaseous Diffusion Plant (PORTS), located in Piketon, Ohio, is one of two operating gaseous diffusion plants leased from the U.S. Department of Energy (DOE) by the United States Enrichment Corporation (USEC) and managed and operated by Martin Marietta Utility Services (MMUS). At these plants, uranium (U), in the form of uranium hexafluoride (UF₆), is enriched via a gaseous diffusion process from its naturally occurring isotopic concentration of about 0.7% ²³⁵U, up to about 5% ²³⁵U. The raw materials and products of this process, both UF₆, are stored in 2.5-, 10-, and 14-ton cylinders in storage lots adjacent to buildings at the plant. Ten-ton cylinders are most common. They are about 10 feet long and 4 feet in diameter². Criticality accidents are considered to be credible where uranium enrichments exceed 1% ²³⁵U.

PORTS originally installed criticality accident alarm systems in all buildings for which nuclear criticality accidents were considered credible.¹ These alarm systems are comprised of neutron radiation detectors with alarm setpoints at 5 millirads per hour (mRad/hr)³, as shown in Photo 1. Each detector "cluster" consists of three detectors which give an alarm if two out of three detectors exceed the alarm setpoint. Currently, alarm systems are not installed in the UF₆ cylinder storage lots.

1.1 Background

The Code of Federal Regulations, 10 CFR Part 76.89, requires that criticality alarm systems be maintained in all areas of the plant. The USEC may describe, for the approval of the NRC, defined areas to be excluded from the monitoring requirement. Historically,

Photo 1. Criticality Accident Alarm System consisting of three detectors, located in a process building. The alarm horns and their associated nitrogen supply are also shown.

criticality accident alarms have not been provided in UF₆ cylinder storage lots and formal technical evaluation of the cylinder storage lots had not been documented.

PORTS currently has 5 storage lots which are used to store cylinders of enriched UF₆. Analyses have not determined that criticality accidents are incredible in these storage lots. It should be noted that none of the gaseous diffusion plants operated in the United State (i.e., ORGDP, Paducah, and PORTS) have ever had a criticality accident.

1.2 Purpose and Scope

This evaluation analyzes the coverage of enriched UF₆ cylinder storage lots at PORTS by the existing criticality accident alarm system currently installed in buildings adjacent to the lots. Monte Carlo calculations are performed on simplified models of the cylinder storage lots and adjacent buildings. The storage lots modelled are X-745B, X-745C, X-745D, X-745E, and X-745F. The criticality radiation detector clusters modelled are located in building X-343, the building X-344A/X-342A complex, and portions of building X-330 (see Figures 1 and 2). These criticality radiation detector clusters are those located closest to the cylinder storage lots.

Figure 1. Overhead View of Building X-343 and Cylinder Storage Lot X-745D.

Figure 2. Overhead View of the Building X-344A/X-342A Complex, Building X-330, and Cylinder Storage Lots X-745B, X-745C, X-745E, and X-745F.

2.0 Storage Lot and Building Descriptions

As shown in Figure 1, cylinder storage lot X-745D is located near building X-343. Its approximate dimensions are 100 by 150 feet. The cylinders in this lot typically contain UF_6 enriched to greater than 1% ^{235}U . Building X-343 contains one criticality radiation detector cluster and alarm.

As shown in Figure 2, cylinder storage lots X-745B and X-745F are located near the building X-344A/X-342A complex. Lot X-745B is to the south of the complex, and lot X-745F is to the north. Lot X-745B has dimensions of approximately 280 by 750 feet. Lot X-745F is divided into two parts whose dimensions are approximately 325 by 425 feet and 200 by 450 feet. Almost all of the cylinders of UF_6 stored in lot X-745F are 10-ton cylinders. They contain UF_6 of various enrichments. Both 10-ton and 2.5-ton cylinders of UF_6 are stored in lot X-745B, as shown in Photo 2. They, too, contain UF_6 of various enrichments. The building X-344A/X-342A complex contains two criticality radiation detector clusters.

Storage lot X-745B is also adjacent to building X-330. In addition, storage lot X-745C is located immediately west of the north end of building X-330, as shown in Figure 2. Lot X-745C, the largest lot, has approximate dimensions of 600 by 1500 feet. Most of the cylinders stored in lot X-745C contain UF_6 at approximately 0.4% enrichment. Uranium at an enrichment level of 0.4% or less is depleted uranium and cannot support a criticality accident. However, other cylinders in this lot contain sizeable heels of UF_6 at higher enrichments.

Building X-330 is equipped with several criticality radiation detector clusters. One is located on the first floor of its northeast corner, near storage lot X-745B.

Lot X-745E is approximately 250 ft by 500 ft, and is located away from plant buildings containing criticality radiation detector clusters. Cylinders stored in this lot contain UF_6 of various enrichments.

Photo 2. Photograph looking north toward the X-344A/X-342A complex across the X-745B storage lot. Two and one-half ton cylinders are visible in the foreground.

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3.0 Method

Simple models were used to calculate the potential range of effectiveness of criticality radiation detector clusters in the buildings closest to the cylinder storage lots. In these models, the cylinders in the storage lots were modelled as a slab of reduced-density, solid UF_6 , rather than as individual storage cylinders. In addition, the models included only major structures, such as building walls and major pieces of equipment, that would provide significant shielding of detectors from radiation from criticality accidents that could occur outside of the buildings where the detectors are located. Calculations using these simplifications provide conservative, yet realistic, estimates of actual detector coverage.

The method for determining neutron dose rates at criticality detector locations was a Monte Carlo technique using the transport code Monte Carlo N-Particle Transport (MCNP)⁴. Using the MCNP code allows the effects of phenomena such as sky shine, ground shine, and neutron streaming to be included in the calculations.

3.1 Building and Storage Lot Models

Whether a criticality radiation detector cluster located inside a building responds to a criticality accident in a storage lot outside of the building depends, in part, on to what extent the detector is shielded by the building structure and equipment. To consider shielding effects requires that building walls and any equipment between a criticality source and a criticality detector be modelled in MCNP. Building X-330, the building X-344A/X-342A complex, and building X-343 were modelled for their shielding effects. For all buildings, the ground was modelled as about 3 ft of concrete. A large volume of air surrounding each building was also included. A brief description of the basic model for each building is provided below.

Building X-330. The southeast corner of building X-330 was modelled in "Analysis of Criticality Alarm System Response to an Accidental Criticality Outside the Cascade Process Buildings at the Portsmouth Gaseous Diffusion Plant."⁵ The model in this report was extrapolated for this set of calculations by assuming that the building was approximately symmetric. This assumption allowed the model to represent the northeast and northwest corners of building X-330 with minimal adjustments.

Several significant barriers between the criticality source and the criticality radiation detector clusters exist in this building. These barriers were accounted for in the model, which includes the structural components of the building (the walls, roof, and concrete floors) and a homogenized representation⁶ of process cells. The number densities used in the calculations are presented in Table 1. This same set of number densities was used throughout the analysis.

The Building X-344A/X-342A Complex. A simplified model of the building X-344A/X-342A complex was developed from existing building drawings^{7,8,9,10}. The only significant barriers identified between the criticality source and the criticality radiation detector clusters were the concrete block walls of the building. Therefore, the only parts of the building X-344A/X-342A complex included in this model were the concrete block walls. A Sabrina¹¹- (a geometry visualization tool for MCNP) generated plot of the building X-344A-X-342A complex is shown in Figure 3.

Building X-343. Building X-343 was modelled in a manner similar to the building X-344A/X-342A complex. However, because the walls of building X-343 are mostly 2-inch-thick insulated metal siding, they provide little neutron shielding. Thus, no significant barriers between criticality source and criticality radiation detector clusters were modelled for this building.

