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FORT ST. VRAIN REFUELING EQUIPMENT CALCULATIONS VERSUS MEASUREMENTS

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1. SUMMARY

Gamma-ray dose rate measurements made during the first refueling of the Fort St. Vrain HTGR (owned and operated by the Public Service Company of Colorado) were compared with calculations in order to check the adequacy of the refueling equipment shielding, validate the analytical methods used, and provide design guidance for the shielding design of future HTGRs.

This first refueling, which took place several weeks after 174 equivalent full-power days operation including several weeks at up to 65% power, was characterized by very low radiation levels at the personnel level on and around the refueling floor. Most of the steady-state dose rates around the fuel handling machine (FHM) and auxiliary transfer cask (ATC) were less than 1 mR/hr. Extrapolations to future refuelings following full power operation indicated that the refueling floor levels will be satisfactory, thus confirming the adequacy of the shielding design.

At locations on or near the FHM and ATC above an 8 foot elevation, where the shielding was intentionally tapered to save weight and cost, the dose rate measurements generally confirmed the predicted increase in radiation levels toward the upper parts of the casks. Two measurements exceeded design predictions, as follows:

1. A high dose rate was observed just under the steel flange of the FHM, some 18 ft above the refueling floor as each fuel block was raised to the inspection/photography position in the cask. It is speculated that the lead shot in the FHM has slightly settled, thus creating a narrow gap at this location; calculations seem to confirm this hypothesis.

2. In the case of control rods which have experienced long periods of full core insertion, the clevis pins at the tops of the rods become highly activated. If these rods and drive mechanisms are raised to their maximum elevations in the ATC, the clevis pins are then located in the lightly shielded upper section of the cask, resulting in higher-than-design dose rates at an elevation of 25 ft above the refueling floor.

Both of the above non-design conditions should be relatively easy to rectify or to prevent from causing a problem. Suggestions for dealing with these conditions are given in Section 6, Conclusions and Recommendations.

Comparisons between measurements and calculations, summarized in Table 1-1, show that generally satisfactory agreement was obtained.

TABLE 1-1
COMPARISONS BETWEEN MEASURED AND CALCULATED DOSE RATES

Location and Conditions	Measured Dose Rate (mR/hr)*	Calculated Dose Rate (mrad/hr)*
Surface of loaded fuel handling machine (FHM) at personnel level	0.34 (average, south face)	0.70
Surface of loaded FHM above flange	250 and 800	250
Surface of FHM just below flange, when fuel block is at photography position	∿2000	In measured range, depending on gap size.
Refueling floor near FHM as block is raised	200 peak transient	>56
Surface of auxiliary transfer cask (ATC) at personnel level containing hot control-rod drive (CRD #44)	0.25	0.15
Elevation 25 ft and distance 25 ft from ATC containing hot CRD # 44	50	110

*PSC reports measured gamma dose rates in units of mR/hr, whereas the GAS PATH code calculates dose rates in units of mrad/hr. For purposes of these comparisons, the units can be assumed equivalent.

2. INTRODUCTION

The first refueling of the Fort St. Vrain HTGR, operated by Public Service Company of Colorado (PSC), took place in March and April, 1979. During these refueling operations, numerous gamma dose rate measurements were made by PSC health physicists, under the direction of Dr. Don R. Alexander. Additional measurements were made by General Atomic Company personnel B. A. Engholm and T. Szenasi on April 4-6, 1979, in order to obtain transient and steady-state dose rates in some locations not measured by PSC. All of these measurements, both those of PSC and GAC, are of great value in (1) checking the adequacy of the refueling equipment shielding, (2) validating the analytical techniques used, and (3) providing design guidance for shielding design of large HTGRs.

A preliminary procedure for the FSV refueling radiation survey was drafted in November 1978, and is attached herewith as Appendix A. Sample data sheets, which were developed later, are included as Appendix B.

Time and funding permitted detailed measurements only during the unloading of fuel region No. R-27, which was an unrodded region. However, these measurements, along with the many additional measurements performed by PSC, permitted some very definite conclusions about the shield design and our calculational methods.

In this report, the refueling equipment and its shield design is first briefly described. Pertinent dose rate measurements are then presented, primarily for region R-27. Updated dose rate calculations for the actual operating and shutdown conditions are then described. Finally, comparisons between calculations and measurements are made, with recommendations for improvements in analytical methods and shielding design.

3. EQUIPMENT DESCRIPTION

3.1. FUEL HANDLING MACHINE

3.1.1. General Description (Refs. 3-1 and 3-2)

The Fort St. Vrain fuel handling machine (FHM), depicted in Fig. 3-1, is a shielded cask containing a fuel transfer mechanism which travels down through a refueling sleeve into the reactor, picks up a fuel or reflector element, and carries it back into the cask portion of the machine. The grapple head lifts the element to a level opposite a camera and viewing device for possible photography. The element is then placed in a circular fuel-storage rack. This rack is capable of holding 28 full-size blocks plus 7 half-size blocks, or any combination thereof such as 63 half-size blocks.

3.1.2. Shielding Design

The original shielding design for the FHM (Ref. 3-3) is shown in Fig. 3-2. The shielding was assumed to consist of steel with a thickness of 18 in. up to a height of 8 ft above the refueling floor. As shown in the drawing, such a thickness limited the direct surface dose rate to about 10 mrem/hr, based on a source term of 44.1 megacuries La140 per core 15.5 hrs after shutdown, and a fully loaded FHM (i.e., all blocks are fuel blocks, even the half-sized blocks). Shielding thickness is tapered above the 8 ft level, allowing direct dose rates as high as 1000 mrem/hr at the top of the FHM.

Subsequent to the above design study, a decision was made to substitute lead shot for much of the steel shielding (Ref. 3-4). The new cask design, shown in Fig. 3-1, uses a 1-1/2 in. steel inner wall, 13-3/4 in. lead shot (65% packing fraction), and a 1-5/8 in. steel outer wall to obtain the 10 mrem/hr dose rate on the personnel level.

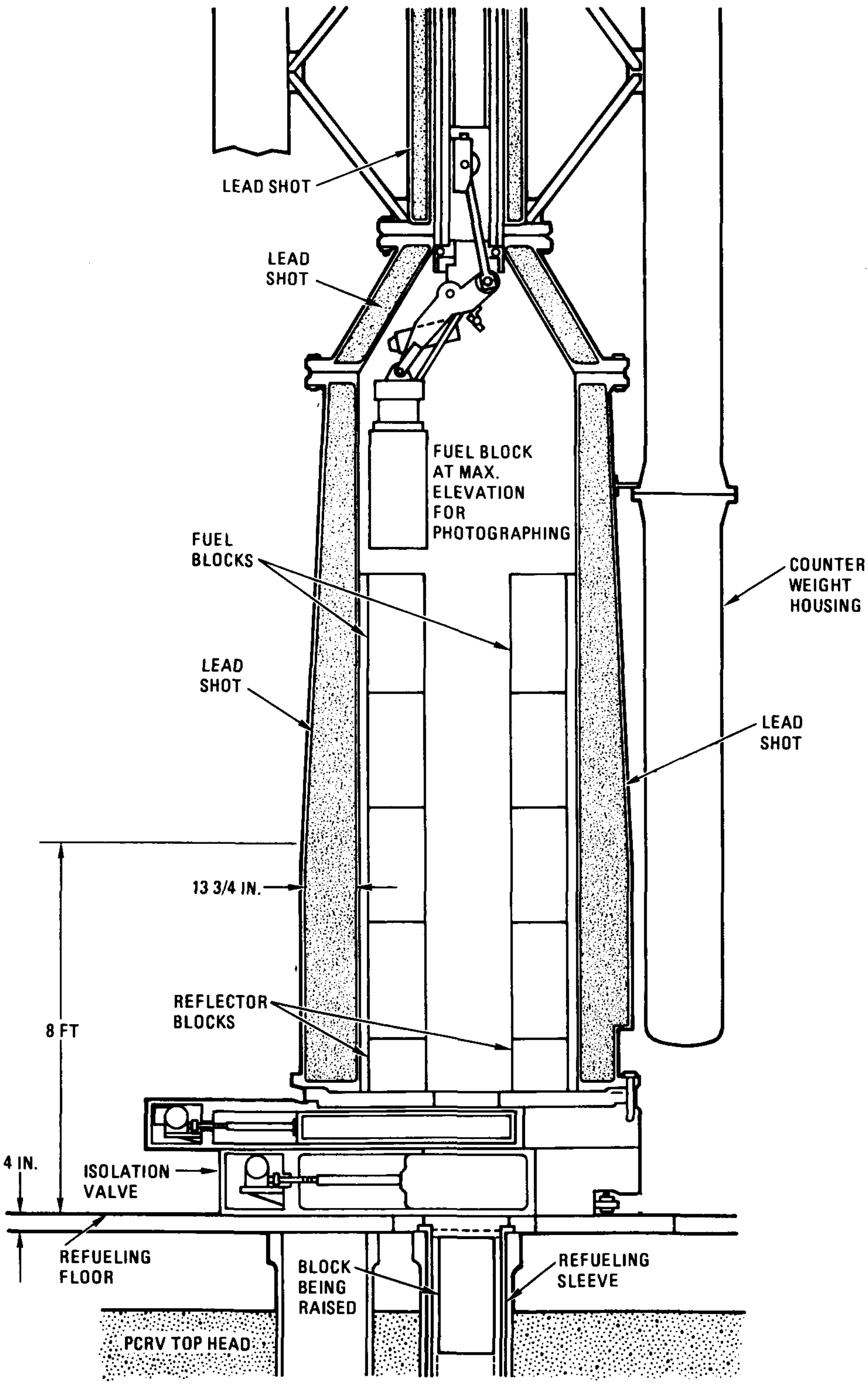


Fig. 3-1. FSV fuel handling machine

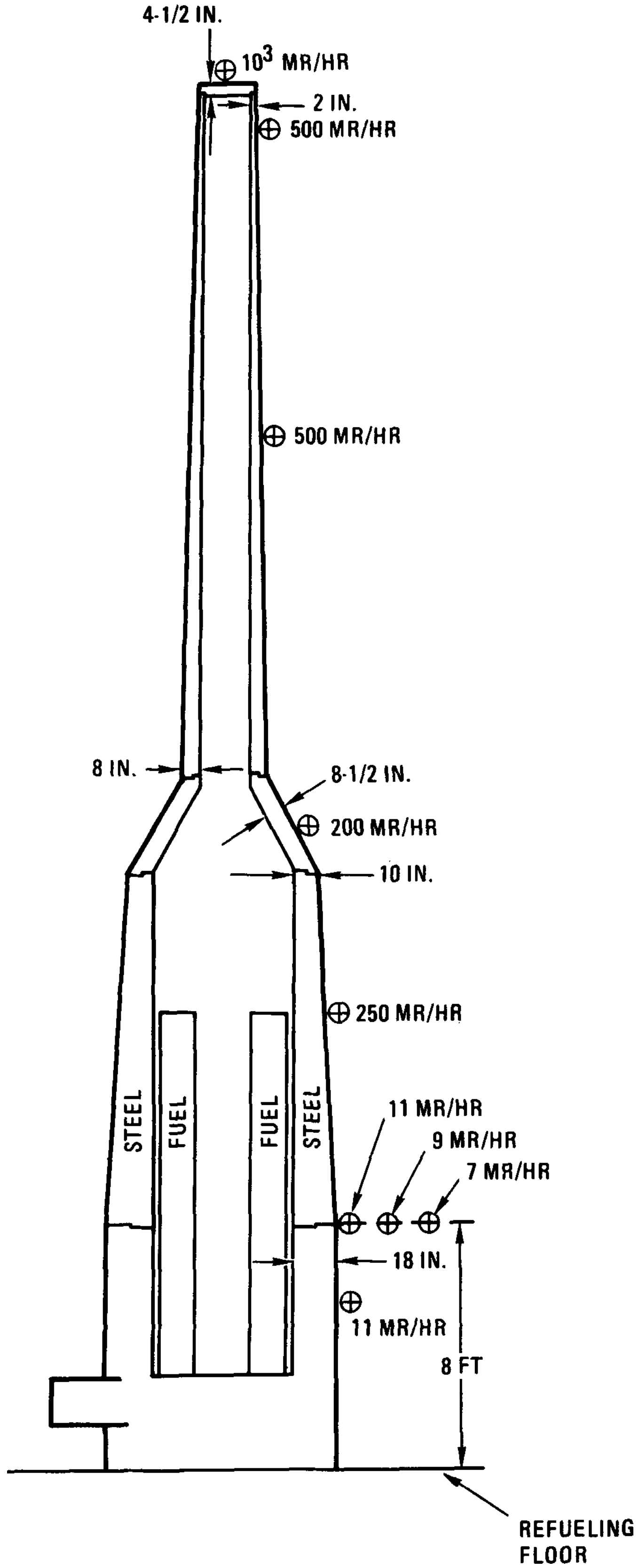


Fig. 3-2. Original shielding design for FSV fuel handling machine

3.2. AUXILIARY TRANSFER CASK

3.2.1. General Description (Refs. 3-1 and 3-2)

The auxiliary transfer cask (ATC), shown in Fig. 3-3, performs the service function of removing the control and orificing assembly which occupies a refueling penetration and replacing it with a refueling sleeve. The ATC is also capable of handling the helium purification system high-temperature filter/adsorber.

3.2.2. Shielding Design

Shielding requirements for the ATC in terms of the necessary wall thicknesses for an iron (steel) shielding medium were determined in Ref. 3-5 for the removal of helium purification system components and control rod drives from penetrations and wells in the PCRV. The maximum gamma radiation level at the surface of the cask was set at 15 mrem/hr over an axial height of 8 ft. Results are shown in Fig. 3-4. The calculated thickness variation was simplified for design purposes to 13-5/8 in. at the base, tapering to 9-7/8 in. eight feet above the base, further tapering to 1-1/4 in. of steel near the top (Ref. 3-6).

3.3. ISOLATION VALVE

3.3.1. General Description

The reactor isolation valve (RIV) provides mechanical coupling between nozzle and cask, isolation of gaseous environments, and shielding to personnel on the refueling floor. The isolation valve, shown in Fig. 3-5, is lifted into place with the building crane and is bolted to the refueling penetrations adjacent to the penetration being serviced.

