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^{16}N RADIATION MEASUREMENTS AT THE DUANE ARNOLD ENERGY CENTER APRIL 1975

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ABSTRACT

A ^{16}N radiation survey was performed at the Duane Arnold Energy Center during April 1975. In cooperation with ERDA/HASL personnel, environmental ^{16}N radiation measurements were made at various distances from the turbine building. A semi empirical equation correlating the exposure rate versus distance measurements is proposed for calculating boundary dosages. Extensive radiation surveys of the main steamlines, the steam system components, and the interior and exterior of the turbine building were performed. Correlations were established between the reactor power, the steamline radiation monitor reading, and the environmental exposure rate. Intercomparison radiation measurements of various survey instruments were made and the use of a commercially supplied TLD/Film badge set was evaluated for ^{16}N radiation surveys.

INTRODUCTION

In the BWR, the turbine building shielding requirements are dictated by the 6.13 MeV gamma radiation associated with the 7.35s steam-borne ^{16}N. Due to the recent EPA proposal to limit annual whole body exposure to 25 mrem/year to any neighbor of a fuel cycle facility and due to design changes in turbine deck components, an increasing need has developed for more accurate ^{16}N source term and environmental measurements. Such data is essential to the verification of shielding design codes and to the ultimate improvement of the shielding design and the turbine building layout.

^{16}N radiation measurements were performed at the Duane Arnold Energy Center during April 1975. The measurement program was undertaken at the request of GE Power Plant Design and was performed by the Reactor Chemistry Unit in cooperation with ERDA/HASL. The ERDA/HASL's principal contribution was to the environmental ^{16}N measurements although numerous comparative measurements were performed by both groups at selected environmental locations and on the main steam system.

Radiation measurements were taken on the main steamlines, the steam system components, and the interior and exterior of the turbine building.

Correlations were established between the reactor power, the steamline radiation monitor reading, and the environmental exposure rate.

In a continuing effort to resolve some of the discrepancies in survey instrument response when they are used in a direct or shielding degraded ^{16}N field, comparison measurements were performed using the CP, PIC-6, Teletector, LiF TLD's, and Eastman Type 2 Personnel Film. All of the instruments or detectors were calibrated against a common ^{60}Co source.

SUMMARY

This report tabulates and discusses the results of a ^{16}N radiation survey performed at the Duane Arnold Energy Center during April 1975. The Duane Arnold Energy Center is representative of the design of the BWR's presently coming on line, although its maximum power, 1590 MW_t, is less than generally encountered. The unit incorporates the recent steam system design utilizing combined moisture separator reheaters located on the turbine deck. The Duane Arnold facility was load following at the time of the measurement program and the reactor power varied between 500 MW_t and 1100 MW_t. The off-gas level is extremely low, less than 200 μCi/sec at the stack, and did not interfere with the environmental ^{16}N radiation measurements. The measurement program included the following series of measurements and results:

1. In a cooperative program of obtaining environmental dose rates, ERDA/HASL personnel made radiation measurements external to and at various distances from the turbine building, utilizing high pressure ion chambers (P.I.C.), and NaI and Ge(Li) spectrometers. Measurements were made along traverses north, south, east, and west of the turbine building. The north-south traverses were on a line as close to the turbine-generator centerline axis as experimentally practical. The east traverse was quite extensive and was made along an axis perpendicular to the turbine-generator centerline axis and intersecting the center of the moisture separator-reheater (M.S./R. 1E-18A). The agreement between GE and HASL/ERDA P.I.C. measurements was excellent (± 10%) and the HASL/ERDA data were combined with the GE data to provide a unified picture of the external radiation field about the Duane Arnold facility. Background radiation level measurements were performed at numerous positions about the site during a reactor outage on April 20, 1975.

Within the experimental uncertainty of the P.I.C. data, the environmental radiation field, E_x, due to ^{16}N was found to be adequately represented by a simplified expression of the form

$$E_x = \frac{E_o B(\mu x) e^{-\mu x}}{x^2}$$

where E_o is the source term, x the distance from the measurement point to the source, μ the total attenuation coefficient, and B(μx) the buildup factor in air.

2. Long-term P.I.C. measurements were made east of and exterior to the turbine building to determine the environmental radiation level due to ^{16}N as a function of reactor power. The external radiation level, relative to a value of 1.0 at 1000 MW_t is given by the expression

$$\text{External Radiation Level} = (1.39 \times 10^{-6} P - 3.91 \times 10^{-4}) P$$

over the range 505 $MW_t \leqslant P \leqslant 1093\ MW_t$. From this expression the full power (1593 MW_t) external exposure rates east and south of the turbine building are estimated to be 2.9 times the value reported at 1000 MW_t. Similar experimental measurements were made by HASL/ERDA north of the turbine building. Their full power extrapolated value is 2.3 times the 1000 MW_t values. The difference between the full power extrapolated factor is related to the source shielding configuration as a portion of the cross-over steam piping projects above the shield walls at the north end of the turbine deck. Of 25 mrem/year, at full power operation, the EPA proposed annual dose occurs at 810 meters north of the turbine building and 625 meters to the east of the turbine building (i.e., dose rate equal to 2.85 μR/hr).

3. An extensive steamline radiation survey was performed using eight different exposure measuring devices. Steamline contact radiation levels were measured using the CP, PIC-6, Teletector, and JUNO instruments. Radiation field measurements were also taken at selected positions below the steamlines using LiF and CaF_2 TLD's, Film and pocket ion chambers in addition to the above-mentioned instruments. Based upon the CP instrument, a contact (0.33m from the centerline of the pipe) radiation level of 1.27 R/hr at a reactor power of 975 MW_t was measured. The noted variability in TLD/Film and instrument response is attributed to the different energy response functions for each and the inability to achieve charge particle equilibrium (CPE) for any of the detection systems in this high energy radiation field.