Figure 3. Sabrina-generated plot looking south over the X-344A/X-342A complex. The UF₆ slab representing the X-745B storage lot is visible in the background.

Cylinder Storage Lot Models. Cylinder storage lots X-745B, X-745C, X-745D, X-745E and X-745F were analyzed for criticality accident alarm coverage. The approximate sizes and locations of these lots were obtained from "Plant Access Plan and Buildings and Facilities Location."¹² The geometrical arrangement of the cylinders in these lots varies widely among lots. In most lots, however, the cylinders are arranged end to end in rows. Therefore, for this calculation, the rows of cylinders were modelled as a slab of reduced density UF_6 . The slab height was modelled according to the particular geometry of the cylinders in the lot. For example, if the cylinders are 4 feet in diameter, then the slab was modelled as 4 feet high. If the cylinders were stacked 2 high, then the slab was modelled as 8 feet high. For all calculations in which the criticality source was located behind a row of cylinders, the slabs were assumed to run the full length of the storage lot.

3.2 Analysis

Estimating criticality radiation detector responses using the MCNP code involved a six-step process: modelling the buildings and storage lots, as described above; establishing a hypothetical criticality accident source term; running the MCNP code; tallying the resulting neutron fluxes at the detectors; applying variance reduction techniques; and converting the MCNP output into absorbed dose rates at the detectors. The last 5 steps are discussed below.

After the building and storage lot models were developed, the extent of coverage provided by existing criticality accident alarm systems was examined. First, the perimeter of the cylinder storage lots was modelled to determine if it was covered by existing alarms. This determination was made by locating a hypothetical criticality accident source at various points along the perimeter of the lots and then calculating the theoretical neutron flux that at a nearby detector.

If calculations showed that the perimeter of a storage lot was covered, then the depth of coverage for the lot was determined. This determination was made by locating a hypothetical criticality source at a depth of four feet (approximately one cylinder diameter) inside the lot and directly across from a nearby criticality detector, and then calculating the neutron flux at that detector. The 4-foot depth was then increased until the neutron flux at the detector fell below the alarm set point of 5 mRad/hr. This methodology provided the maximum depth of coverage that a detector could provide over a cylinder storage lot.

Number Densities and Source Term. For consistency with previous calculations of criticality alarm response in the PORTS buildings^{5,13}, both the number densities and the source leakage spectra used in these calculations were taken predominantly from Reference 6. The only exception is the number densities used for the UF₆ mixture in the cylinders. Because the cylinders are only approximately $\frac{2}{3}$ full by volume, the number densities for the cylinder contents were based on reduced density (67% theoretical density) UF₆, that would fill the entire cylinder volume¹⁴. The actual number densities used throughout the report are given in Table 1.

The source was assumed to be a critical sphere of enriched (4.95%) UO₂F₂ solution. However, because of the large distances between the source and the detectors, it was modelled as an isotropic point source, placed at selected locations in and around the storage lots. This modelled source is based on a source calculated by Westfall et al.⁶ that corresponds to the minimum accident of concern. The minimum accident of concern is defined by ANSI/ANS 8.3-1986¹⁵ (also conditionally endorsed by 10 CFR Part 76.89) as the accident that delivers the "equivalent of an absorbed dose in free air of 20 rads at a distance of 2 meters from the reaction material in 60 seconds."

The power level corresponding to the minimum accident of concern for this source is about 2100 watts. Based on a neutron leakage fraction of 0.28, this number equates to a source strength of approximately 4.86×10^{13} neutrons per second⁶. The leakage spectra for this

source is given in Table 2. Because the response function contribution to neutron absorbed dose is small for neutrons below 17 KeV, to reduce calculation time, the source was modelled to generate only neutrons above 17 KeV. Further, because the criticality radiation detector clusters detect only neutrons, the MCNP code tracked only neutrons.

Flux Tallys. The neutron flux at the detector locations was tallied in MCNP using point detectors. Point detectors were selected because of the inherent variance reduction present in this type of tally, as discussed in the following section.

Variance Reduction. Because the neutrons tracked in these Monte Carlo simulations have low probabilities of reaching a detector, the large size of the buildings and storage lots in these calculations, coupled with the thicknesses of solid UF_6 that may be encountered, could result in calculations that require an enormous amount of computer time. To avoid extremely long computation times, variance-reduction techniques were used. These techniques included point detectors, source bias in both energy and direction, and energy cut off in a particle's random walk. Individual cases were run for approximately 2 to 12 million histories to obtain reasonable statistics.

Table 1. Number Densities of Compounds Used in the Analysis

Material	Element	Number Density (atoms/barn-cm)
Air ⁶	Nitrogen	3.570e-5
	Oxygen	7.840e-6
Concrete ⁶	Hydrogen	1.487e-2
	Carbon	3.814e-3
	Oxygen	4.152e-2
	Sodium	3.040e-4
	Magnesium	5.870e-4
	Aluminum	7.350e-4
	Silicon	6.037e-3
	Calcium	1.159e-2
	Iron	1.968e-4
Steel ⁶	Carbon	3.921e-3
	Iron	1.968e-4
Homogenized Cell ⁶	Carbon	8.348e-2
	Fluorine	8.880e-5
	Aluminum	8.420e-5
	Silicon	1.666e-5
	Chlorine	8.800e-5
	Manganese	1.703e-5
	Iron	5.934e-4
	Nickel	4.563e-4
	Copper	3.273e-5
Solid UF ₆ (67% theoretical density)	Uranium	5.788e-3
	Fluorine	3.473e-2

Table 2. Neutron Leakage Source Distribution (Normalized to One Leaking Neutron)⁶

Group	Upper Energy (eV)	Group Fraction	Group	Upper Energy (eV)	Group Fraction
1	2.00e7	1.99e-2	15	3.05e0	1.02e-2
2	6.43e6	1.11e-1	16	1.77e0	5.93e-3
3	3.00e6	1.21e-1	17	1.30e0	2.69e-3
4	1.85e6	6.45e-2	18	1.13e0	2.34e-3
5	1.40e6	7.98e-2	19	1.00e0	4.33e-3
6	9.00e5	1.14e-1	20	8.00e-1	1.38e-2
7	4.00e5	9.77e-2	21	4.00e-1	4.00e-3
8	1.00e5	6.51e-2	22	3.25e-1	7.25e-3
9	1.70e4	4.66e-2	23	2.25e-1	2.30e-2
10	3.00e3	4.08e-2	24	1.00e-1	2.92e-2
11	5.50e2	3.77e-2	25	5.00e-2	1.70e-2
12	1.00e2	2.46e-2	26	3.00e-2	1.32e-1
13	3.00e1	2.14e-2	27	1.00e-2	2.36e-3
14	1.00e1	2.10e-2			

Point detectors were used because each interaction in a neutron's random walk results in a contribution to the detector tally. Therefore, a neutron need not arrive at a detector location in order to contribute to the tally. A source energy bias was used to preferentially produce neutrons with desirable energies, those that have the potential to provide significant contributions to the tally. This bias is slightly conservative. That is, the response calculated in the detector would be slightly low because the dose that thermal neutrons from the source would contribute is not counted.

The directional source bias used allowed the source to emit neutrons only in the direction of the detector, while appropriately reducing their significance in the tally. Finally, an energy cutoff was imposed to terminate the random walk of a neutron whose energy falls below 17 KeV. By eliminating particles whose potential contribution to the tally is extremely low, computational time was greatly reduced. This energy level cutoff is consistent with the source energy bias and is also conservative because it slightly reduces detector response.