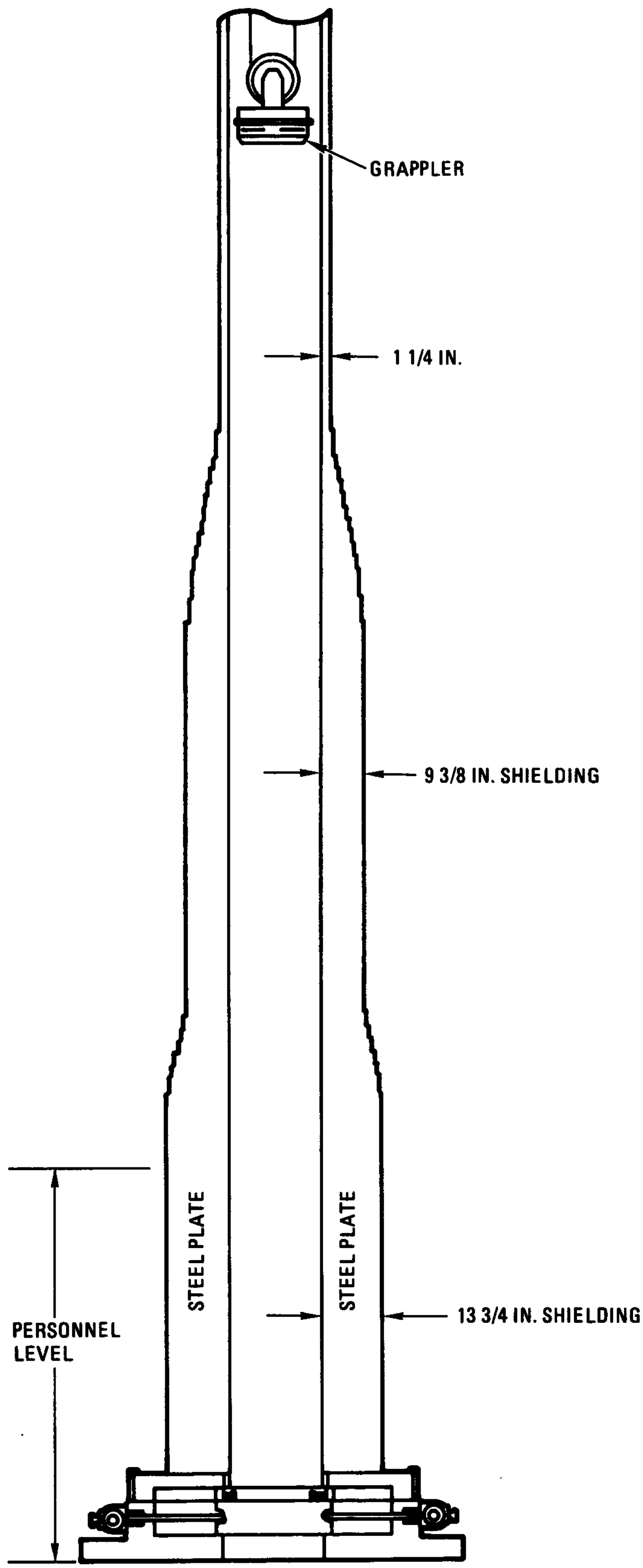


Fig. 3-3. FSV auxiliary transfer cask

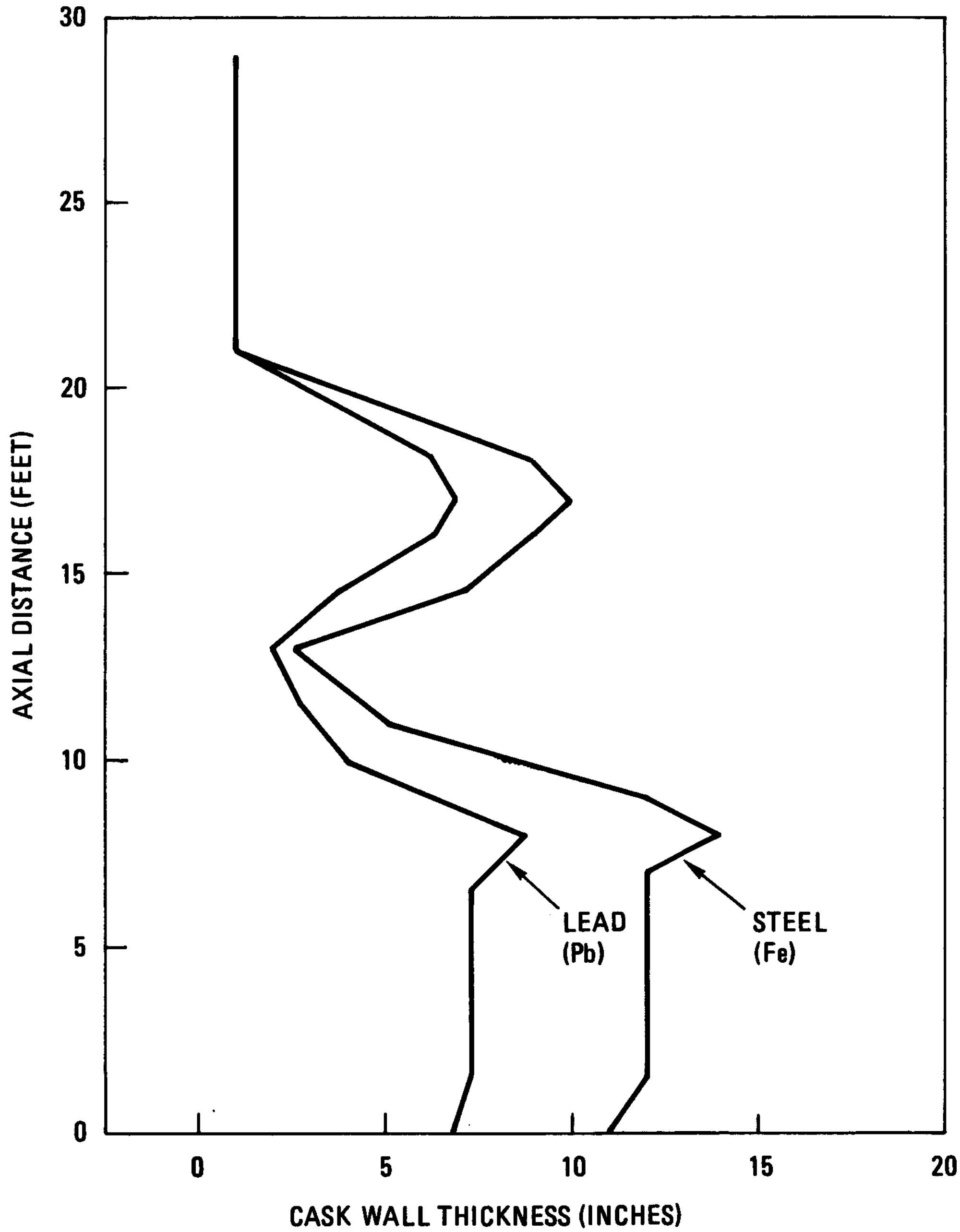


Fig. 3-4. Calculated shielding requirements for FSV auxiliary transfer cask

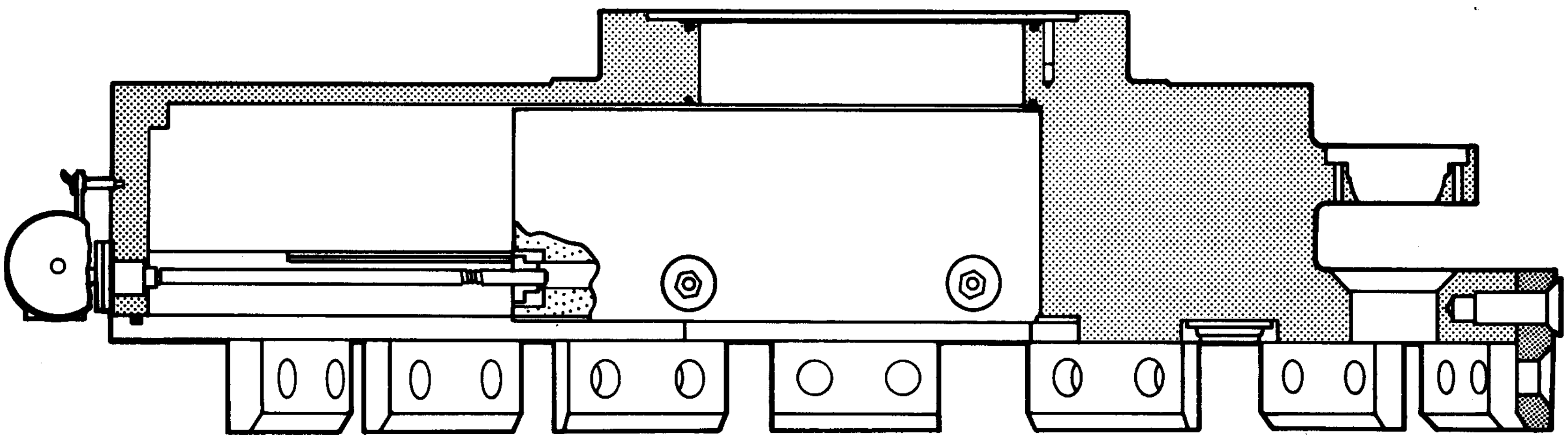


Fig. 3-5. FSV isolation valve

3.3.2. Shielding Design

The shielding thickness in the radial direction was established in Ref. 3-3 as 18 in. of steel.

The thickness of the RIV in the vertical direction on the centerline is 14.5 in. of cast iron. This dimension was established by considering radiation from a fuel element about 27 ft 6 in. below the valve. Although it is not anticipated that operating personnel will be on top of the isolation valve after the loaded FHM leaves for the fuel storage facility, radiation levels will be tolerable on top of the valve.

3.4. REFUELING SLEEVE

3.4.1. General Description

The refueling sleeve, depicted in Fig. 3-6, serves the functions of providing an accurate, wear-resistant surface for guiding the fuel transfer mechanism, and of providing some gamma shielding for spent fuel blocks as they pass above the PCRV concrete into the isolation valve and FHM.

3.4.2. Shielding Design

The shielding requirements for the refueling sleeve are discussed in Ref. 3-7, in which a 2-in.-thick lead sleeve is recommended in order to limit the transient dose rate on the refueling floor when an element is lifted into the FHM. The actual as-built design consists of 1/4 in. steel plus 1-3/8 in. lead.

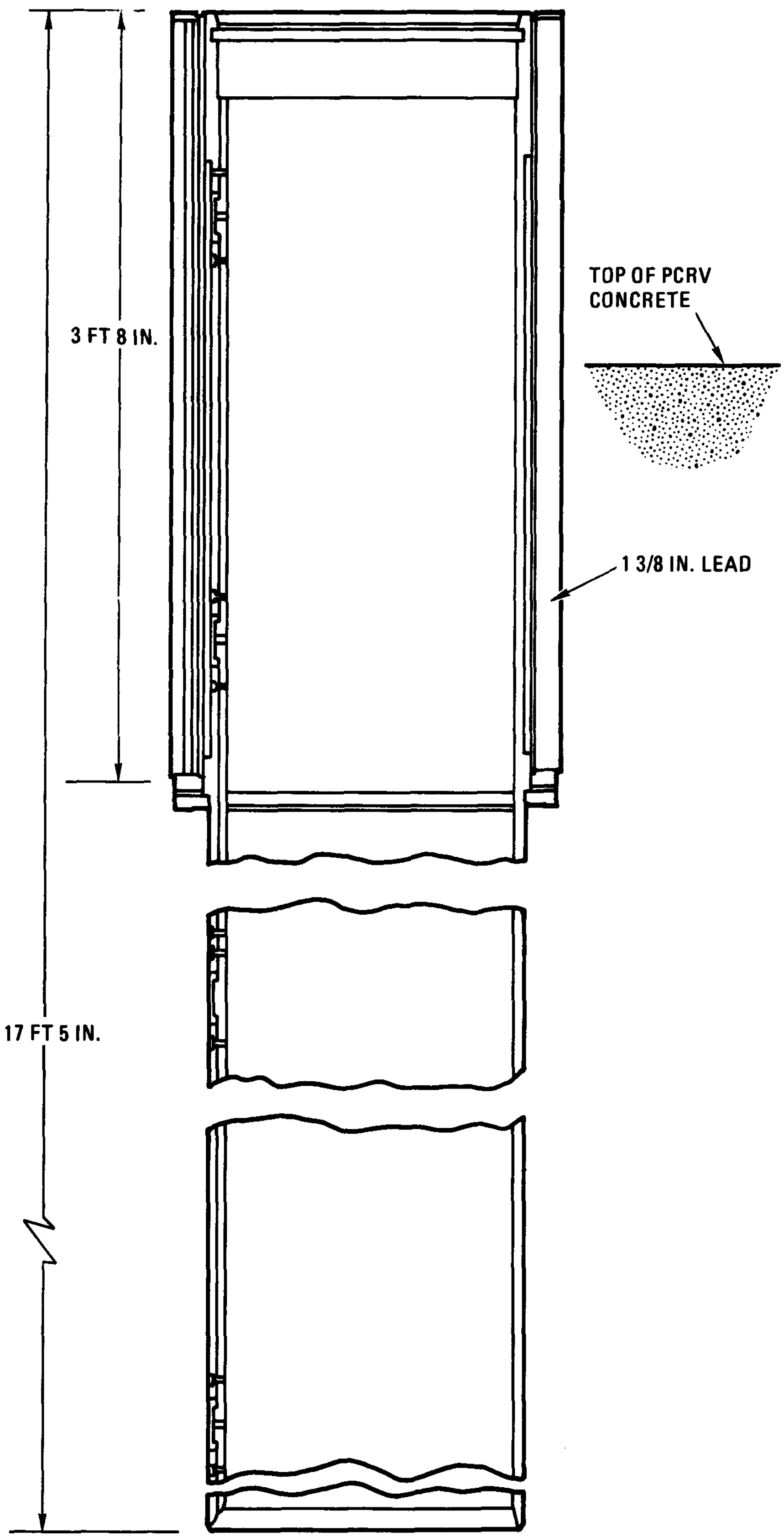


Fig. 3-6. FSV refueling sleeve

4. MEASUREMENTS

4.1. FUEL HANDLING MACHINE

4.1.1. GAC Measurements

The GAC measurements on the FHM were made during the unloading of spent fuel from region R-27 on April 5-6, 1979. Instrumentation consisted of the following:

Model No.	Serial No.	Type	Range
Eberline RO-2	551	Ion Chamber	0-5000 mR/hr
HPI 1010	10108-207	GM	0-1000 mR/hr
Technical Associates 8	5089	Ion Chamber	0-50,000 mR/hr

In addition, a microrem meter was borrowed from PSC for some of the measurements.

Table 4-1 summarizes the GAC measurements on the FHM. Detailed locations of detector points are shown on the figures in Appendix A.

4.1.2. PCS Measurements

Relevant PSC measurements on the FHM consist of:

1. Gamma dose rates recorded on a strip chart as fuel elements were loaded into the FHM. The detector was located in a change area adjacent to the refueling control room. The strip chart readings are valuable in displaying the relative magnitude of transient dose rates when fuel blocks momentarily reach the maximum elevation in the FHM (at the inspection/photography level).

TABLE 4-1
GAC DOSE RATE MEASUREMENTS ON FUEL HANDLING MACHINE

Detector Point No.	Location	Time and Date	Block or Blocks Being Measured	Measured Gamma Dose Rate
R14	Top of refueling floor, just south of FHM	0031, 4/6/79	Orifice can from R-27 being raised	40 μR/hr transient peak
		0215, 4/6/79	Orifice can from R-27 being raised	22 μR/hr transient peak
		0205, 4/6/79	Fuel block #221 being raised	90 mR/hr transient peak
R15	Top of refueling floor, 1/2 ft from R14	0205, 4/6/79	Fuel block #221 being raised	45 mR/hr transient peak
R1	On surface of refueling floor, as shown in Fig. A-4	0215, 4/6/79	Fuel block #223 being raised	200 mR/hr transient peak
R2	On surface of refueling floor, as shown in Fig. A-4	0215, 4/6/79	Fuel block #223 being raised	200 mR/hr transient peak
R3	On surface of refueling floor, as shown in Fig. A-4	NA, 4/6/79	Fuel block # NA being raised	60 mR/hr transient peak
R4	On surface of refueling floor, as shown in Fig. A-4	NA, 4/6/79	Fuel block # NA being raised	20 mR/hr transient peak
--	Standing on refueling floor about 8 ft out from R14	0300, 4/6/79	Fuel block #232 being raised	1 mR/hr transient peak

TABLE 4-1 (continued)

Detector Point No.	Location	Time and Date	Block or Blocks Being Measured	Measured Gamma Dose Rate
F5	On side surface of machine just below first flange	0223, 4/6/79	Fuel block #223 in inspection/photography position inside FHM	2 R/hr
		0234, 4/6/79	Fuel block #224 in inspection/photography position inside FHM	2 R/hr
F20	Cover of viewing device port	0240, 4/6/79	Fuel block #228 in inspection/photography position inside FHM	50 mR/hr
F22	Cover of unnamed port N by NW	0251, 4/6/79	Fuel block #231 in inspection/photography position inside FHM	Low
--	Cover of unnamed port between F18 and F22	0251, 4/6/79	Fuel block #231 in inspection/photography position inside FHM	50 mR/hr
F15, F16, F17	Around base of FHM	∿0300, 4/6/79	FHM partially loaded	No radiation streaming detected

2. Steady-state dose rate measurements around the FHM when fully or partially loaded, including detector locations at various elevations at the side of the reactor building.

3. A few transient dose rate measurements during the initial refueling operations.

The FHM measurements useful for validating the shielding design are listed in Tables 4-2 and 4-3.

The variation of dose rate with distance from the FHM surface is plotted in Fig. 4-1, along with a similar plot for the auxiliary transfer cask.

4.2. AUXILIARY TRANSFER CASK

4.2.1. GAC Measurements

The control rod drives being moved when GAC personnel were making measurements exhibited lower activites than some measured earlier by PSC, owing to the fact that these particular control rods had been only partially inserted into the core. For the most part, the dose rates observed by GAC personnel around the ATC, both transient and steady-state, were small. The transient measurements are summarized in Table 4-4.

4.2.2. PSC Measurements

No transient measurements of a hot CRD seem to be available, except a measurement of 6 mR/hr on the floor near the valve when a CRD was pulled into the ATC on 3/1/79.

The most interesting CRD measurements were made on 3/30/79 when CRD #44 from Region 28 was drawn into the ATC. Some of these are plotted in Fig. 4-1. A peak dose rate of 50 mR/hr was measured at an elevation of 25 ft above the refueling floor at a distance of ∿25 ft from the ATC centerline.