The power dependence of the steamline radiation level as a function of reactor recirculation flow was obtained from a review of the steamline radiation monitor stripchart recorder and the control room periodic log. The steamline radiation level, relative to a value of 1.0 at 1000 MW_t is given by the expression

$$\text{Relative Steamline Radiation Monitor Response} = -0.516 + 1.712 \times 10^{-3}P - 1.958 \times 10^{-7}P^2$$

over the measured range of 500 $MW_t \leq P \leq 1593$ MW_t. During this study the power changes were made solely by changing recirculation flow.

4. An extensive survey was performed on the turbine deck components, on the turbine building interior shield walls, and on the turbine building roof. The moisture separator-reheater, the high pressure turbine, and the cross-over steamlines were the major radiation sources on the turbine deck. At a reactor power of $\sim$980 MW_t, centerline contact readings taken with the CP on the M.S./R. averaged 190 mR/hr,

the high pressure turbine hood contact readings averaged 185 mR/hr, and the contact readings on the cross-over steamlines were approximately 150 mR/hr. Contact readings on the low pressure turbine hoods were between 30-40 mR/hr.

Surveys of the low pressure stop and intermediate valves were also made along with measurements of other turbine deck components such as the low pressure feedwater heaters and the moisture separator drain tanks.

A TLD-Film-CP comparison survey of the turbine deck components was performed. The TLD/Film combination readings agreed quite well with the CP instrument although in a shielding degraded field the CP read lower. It was concluded that the TLD's and Film are useful adjuncts in dosimetry measurements especially in high radiation fields where it is desirable to limit personnel exposure and in positions that are difficult to measure with a survey instrument. The principal difficulty in the use of a commercial service to supply and read the TLD's is that exposures in excess of 100 mR are required to achieve a reasonable level of precision. LiF TLD's have nearly a linear uniform response over the energy region of interest and further developmental work in the area of dosimetry measurements in a mixed radiation field is justified.

A survey was made of the east side of the inner shield wall that is located next to the M.S./R. 1E-18A along with the interior of the east exterior shield wall. The data indicate that the shield walls are effective in reducing the radiation exposure in the eastwardly direction.

5. An extensive survey was performed of the turbine building roof using the CP, PIC-6, and Teletector along with a partial Teletector survey of the east turbine building wall. There is no overhead shielding of the turbine deck components with

the exception of the roof structure. The highest radiation field on the roof (17-19 mR/hr at 1100 MW_t) is located along the turbine generator centerline axis at a position just south of the center of the M.S./R. 1E-18B in an area where the cross-over steamlines may contribute significantly.

DISCUSSION

A. External Pressurized Ion Chamber† (P.I.C.) Measurements

In cooperation with ERDA/HASL personnel comparative radiation measurements were made external to and at various distances from the turbine building. The Duane Arnold Energy Center is a 1593 MW_t GE BWR with a GE turbine generator set. The plant was load following during the time of the measurement program. The steam system incorporates a combination moisture separator-reheater located on the turbine deck. The turbine deck components have side wall shielding but no overhead shielding.‡

During the study measurements were taken at variable power levels. On the last day of the study at Duane Arnold the reactor was shut down and numerous environmental background measurements were performed. A summary of the GE P.I.C. measurements taken at Duane Arnold is presented in Table 1, and the measurement points are located on the site drawing, Figure 1.

Where the radiation levels were high, the precision and accuracy of the measurement are considered excellent. Far from the turbine building where the radiation level approaches natural background the uncertainty in the net, ^{16}N level is large. One method of approaching the problem of reliably determining the radiation levels at large distances is to obtain measurements closer to the source where the exposure rates are larger and to empirically fit the net data relating ^{16}N radiation with distance to a theoretically plausible mathematical expression and to extrapolate to the boundary distances. Unfortunately, the complexity of the calculation of the direct and skyshine radiation field is immense when one considers the multitude of sources on the turbine deck, the complexity of the shielding geometry, and the general site tropology. It cannot be expected

† Reuter Stokes, Cleveland, Ohio, Model RS-111, S/N P-3257
‡ See Bechtel Drawings Nos. M-3, M-6, M-8 for Duane Arnold for information on turbine building shielding thicknesses and heights.

TABLE 1

P.I.C. Measurements

Duane Arnold Energy Center

Measurement Number	Location	Date-Time	Reactor Power (MW_t)	Total* Exposure μR/hr
14	127.7 m south of turbine bldg. south wall and 1.8 m west of turbine centerline.	4/17/75 1256	1115	11.5
15	191.4 m south of turbine bldg. south wall and 1.8 m west of turbine centerline.	4/17/75 1307	1079	7.8
16	14.9 m west of machine shop west wall and on line with machine shop - radwaste bldg. junction.	4/17/75 1330	1079	7.1
17	63.7 m west of machine shop west wall and on line with machine shop - radwaste bldg. junction.	4/17/75 1335	1079	7.0
18	148.1 m west of machine shop west wall and on line with machine shop - radwaste bldg. junction.	4/17/75 1345	1079	6.1
19	75.6 m east of turbine bldg. east wall and centered on M.S.&R. 1E-18A. See also #3. For background see #30.	4/17/75 1406	1091 ± 20	28.7
20	150.9 m east of turbine bldg. east wall and centered on M.S.&R. 1E-18A.	4/17/75 1413	1091 ± 20	12.9
21	191.7 m east of turbine bldg. east wall and centered on M.S.&R. 1E-18A.	4/17/75 1421	1091 ± 20	11.0
22	229.2 m east of turbine bldg. east wall and centered on M.S.&R. 1E-18A. Comparison point with HASL.	4/17/75 1431	1091 ± 20	9.4
23	329.5 m east of turbine bldg. east wall and centered on M.S.&R. 1E-18A.	4/17/75 1500	1091 ± 20	8.2
24	463.9 m east of turbine bldg. east wall and centered on M.S.&R. 1E-18A.	4/17/75 1508	1091 ± 20	7.5
25	Background‡ SE corner warehouse bldg. roof. Same position as #6.	4/20/75 1040	0	5.0
26	Background. Warehouse bldg. roof. Same position as #7.	4/20/75	0	5.0
27	Background. 26.1 m north of turbine bldg. north wall and 1.3 m west of turbine center-line. Same position as #11.	4/20/75 1140	0	5.7