Flux-to-Absorbed-Dose Rate Conversion. The MCNP code calculates neutron flux per source neutron at a hypothetical detector. The absorbed dose rate at this detector is then calculated on an energy-bin basis, as shown below.

$$\dot{D}_i = 4.86e13 \left(\frac{\text{neutrons leaked}}{\text{sec}} \right) \Phi_{i,MCNP} \left(\frac{\text{number}}{\text{cm}^2\text{-sec-srcn}} \right) 0.673 \left(\frac{\text{srcn}}{\text{neutrons leaked}} \right)$$

$$K_{i,HEND} \left(\frac{\text{Rads}}{\text{n/cm}^2} \right) \left(\frac{3600\text{sec}}{\text{hr}} \right) \left(\frac{1000\text{mR}}{\text{Rad}} \right) = 1.177 \times 10^{20} \Phi_{i,MCNP} K_{i,MCNP} \left(\frac{\text{mR}}{\text{hr}} \right)$$

where:

$\dot{D}_i$	=	Dose Rate
$\Phi_{i,MCNP}$	=	Neutron flux per source neutron
$K_{i,HEND}$	=	Henderson flux to Dose Converse Factor
i	=	energy bin index

The total absorbed dose rate at the detector is calculated by summing the absorbed dose rate contributions of the individual energy bins. The Henderson Free-In-Air neutron absorbed dose response function¹⁶ was used to convert flux to dose. Values for the Henderson flux-to-dose conversion factors are shown in Table 3.

Table 3. Henderson Free-In-Air Neutron Flux-to-Dose Conversion Factors

Group	Upper Energy (MeV)	Henderson Free-In-Air Conversion Factor (rads/n/cm ²)
1	20.0	4.72e-9
2	6.43	4.18e-9
3	3.0	3.22e-9
4	1.85	2.79e-9
5	1.4	2.44e-9
6	0.9	1.79e-9
7	0.4	1.08e-9
8	0.1	3.12e-10

Finally, calculations were conducted to estimate the effective radius of a detector located in a storage lot. These calculations assumed a criticality source near the center of an effectively infinite lot of cylinders. To allow limited credit to be taken for neutron streaming between cylinders, the cylinders for these cases were modelled as actual cylinders rather than slabs of UF₆. Two cases were modelled, one of a single layer of cylinders, and one of cylinders stacked two high.

3.3 Estimation of Detectors Needed for Full Protection

To estimate the number of additional criticality radiation detector clusters and alarms needed to provide full coverage of the cylinder storage lots, calculations were performed to determine the radial coverage of a single detector cluster in the cylinder storage lots. The radius of coverage of a single detector cluster was determined by placing a hypothetical criticality source at ground level directly below a hypothetical detector unit. The source was then moved in directions parallel and perpendicular to the axis of the cylinders in the lot until the calculated neutron absorbed-dose rate at the detector fell below the alarm set point of 5 mRad/hr.

The cylinder storage lot was modelled as a 500- by 500-foot lot of single or double stacked cylinders. A Sabrina-generated plot of the double-stacked case is shown in Figure 4. Material in the cylinders was assumed to be solid UF_6 with a density 67% of the theoretical density. To model neutron streaming in the space between cylinders, the cylinders were assumed to be spaced 3 inches apart. The ground of the cylinder lot was modelled as an approximately 7-foot-thick concrete slab extending to the edge of the lot. The flux tallies were taken at a point in the center of the cylinder storage lot at a height of 40 feet above ground level. The neutron source spectrum, variance reduction techniques, and conversion of flux to dose rates were identical to those described earlier. The source spectrum and the flux-to-dose conversions factors are given in Tables 2 and 3, respectively.

Figure 4. Sabrina-generated plot of hypothetical storage lot used for determining the effective radius in a lot of cylinders stacked two high.

4.0 Results

The results of this analysis indicate that the criticality radiation detector clusters currently installed at PORTS are largely ineffective in detecting criticality accidents in most of the cylinder storage lots at PORTs, except, sometimes, along portions of their peripheries.

Calculations indicate that only small parts of the UF_6 cylinder storage lots at PORTS are currently covered by criticality accident alarm systems. Those portions that are covered receive only limited coverage along their peripheries. This coverage is provided from criticality radiation detector clusters located in nearby buildings. Usually, coverage is limited to only the first row of cylinders stored in any lot. In a few cases, coverage may extend slightly beyond the first row. The approximate extent of coverage of the cylinder storage lots is shown in Figures 5 and 6. These figures also show the locations of the criticality radiation detector clusters and the hypothetical criticality point sources that were modelled.

4.1 Storage Lot X-745B

Storage lot X-745B is adjacent to two buildings equipped with criticality radiation detectors. Its coverage is provided by three detector clusters, two in the building X-344A/X-342A complex and one in the north end of the ground floor of building X-330.

Several sets of calculations were made for this lot. The first set examined coverage provided to the south perimeter of the lot by the detector in building X-330. Two criticality point sources were postulated, one at each corner of the lot. Resulting calculations indicated that limited coverage is provided along the south periphery of the lot.

Figure 5. Plan view of the X-344A/X-342A complex and the X-330 building showing the relative location of the surrounding storage lots. The portions of the storage lots currently protected by installed alarm systems is shaded in blue.

Figure 6. Plan view of the X-343 building and the X-745D storage lot. The portion of the lot currently protected by the installed alarm system is shaded in blue.

Next, a criticality point source was located 4 feet into the lot, directly north of the detector in building X-330. Resulting calculations yielded a theoretical absorbed-dose rate at the detector below the alarm setpoint of 5mRad/hr, indicating that little or no coverage is provided for inside the lot.

Results for the north perimeter of the lot were similar. All criticality point sources postulated on the north perimeter of lot X-745B were covered by detectors located in the building X-344A/X-342A complex.** Modelling a point source 4 feet into the lot, directly opposite a detector, generated an absorbed dose rate of 5 mRad/hr. Thus, there is a high degree of confidence that a criticality accident on either the north or the south perimeter of lot X-745B would be detected. However, as the distance into the lot increases more than a few feet, detection drops off dramatically.

4.2 Storage Lot X-745C

The two detector clusters closest to storage lot X-745C are located on the west side of the cell floor at the north end of building X-330. Six calculations were conducted to determine existing coverage of this lot. First, a criticality point source was hypothesized to be at X-330-P1. As shown in Figure 5, this source is located at the edge of lot X-745C directly west of criticality radiation detector cluster 29-1-W in building X-330. The dose rate generated at the detector from this point was about 59 mRad/hr, clearly far above the 5 mRad/hr setpoint of the detector.

**The building X-344A/X-342A complex includes 2 detectors that cover storage lot X-745B. Thus, 2 absorbed-dose values are calculated for each criticality point source postulated on the perimeter of the lot. Because shielding varies between the criticality source and the 2 detectors, the detectors' responses also vary. As the amount of shielding between the source and a detector increases, the flux tally decreases, and, usually, the error in the tally is large. However, this error decreases with increased computation time.

For the X-344A/X-342A model, calculations were terminated when the flux tally for one of the detectors obtained a satisfactorily small error. At this point, the error value for the second detector may still be large, as is the case for the vault detector for criticality point source X-344-B2 (see Table 4).