TABLE 4-2
PSC DOSE RATE MEASUREMENTS ON FUEL HANDLING MACHINE

Detector Point No.	Location	Time and Date	Block or Blocks Being Measured	Measured Gamma Dose Rate
F5	On side surface of machine just below first flange	NA, 3/30/79	Block from Region 28 at inspection/photography position	2.5 R/hr
--	About 1-1/2 ft below F5	NA, 3/30/79	Block from Region 28 at inspection/photography position	225 mR/hr
--	About 4-1/2 ft below F5	NA, 3/30/79	Block from Region 28 at inspection/photography position	80 mR/hr
R1	On surface of refueling floor, near valve	NA, 3/3/79	Block from Region 35 being raised	200 mR/hr, transient peak
F6 and F7	On side surface of machine above first flange	0705, 3/23/79	FHM loaded with 21 spent fuel elements from Region 5	250 mR/hr
		0215, 3/31/79	FHM loaded with 21 spent fuel elements from Region 28	800 mR/hr
--	Strip chart in change room	∿0800, 4/6/79	Hottest block from Region 27 at inspection/ photography position	∿2 mR/hr, transient peak
F24	On bottom surface of machine	0400, 3/28/79	FHM loaded with 21 spent fuel elements from Region 21	20 mR/hr

TABLE 4-2 (Continued)

Detector Point No.	Location	Time and Date	Block or Blocks Being Measured	Measured Gamma Dose Rate
F5	On side surface of machine just below first flange	0400, 3/28/79	FHM loaded with 21 spent fuel elements from Region 21	900 mR/hr
--	On side surface of machine, 5 ft above valve	1910-1925, 4/6/79	FHM loaded with 21 spent fuel elements from Region 27	N-0.13 mR/hr S-0.17 E-0.06 W-0.09
--	5 ft from side surface of FHM, 4 ft above refueling floor			N-0.18 S-0.08 E-0.07 W-0.06
--	15 ft from side			N-0.15 S-0.06 E-0.05 W-0.025
--	20 ft from side			N-0.08 S-0.035 E-0.03 W-0.02
--	On southerly side surface of machine, 5 ft above valve	All measurements from 3/28 through 4/6	FHM loaded with spent fuel elements	See Table 4-3

TABLE 4-3
DOSE RATE MEASUREMENTS MADE BY PSC ON SOUTHERLY SURFACE OF FHM

Fuel Region	Date	Measured Dose Rate (mR/hr)	Relative Radial Power P(r) (Ref. 4-1)	Dose Rate (mR/hr) Normalized to 4/6/79 and P(r)=1
21	3/28/79	0.6	0.70	0.53
28	3/30	0.39	0.63	0.69
28	3/30	0.26	0.63	0.42
28	3/31	0.6	0.63	0.28
17	4/1	0.8	0.96	0.64
17	4/1	0.4	0.96	0.32
10	4/3	0.18	0.84	0.19
10	4/4	0.2	0.84	0.20
27	4/6	0.09	1.3	0.07
27	4/6	0.35	1.3	0.27
27	4/6	0.17	1.3	0.13
			Average	0.34

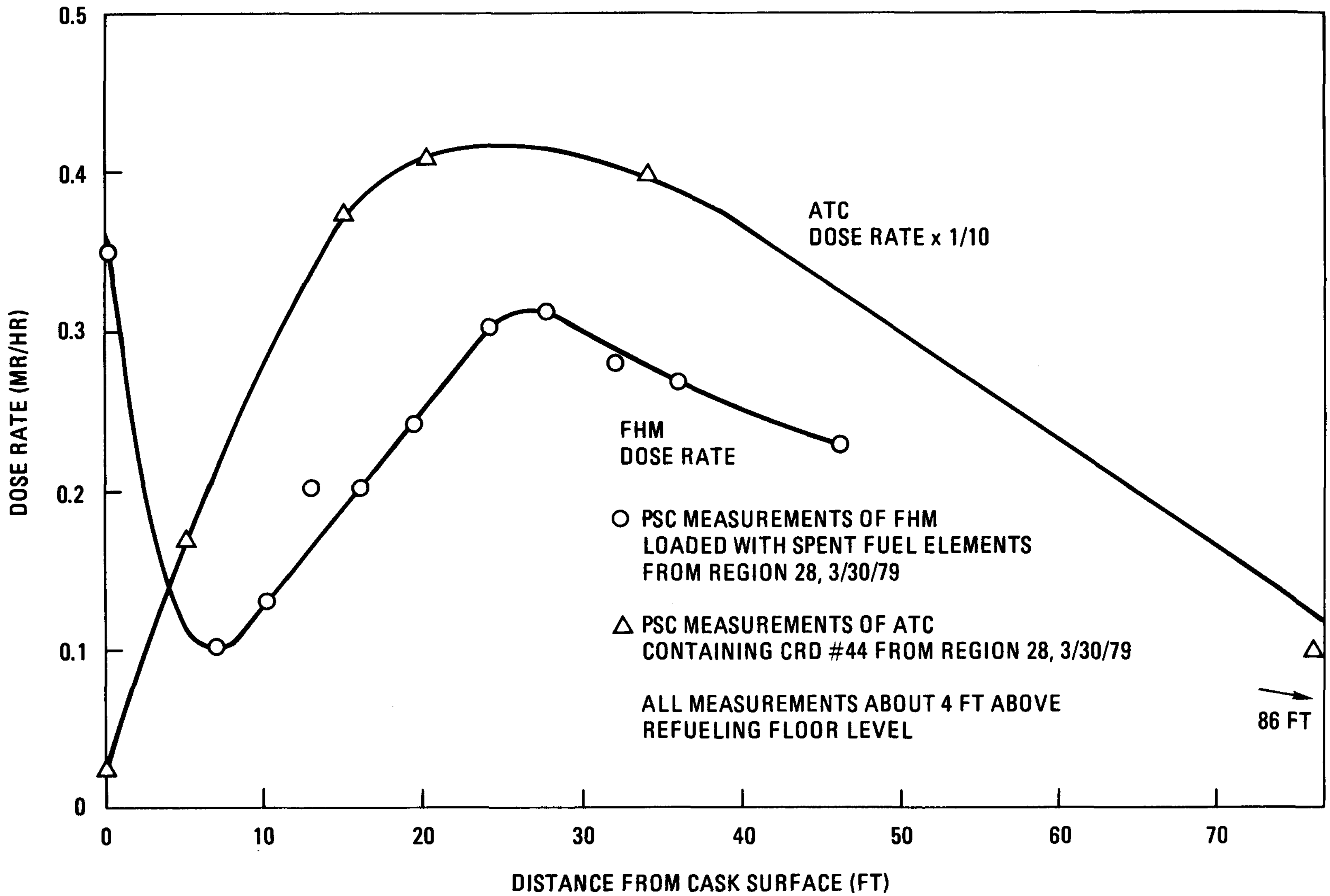


Fig. 4-1. Variation of measured dose rate with distance from cask

TABLE 4-4
GAC DOSE RATE MEASUREMENTS ON AUXILIARY TRANSFER CASK

Detector Point No.	Location	Time and Date	CRD Being Measured	Measured Gamma Dose Rate
R1	On surface of refueling floor as shown in Fig. A-4	1328, 4/5/79	CRD being removed from Region 27	7.6 mR/hr transient peak
R1	↓	1644, 4/5/79	CRD being placed into Region 10	>10 mR/hr transient peak
R2	↓	1644, 4/5/79	CRD being placed into Region 10	2.5 mR/hr transient peak

This elevation is in line with the thinnest part of the cask (only 1-1/4 in. steel shielding; see Fig. 3-3).

4.3. REACTOR ISOLATION VALVE

All dose rate measurements around or near the RIV indicated more than adequate shielding.

4.4. FUEL STORAGE FACILITY

All dose rate measurements above and to the side of the fuel storage facility indicated negligible dose rates, except for one well which had only a temporary shield cover. Dose rates in this well measured by PSC were fairly high owing to radiation short-circuiting from a loaded neighboring well.

5. CALCULATIONS

5.1. FSV POWER HISTORY

The Fort St. Vrain plant accumulated 110 equivalent full-power days (EFPD's) between April 1, 1978 and February 1, 1979, when the plant was shut down for refueling.* During this period, the average power level was 35.5% and the peak power level was 70% of 842 MW(t). From 11/7/78 to 11/29/78, 12/9/78 to 1/19/79, and 1/23/79 to 1/29/79 the power level was between 60 and 65%.

5.2. FUEL BLOCK SOURCE TERMS

The shutdown time before refueling commenced was 30 days. Shutdown time for the GAC measurements was 65 days. Past experience has shown that most of the shielded dose rate from blocks with this decay time would come from Ba/La140 and Pr144, with Zr/Nb95 and Ru103 also contributing a minor amount in less shielded locations. Therefore, estimates of the inventories of these nuclides in an average spent fuel block were needed.

The La140 inventory (Ba140 parent half life = 12.79 days) should reflect generation at 60% power, or a fuel block power density of 0.6 x 6.3 = 3.78 W/cm^3. The Pr144 inventory, on the other hand, with a Ce144 parent half life of 284.4 days, will more nearly reflect the average power of 35.5% during the 10-month operating period.

Fission-product inventories for a one-year, 80% load factor, 8.5-W/cm^3 fuel block are given in Ref. 5-1 for a decay time of 180 days as follows:

La140 = 2.74 Ci
Pr144 = 11,707 Ci

*Since plant startup in 1976, a total of 174 EFPD's was accumulated.

Corrected to 65 days decay time, these figures become:

La140 = 1390 Ci

Pr144 = 15,500 Ci

Finally, correcting for power density, we have

La140 = 618 Ci

Pr144 = 4080 Ci

for the average FSV spent fuel block on 4/1/79.

The La140 figure used for FHM design was, from subsection 3.1.2, 44.1 (+6) Ci/1482 blocks = 29,760 Ci. Decayed to 65 days, this figure becomes 881 Ci, and converted to 60% power is 529 Ci, in fairly good agreement with 618 Ci. Pr144 was not considered in the original FHM design.

Analogous calculations result in 7000 Ci of Zr95, 8900 Ci of Nb95, and 2100 Ci of Ru103 in the average 65-day fuel block.

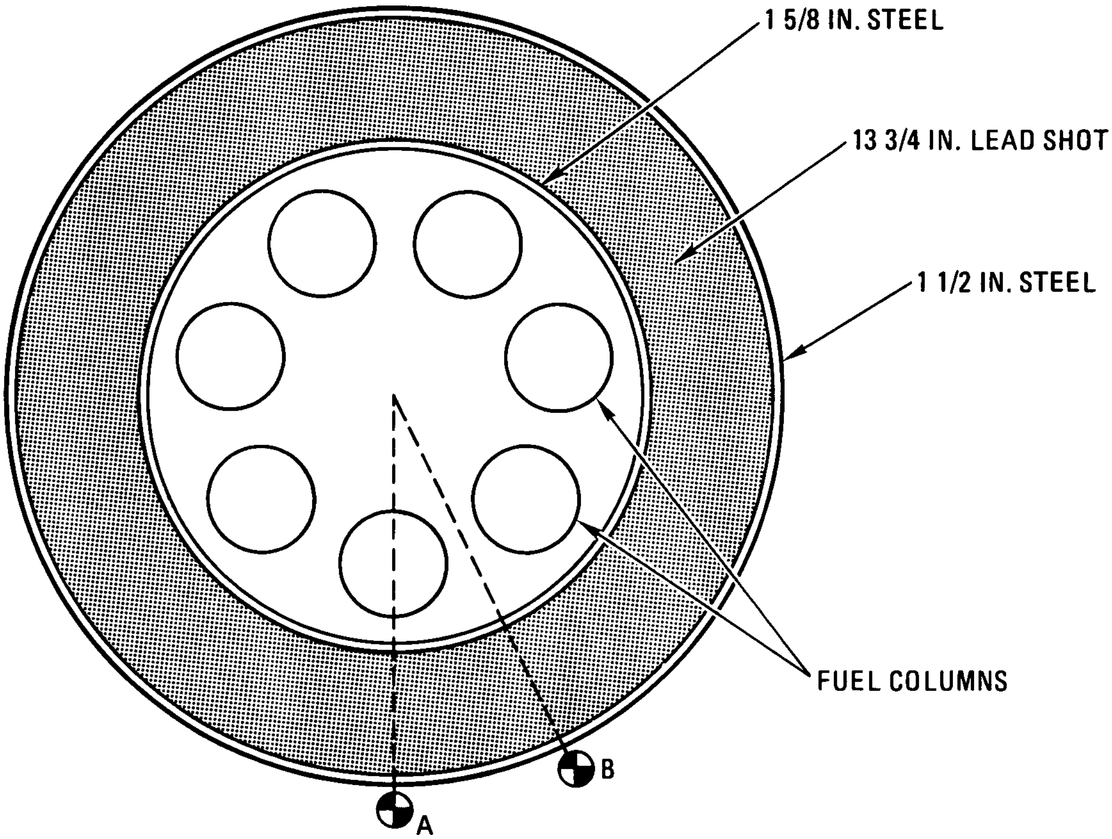
5.3. RESULTS OF RECENT CALCULATIONS ON FHM

5.3.1. Surface Dose Rate at Personnel Level

Su in Ref. 5-2 calculated the gamma dose rate outside the FHM for the large HTGR for a steel thickness of 18 in., which is approximately equivalent to 13-3/4 in. of lead shot plus 3-1/8 in. of steel.* He utilized slab and cylindrical geometries in P_3, S_{16} DTFX transport calculations, and obtained surface dose rates of 40 and 25 mrem/hr, respectively, of which about 90% is contributed by La140 and 10% by Pr144. His La140 source term was 29,200 Ci/element and his Pr144 source term was 18,200 Ci/element. Hence, if the La140 is reduced to 618 Ci and the Pr144 to 4080 Ci, we would expect a gamma dose rate of between 1.7 and 1.05 mrem/hr for the FSV case.

*13-3/4 in. x 0.65 x 1.7 = 15.2 in. plus 3-1/8 in. = 18.3 in.

PATH (Ref. 5-3) calculations were made for the Fort St. Vrain FHM loaded with average spent fuel blocks, having decay times of 55, 60, and 65 days, using the configuration sketched below:



The resulting dose rates at the two detector points indicated in the sketch are tabulated in Table 5-1.

The calculated value of 0.70 mrad/hr at A is approximately twice the average of the measurements, corrected for core radial power variation and for decay time (see Table 4-3). However, the individual measurements ranged from 0.69 mR/hr down to 0.07 mR/hr; hence, the calculated value conservatively brackets the range of measurements. It is worthwhile pointing out that if the lead shot packing fraction were 0.69 instead of 0.65, perfect agreement between calculation and average measurement would have been achieved.

TABLE 5-1
FHM SURFACE DOSE RATES CALCULATED BY PATH FOR AVERAGE FSV ELEMENTS
(mrad/hr)

	Dose Point					
	A			B		
	Decay Time (days)					
	55	60	65	55	60	65
La140	1.00	0.76	0.58	0.77	0.59	0.45
Pr144	0.12	0.12	0.12	0.10	0.10	0.10
Total	1.12	0.88	0.70	0.87	0.69	0.55

5.3.2. Dose Rate Above Flange

The dose rate of 250 mR/hr measured by PSC between F6 and F7 above the flange (see Table 3-2) was verified as follows. First, the 250 mR/hr on 3/23 was decayed to 65 days on 4/6, resulting in a dose rate of 130 mR/hr, assuming average blocks. A PATH calculation for a full load of average 65-day fuel blocks also yielded a dose rate of 130 mrad/hr at this location. Thus, excellent agreement was achieved between this particular measurement and the calculation.

However, the dose rate of 800 mR/hr later measured by PSC is higher than predicted by design and could possibly be in error. At the time this measurement was made, the dose rate at the side of the FHM at the personnel level was measured as ∿0.5 mR/hr. The ratio of 1600 between these measurements seems unrealistic.

5.3.3. Dose Rate Below Flange

Additional PATH calculations were performed for the first flange location in the FHM, using the geometry of Fig. 5-1 where a quarter-inch gap due to settling is assumed at the top of the lead shot. The dose rate for an average 65-day fuel block at the same height as the gap was calculated to be