TABLE 1

P.I.C. Measurements

Duane Arnold Energy Center

[illegible]	Location	Date-Time	Reactor Power (MW_t)	Total* Exposure μR/hr
	[illegible] m east of turbine bldg. east wall and 2.7 m north of turbine bldg. center. Comparison point with HASL. See #31 for background.	4/16/75 1600	1050	11.1
2	[illegible].0 m east of turbine bldg. east wall and 2.7 m north of turbine bldg. center.	4/16/75 1709	1050	18.8
3	[illegible]6.2 m east of turbine bldg. east wall and center on M.S.&R. 1E-18A. See #30 for background.	4/16/75 1737	1060	26.1
4	61.0 m east of turbine bldg. east wall and centered on M.S.&R. 1E-18A.	4/16/75 1747	1065	34.3
5	30.5 m east of turbine bldg. east wall and centered on M.S.&R. 1E-18A. See #29 for background.	4/16/75 1757	1069	54.6
6	SE corner, top of warehouse roof. 57.3 m north of turbine bldg. north wall and 15.2 m west of turbine bldg. centerline. See #25 for background.	4/16/75 1817	1070	56.3
7	On warehouse roof. 103.0 m north of turbine bldg. north wall and 15.2 m west of turbine bldg. centerline. See #26 for background.	4/16/75 1826	1070	36.8
8	On warehouse roof. 148.7 m north of turbine bldg. north wall and 15.2 m west of turbine bldg. centerline.	4/16/75 1840	1070	22.9
11	26.1 m north of turbine bldg. north wall and 1.3 m west of turbine centerline. See #27 for background. Comparison point with HASL.	4/17/75 1143	1190	48.7
12	31.5 m south of turbine bldg. south wall and 1.8 m west of turbine centerline.	4/17/75 1228	1113	22.9
13	78.0 m south of turbine bldg. south wall and 1.8 m west of turbine centerline	4/17/75 1246	1113	17.2

TABLE 1

P.I.C. Measurements

Duane Arnold Energy Center

Measurement Number	Location	Date-Time	Reactor Power (MW_t)	Total* Exposure μR/hr
28	Top of rock pile in front of pump house. Background for external radiation level vs. power study.	4/20/75	0	5.4
29	Background. 30.5 m east of turbine bldg. east wall and centerline to M.S.&R. 1E-18A. Same position as #5.	4/20/75 1209	0	5.9
30	Background. 75.6 m east of turbine bldg. east wall and centered on M.S.&R. 1E-18A. Same position as #19 and #3.	4/20/75 1222	0	6.1
31	Background. 166.7 m east of turbine bldg. east wall and 2.7 m north of turbine bldg. center. Same position as #1.	4/20/75 1235	0	7.3
32	Background. Same position as #31 except the P.I.C. was placed on the ground.	4/20/75 1240	0	7.6
33	Background. 141.7 m east of turbine bldg. east wall and centered on M.S.&R. 1E-18A. Comparison point with HASL.	4/20/75 1248	0	7.1

*It is possible that these measurements may be slightly in error due to an invalid method of setting the instrument zero level. From our subsequent experiements, we estimate our zero level uncertainty at ± 5 mV. With a calibration factor for our instrument of 347.6 μR/hr/volt this magnitude of zero level uncertainty would yield an additional uncertainty in the reported value of ± 1.7 μR/hr. The error is minor in the higher radiation fields but becomes significant at background levels.

†Background here is defined to be the sum contribution of all sources contributing to the environmental radiation level when the plant is shut down, a cosmic radiation, fallout deposition and natural occurring activities. Because of their measurement technique, HASL defines the background as the measured terrestrial radiation level and adds to it a cosmic contribution which is then subtracted from the gross radiation measurement to obtain the net N-16 contribution.