Table 4. Numerical Results for Storage Lot X-745B

Criticality Point Source	Storage Lot	Location	Detector Modelled	Absorbed Neutron Dose Rate at Detector (mRad/hr)
X-330-G1	X-745B	Southeast corner of lot, on perimeter	X-330 Col. 87-DD	274 ± 2
X-330-G2	X-745B	Southwest corner of lot, on perimeter	X-330 Col. 87-DD	24 ± 1
X-330-GB1	X-745B	South side, 4 feet into lot, due north of detector	X-330 Col. 87-DD	3 ± 0.2
X-344-P5	X-745B	Northeast corner on perimeter	X-344 Col. Cg-19	20 ± 2
			X-344 Vault	15 ± 4
X-344-P6	X-745B	Northeast corner of inset, on perimeter	X-344 Col. Cg-19	105 ± 3
			X-344 Vault	56 ± 14
X-344-P7	X-745B	Northwest corner of inset, on perimeter	X-344 Col. Cg-19	241 ± 13
			X-344 Vault	72 ± 3
X-344-P8	X-745B	Northwest corner on perimeter	X-344 Col. Cg-19	35 ± 4
			X-344 Vault	55 ± 4
X-344-B2	X-745B	4 feet into the north side directly south of the eastern X-344 detector (Reliable results were not obtained from the vault detector due to the large amount of shielding provided by the intervening concrete.)	X-344 Col. Cg-19	5 ± 1
			X-344 Vault	123 ± 82

Additional calculations were made for the perimeter of lot X-745C postulating criticality point sources to a point half way to the next detector in building X-330. The dose rate from this point was about 30 mRad/hr. At this point, credit is taken for the symmetry of the lot and building, allowing the conclusion that all other points on the east perimeter are bounded by the calculations conducted.

The final calculation made for lot X-745C assumed a criticality point source 4 feet inside of the lot. With the source located at this point, the absorbed dose rate at the detector was insufficient to trigger an alarm. Therefore, criticality accidents occurring on the periphery of the east perimeter of lot X-745C would probably be detected. However, if the criticality occurred 2 to 3 feet inside the lot, then it would probably not be detected. The results of these calculations are shown in Table 5.

Table 5. Numerical Results for Storage Lot X-745C

Criticality Point Source	Storage Lot	Location	Detector Modelled	Absorbed Neutron Dose Rate at Detector (mRad/hr)
X-330-P1	X-745C	East side, on perimeter directly west of detector	X-330 29-1-W	59 ± 1
X-330-P2	X-745C	East side, on perimeter 196 feet south of P1	X-330 29-1-W	30 ± 1
X-330-P5	X-745C	East side, on perimeter 147 feet south of P1	X-330 29-1-W	41 ± 1
X-330-P4	X-745C	East side, on perimeter 98 feet south of P1	X-330 29-1-W	51 ± 1
X-330-P3	X-745C	East side, on perimeter 49 feet south of P1	X-330 29-1-W	55 ± 2
X-330-B1	X-745C	East side, 4 feet into lot, due west of detector	X-330 29-1-W	1 ± 0.1

4.3 Storage Lot X-745D

Storage lot X-745D is adjacent to building X-343 which has one criticality radiation detector cluster. Three sets of calculations were made for this lot. To determine the degree of coverage provided to the perimeter of the lot, criticality point sources, X-343-P1 and X-343-P2, were postulated at locations shown in Figure 6.*** The results of these two

*** Although these postulated sources are farther from their detector than the source postulated for lot X-745B is from its detector, calculations show higher absorbed dose rates at the detectors in building X-343. The lower absorbed dose rates at the detector in building X-330 result from shielding provided primarily by the concrete cell floor of the building.

calculations were 167 mRad/hr and 261 mRad/hr, respectively. All points on the perimeter of the lot between these two are bounded by the results from these calculations.

Next, the point source was located approximately 4 feet into the lot. Resulting calculations showed that the absorbed dose rate at the detector decreased greatly, but was still sufficient to trigger an alarm. Movement of the source farther into the lot would further decrease the absorbed dose rate at the detector. In addition, shielding by the solid UF_6 in the cylinders would result in negligible increases in the range of protection. Thus, there is a high degree of probability that criticality accidents occurring in the outermost row of cylinders facing building X-343 would be detected. However, there is little assurance that criticalities occurring farther into the lot would be detected. The results of these calculations are shown in Table 6.

Table 6. Numerical Results for Storage Lot X-745D

Criticality Point Source	Storage Lot	Location	Detector Modelled	Absorbed Neutron Dose Rate at Detector (mRad/hr)
X-343-P1	X-745D	Northwest corner, on perimeter	X-343	167 ± 3
X-343-P2	X-745D	Southeast corner, on perimeter	X-343	261 ± 5
X-343-B1	X-745D	Southwest corner, 4 feet diagonal into lot	X-343	8 ± 0.4

4.4 Storage Lot X-745E

One calculation was made for storage lot X-745E. This calculation was based on a hypothetical criticality point source located at the southeast corner of the lot, and the detector

located in building X-330. Because of the distance between the point source and the detector and because the calculated absorbed dose rate at the detector was 5 mRad/hr, the alarm setpoint, there is minimal assurance that a criticality accident occurring in this lot would be detected.

Table 7. Numerical Results for Storage Lot X-745E

Criticality Source Point	Storage Lot	Location	Detector Modelled	Absorbed Neutron Dose Rate at Detector (mRad/hr)
X-330-P6	X-745E	Southeast corner on perimeter	X-330 29-1-W	5 ± 1

4.5 Storage Lot X-745F

Storage lot X-745F is divided into two parts. However, as with the other lots, the first set of calculations made for this lot placed hypothetical criticality point sources along the perimeter of the lot nearest the detectors located in the building X-344A/X-342A complex.

These calculations indicate that detectable absorbed dose rates are received at the detectors from all point sources along the southern perimeter of the lot. In addition, if a source point is located 4 feet into the lot directly opposite a detector, the calculated absorbed dose rates at the detector exceed the alarm set point. Thus, criticality accidents occurring on the south perimeter of storage lot X-745F as deep as 4 feet into the lot would be detected. Beyond this distance, there is minimal confidence of detection.

Table 8. Numerical Results for Storage Lot X-745F

Criticality Point Source	Storage Lot	Location	Detector Modelled	Absorbed Neutron Dose Rate at Detector (mRad/hr)
X-344-P1	X-745F	Southwest corner, on perimeter	X-344 Col. Cg-19	53 ± 3
			X-344 Vault	247 ± 10
X-344-P2	X-745F	South side, on perimeter, approximately due north of detector on column Cg-19	X-344 Col. Cg-19	94 ± 3
			X-344 Vault	62 ± 3
X-344-P3	X-745F	Southeast corner of western X-745F lot, on perimeter	X-344 Col. Cg-19	105 ± 5
			X-344 Vault	73 ± 25
X-344-P4	X-745F	Southeast corner of eastern X-745F lot, on perimeter	X-344 Col. Cg-19	49 ± 3
			X-344 Vault	16 ± 1
X-344-B1	X-745F	Four feet into the south side, directly north of the eastern X-344 detector	X-344 Col. Cg-19	14 ± 2
			X-344 Vault	19 ± 4

4.6 Estimate of Coverage Radius for Detectors Installed in Cylinder Storage Lots

Estimation of the number of detector clusters needed to provide full coverage for the PORTS enriched- UF_6 cylinder storage lots required two sets of calculations. First, the approximate radius of coverage provided by a single detector located 40 feet above ground above a single layer of cylinders was determined. Results of these calculations showed that a detector at this height will, to a high degree of confidence, detect criticality accidents to a radius of about 75 feet. This radius is much smaller than the traditional radius of 350³ ft applied at PORTS³ due to the enormous shielding capability provided by solid UF_6 . The 350-ft radius is based on calculations conducted on the interior of a process building where solid UF_6 will not be encountered. Therefore, about one detector for every 17,600 square feet of storage lot would have to be installed for complete coverage.

Next, the same set of calculations were performed for cylinders of UF_6 stacked 2 high. Results of these calculations showed that, at a height of 40 feet above ground, a criticality radiation detector cluster will respond to a criticality accident only if the detector is located almost directly above the source. The numerical results of both sets of calculations are shown in Table 9.