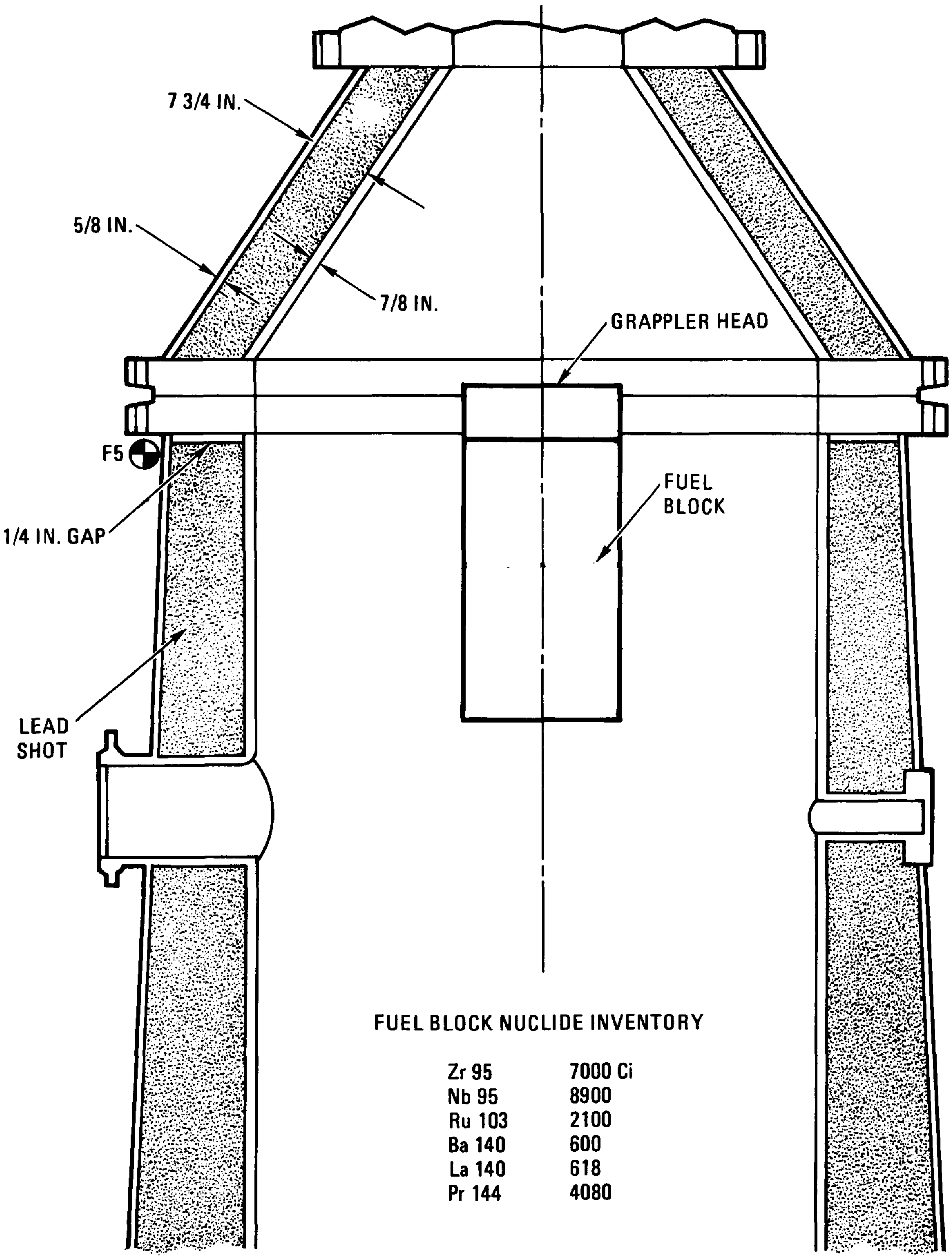
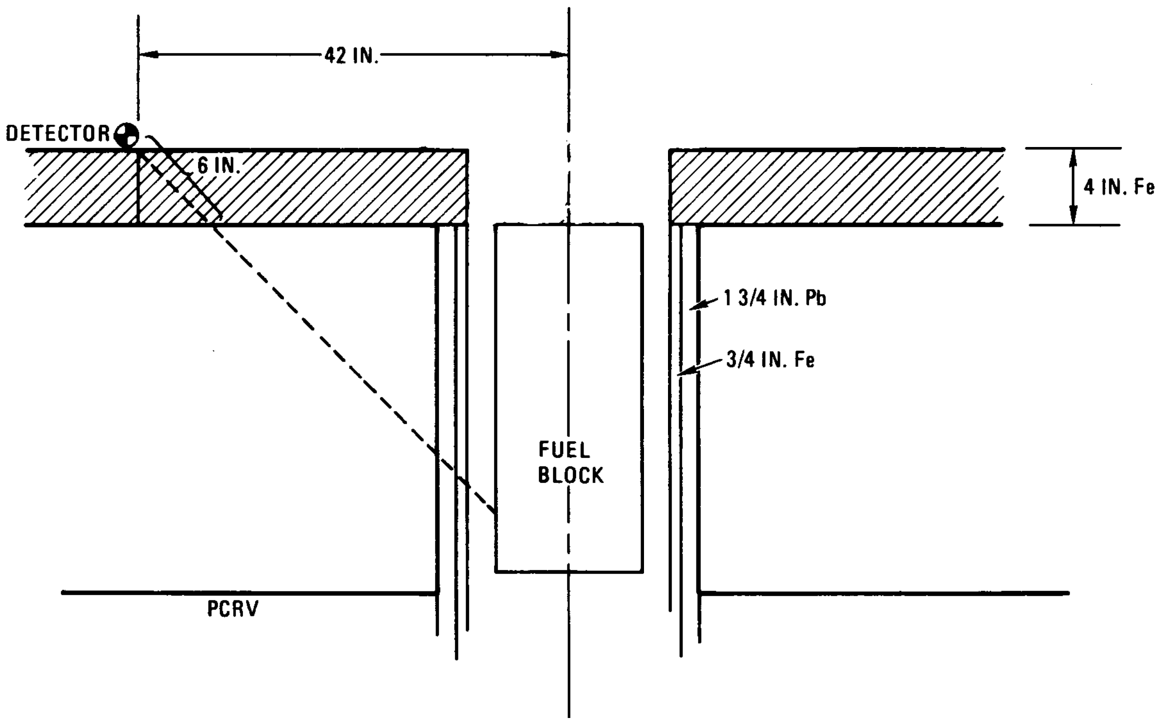


Fig. 5-1. Geometry for PATH calculation of dose rate at F5 outside FHM

28 rad/hr. However, since the block is actually somewhat below the gap (as shown in Fig. 3-1), the streaming dose rate could be an order of magnitude lower. As the measured dose rate was ∿2 rad/hr, the existence of a gap seems probable.

5.3.4. Transient Dose Rate on Floor

PATH calculations were also performed for the case of a fuel block being drawn up into the FHM, using the geometry sketched below.



The calculated transient dose rate from an average 65-day-old fuel block was 56 mrad/hr with no gap in the floor. Since the 4-in.-thick steel refueling floor is comprised of hexagonal coverplates over the refueling nozzles, a small gap could easily cause a higher measured dose rate. Additional buildup due to oblique gamma penetration (Ref. 5-4) could account for as much as a factor of two difference. Hence, the measured transient dose rate of ∿200 mR/hr (Tables 4-1 and 4-2) is reasonable.

5.3.5. Dose Rates Away From Surface

Finally, it is of interest to confirm the PSC-measured gamma traverse from the FHM surface out to a distance of 45 ft (plotted in Fig. 4-1). PATH calculations were made of the dose rate variation for this case. The comparison, shown in Fig. 5-2, reflects the overestimate by PATH of the surface dose rate, but beyond 25 ft the calculations underestimate the dose rate. It is probable that scattered gammas from the top of the cask are contributing to the measured dose rate, but could not be accounted for in the PATH analysis.

5.4. CONTROL ROD SOURCE TERMS AND DOSE RATES

5.4.1. Surface Dose Rates at Personnel Level

It was not feasible in most cases to calculate control rod activation levels because of the widely varying exposure history of the rods and the difficulty of obtaining detailed records of the position vs time history for each rod. In any event, as discussed in subsection 4.2, the measured dose rates on the surface of the auxiliary transfer cask when containing a control rod drive were generally low, ranging from zero to 1.0 mR/hr at 5-ft. elevation. CRD #44 showed a surface does rate of 0.25 mR/hr (Fig. 4-1), some of which might have arisen from scattered gammas from the clevis pins (see paragraph 5.4.2).

Calculations of FSV control rod activity were performed in 1975 by Su (Ref. 5-5) for the case of 12.6 MW(t) power level, 4 days operating time, and 81 days decay time, from which he obtained 1450 μCi/cm of Co58 and 32 μCi/cm of Co60 per rod. Converted to 174 EFPD's and 65-day decay these activites become ∿1.0 Ci/cm Co58 and ∿0.1 Ci/cm Co60. The calculated direct surface dose rate on the ATC is 0.15 mrad/hr (Ref. 5-6), in fair agreement with the measurement on CRD #44. No calculation was attempted for the scattered gamma dose rate.

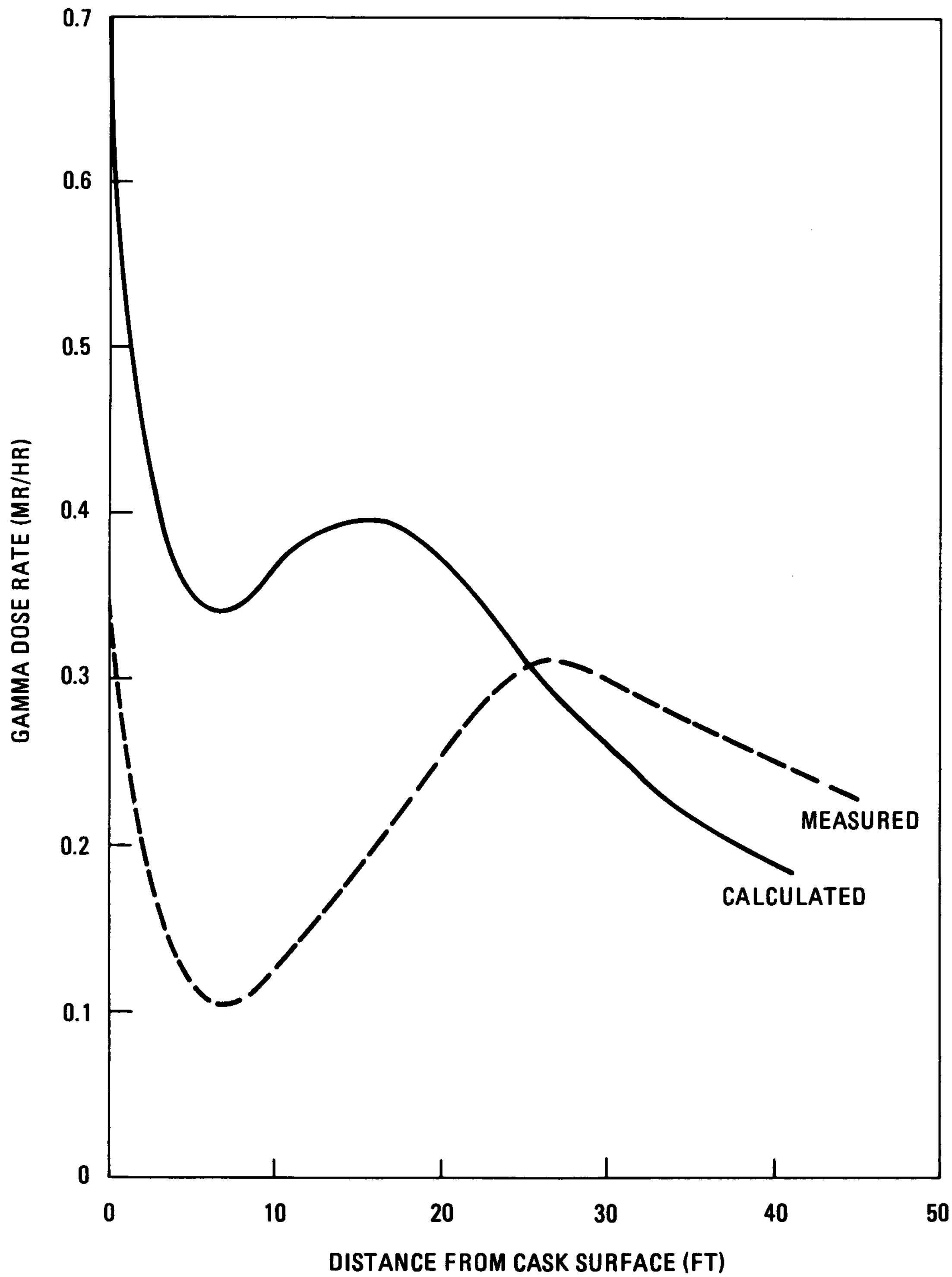


Fig. 5-2. Comparison of measured and calculated dose-rate variation with distance from loaded FHM

5.4.2. Clevis Pin Dose Rate

The rather high dose rate of 50 mR/hr measured by PSC at a location 25 ft from the ATC centerline at an elevation of 25 ft above the refueling floor is probably due to induced activity in the 321SS clevis pins attaching the control rods to their cables. As shown in Fig. 5-3, when the rods are fully withdrawn into the CRD, and the latter is at its maximum elevation inside the ATC, the clevis pins are shielded by only 1-1/4 in. of steel at the 25 ft elevation. While there is no major problem on the refueling floor near the cask (because slant penetration through a greater thickness of steel substantially reduces the dose rate), as the detector is moved out from the cask or to a greater elevation, the dose rate increases. The horizontal effect is depicted in Fig. 4-1, while the vertical effect can be judged from the increase in dose rate by an order of magnitude.

The calculation of the clevis pin activity is shown in Table 5-2.

Even though several of the input parameters were guessed at (such as the cobalt concentration in the steel), the result seems to confirm the origin of the measured 50 mR/hr dose rate at the 25-ft elevation.

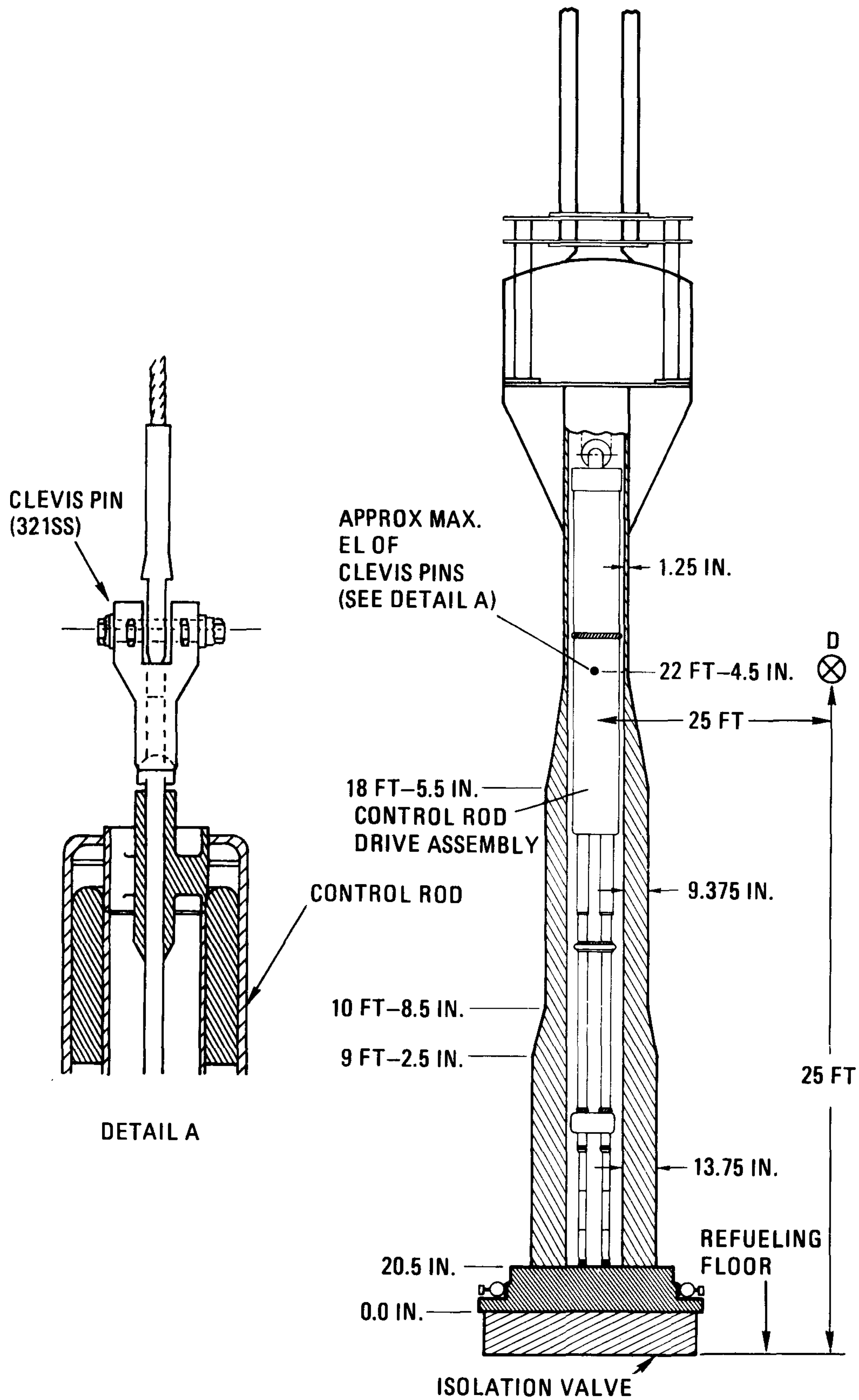


Fig. 5-3. Clevis pin location in ATC

TABLE 5-2
INDUCED ACTIVITY IN CLEVIS PINS

Full power thermal flux in top reflector, at location of clevis pins with rods inserted	5×10^{13} n/cm^2-sec
Average thermal neutron energy	0.1 eV
Fractional power for Co60 calculation	174 EFPD
Fractional power for Fe59 calculation	60%
Assumed cobalt content of 321 SS	500 ppm
Volume of clevis pins	63 cm^3
Decay time	65 days
Calculated Co60 activity	5.8 Ci
Calculated Fe59 activity	2.7 Ci
Dose rate at 25 ft from Co60 (PATH calc)	89 mrad/hr
Dose rate at 25 ft from Fe59 (PATH calc)	21 mrad/hr
Total calculated dose rate	110 mrad/hr

6. CONCLUSIONS AND RECOMMENDATIONS

6.1. CONCLUSIONS

Comparisons between Ft. St Vrain refueling does rate measurements and calculations, as displayed in Table 1-1 and elsewhere in this report, generally show agreement within a factor of two. This margin of agreement is considered satisfactory in view of uncertainties in predicted nuclide inventories in the spent fuel, block configurations in the FHM, detector positioning, material compositions in the control-rod assemblies, and history of control-rod insertion. To this extent, the measurements provided validation of the PATH code.

Measured does rates were generally very low throughout the refueling operation, especially those associated with the isolation valve and the fuel storage facility, thus confirming the conservative design of the FSV refueling equipment.

Measured values which had not been predicted by earlier design calculations included:

1. The dose rate just under the steel flange of the FHM, some 18 ft above the refueling floor, when a spent fuel block was raised to the photography position in the cask (2000 mR/hr).

2. The dose rate 25 ft from the ATC and 25 ft above the refueling floor, when a "hot" control rod drive was raised to the maximum elevation inside the cask (50 mR/hr).

However, both these measurements were verified by new calculations which took account of non-design conditions.