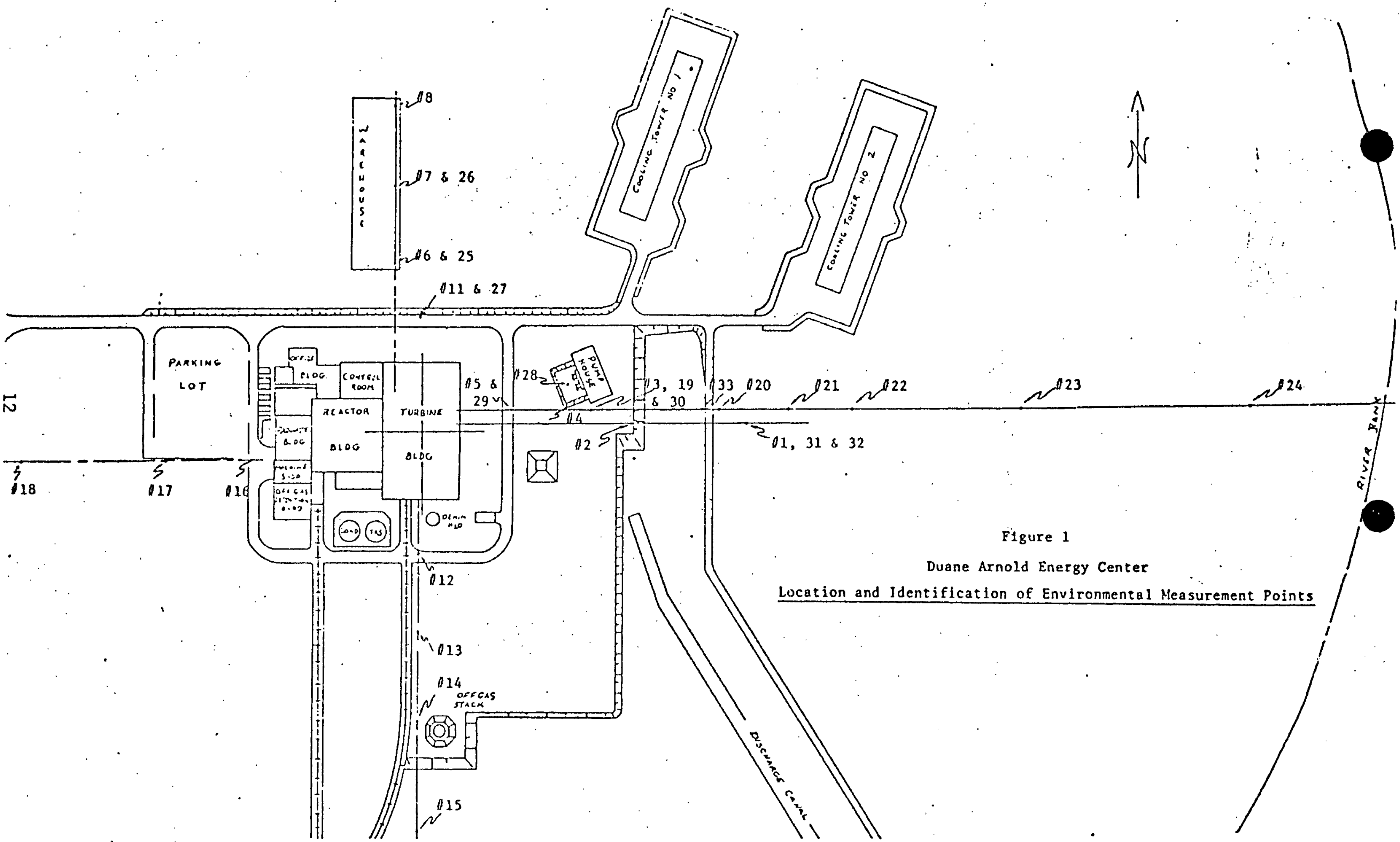

Figure 1

Duane Arnold Energy Center

Location and Identification of Environmental Measurement Points that the equation fitted to any given ^{16}N traverse will hold for another traverse in a different direction from the turbine building, and certainly it cannot be expected that the same equation can be used to predict the radiation levels from a different plant.

The currently proposed EPA radiation restriction (0.003 mR/hr) of a maximum annual dose equivalent of 25 mR/year for the entire fuel cycle and the significant costs associated with turbine deck component shielding, requires that the shielding design and the accuracy of the shielding design codes be optimized in order to minimize turbine building costs. It was the intent of this study to provide reliable and consistent estimates of the exterior site radiation levels of the turbine deck component radiation levels, and source-term data. Consequently, in the following discussion of the data, we have combined the GE and ERDA/HASL results into a cohesive picture of the external radiation levels at Duane Arnold.

Gamma rays transmitted through a scattering and absorbing media are attenuated both by inverse square law and by absorption and scattering phenomenon. The exposure rate, E_x, at a distance x from a point source embedded in an infinite homogeneous medium can be represented by the equation

$$E_x = \frac{E_o B_\infty(\mu x) e^{-\mu x}}{x^2} \qquad (1)$$

where E_o is the source strength in terms of exposure rate in vacuum at unit distance, the exponential term represents attenuation of the direct radiation (μ is the total attenuation coefficient) and B_∞ (μx) is a buildup term representing the extra photons scattered into the detector by the absorbing and scattering medium.

The point source buildup factor can be adequately represented by the expression

$$B_\infty(\mu x) = 1 + k(\mu x) \quad \text{for } \mu x \leq 1.$$

For ^{16}N radiation in air $\mu = 3.25 \times 10^{-3}\ m^{-1}$ and $k = 0.46$.[1]

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1. Jaeger, R. G. (Ed.), Engineering Compendium on Radiation Shielding, Vol. 1, Springer-Verlag, New York, 1968.

The first step in the evaluation of the data was to normalize all our measurements to a power level of 1000 MW_t. This was done for two reasons: 1) The Duane Arnold reactor was load following and the measurements were made at various power levels around 1000 MW_t, and 2) The ERDA/HASL data are all normalized to 1000 MW_t and thus the intercomparison between the two groups of measurements can be made directly. To do the normalization, use was made of the data obtained during the long-term P.I.C. measurements made on the rock pile in front of the pump house, where the environmental radiation level was monitored as a function of reactor power. These data are presented in Table 2 and Figure 2. The following empirical expression obtained by nonlinear regression was found to adequately represent the data.

$$\text{Net } (\mu R/hr) = \frac{(2.81 \times 10^{-2}\ P - 7.9)P}{1000}$$

where P is the reactor power in MW_t. From this expression the full power (1593 MW_t) external dose rates east of the turbine building are estimated to be 2.9 times the values reported at 1000 MW_t.