Table 9. Numerical Results for Effective Radius Calculation

Case	Description	Absorbed Neutron Dose Rate at Detector mRad/hr
R ₁	Single layer of cylinders, Detector 40 ft up Source directly under detector (r=0)	951 ± 14
R ₂	Single layer of cylinders, Detector 40 ft up Source 50 ft out from detector in x and y (r=50)	38 ± 1
R ₃	Single layer of cylinders, Detector 40 ft up Source 75 ft out from detector in x and y (r=75)	16 ± 1
D ₁	Double layer of cylinders, Detector 40 ft up Source directly under detector (r=0)	5.2 ± 0.3
D ₂	Double layer of cylinders, Detector 40 ft up Source 10 ft out from detector in x and y (r=10)	4.7 ± 0.4

5.0 Conclusions

Results of this analysis indicate with a fairly high degree of confidence that criticality accidents occurring in the outside row of UF_6 cylinders on the perimeter of most storage lots at PORTS will be detected by criticality radiation detector clusters in buildings adjacent to the storage lots. The covered area for each of the storage lots modelled is shown in Figures 5 and 6. Beyond the first row of cylinders, however, there is generally little to no assurance that a minimum accident of concern will be detected. Criticality accidents having higher power levels than a minimum accident of concern with correspondingly higher radiation levels are more likely to be detected. In addition, because storage lot X-745E is located far away from buildings equipped with criticality detectors, it currently has no coverage at all.

The calculations performed in this report are simple and do not take credit for neutron streaming paths that might exist between cylinders, except for the calculations to estimate effective radius for a detector installed in a lot. More detailed calculations might show that coverage is provided slightly further into the lots than is estimated here. However, because of the large size of the storage lots and the great shielding capacity of UF_6 , full coverage of the lots does not currently exist. Thus, even the most sophisticated models will show only limited coverage of the lots by the detectors currently in place in adjacent buildings.

To obtain complete coverage for cylinder storage lots that do not contain stacked cylinders requires the installation of approximately one detector for every 17,600 square feet of lot. This figure is based on a detector height of approximately 40 feet above ground, and an alarm setpoint of 5 mRad/hr, which gives an effective detector radius of approximately 75 feet. Because of the great shielding capability of UF_6 , a much smaller effective radius for detectors is obtained for lot X-745C, which contains stacked cylinders. For this lot, calculations indicate that a criticality accident may not be detected unless the detector is located almost directly above it. Thus, rather than install detectors in lot X-745C, the

cylinders containing enriched heels could be removed from this lot and placed in another lot in which cylinders are not stacked.

The absorbed dose rate at the detector was calculated using the Henderson neutron flux-to-dose conversion factors. It has long been assumed that the detector response function is similar to these conversion factors.⁶ The Henderson conversion factors for neutrons becomes quite small below 17 KeV. Therefore, an energy cut-of at 17 KeV was chosen to improve computational efficiency for the Monte-Carlo calculation. Specifications for the PORTS criticality accident alarm system radiation detectors call for use of scintillators incorporating ^6Li or ^{10}B .¹⁷ The ^6Li or ^{10}B improves the detector's sensitivity to thermal neutrons. Use of a detector response function more closely approximating the detector will likely also result in our increase in the area of radial coverage.

The models constructed of the cylinder storage lots were generic and simple representations of the storage lots examined, and as such do not take any credit for the specific cylinder spacing and positioning which exists in the actual lots. In actuality, the majority of the cylinders in the X-745B lot are 2.5-ton cylinders. These cylinders have a diameter of approximately 30 inches rather than the 48 inches modelled for 10-ton cylinders. Additionally, the models assumed the cylinders were spaced edge to edge, with no intervening spacing for access. In the X-745F lot, the cylinders in storage are 10-ton cylinders, spaced approximately 10 feet apart in double rows. Each double row is several feet apart from the next double row to allow access by equipment. Including this level of detail in the models will show that actual coverage probably extends beyond that currently estimated. This would reduce the number of additional detectors needed to assure full coverage for the cylinder storage lots.

Neither a more accurate model of cylinder spacing in the storage lots nor inclusion of thermal neutrons in the calculation of the detector response will result in coverage of the storage lots by the existing criticality accident alarm system. These refinements in the

calculations will more likely have a positive effect in extending the zone of coverage for placement of additional detector clusters in the storage lots.

6.0 References

1. S. A. Jones, "Technology Transfer for Criticality Radiation Alarm Monitors," GAT-T-3225, Rev. 1, Portsmouth Gaseous Diffusion Plant, 10/84
2. "Uranium Hexafluoride: A Manual of Good Handling Practices," ORO-651, Rev. 6, U.S. Department of Energy, 10/91
3. "GDP Criteria for Radial Coverage and Alarm SetPoint for Neutron Sensing Radiation Alarm Clusters," GAT-DM-1535, Portsmouth Gaseous Diffusion Plant, 5/83
4. J. Briesmeister (Editor), "MCNP - A General Monte Carlo Code for Neutron and Photon Transport", Version 4a, LA-12625-M, (Available from the Radiation Shielding Information Center as Code Package CCC-200), 11/93
5. S. B. Negron, et al., "Analysis of Criticality Alarm System Response to an Accidental Criticality Outside the Cascade Process Buildings at the Portsmouth Gaseous Diffusion Plant", POEF-SH-19, 5/94
6. R. M. Westfall and J.R. Knight, "Radiation Levels in a Gaseous Diffusion Plant Assuming a Low Enriched Criticality Event Corresponding to the ANSI Standard Minimum Accident of Concern," ORNL/CSD/INF-82-7, 1/17/83
7. X-342 Ground Floor Plan, X-342-2A, Rev. 2, 1/20/53
8. X-344A Building Area III Floor Plan, X-344A-109A, Rev. 4, 7/11/74
9. X-344A Building Area II Floor Plan, X-344A-105A, Rev.2, 7/31/73
10. X-344A Ground Floor Plan, X-344A-100A, Rev. 3, 8/31/73
11. K.A. Van Riper, "SABRINA User's Guide," LA-UR-93-3696, (Available from the Radiation Shielding Information Center as Code Package PSR-242), 10/93
12. Plant Access Plan Buildings and Facilities Location, DX-761-1084-A, Rev. 0, 10/20/94
13. S. B. Negron and R. W. Tayloe, Jr., "Analysis of the Proposed Relocation of the Neutron Criticality Clusters in the Process Buildings for the Portsmouth Gaseous Diffusion Plant, POEF-SH-12, 1/94
14. "Aspects of Chemistry and Plant Parameters, Section 2: Uranium Materials Handling", Portsmouth Gaseous Diffusion Plant, POEF-2060, August 1992
15. "American National Standard Criticality Accident Alarm System," ANSI/ANS-8.3-1986, American Nuclear Society, 1986

16. C. Fithian, et al., "Data Catalogue of the 1980 Sheba Experiments," H & R Technical Associates, Inc., May 1983
17. G. M. Crandall, "GAT GDP Neutron Sensitive Criticality Alarm Clusters," Equipment Specification No. ES-C-28, Rev. 1, Feb. 1985

Appendix A: Sample MCNP Inputs for Each of the Major Geometry Models

Sample MCNP input for the building X-344A/X-342A complex. This input is associated with the storage lot on the north side of the facility.