6.2. RECOMMENDATIONS

Although the PATH point kernel code was generally substantiated by the measurements, scattering calculations using GGG, MUSCAT or MORSE should be performed to check against some of the PSC measurements made at various distances from the FHM and ATC. The relative contributions of building scattering and direct radiation should be determined. Time and funding did not permit scattering calculations in the present study.

The non-design conditions referred to in paragraph 6.1 could be alleviated by relatively simple procedures:

1. The 2000 mR/hr dose rate near the flange of the FHM is almost certainly caused by the gradual settling of the lead shot. It would be easy to add lead shot in this region, either by disassembling the machine at the flange or by drilling small filler holes. Alternatively, a modest shield sleeve or ring could be wrapped around the cask just below the flange.

2. The solution to the activated clevis pin problem is even simpler. When loading the CRD into the ATC, the drive and rods should be kept at their <u>minimum</u> elevation rather than maximum elevation, thus lowering the "hot" clevis pins into a more heavily shielded region of the cask.

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APPENDIX A

PRELIMINARY PROCEDURE FOR FSV REFUELING RADIATION SURVEY

ABSTRACT

A preliminary procedure is presented for a radiation survey to be conducted during the first FSV refueling operation. Approximately 80 detector locations are proposed. Both steady-state and transient measurements are called for, some of which should be repeated during the refueling period in order to evaluate the effect of decay time.

A.1. PURPOSE

The purpose of the FSV refueling radiation survey is to verify the adequacy of the refueling equipment and storage facility shielding, confirm theoretical predictions of steady-state and transient dose rates, identify detector locations which should be used for future measurements, and provide design guidance for shielding design for the large HTGR. Such a survey was not possible as part of Startup Test No. B-12, "Shielding Surveys," which was conducted at 30% power in the absence of any spent fuel on the reactor site (Ref. A-1).

2.0. SUMMARY

While the FSV reactor is undergoing its first refueling in early 1979, a radiation survey will be conducted on the refueling floor, around the fuel handling machine (FHM), around the auxiliary transfer cask (ATC), and on the fuel and control-rod-drive (CRD) storage facility, to determine the adequacy of the associated shielding. The survey will indicate any area which may require additional shielding or access control before the refueling operation proceeds further.

A.3. REACTOR AND PLANT CONDITIONS

The reactor will be shut down and depressurized. Decay time when the first CRD is removed will be 24 hours or more.

A.4. PLANT LIMITATIONS

No special limitations due to the shielding survey are placed on the plant. Health Physics supervision is required at locations where the dose rate is expected to exceed 10 mrem/hr. Measurements which require personnel to ascend up the side of the FHM or ATC, or to stand underneath a hoisted cask, must have the approval of the Plant Safety Officer.

A.5. INSTRUMENTATION

No significant neutron levels are expected from HEU fuel; hence, all measurements are gamma dose rates as measured by an appropriate, calibrated ionization chamber with a range of 1 to 1000 mrem/hr and a rapid response time.

For some measurements, an integrating gamma dosimeter would be valuable.

A.6. PROCEDURE

This procedure is significantly different from the SUT B-12 procedure described in Ref. A-1 in that both transient and steady-state measurements are desired during the refueling operation. The steady-state measurements consist of detector points on the FHM and the ATC when loaded, and on the storage facility floor with the well(s) loaded. The transient measurements apply when fuel blocks, CRD's, or the high-temperature filter adsorber (HTF/A) is being drawn up into a cask from the PCRV, or is being lowered into a storage well. A few transient dose rates are also desired on the FHM itself.

A.6.1. Auxiliary Transfer Cask Measurements

Table A-1 and Fig. A-1 list the detector locations proposed for a radiation survey of the ATC. All measurements are made with the ATC loaded with either a CRD or HTF/A, preferably early in the refueling sequence and preferably one of the hotter CRD's.

Detector points A1 through A7 will check the adequacy of the cask side shielding for direct gammas (Ref. A-2). Points A8 through A10 will measure the intentionally high direct dose rate allowed to exist well above the personnel level. Scattered gammas from the top regions of the ATC arriving back at the personnel level will be checked by detector points A11 through A14 (Ref. A-3). Weaknesses in the bottom shielding should be uncovered by measurements at A15, A16, and A17.

Data required include detector point number, time and date, contents of ATC, and gamma dose rate.

A.6.2. Fuel Handling Machine Measurements

Table A-2 and Figs. A-2 and A-3 describe the survey proposed for the FHM. Most measurements should be performed with the machine fully loaded with spent fuel, as soon after the start of refueling as possible. Where one or more fuel columns also contain reflector blocks, measurements should be moved adjacent to a column which is entirely fuel.

Detector points F2, F3, and F4 will check the adequacy of the cask side shielding for direct gammas (Ref. A-4). Detector point F1 is to determine streaming effects through the steel below the lead slot. Points F5 through F13 are to verify the intentionally increasing direct gamma dose rate as the detector is moved up the cask wall and on top, where Ref. A-4 mentions a dose rate of 1 rem/hr.

The measurements at F4 through F7 are to be repeated with the grappler head and fuel block at maximum height, to ascertain what, if any, increase in direct dose rate this condition might entail.

TABLE A-1
AUXILIARY TRANSFER CASK MEASUREMENTS

Detector Point No.	Location (see Fig. A-1)	Cask Conditions*
A1	On side surface of cask just above pedestal	A, C B, C
A2	On side surface of cask ~3 ft above pedestal	A, C B, C
A3	On side surface of cask just below start of first taper	A, C B, C
A4	On side surface of cask just above start of first taper	A, C B, C
A5	On side surface of cask ~3 ft above A4	A, C B, C
A6	On side surface of cask just below start of second taper	A, C B, C
A7	On side surface of cask ~28 in. above A6	A, C B, C
A8	On side surface of cask just above end of second taper	A, C B, C
A9	On side surface of cask ~28 in. above A8	A, C B, C
A10	On side surface of cask just below platform structure	A, C B, C
A11	3 ft from side surface of cask, 4 ft above refueling floor	A, C B, C

TABLE A-1 (Continued)

Detector Point No.	Location (see Fig. A-1)	Cask Conditions*
A12	6 ft from side surface of cask, 4 ft above refueling floor	A, C B, C
A13	9 ft from side surface of cask, 4 ft above refueling floor	A, C B, C
A14	12 ft from side surface of cask, 4 ft above refueling floor	A, C B, C
A15	On bottom surface of cask, on centerline	A, D B, D
A16	On bottom surface of cask, 1 ft from centerline	A, D B, D
A17	On bottom surface of cask, 2 ft from centerline	A, D B, D

*A. Cask loaded with hot control-rod drive as soon after reactor shutdown as possible.
B. Cask loaded with spent high-temperature filter-adsorber as soon after reactor shutdown as possible.
C. Cask in place on refueling floor.
D. Cask hoisted above isolation valve.

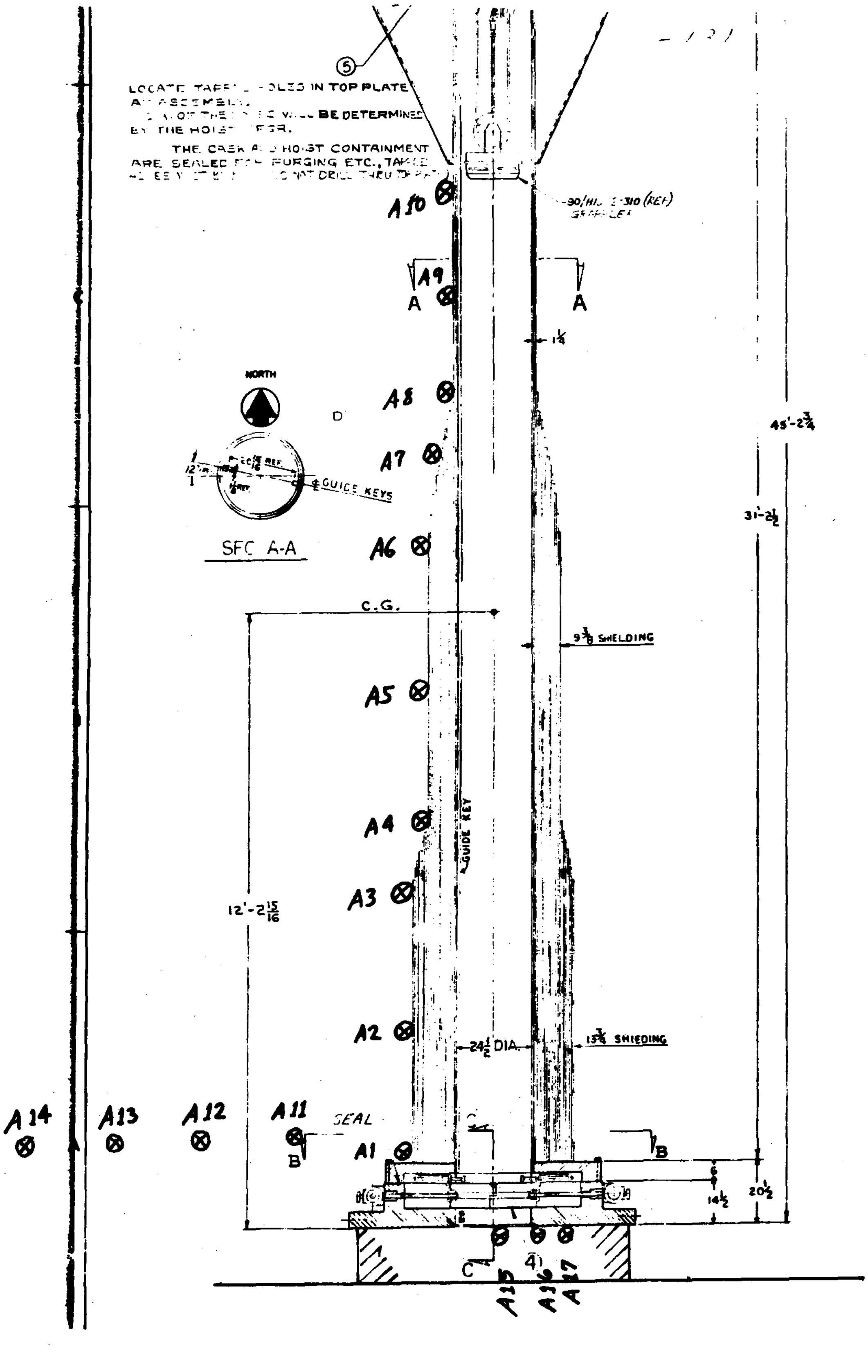

Fig. A-1. ATC detector locations.

TABLE A-2
FUEL HANDLING MACHINE MEASUREMENTS

Detector Point No.	Figure	Location	Machine Conditions*
F1	A-2	On side surface of machine, just below lead shielding	E, G
F2	A-2	On side surface of machine ~3½ ft above F1	E, G
F3	A-2	On side surface of machine ~7 ft above F1	E, C
F4	A-2	On side surface of machine ~3½ ft below F5	E, G F, G
F5	A-2	On side surface of machine just below first flange	E, G F, G
F6	A-2	On side surface of machine just above first flange	E, G F, G
F7	A-2	On side surface of machine just above second flange	E, G F, G
F8	A-2	On side surface of machine ~3 ft above F7	E, G
F9	A-2	On side surface of machine ~6 ft above F7	E, G
F10	A-2	On side surface of machine ~9 ft above F7	E, G
F11	A-2	On side surface of machine ~12 ft above F7	E, G
F12	A-2	On side surface of machine ~15 ft above F7	E, G
F13	A-2	On top platform of machine on centerline	E, G
F14	A-2	On top platform of machine, ~1½ ft from centerline	E, G
F15	A-3	On side of machine near base, at indentation in lead shield	E, G
F16	A-3	On side surface of machine at same elevation as F2, but opposite steel strut @ W by NW	E, G
F17	A-3	On side surface of machine at same elevation as F2, but opposite steel strut @ S by SE	E, G

TABLE A-2 (Continued)

Detector Point No.	Figure	Location	Machine Conditions*
F18	A-3	On cover of light fixture port	E, G
F19	A-3	On side of extension of viewing device port	E, G
F20	A-3	On cover of viewing device port	E, G
F21	A-3	On cover of unnamed port N by NE	E, G
F22	A-3	On cover of unnamed port N by NW	E, G
F23	A-3	On side of extension of unnamed port N by NW	E, G
F24	A-2	On bottom surface of machine, just beyond lead shutter (15 in. from centerline)	E, H
F25	A-2	On bottom surface of machine ~1 ft beyond F24	E, H
F26	A-2	3 ft from side surface of machine, 4 ft above refueling floor	E, G
F27	A-2	6 ft from side surface of machine, 4 ft above refueling floor	E, G
F28	A-2	9 ft from side surface of machine, 4 ft above refueling floor	E, G
F29	A-2	12 ft from side surface of machine, 4 ft above refueling floor	E, G
F30	A-2	15 ft from side surface of machine, 4 ft above refueling floor	E, G

*E. Machine loaded with fuel blocks as soon after shutdown as possible.
F. Grappler with fuel block at maximum height in machine, as soon after shutdown as possible.
G. Machine in place on refueling floor.
H. Machine hoisted above isolation valve.

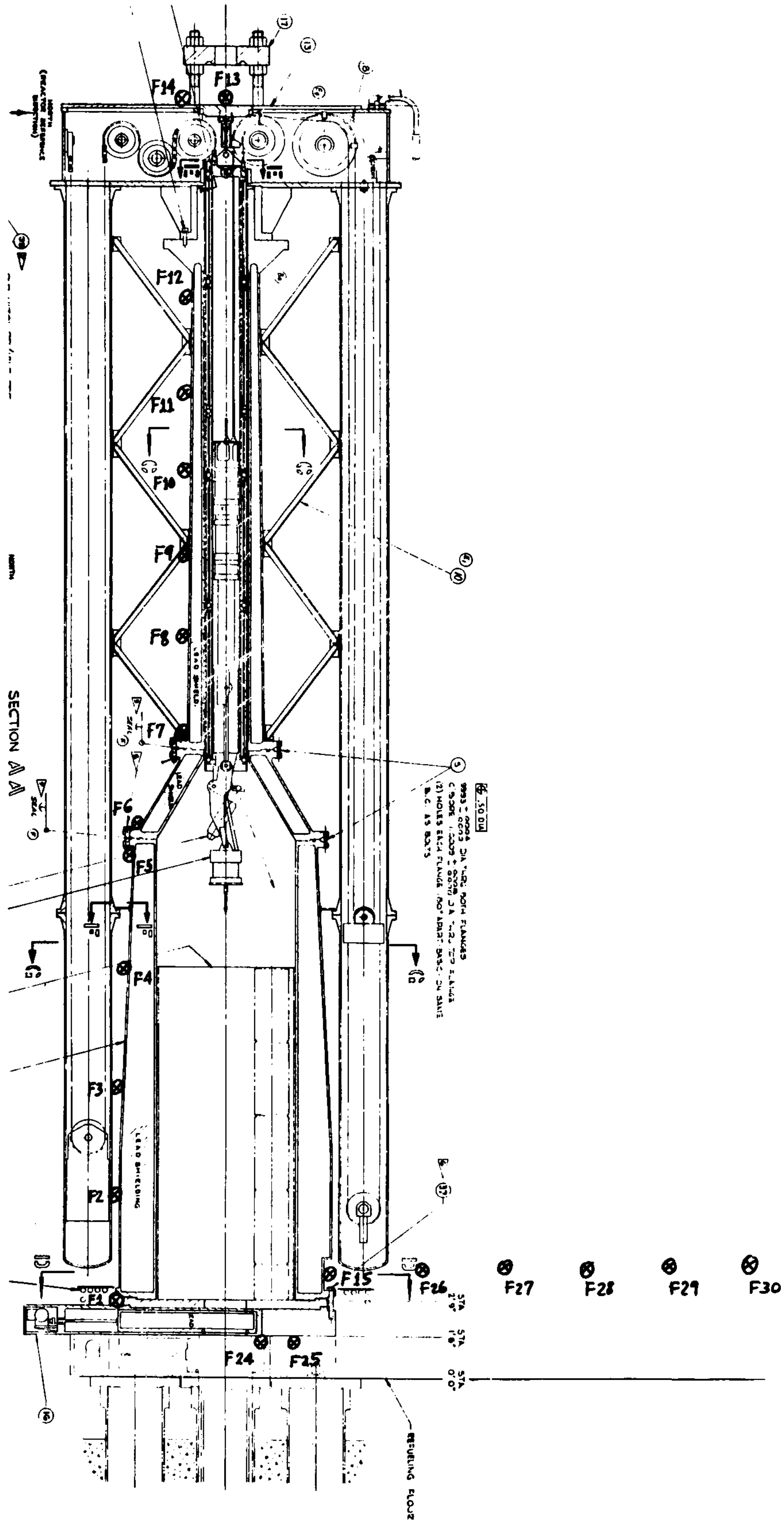

Fig. A-2. FHM detector locations.