Measurements taken by ERDA/HASL (Appendix A) were normalized to 1000 MW_t by use of external P.I.C. data obtained in a warehouse

TABLE 2

External Radiation Levels vs. Reactor Power[a]
P.I.C. Measurements
Duane Arnold Energy Center

Date	Time	MW_t	P.I.C.[b] Reading (Volts)	Gross μR/h	Net[c] μR/h
4/17/75	1900-2000	1061	0.0810	28.2	22.8
4/18/75	0300-0400	537	0.0274	9.5	4.1
	0500-0600	645	0.0333	11.6	6.2
	0800-0900	1093	0.0853	29.7	24.3
	0900-1000	1041	0.0795	27.6	22.2
	1100-1200	985	0.0720	25.0	19.6
	2000-2100	994	0.0776	27.0	21.6
4/19/75	0200-0300	506.0	0.0251	8.7	3.3
	0300-0400	505.0	0.0245	8.5	3.1
	1000-1100	855.0	0.0530	18.4	13.0

a Measurements were made on top of the rock pile directly in front of the pumphouse at a distance of 68.6 m from the east wall of the Turbine Building.

b The P.I.C. calibration factor, based upon ^{60}Co radiation, is 347.6 μR/h/volt.

c A background radiation level of 5.4 μR/h was measured on April 20, 1975 during a reactor outage.

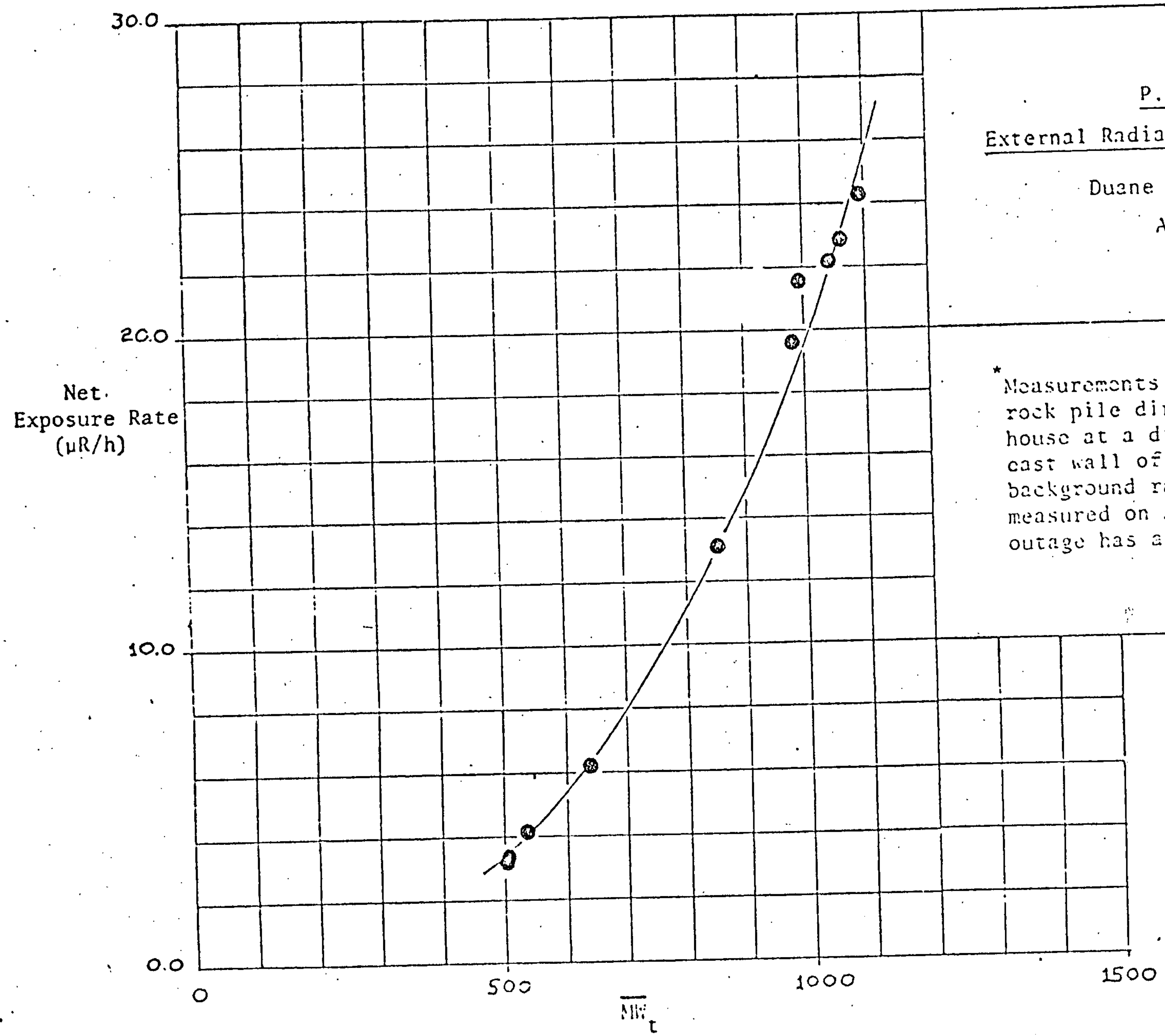

Figure 2

P.I.C. Measurements

External Radiation Levels vs. Reactor Power*

Duane Arnold Energy Center

April 17-19, 1975

*Measurements were made on top of the rock pile directly in front of the pump house at a distance of 68.6 m from the east wall of the turbine building. A background radiation level of 5.4 μR/hr measured on April 20, 1975 during an outage has already been subtracted.