This is the model of the building X344A/X342A complex for the alarm study.

```

c
c
c *****
c
c               cell cards
c *****
10  1  4.354e-5  420  -540  10  -30  640  -650  imp:n=1  $ room
20  1  4.354e-5  420  -540  40  -120  640  -650  imp:n=1
30  1  4.354e-5  420  -480  130  -160  640  -650  imp:n=1
40  1  4.354e-5  420  -480  170  -200  640  -650  imp:n=1
50  1  4.354e-5  420  -480  210  -240  640  -650  imp:n=1
60  1  4.354e-5  420  -440  250  -280  640  -650  imp:n=1
70  1  4.354e-5  (420  -460  290  -360  640  -650):
      (450  -460  250  -290  640  -650):  imp:n=1
80  1  4.354e-5  430  -460  370  -390  640  -650  imp:n=1
90  1  4.354e-5  470  -480  250  -330  640  -650  imp:n=1
100 1  4.354e-5  470  -480  350  -400  640  -650  imp:n=1
110 1  4.354e-5  510  -520  130  -300  640  -650  imp:n=1
120 1  4.354e-5  (130  -310  490  -500  640  -650):
      (490  -520  310  -400  640  -650):  imp:n=1
130 1  4.354e-5  (540  -550  10  -120  640  -650):
      (550  -560  10  -70  640  -650):
      (560  -620  10  -20  640  -650):  imp:n=1
140 1  4.354e-5  (530  -550  130  -140  640  -650):
      (550  -560  70  -140  640  -650):  imp:n=1
150 1  4.354e-5  530  -560  150  -260  640  -650  imp:n=1
160 1  4.354e-5  530  -560  270  -400  640  -650  imp:n=1
170 1  4.354e-5  560  -620  20  -50  640  -650  imp:n=1
180 1  4.354e-5  (570  -610  60  -80  640  -650):
      (570  -590  80  -90  640  -650):
      (570  -610  90  -100  640  -650):
      (570  -580  100  -110  640  -650):
      (570  -610  110  -140  640  -650):
      (560  -570  60  -70  640  -650):  imp:n=1
190 1  4.354e-5  570  -600  150  -180  640  -650  imp:n=1
200 1  4.354e-5  570  -600  190  -220  640  -650  imp:n=1
210 1  4.354e-5  570  -600  230  -260  640  -650  imp:n=1
220 1  4.354e-5  570  -600  270  -320  640  -650  imp:n=1
230 1  4.354e-5  570  -600  340  -370  640  -650  imp:n=1
240 1  4.354e-5  570  -600  380  -400  640  -650  imp:n=1
250 1  4.354e-5  (600  -610  140  -400  640  -650):
      (610  -620  50  -400  640  -650):  imp:n=1
c
c Here comes the concrete
c
260 2  3.9827e-2  420  -540  30  -40  640  -650  imp:n=1
270 2  3.9827e-2  420  -550  120  -130  640  -650  imp:n=1
280 2  3.9827e-2  420  -490  160  -170  640  -650  imp:n=1
290 2  3.9827e-2  420  -490  200  -210  640  -650  imp:n=1
300 2  3.9827e-2  420  -490  240  -250  640  -650  imp:n=1
310 2  3.9827e-2  420  -450  280  -290  640  -650  imp:n=1
320 2  3.9827e-2  500  -530  300  -310  640  -650  imp:n=1
330 2  3.9827e-2  460  -490  330  -350  640  -650  imp:n=1
340 2  3.9827e-2  420  -470  360  -370  640  -650  imp:n=1
350 2  3.9827e-2  420  -470  390  -400  640  -650  imp:n=1
360 2  3.9827e-2  420  -430  370  -390  640  -650  imp:n=1
370 2  3.9827e-2  440  -450  250  -280  640  -650  imp:n=1
380 2  3.9827e-2  460  -470  250  -330  640  -650  imp:n=1
390 2  3.9827e-2  460  -470  350  -360  640  -650  imp:n=1
400 2  3.9827e-2  460  -470  370  -390  640  -650  imp:n=1

```

```

410 2 3.9827e-2 480 -490 130 -160 640 -650 imp:n=1
420 2 3.9827e-2 480 -490 170 -200 640 -650 imp:n=1
430 2 3.9827e-2 480 -490 210 -240 640 -650 imp:n=1
440 2 3.9827e-2 480 -490 250 -330 640 -650 imp:n=1
450 2 3.9827e-2 480 -490 350 -400 640 -650 imp:n=1
460 2 3.9827e-2 500 -510 130 -300 640 -650 imp:n=1
470 2 3.9827e-2 520 -530 130 -140 640 -650 imp:n=1
473 2 3.9827e-2 520 -530 150 -260 640 -650 imp:n=1
477 2 3.9827e-2 520 -530 270 -300 640 -650 imp:n=1
480 2 3.9827e-2 520 -530 310 -400 640 -650 imp:n=1
490 2 3.9827e-2 560 -610 50 -60 640 -650 imp:n=1
500 2 3.9827e-2 590 -610 80 -90 640 -650 imp:n=1
510 2 3.9827e-2 580 -610 100 -110 640 -650 imp:n=1
520 2 3.9827e-2 520 -600 140 -150 640 -650 imp:n=1
530 2 3.9827e-2 560 -600 180 -190 640 -650 imp:n=1
540 2 3.9827e-2 560 -600 220 -230 640 -650 imp:n=1
550 2 3.9827e-2 520 -600 260 -270 640 -650 imp:n=1
560 2 3.9827e-2 560 -600 320 -340 640 -650 imp:n=1
570 2 3.9827e-2 560 -600 370 -380 640 -650 imp:n=1
580 2 3.9827e-2 560 -570 70 -140 640 -650 imp:n=1
590 2 3.9827e-2 560 -570 150 -180 640 -650 imp:n=1
600 2 3.9827e-2 560 -570 190 -220 640 -650 imp:n=1
610 2 3.9827e-2 560 -570 230 -260 640 -650 imp:n=1
620 2 3.9827e-2 560 -570 270 -320 640 -650 imp:n=1
630 2 3.9827e-2 560 -570 340 -370 640 -650 imp:n=1
640 2 3.9827e-2 560 -570 380 -400 640 -650 imp:n=1
700 2 3.9827e-2 700 -710 720 -730 630 -640 imp:n=1
710 1 4.354e-5 (700 -420 720 -730 640 -660):
              (420 -620 720 -730 650 -660):
              (420 -620 400 -730 640 -650):
              (420 -620 720 -10 640 -650):
              (620 -710 720 -730 640 -660) imp:n=1
900 0 (-700:710:-720:730:-630:660) -999 imp:n=1
999 0 999 imp:n=0

```

```

c
c *****
c surface cards
c *****
c
10 py 0 $ south exterior wall
20 py 487 $
30 py 1524 $
40 py 1554 $
50 py 1859 $
60 py 1879 $
70 py 2286 $
80 py 2682 $
90 py 2702 $
100 py 2773 $
110 py 2793 $
120 py 3048 $
130 py 3078 $
140 py 3535 $
150 py 3555 $
160 py 3890 $
170 py 3910 $
180 py 4100 $
190 py 4120 $
200 py 4459 $
210 py 4479 $
220 py 4600 $
230 py 4620 $
240 py 4735 $
250 py 4755 $
260 py 5100 $
270 py 5120 $

```

```

280 py 5202      $
290 py 5222      $
300 py 5349      $
310 py 5379      $
320 py 5600      $
330 py 5609      $
340 py 5620      $
350 py 5629      $
360 py 6080      $
370 py 6100      $
380 py 6120      $
390 py 6411      $
400 py 6431      $
410 px 0          $
420 px 1737      $
430 px 1757      $
440 px 2448      $
450 px 2468      $
460 px 2631      $
470 px 2651      $
480 px 3371      $
490 px 3391      $
500 px 3615      $
510 px 3645      $
520 px 6736      $
530 px 6756      $
540 px 7346      $
550 px 8870      $
560 px 9800      $
570 px 9820      $
580 px 10413     $
590 px 11652     $
600 px 12700     $
610 px 13461     $
620 px 14680     $
630 pz -100      $ concrete ground
640 pz 0          $ ground level
650 pz 366       $ top of 344 bldg
660 pz 5000      $ top of air
700 px -50000
710 px 50000
720 py -50000
730 py 50000
999 so 200000