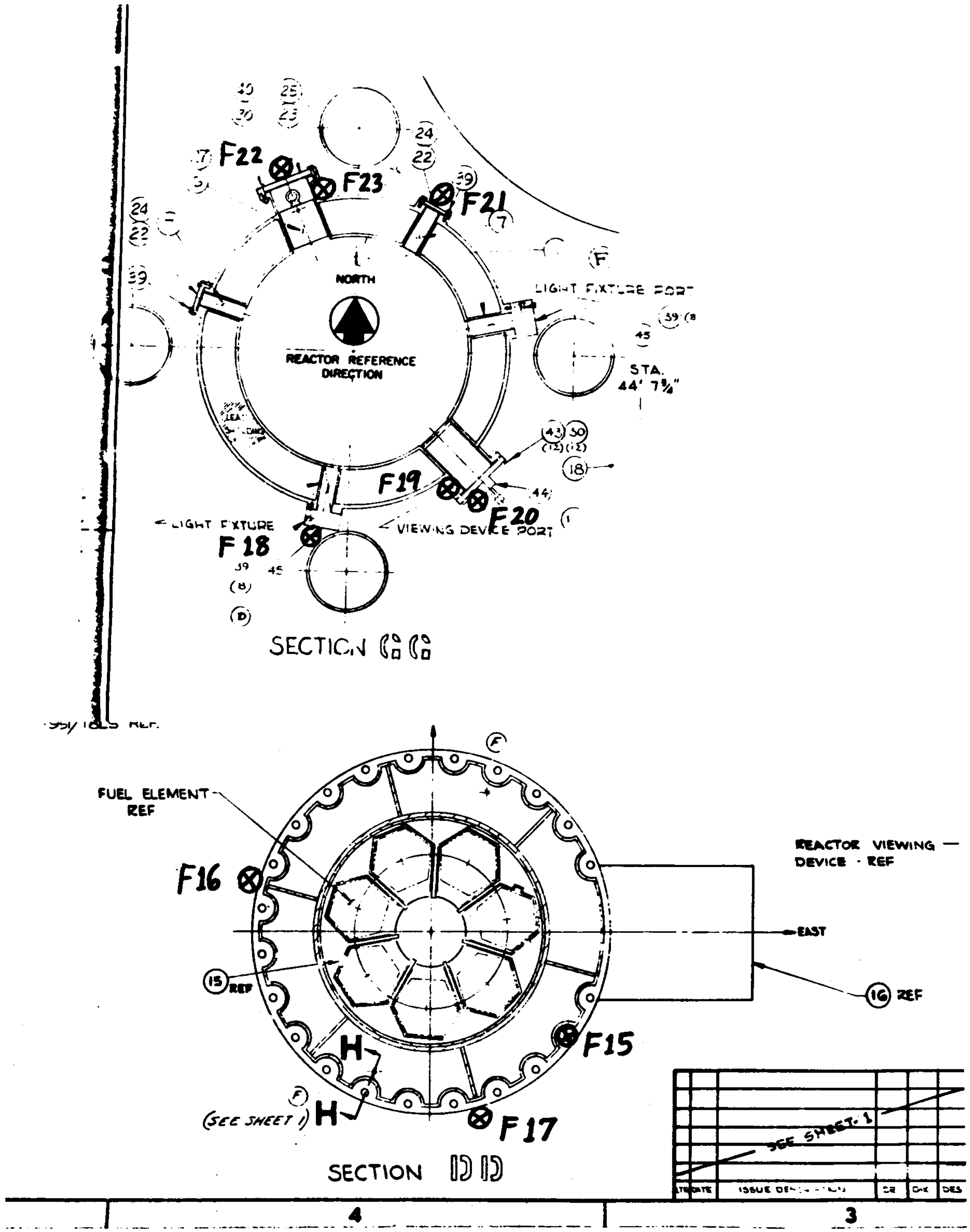

Fig. A-3. Selector locations on side of FHM.

Dose rates at F8 through F14 may also display variations depending on the fuel block configuration in the machine. While not mandatory, it would be desirable to continuously record the dose rate at F13 (for example) during the entire loading cycle of the FHM, since for certain positions of the grappler arm the dose rate at F13 may peak.

The purpose of detector location F15 is to check for an increased gamma dose rate where the lead shielding is indented for bolt access. Points F16 and F17 check for streaming through steel struts.

Detector points F18 through F23 will identify streaming or short-circuiting through the various ports in the FHM. For example, point F19 will measure gamma short-circuiting through a steel plug in the viewing device port.

As with the ATC, scattered gammas from the top of the FHM reaching the personnel level are to be measured at F26 through F30. If the dose rate at F30 appears to be level or increasing with distance from the cask, measurements should be extended farther out at 3-ft intervals. The calculation of these scattered dose rates is extremely difficult and the results highly uncertain (see Refs. A-5 and A-6); hence, measurements are sorely needed.

Data required include detector point number, time and date, contents and internal configuration of FHM, and gamma dose rate.

A.6.3. Refueling Floor Measurements

All refueling floor measurements are to be made under transient conditions, i.e., while a radioactive component is being raised from the PCRV into a cask. The purpose of these measurements is to verify the transient dose rates discussed in Refs. A-7 and A-8, and elsewhere. Shielding efficacy of the refueling floor; the concrete, steel, and lead outer shield; and the FHM shielding sleeve will be checked by these measurements.

Table A-3 lists the detector points associated with the refueling floor. In Fig. A-4 a typical central nozzle is shown with the ATC or the FHM, mounted on top and a CRD or a fuel block being withdrawn.

The associated detector points are numbered R1 through R5. The gamma dose rate at R1 should first be monitored with the CRD or fuel block passing from the PCRV into the cask, and at least the peak dose rate noted, if possible keying it with the vertical location of the CRD or fuel block at that time. The same procedure should take place for detector points R2 through R5, although in the case of the CRD one would have to relocate at another nozzle. Note that successive fuel blocks may not produce exactly the same dose rate at a detector point, because their relative operating power may have differed by as much as 50%.

Figure A-5 depicts outboard nozzle No. 35, which happens to be near the concrete shield wall. Detector point R6 is provided to check the shield effectiveness of this wall.

Figure A-6 concerns nozzle No. 20, which is an outboard nozzle near the manned access port. As a fuel block or CRD is lifted through this nozzle, there may exist a "short-circuit" path for gamma radiation through the empty access port. Detector points R7 through R10 are proposed to check this possibility.

During the design and construction of the NSSS, it was found impossible to run a continuous concrete shield wall around the outside of the refueling floor. Therefore, several steel or lead shadow shields were substituted, with accompanying gaps for piping and wiring. In some cases, nozzle extensions above the PCRV surface are relied on to provide shadow shielding. The purpose of detector points R11, R12, and R13 (outboard from nozzle 33; see Fig. A-7) is to provide valuable data on gamma streaming through these gaps. Both fuel blocks and CRD's are of interest.

Some outboard nozzles are not "shadowed" by other nozzles; such is the case with nozzles 27 or 28, shown in Fig. A-8. Detector points R14,

TABLE A-3
REFUELING FLOOR MEASUREMENTS

Make as many measurements as possible while CRD or HTF/A is being pulled up into ATC or while fuel blocks are being pulled up into FHM. Record time of measurement and attempt to relate to vertical location of radio active component with respect to top of PCRV concrete.

<u>Case I - Fig. A-4 -- Typical central nozzle</u>

Detector Point No.	Location
R1, R2, R3, R4, R5	On surface of refueling floor, as shown in Fig. A-4

<u>Case II - Fig. A-5 -- Outboard nozzle near solid concrete shield wall (Nozzle ID No. 35)</u>

R6	Other side of concrete shield wall, elevation about 1 ft above PCRV top head, as shown in Fig. A-5

<u>Case III - Fig. A-6 -- Outboard nozzle near manned access port (Nozzle ID No. 20)</u>

R7	Top of manned access port, nearest FHM
R8	Top of manned access port, 1 ft out from R7
R9	Top of manned access port, 2 ft out from R7
R10	Top* or side* of manned access, 3 ft out from R7

<u>Case IV - Fig. A-7 -- Outboard nozzle near westerly shield gaps (Nozzle ID No. 33)</u>

R11	Top of refueling floor 1 ft from edge of FHM, as shown in Fig. A-7
R12	Top of refueling floor 2 ft from edge of FHM, as shown in Fig. A-7
R13	Outside shield gap near lip, as shown in Fig. A-7

TABLE A-3 (Continued)

Detector	Location
Case V - Fig. A-8 -- Either of the nozzles nearest shield block "A" (Nozzle ID Nos. 27 or 28)	
R14	Top of refueling floor, just south of FHM
R15	Top of refueling floor, ½ ft out from R14
R16	Top of refueling floor, 1 ft out from R14
Case VI - Fig. A-9 -- Either HTF/A nozzle	
R17	Top of refueling floor, near ATC at location which "sees" between adjacent nozzles
R18	Outboard of ATC in shield wall gap
R19	About 1-½ ft outboard from R18

*Whichever yields the higher dose rate.

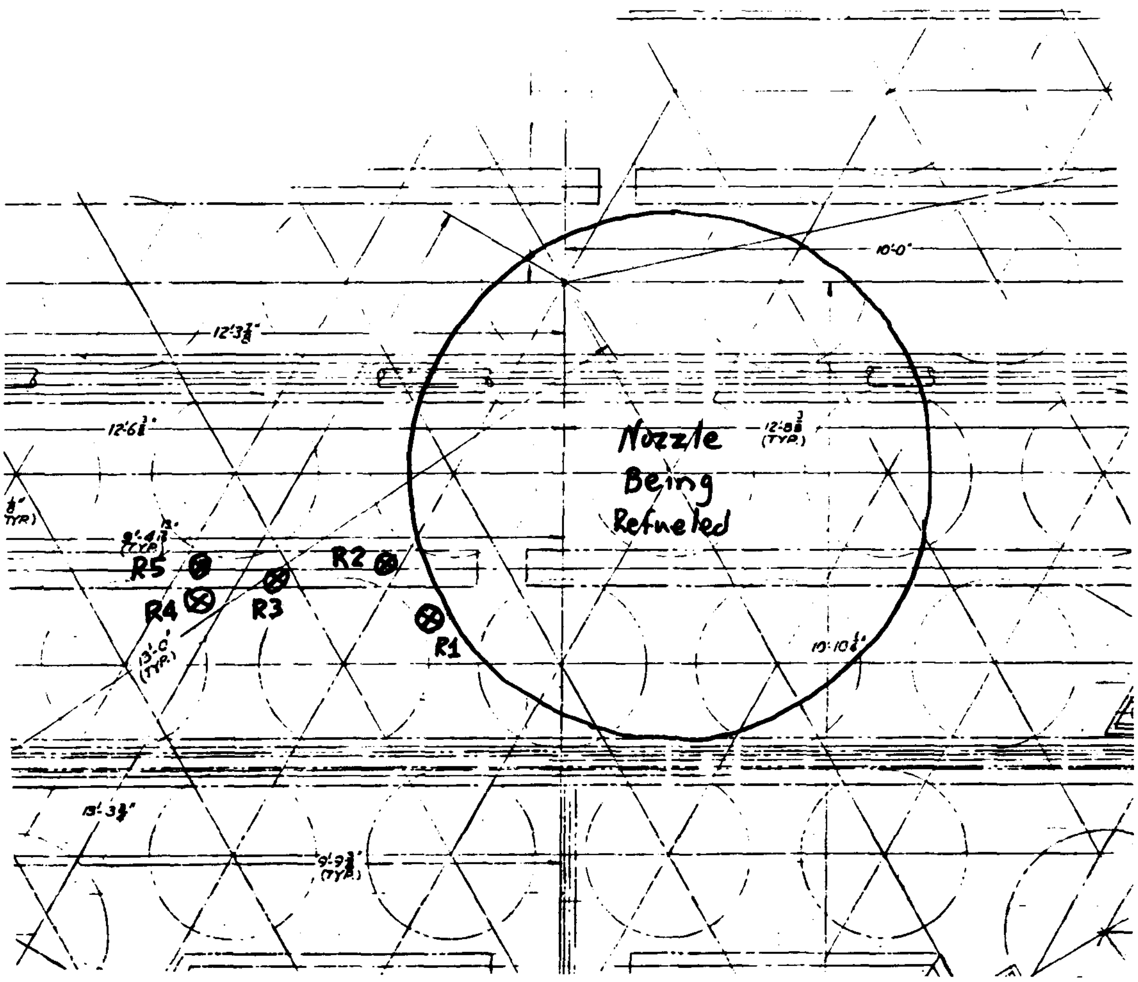

Fig. A-4. Detector locations on refueling floor near typical central nozzle.

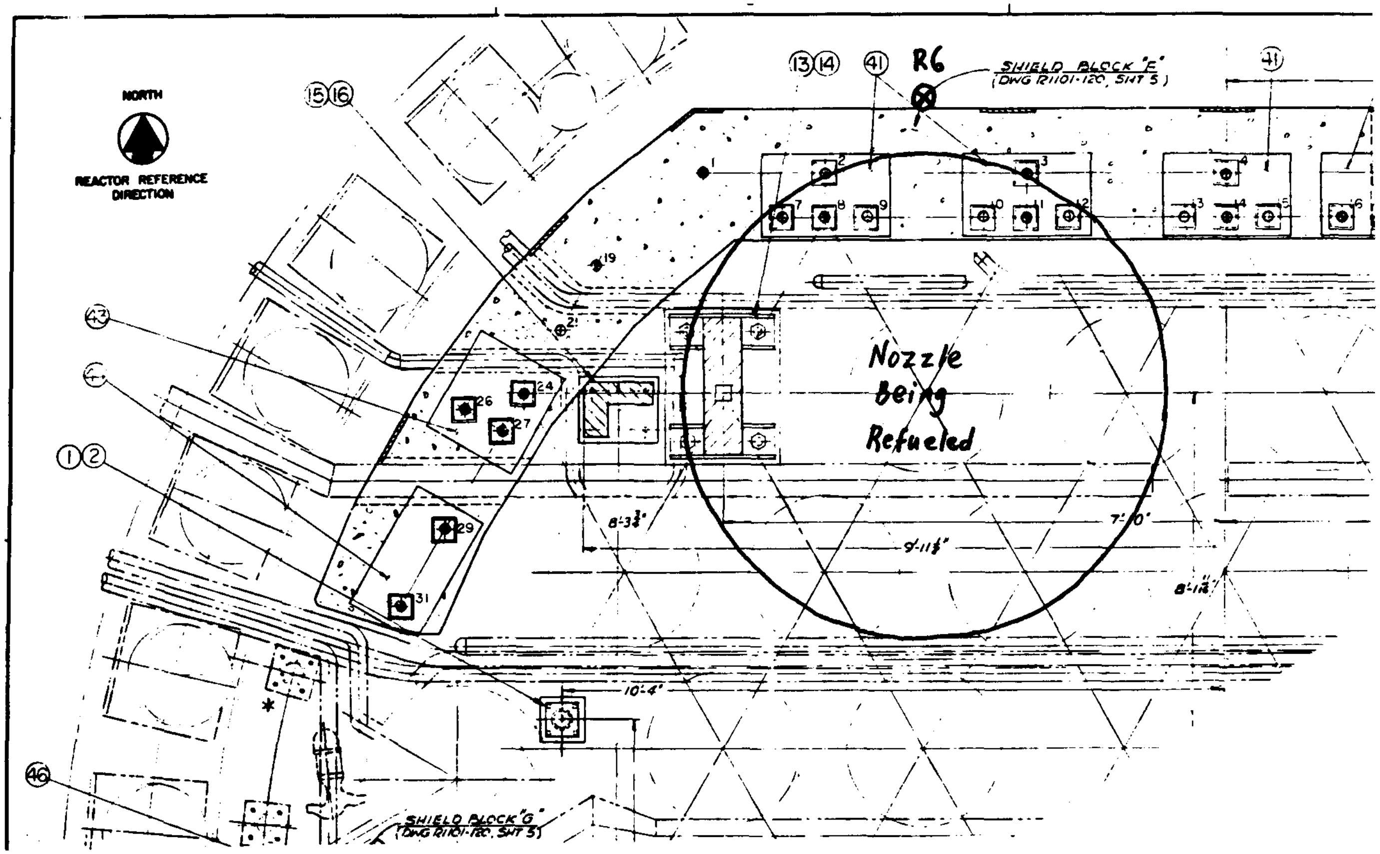

Fig. A-5. Detector locations near concrete shield wall.