north-west of the north face of the turbine building. Their extrapolation to full power is 2.3 times the 1000 MW_t value. The difference between the two full power extrapolation factors is readily rationalized. The shield walls at the north end of the turbine building are not sufficiently high to completely shield the ERDA/HASL P.I.C. from the direct ^{16}N radiation present in the cross-over piping from the moisture separator to the low pressure turbine. The external exposure rate power dependence curve generated from the ERDA/HASL data likely represents an exposure rate due to a mixture of direct and scattered radiation while the GE P.I.C. measurements made on the east side of the turbine building contain primarily scattered radiation. The direct radiation is expected to follow an exposure rate versus power dependence similar to that observed for the steamline radiation monitor (see Table 3 and Figure 3). The steamline radiation monitor reading versus power data can be represented by the following empirical expression

$$\text{Steamline Radiation Monitor Reading} = -34.8 + 0.1154P - 1.32 \times 10^{-5}P^2$$

$$\text{for } 500\ MW_t \leq P \leq 1593\ MW_t.$$

The full power extrapolation factor for the steamline radiation monitor from 1000 MW_t is 1.7. The ERDA/HASL full power extrapolation factor, as expected, is in between the two possible extremes (e.g., 1.7 and 2.9).

In the application of Eqn. 1 to the P.I.C. measurements two parameters in the expression need to be evaluated, E_o and x. In the experimental study, the distance measured was the distance from the detector to the outer surface of the turbine building wall, not the source to detector distance required by the expression.

TABLE 3

Steamline Radiation Monitor Readings vs. Reactor Power[a]

Duane Arnold Energy Center

Date	Time	Reactor Power (MW_t)	Steamline Radiation Monitor Reading
4/ 3/75	1300-1400	1589	116.6
4/16/75	0200-0300	774	47.1
	0900-1000	1483	105.7
	1300-1400	1124	78.9
	1800-1900	1069	72.4
4/17/75	0300-0400	584	27.5
	1300-1400	1079	74.5
	1600-1700	1068	73.6
	1900-2000	1061	71.5
4/18/75	0300-0400	537	23.5
	1300-1400	980	65.8
	1500-1600	975	64.9
	2000-2100	994	67.7
4/19/75	0300-0400	505	19.8
	1000-1100	855	54.9
	1400-1500	844	53.4

a. Data were obtained from reactor hourly operating log and the steamline radiation monitor traces. The time periods chosen in this survey were ones for which the reactor power remained relatively constant over the time period of one hour before to one hour after the reported reading.