```

```

mode n
sdef erg=d1 pos= 4785 8717 100 dir=d2 vec 0 -1 0 $ eastern source position in cm
cut:n 1e50 0.017 -0.50 -0.25 0
sc1 source energy distribution cut off below 17 kev
si1 h 0.017 0.1 0.4 0.9 1.4 1.85 3.0 6.43 20
sp1 0 0.0651 0.0977 0.114 0.0798
    0.0645 0.121 0.111 0.0199
sc2 distribution of source angles 180 - 0 biased forward
si2 h -1 -.9 -.8 -.7 -.6 -.5 -.4 -.3 -.2 -.1 0
    .1 .2 .3 .4 .5 .6 .7 .8 .9 1
sp2 d 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
    1 1 1 1
sb2 d 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1
    1 1 1 1
f5:n 3655 4000 100 5
fc5 This is the west point detector
e5 1.00e-11 1e-8 3e-8 5e-8 1e-7 2.25e-7 3.25e-7 4e-7 8e-7
    1e-6 1.13e-6 1.3e-6 1.77e-6 3.05e-6 1e-5 3e-5 1e-4 5.5e-4
    0.003 0.017 0.1 0.4 0.9 1.4 1.85 3.0 6.43 20
f15:n 10600 4000 100 5
fc15 This is the east point detector
e15 1.00e-11 1e-8 3e-8 5e-8 1e-7 2.25e-7 3.25e-7 4e-7 8e-7

```


1e-6 1.13e-6 1.3e-6 1.77e-6 3.05e-6 1e-5 3e-5 1e-4 5.5e-4
 0.003 0.017 0.1 0.4 0.9 1.4 1.85 3.0 6.43 20

c
 c *****
 c material cards
 c *****

m1 7014.50c 3.570e-5 \$ air
 8016.50c 7.840e-6
 m2 1001.50c 1.487e-2 \$ concrete
 6012.50c 3.814e-3
 8016.50c 4.152e-2
 11023.50c 3.040e-4
 12000.51c 5.870e-4
 13027.50c 7.350e-4
 14000.50c 6.037e-3
 20000.51c 1.159e-2
 26000.50c 1.968e-4

ctme 60
 nps 100000000
 print

This model is associated with detector coverage around building X-343. Because the building provides no substantial sources of shielding, it is excluded from the model.

This model determines protection provided by detectors in building X-343.

```
c
c
10 2 7.9654e-2 30 -40 50 -60 10 -20 imp:n=1 $ concrete slab
20 1 4.354e-5 30 -40 50 -60 20 -70 #30 #35 imp:n=1 $ air mass
30 3 4.052e-2 80 -90 110 -100 20 -120 imp:n=1 $ barrels
35 3 4.052e-2 85 -90 100 -105 20 -120 imp:n=1 $ barrels
40 0 (-10:-30:40:-50:60:70) -999 imp:n=1 $ internal world
50 0 999 imp:n=0 $ external world
```

```
10 pz -100 $ bottom of the concrete slab
20 pz 0 $ ground level
30 px -50000 $ - px define giant air mass
40 px 50000 $ px
50 py -50000 $ - py
60 py 50000 $ py
70 pz 50000 $ top of sky
80 px -4572 $ - px define UF6 slab
85 px -172.4 $ - px
90 px 0 $ px
100 py 172.4 $ - py
105 py 3048 $ - py
110 py 0 $ py
120 pz 122 $ top of barrels
999 so 99999 $ boundary of internal world
```

```
mode n
sdef erg=d1 pos= -173.4 173.4 100 dir=d2 vec 4745.4 -3983.4 0 $ source position
cut:n 1e50 0.017 -0.50 -0.25 0
sc1 source energy distribution cut off below 17 kev
si1 h 0.017 0.1 0.4 0.9 1.4 1.85 3.0 6.43 20
sp1 0 0.0651 0.0977 0.114 0.0798
0.0645 0.121 0.111 0.0199
sc2 distribution of source angles 180 - 0 biased forward .
si2 h -1 -.9 -.8 -.7 -.6 -.5 -.4 -.3 -.2 -.1 0
.1 .2 .3 .4 .5 .6 .7 .8 .9 1
sp2 d 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
sb2 d 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1
f5:n 4572 -3810 100 5
fc5 This is the point detector
e5 1.00e-11 1e-8 3e-8 5e-8 1e-7 2.25e-7 3.25e-7 4e-7 8e-7
1e-6 1.13e-6 1.3e-6 1.77e-6 3.05e-6 1e-5 3e-5 1e-4 5.5e-4
0.003 0.017 0.1 0.4 0.9 1.4 1.85 3.0 6.43 20
m1 7014.50c 3.570e-5 $ air
8016.50c 7.840e-6
m2 1001.50c 1.487e-2 $ concrete
6012.50c 3.814e-3
8016.50c 4.152e-2
11023.50c 3.040e-4
12000.51c 5.870e-4
13027.50c 7.350e-4
14000.50c 6.037e-3
20000.51c 1.159e-2
26000.50c 1.968e-4
m3 92238.50c 8.682e-3 $ UF6 in barrels
9019.50c 5.209e-2
ctme 120
nps 10000000
```