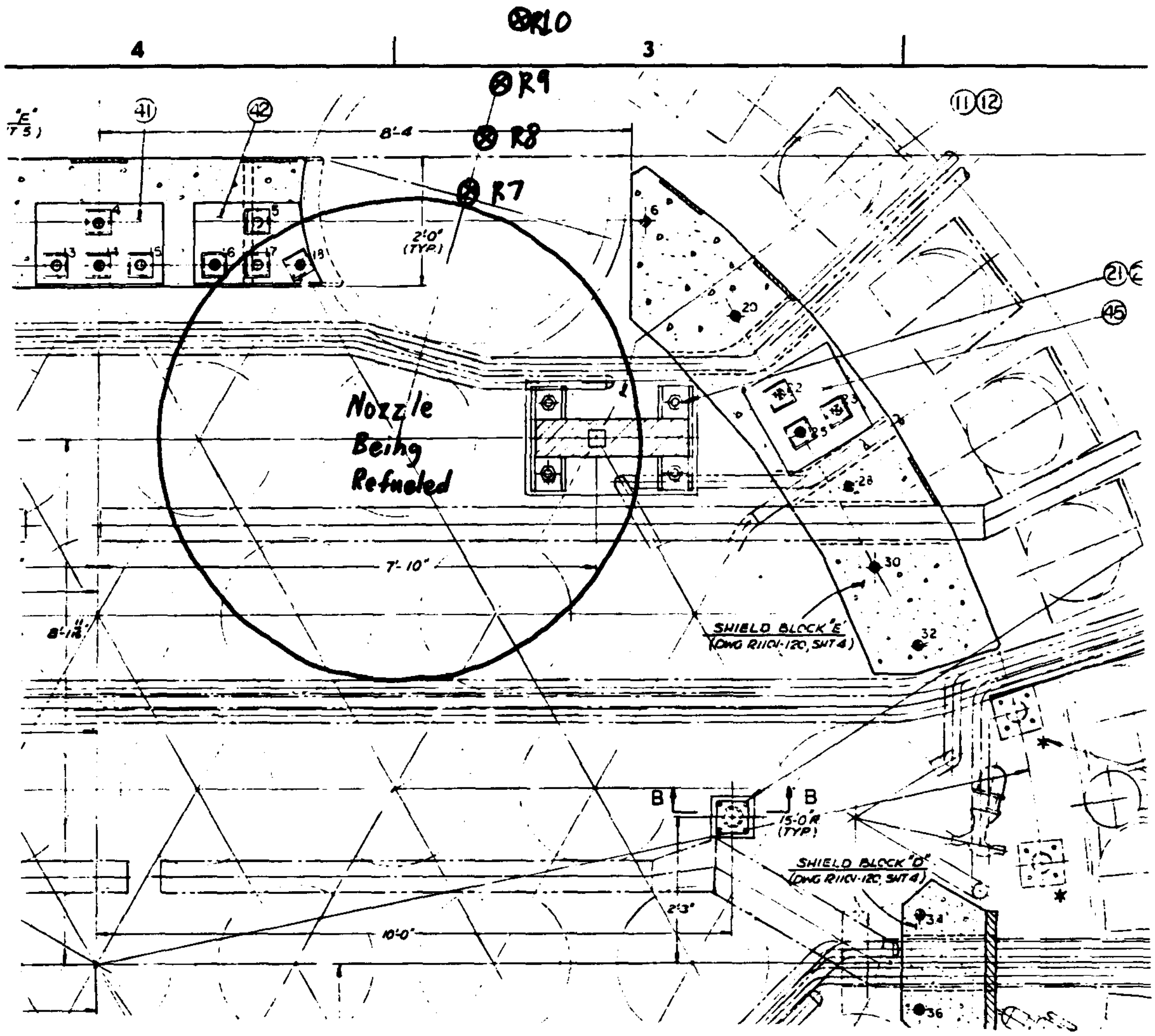

Fig. A-6. Detector locations near manned access port.

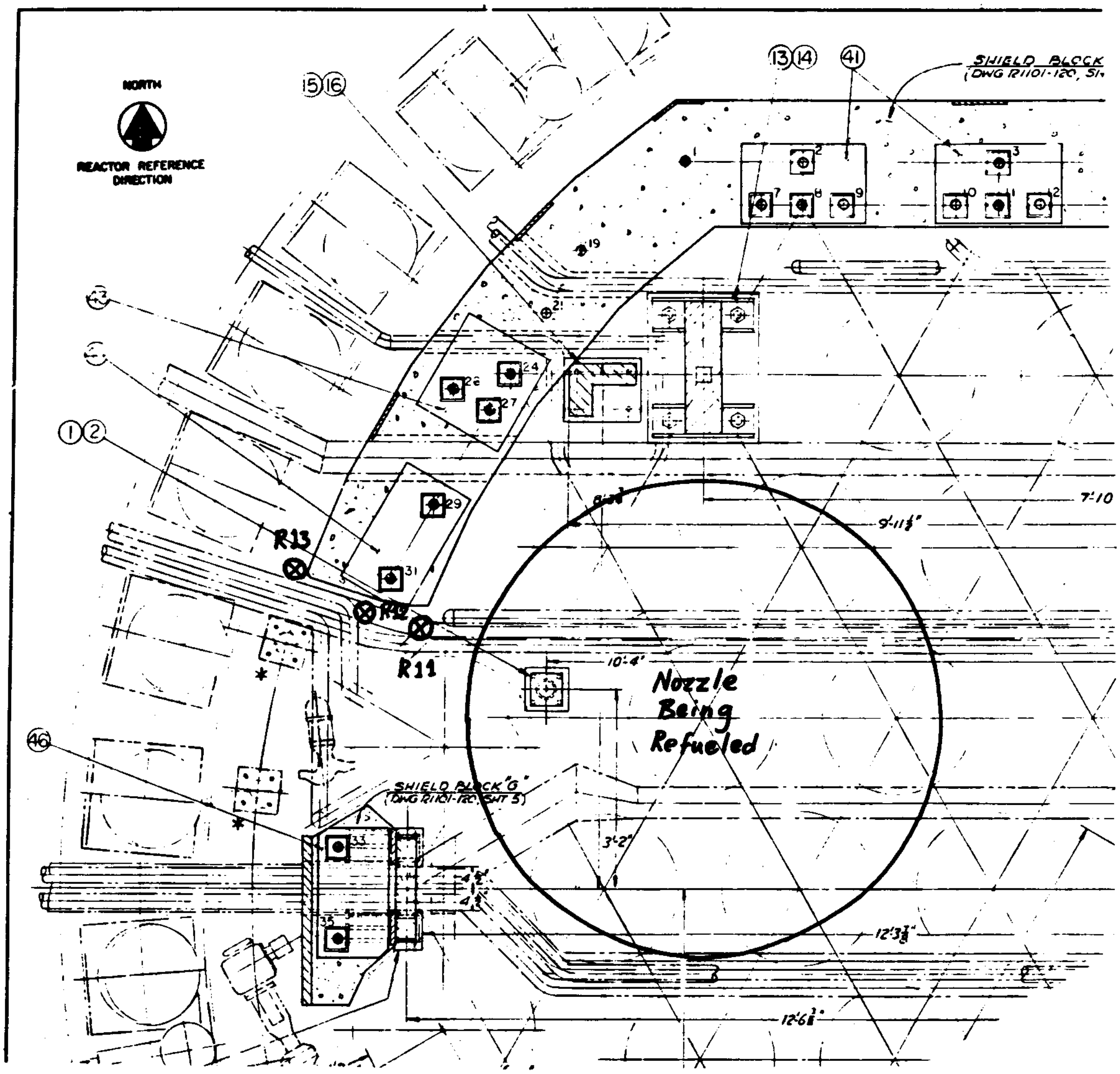

Fig. A-7. Detector locations near shield wall gaps.

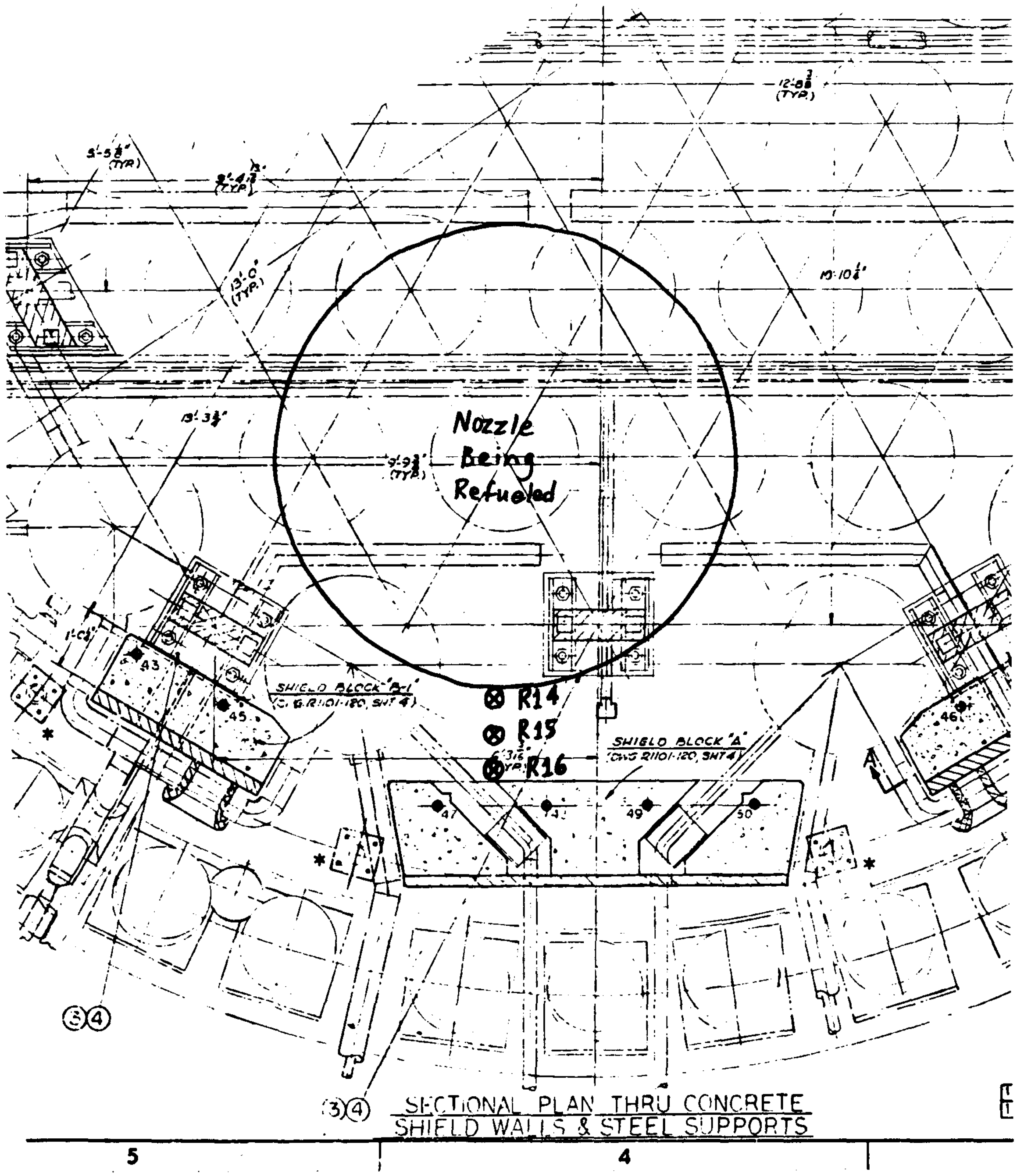

Fig. A-7. Detector locations on refueling floor near nozzles 27 or 28.

R15, and R16 should display somewhat higher transient dose rates as a fuel block or CRD is withdrawn.

Measurements are also to be made on the floor (or below) around the ATC when removing an HTF/A, as shown in Fig. A-9.

Data requirements are more complex for the refueling floor measurements, since it is important for an instantaneous dose rate measurement to be related to the instantaneous vertical location of the fuel block, CRD, or HTF/A. Cooperation between health physicists, core physicists, operating engineers, instrumentation engineers, and others will be necessary. In the absence of time and motion information, it will generally be possible only to record the maximum dose rate during the component's ascent into the cask.

Hence, the data requirements will generally be: detector point number, date, item being raised into cask, time of measurement, dose rate, and vertical location of component at that time. If the component location is unavailable, then just record the maximum dose rate. Special conditions such as removed cover plates or shield segments should be noted.

In cases where only the maximum dose rate can be read, an auxiliary integrating detector would be of value to obtain the total gamma dosage per component removal (this is the important quantity for NRC purposes).

6.4. Fuel and CRD Storage Facility Measurements

Table A-4 and Figs. A-10 and A-11 summarize the dose rate measurements needed at the storage facility. The purpose is to verify the shielding adequacy of the facility when loaded (steady state) as well as the transient dose rates as the components are lowered into the wells.

Detector points S1 through S6 apply to a fuel storage well as it is being loaded. Therefore, the same provisos apply as under the refueling floor discussion regarding dose rate as a function of vertical position of

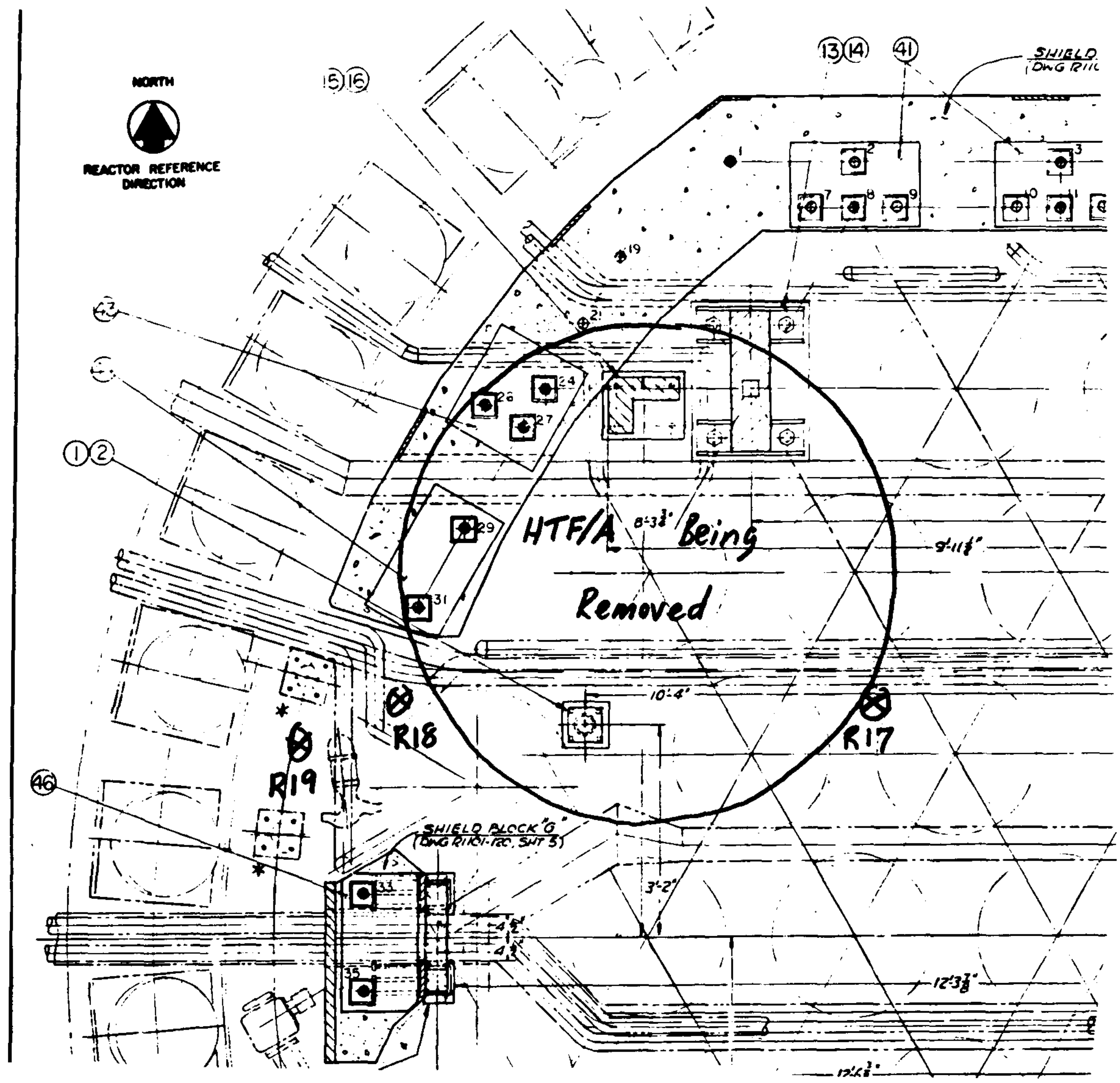

Fig. A-9. Detector locations on refueling floor with HTF/A being removed.