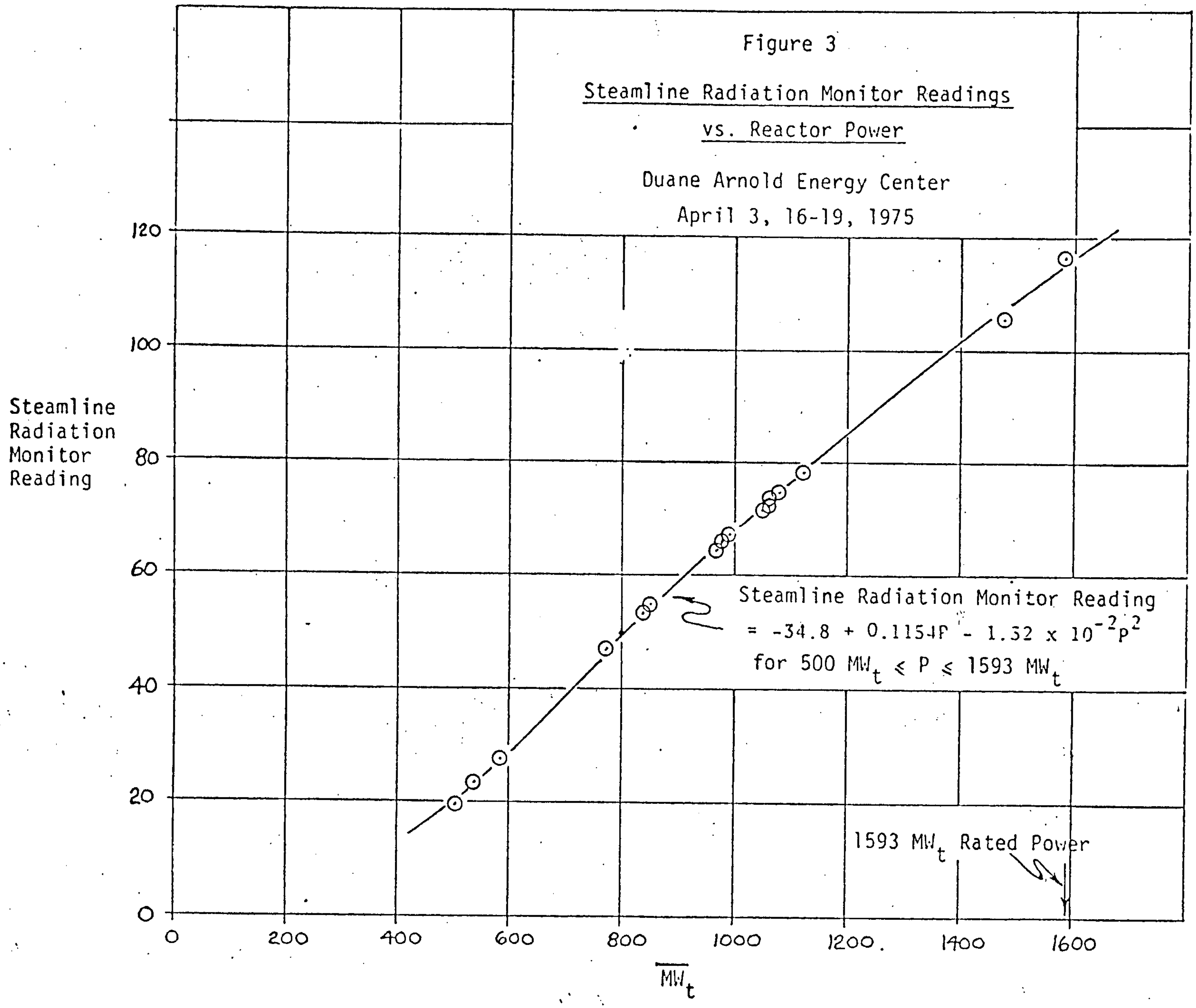

Figure 3

Steamline Radiation Monitor Readings vs. Reactor Power

Duane Arnold Energy Center
April 3, 16-19, 1975

Numerous sources exist on the turbine deck at Duane Arnold, the largest being the two moisture separators-rehcaters. In the analysis of the data taken on the east side of the turbine building (see Table 4), the turbine-generator centerline (located 20.0m inside the outer eastern wall surface) was chosen as the source reference position.

To evaluated E_o (east side) two points (measurements at 76.2m and 150.9m), where the error in the measured dose rates are considered relatively small, were chosen. An average value of E_o of 1.69×10^6 mR m^2/year was calculated. Using this value of E_o, Eqn. 1 was evaluated at the other experimental observation points. The results of these calculations are presented below in Table 5, and are presented graphically along with the experimental values in Figure 4.

TABLE 5

Calculated ^{16}N Exposure Rates at 1000 MW_t vs. Distance from Turbine Building East Wall

Distance from Turbine Bldg. East Wall (m)	x (m)	E_x (mR/y)	Measured (mR/y)	Percent Difference
61.0	81.0	221.9	218.2	-1.7
76.2	96.2	152.8	155.0	1.4
150.9	170.9	41.7	41.0	-1.7
191.7	211.7	24.9	27.3	9.6
229.2	249.2	16.6	16.1	-3.0
329.5	349.5	6.8	7.7	13.2
463.9	483.9	2.6	2.8	7.7

The agreement between the predictions of Eqn. 1 and the measured values is excellent. The full power estimate is 2.9 times the 1000 MW_t values and is represented by the dashed curve. As a point of comparison, the ERDA/HASL values are also

TABLE 4

Dose Rate vs. Distance from Turbine Building East Wall

Survey Number	Measured[a] μR/hr	Background[a] μR/hr	Net μR/hr	MW_t	Net[b] mR/Yr @1000 MW_t	Estimated[c] mR/Yr @1593 MW_t	Distance[d] Meters
5	54.6	5.9	48.7	1069	367.8	1070.2	30.5
4	34.3	5.9	28.4	1065	218.2	635.1	61.0
3	26.1	6.1	20.0	1060	155.0	451.2	76.2
20	12.9	7.1	5.8	1090	41.0	119.2	150.9
21	11.0	7.1	3.9	1090	27.3	79.3	191.7
22	9.4	7.1	2.3	1090	16.1	46.8	229.2
23	8.2	7.1	1.1	1090	7.7	22.4	329.5
24	7.5	7.1	0.4	1090	2.8	8.1	463.9

a. It is probable that these measurements may be slightly in error due to an invalid method of setting the instrument zero level. From our subsequent experiments, we estimate our zero level uncertainty at ± 5 mV. With a calibration factor for our instrument of 347.6 μR/hr/volt this magnitude of zero level uncertainty would yield an additional uncertainty in the reported value of ± 1.7 μR/hr. The error is minor in the higher radiation fields but becomes significant at background levels.

b. Normalization to 1000 MW_t was made by using the external radiation levels versus reactor power data obtained with the P.I.C.

c. From curve fitting the external radiation level versus reactor power data and extrapolating the curve to full power (1593 MW_t) it is estimated that the full power values are 2.9 times the 1000 MW_t values.

d. Distances are referenced to the outer surface of the turbine building east wall.