Model of north end of building X-330. This model determines detector responses for hypothetical criticalities in storage lots X-745B and X-745C.

```

Building X-330      +py  -py  +px  -px +pz  -pz
c  x330
c  north east corner
c  4.95% enriched optimum h/u source
1  2  7.9654e-2  100 -112 200 -206 1 -2 imp:n=1 $ concrete ground
2  1  4.354e-5  100 -101 201 -209 2 -7 imp:n=1 $ ae air
3  1  4.354e-5  101 -112 200 -201 2 -7 imp:n=1 $ as air
4  1  4.354e-5  101 -114 201 -208 2 -3 imp:n=1 $ 1st level
5  2  7.9654e-2  101 -112 201 -206 3 -4 imp:n=1 $ concrete floor
6  6  1.0003e-3  101 -114 208 -206 4 -5 imp:n=1 $ 2a homo process area
7  6  1.0003e-3  114 -112 201 -206 4 -5 imp:n=1 $ 2b homo process area
8  1  4.354e-5  101 -112 201 -206 5 -6 imp:n=1 $ upper bay
9  5  9.0726e-2  101 -112 201 -206 6 -7 imp:n=1 $ roof
10 1  4.354e-5  101 -102 201 -208 4 -5 imp:n=1 $ a1
11 1  4.354e-5  102 -103 201 -202 4 -5 imp:n=1 $ w1
12 4  1.6021e-3  102 -103 202 -203 4 -5 imp:n=1 $ c1
13 1  4.354e-5  102 -103 203 -204 4 -5 imp:n=1 $ i1
14 4  1.6021e-3  102 -103 204 -205 4 -5 imp:n=1 $ c2
15 1  4.354e-5  103 -104 201 -208 4 -5 imp:n=1 $ a2
16 1  4.354e-5  104 -105 201 -202 4 -5 imp:n=1 $ w2
17 4  1.6021e-3  104 -105 202 -203 4 -5 imp:n=1 $ c3
18 1  4.354e-5  104 -105 203 -204 4 -5 imp:n=1 $ i2
19 4  1.6021e-3  104 -105 204 -205 4 -5 imp:n=1 $ c4
20 1  4.354e-5  105 -106 201 -208 4 -5 imp:n=1 $ a3
21 1  4.354e-5  106 -107 201 -202 4 -5 imp:n=1 $ w3
22 4  1.6021e-3  106 -107 202 -203 4 -5 imp:n=1 $ c5
23 1  4.354e-5  106 -107 203 -204 4 -5 imp:n=1 $ i3
24 4  1.6021e-3  106 -107 204 -205 4 -5 imp:n=1 $ c6
25 1  4.354e-5  107 -108 201 -208 4 -5 imp:n=1 $ a4
26 1  4.354e-5  108 -109 201 -202 4 -5 imp:n=1 $ w4
27 4  1.6021e-3  108 -109 202 -203 4 -5 imp:n=1 $ c7
28 1  4.354e-5  108 -109 203 -204 4 -5 imp:n=1 $ i4
29 4  1.6021e-3  108 -109 204 -205 4 -5 imp:n=1 $ c8
30 1  4.354e-5  109 -110 201 -208 4 -5 imp:n=1 $ a5
31 1  4.354e-5  110 -111 201 -202 4 -5 imp:n=1 $ w5
32 4  1.6021e-3  110 -111 202 -203 4 -5 imp:n=1 $ c9
33 1  4.354e-5  110 -111 203 -204 4 -5 imp:n=1 $ i5
34 4  1.6021e-3  110 -111 204 -205 4 -5 imp:n=1 $ c10
35 1  4.354e-5  102 -103 205 -207 4 -5 imp:n=1 $ j1
36 4  1.6021e-3  102 -103 207 -208 4 -5 imp:n=1 $ c11
37 1  4.354e-5  104 -105 205 -207 4 -5 imp:n=1 $ j2
38 4  1.6021e-3  104 -105 207 -208 4 -5 imp:n=1 $ c12
39 1  4.354e-5  106 -107 205 -207 4 -5 imp:n=1 $ j3
40 4  1.6021e-3  106 -107 207 -208 4 -5 imp:n=1 $ c13
41 1  4.354e-5  108 -109 205 -207 4 -5 imp:n=1 $ j4
42 4  1.6021e-3  108 -109 207 -208 4 -5 imp:n=1 $ c14
43 1  4.354e-5  110 -111 205 -207 4 -5 imp:n=1 $ j5
44 4  1.6021e-3  110 -111 207 -208 4 -5 imp:n=1 $ c15
45 1  4.354e-5  111 -113 201 -208 4 -5 imp:n=1 $ a6
46 1  4.354e-5  113 -114 201 -202 4 -5 imp:n=1 $ w6
47 4  1.6021e-3  113 -114 202 -203 4 -5 imp:n=1 $ c16
48 1  4.354e-5  113 -114 203 -204 4 -5 imp:n=1 $ i6
49 4  1.6021e-3  113 -114 204 -205 4 -5 imp:n=1 $ c17
50 1  4.354e-5  113 -114 205 -207 4 -5 imp:n=1 $ j7
51 4  1.6021e-3  113 -114 207 -208 4 -5 imp:n=1 $ c18
c  101 1 4.354e-5 -301 imp:n=1 $ cell level det
200 1 4.354e-5 100 -101 200 -201 2 -7 imp:n=1 $ ase air
201 1 4.354e-5 101 -114 208 -206 2 -3 imp:n=1 $ 1a
202 1 4.354e-5 114 -112 201 -206 2 -3 imp:n=1 $ 1b
203 1 4.354e-5 100 -101 209 -206 2 -7 imp:n=1 $ ase
c  204 1 4.354e-5 -400 100 201 2 -7 imp:n=1 $ ae lower
900 0 -100:112:-200:206:-1:7 imp:n=0 $ universe

```

Final Report

March 1995

Evaluation of Coverage of Enriched UF₆ Cylinder Storage Lots
by Existing Criticality Accident Alarms

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```

1 pz -100
2 pz 0
3 pz 700
4 pz 720
5 pz 1050
6 pz 2370
7 pz 2380
100 py -8000.1 $
101 py 0
102 py 2000
103 py 3300
104 py 3700
105 py 5000
106 py 5400
107 py 6700
108 py 7100
109 py 8400
110 py 8800
111 py 10100
112 py 19400
113 py 10500
114 py 11800
200 px -8000.1 $
201 px 0
202 px 600
203 px 2900
204 px 3700
205 px 6000
206 px 66300
207 px 6800
208 px 9100
209 px 9751 $ see plane
301 s 3860 3000 881 100

```

```

mode n
sdef erg=d1 pos= -3810 18288 100 dir=d2 vec 6096 -17008 0 $ source position in cm
cutin 1e50 0.017 -0.50 -0.25 0
sc1 source energy distribution cut off below 17 kev
sl1 h 0.017 0.1 0.4 0.9 1.4 1.85 3.0 6.43 20
sp1 0 0.0651 0.0977 0.114 0.0798
0.0645 0.121 0.111 0.0199
sc2 distribution of source angles 180 - 0 biased forward
sl2 h -1 -.9 -.8 -.7 -.6 -.5 -.4 -.3 -.2 -.1 0
.1 .2 .3 .4 .5 .6 .7 .8 .9 1
sp2 d 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
sb2 d 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1
c f4:n 101
c e4 0.017 0.1 0.4 0.9 1.4 1.85 3.0 6.43 20
c em4 0.0 4.969e10 1.959e11 3.097e11 4.164e11 4.654e11 5.651e11
c 7.488e11 8.975e11
c fc4 cell average dose rate (mrad/h)
f5:n 2286 1280 100 5
fc5 This is the point detector
e5 1.00e-11 1e-8 3e-8 5e-8 1e-7 2.25e-7 3.25e-7 4e-7 8e-7
1e-6 1.13e-6 1.3e-6 1.77e-6 3.05e-6 1e-5 3e-5 1e-4 5.5e-4
0.003 0.017 0.1 0.4 0.9 1.4 1.85 3.0 6.43 20
m1 7014.50c 3.570e-5 $ air
8016.50c 7.840e-6
1001.50c 1.487e-2 $ concrete
6012.50c 3.814e-3
8016.50c 4.152e-2
11023.50c 3.040e-4
12000.51c 5.870e-4
13027.50c 7.350e-4
14000.50c 6.037e-3
20000.51c 1.159e-2
26000.50c 1.968e-4

```

m3	6012.50c	3.921e-3	\$ steel
	26000.50c	8.349e-2	
m4	6012.50c	6.230e-5	\$ homogenized cell material
	9019.50c	8.880e-5	
	13027.50c	8.420e-5	
	14000.50c	1.666e-5	
	17000.50c	8.880e-5	
	24000.50c	1.619e-4	
	25055.51c	1.703e-5	
	26000.50c	5.934e-4	
	28000.50c	4.563e-4	
	29000.50c	3.273e-5	
m5	1001.50c	4.288e-2	\$ roof
	6012.50c	1.812e-2	
	8016.50c	1.896e-3	
	26000.50c	2.783e-2	
m6	7014.50c	1.378e-5	\$ homogenized x-333 process area
	8016.50c	3.027e-6	
	6012.50c	3.824e-5	
	9019.50c	5.451e-5	
	13027.50c	5.169e-5	
	14000.50c	1.023e-5	
	17000.50c	5.451e-5	
	24000.50c	9.934e-5	
	25055.51c	1.045e-5	
	26000.50c	3.643e-4	
	28000.50c	2.801e-4	
	29000.50c	2.009e-5	
m7	7014.50c	3.570e-5	\$ homogenized ground level
	8016.50c	7.840e-6	
	26000.50c	1.669e-3	
	6012.50c	7.842e-5	
nps	999999999		
ctme	10		
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