TABLE A-4
FUEL AND CRD STORAGE FACILITY MEASUREMENTS

Detector Point No.	Figure	Location	Conditions
S1	A-10	On fuel storage facility floor just north of FHM	Fuel elements being lowered into storage well
S2	A-10	About 1' out from S1	Fuel elements being lowered into storage well
S3	A-10	About 2' out from S1	Fuel elements being lowered into storage well
S4	A-10	About 3' out from S1	Fuel elements being lowered into storage well
S5	A-10	On fuel storage facility floor just NNE of FHM	Fuel elements being lowered into storage well
S6	A-10	On fuel storage facility floor just NE of FHM	Fuel elements being lowered into storage well
S7	A-10	Directly above shield plug on fuel storage well	Well loaded with fuel elements
S8	A-10	Above edge of shield plug	Well loaded with fuel elements
S9	A-10	About 1' out from S8	Well loaded with fuel elements
S10, S11, S12, S13, S14, S15	A-11	On CRD/HTF-A storage facility floor around ATC at locations shown in Fig. A-10	CRD or HTF/A being lowered into storage well
S16	A-11	Directly above shield plug on CRD storage well	Well loaded with CRD or HTF/A
S17	A-11	Above edge of shield plug	Well loaded with CRD or HTF/A
S18	A-11	About 1' out from S17	Well loaded with CRD or HTF/A

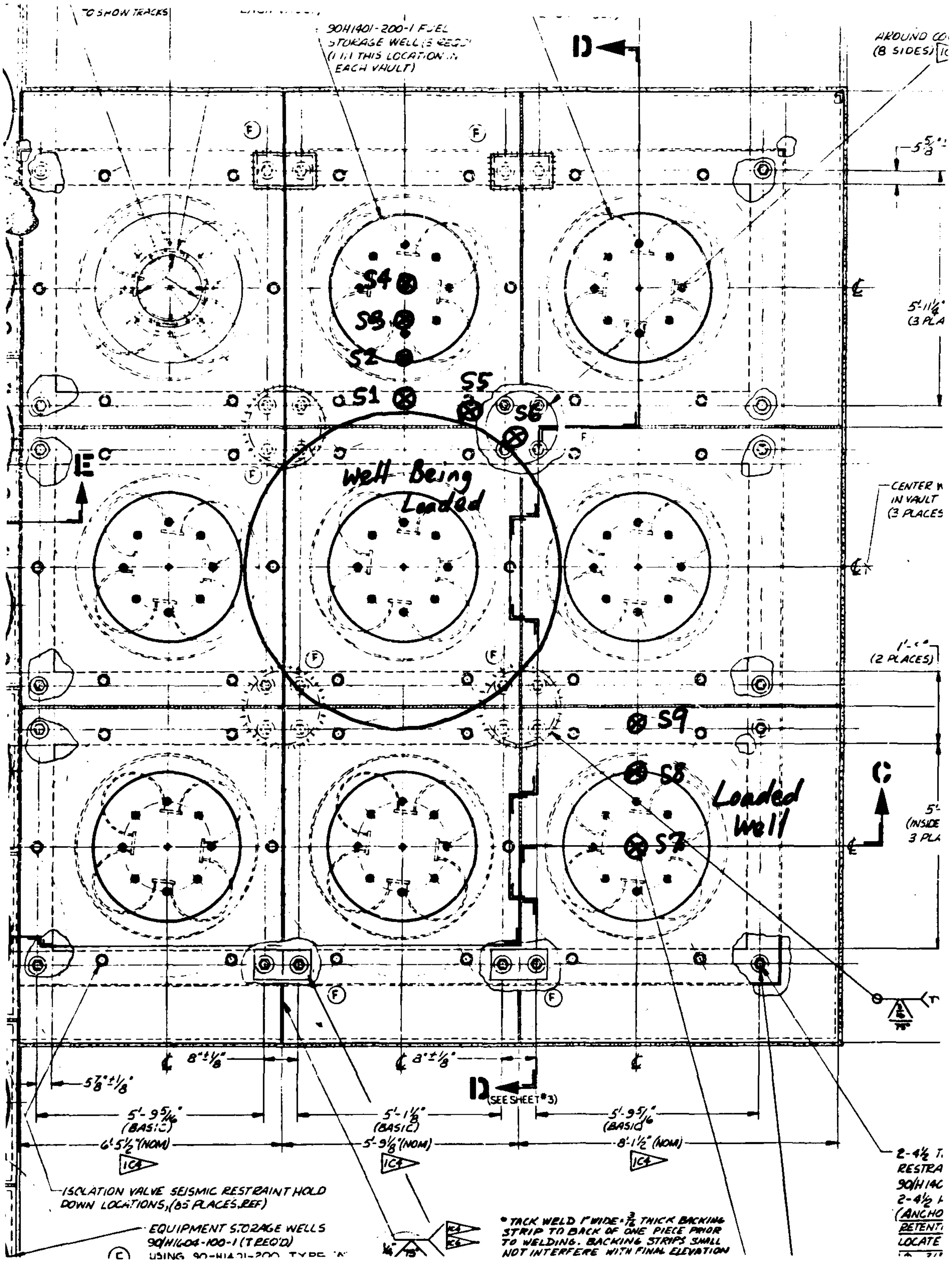

Fig. A-10. Detector locations on fuel storage facility.

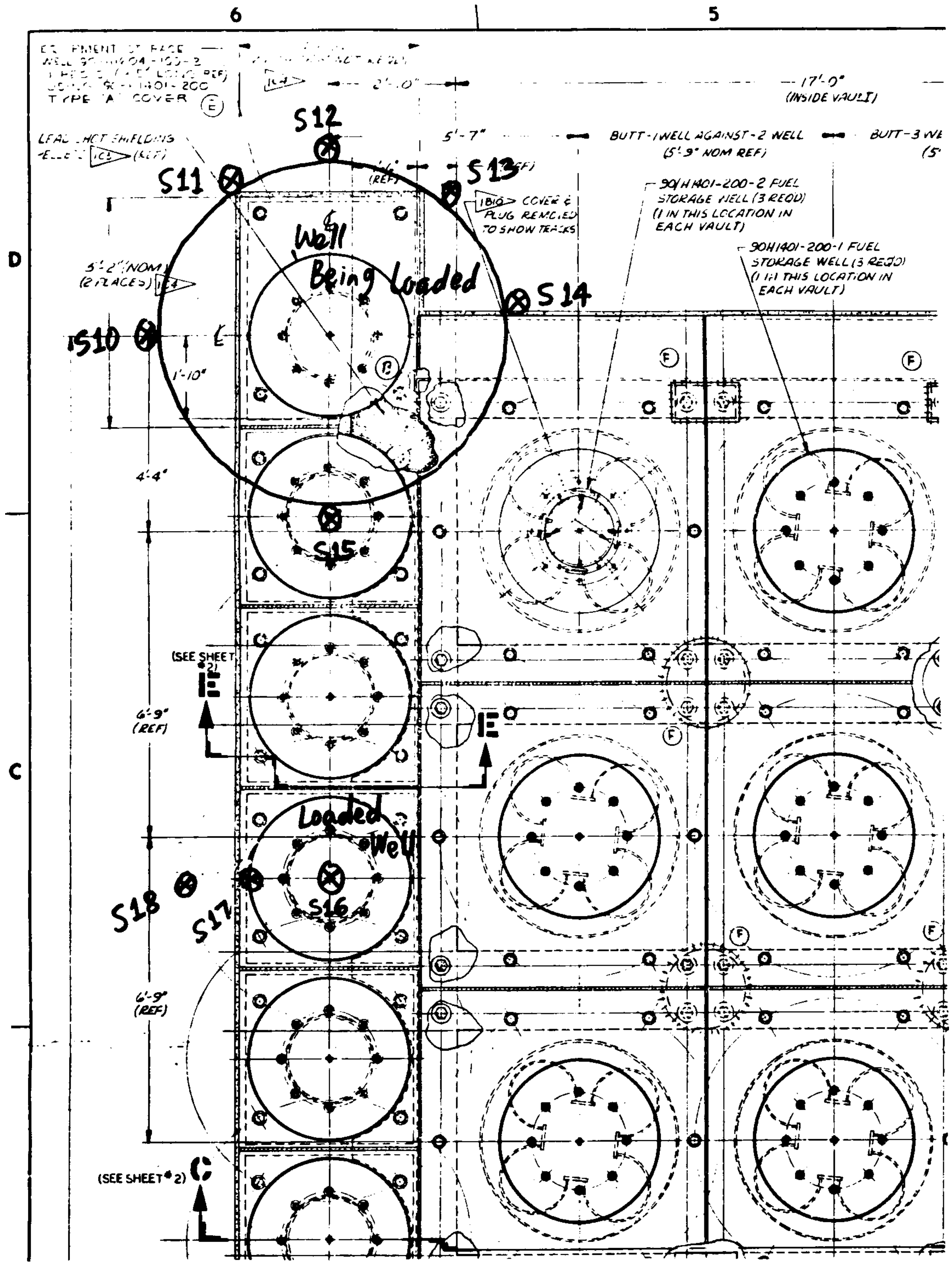

Fig. A-11. Detector locations on CRD storage facility.

the fuel block. The detector locations are chosen in an attempt to identify short-circuit paths from one well to an adjoing well.

Detector points S7, S8, and S9 are steady-state measurements made above a loaded fuel-storage well. These measurements should be repeated every day during the refueling operation to obtain a curve of gamma dose rate versus decay time.

Figure A-11 shows CRD/HTF/A wells being loaded or already loaded. Two sets of measurements are required - one set for a CRD and one set for the HTF/A. An outer well is shown for the transient measurements at points S10 through S15 because of the possibility of short-circuiting through ordinary concrete. Obviously, only a CRD or the HTF/A can be measured in this outermost position.

A.7. DATA SHEETS

Data sheets will be developed after agreement is reached on the detector point locations, number of measurements, supplementary data, etc.

A.8. ANTICIPATED RESULTS

With difficulty, some anticipated results could be supplied for inclusion on the data sheets. It may be more practical to categorize the expected dose rates into three or four ranges, like 1-10 mrem/hr, 10-50, etc.

REFERENCES

A-1. "Fort St. Vrain Nuclear Generating Station Start-up Test B-12, Shielding Surveys," General Atomic Company unpublished data, November 15, 1973.

A-2. Finch, W. C., "Final Design Report for Shielding of the Fort St. Vrain Auxiliary Transfer Cask," General Atomic Company unpublished data.

A-3. Engholm, B. A., "Comparison of Measurements with Calculations for FSV Auxiliary Transfer Cask," General Atomic Company unpublished data, August 30, 1978.

A-4. Finch, W. C., "Final Shielding Design Report for the Fort St. Vrain Fuel Handling Machine," General Atomic Company unpublished data, October 16, 1970.

A-5. Buckley, D. W., "Gamma Scattering Dose Rates from Fuel Handling Machine Tower," General Atomic Company unpublished data, November 13, 1972.

A-6. Sund, R. E., "Shielding Analysis for Tower of Fuel Handling Machine," General Atomic Company unpublished data, July 18, 1974.

A-7. Engholm, B. A., "Dose Rates from Spent Fuel Block Passing Through Nozzle," General Atomic Company unpublished data, August 6, 1970.

A-8. Engholm, B. A., "Transient Dose Rates During CRD Removal," General Atomic Company unpublished data, February 6, 1970.

APPENDIX B

SAMPLE DATA SHEETS

FSV REFUELING SHIELDING SURVEY

LOG SHEET NO.__________ DATE________________

MEASUREMENTS TAKEN BY____________________________

DATA TAKEN BY____________________________

TYPE OF SURVEY____

TIME SURVEY STARTED_________________ ENDED___________________

INSTRUMENT(S) USED FOR SURVEY:

MODEL NO.	SERIAL NO.	TYPE OF DETECTOR	RANGE

CONTENTS OF:

FUEL HANDLING MACHINE

INITIAL *,**

1.____

2.____

3.____

4.____

5.____

6.____

FINAL *,**

1.____

2.____

3.____

4.____

5.____

6.____

* South column, then counter clockwise ** Bottom block first

AUXILIARY TRANSFER CASK

INITIAL____

FINAL ____

FUEL STORAGE WELLS

**

INITIAL 1.____

2.____

3.____

4.____

5.____

6.____

7.____

8.____

9.____

FINAL 1.____

2.____

3.____

4.____

5.____

6.____

7.____

8.____

9.____

EQUIPMENT STORAGE WELLS

INITIAL 1.______________________________

2.______________________________

3.______________________________

4.______________________________

5.______________________________

6.______________________________

7.______________________________

8.______________________________

9.______________________________

10.______________________________

FINAL 1.______________________________

2.______________________________

3.______________________________

4.______________________________

5.______________________________

6.______________________________

7.______________________________

8.______________________________

9.______________________________

10.______________________________

FUEL HANDLING MACHINE SURVEY
STEADY-STATE MEASUREMENTS
MACHINE ON FLOOR

LOG SHEET NO. ____________ DATE ____________

SURVEY MADE BY ______________________

DETECTOR POINT NO.	LOCATION	TIME	GAMMA R/hr	
			MEASURED	ANTICIPATED
F1	Side, just below lead shielding			
F2	Side, 3-1/2 ft above F1			
F3	Side, 7 ft above F1			
F4	Side, 3-1/2 ft below F5			
F5	Side, just below first flange			
F6	Side, just above first flange			
F7	Side, just above second flange			
F8	Side, 3 ft above F7			
F9	Side, 6 ft above F7			
F10	Side, 9 ft above F7			
F11	Side, 12 ft above F7			
F12	Side, 15 ft above F7			
F13	Top platform on centerline			
F14	Top platform, 1-1/2 ft from CL			
F15	Side near base, at lead shield identation			
F16	Side near base, opposite steel strut @ W by NW			
F17	Side near base, opposite steel strut @ S by SE			
F18	Cover of light fixture port			
F19	Side of extension of viewing device port			
F20	Cover of viewing device port			
F21	Cover of unnamed port N by NE			
F22	Cover of unnamed port N by NW			
F23	Side of extension of unnamed port N by NW			
F26	3 ft from side, 4 ft above floor			
F27	6 ft from side, 4 ft above floor			
F28	9 ft from side, 4 ft above floor			
F29	12 ft from side, 4 ft above floor			
F30	15 ft from side, 4 ft above floor			

FUEL HANDLING MACHINE SURVEY

STEADY STATE

MACHINE HOISTED

LOG SHEET NO. ______________ DATE ________________

SURVEY MADE BY ________________________________

DETECTOR POINT NO.	LOCATION	TIME	GAMMA MR/hr	
			MEASURED	ANTICIPATED
F24	On bottom surface of machine, just beyond lead shutter (∿15 in. from centerline).			
F25	On bottom surface of machine ∿1 ft beyond F24.			

FUEL HANDLING MACHINE SURVEY

TRANSIENT MEASUREMENTS

LOG SHEET NO. ________________ DATE __________________

SURVEY MADE BY ____________________________________

DETECTOR POINT NO.	TIME	FUEL BLOCK NO. AND POSITION OF GRAPPLER HEAD	GAMMA MR/hr	
			MEASURED	ANTICIPATED
F4				
F5				
F6				
F7				
F8				
F9				
F10				
F11				
F12				
F13				
F14				

AUXILIARY TRANSFER CASK SURVEY

MACHINE ON FLOOR

LOG SHEET NO. ______________ DATE ______________

SURVEY MADE BY ______________________________

DETECTOR POINT NO.	LOCATION	TIME	GAMMA MR/hr	
			MEASURED	ANTICIPATED
A1	Side, just above pedestal			
A2	Side, ∿3 ft above pedestal			
A3	Side, just below start of first taper			
A4	Side, just above start of first taper			
A5	Side, ∿3 ft above A4			
A6	Side, just below start of second taper			
A7	Side, ∿28 in. above A6			
A8	Side, just above end of second taper			
A9	Side, ∿28 in. above A8			
A10	Side, just below platform structure			
A11	3 ft from side, 4 ft above floor			
A12	6 ft from side, 4 ft above floor			
A13	9 ft from side, 4 ft above floor			
A14	12 ft from side, 4 ft above floor			

AUXILIARY TRANSFER CASK SURVEY

MACHINE HOISTED

LOG SHEET NO. ______________ DATE ______________

SURVEY MADE BY ______________________________

DETECTOR POINT NO.	LOCATION	TIME	GAMMA MR/hr	
			MEASURED	ANTICIPATED
A15	Bottom, on centerline			
A16	Bottom, 1 ft from centerline			
A17	Bottom, 2 ft from centerline			

REFUELING FLOOR SURVEY

FUEL BLOCKS

LOG SHEET NO. ____________________ DATE ____________________

SURVEY MADE BY ____

DETECTOR POINT NO.	TIME	FUEL BLOCK NO. AND POSITION	GAMMA MR/hr	
			MEASURED	ANTICIPATED
R1				
R2				
R3				
R4				
R5				
R14				
R15				
R16				

REFUELING FLOOR SURVEY

CONTROL RODS

LOG SHEET NO. ____________ DATE ____________

SURVEY MADE BY ______________________

DETECTOR POINT NO.	TIME	CRD NO. AND POSITION OF SHOCK ABSORBER	GAMMA MR/hr	
			MEASURED	ANTICIPATED
R1				
R2				
R3				
R4				
R5				

STORAGE FACILITY MEASUREMENTS

STEADY STATE

LOG SHEET NO. ________________ DATE ________________

SURVEY MADE BY ________________________________

DETECTOR POINT NO.	LOCATION	TIME	GAMMA MR/hr	
			MEASURED	ANTICIPATED
S7	Directly above shield plug on loaded fuel storage well.			
S8	Above edge of same shield plug.			
S9	About 1 ft out from S8			
S16	Directly above shield plug on loaded CRD storage well.			
S17	Above edge of same shield plug			
S18	About 1 ft out from S17			
B2a	El 4864', north side of fuel storage facility, opposite loaded well.			
B2b	El 4864', east side of fuel storage facility, opposite loaded well.			

STORAGE FACILITY MEASUREMENTS

TRANSIENT

LOG SHEET NO. ____________ DATE ____________

SURVEY MADE BY ______________________________

DETECTOR POINT NO.	LOCATION	FUEL BLOCK NO. AND POSITION	TIME	GAMMA MR/hr	
				MEASURED	ANTICIPATED
S1	Fuel Storage facility floor, just north of FHM				
S2	About 1 ft out from S1				
S3	About 2 ft out from S1				
S4	About 3 ft out from S1				
S5	Fuel storage facility floor just NNE of FHM				
S6	Fuel storage facility floor just NE of FHM				

Page ______ of ______

LOG SHEET NO. ____________________ DATE ____________________

SURVEY MADE BY ____

DETECTOR POINT NO.	LOCATION	CRD NO. AND POSITION	TIME	GAMMA MR/hr	
				MEASURED	ANTICIPATED
S10	On CRD storage facility floor				
S11					
S12					
S13					
S14					
S15					