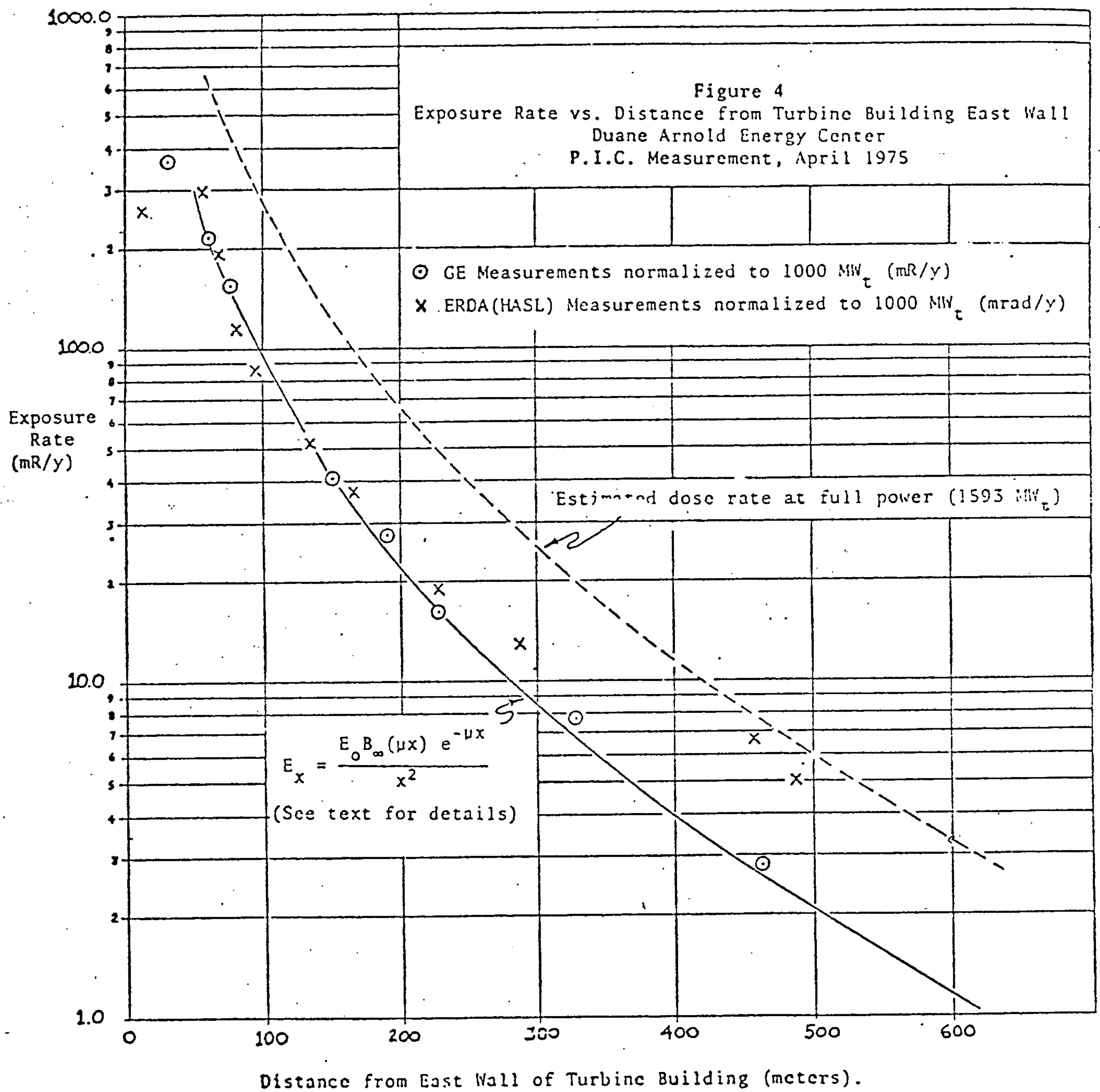

Figure 4
Exposure Rate vs. Distance from Turbine Building East Wall
Duane Arnold Energy Center
P.I.C. Measurement, April 1975

plotted. One can see that the agreement between the ERDA/HASL and GE P.I.C.'s is excellent in the regions of higher dose rate. At the lower dose rates the differences are larger but not significant. The difference between the GE and ERDA/HASL results at 465 meters is about 3.2 mR/year or 0.37 μR/hr and well within experimental uncertainties. As mentioned in the footnote in Table 1, due to zero level uncertainties there is a possibility that our measurements are in error in the low dose rate region. Eqn. 1 is well founded, fundamentally. It is useful for a point source and a point detector in a homogeneous medium, it does not account for skyshine from a partially shielded source, or sources, as is the case on the Duane Arnold turbine deck, although an equation of this form has been used for neutron skyshine calculations at accelerators.[2,3]

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2. Distenfeld, C. H. and R. D. Colvett, Nucl. Sci. Engrg., 26, 117 (1966).
3. Jenkins, T. M., Health Physics, 27, 251 (1974).

Some estimation of the contribution of skyshine to the measured radiation field at large distances from the turbine building can be assessed from the measurements taken along the west traverse where the turbine deck components are well shielded by the reactor building. The measured radiation field along this traverse is due to skyshine, radwaste, and natural background. The estimated net field at 236m west of the turbine-generator centerline is a negligible 0.7 mR/yr. If this field is attributed completely to skyshine, it is evident that the skyshine contribution to the observed exposure rate in the east direction is also negligible and Eqn. 1 can justifiably be used to represent the observed data.

The two observations, one by ERDA/HASL at 11m and the other by GE at 30.5m, are significantly lower than the extrapolation of the curve would predict. This reduction in the radiation fields at these points is a result of partial or complete shielding of the moisture separators from the detector by the concrete operating floor. The P.I.C. measurements, although performed above grade level, were made at an elevation approximately 7 meters below the operating floor elevation. Similar analysis of the data taken along the north and south traverse show that measurement position at distances less than 60 meters from either wall surface are in the shadow of the concrete operating floor and are as a result lower than predicted.

In the interpretation of the data along the north (Figure 5) and south (Figure 6) traverses, the GE and ERDA/HASL results were consolidated. The net radiation field measured along the north traverse results primarily from the four cross-over steam lines. The average distance from the center of these cross-over steamlines to the exterior of the north wall is 33.6 meters. Using this distance and the data from the two GE points at 103.0m and 148.7m, an effective source strength of 6.0×10^6 mR m^2/year was calculated. See Figure 5 for a representation of Eqn. 1 predictions and the GE and ERDA/HASL data. The fit of the outlying ERDA/HASL data points to Eqn. 1 is reasonable.

The three close-in measurements are considerably lower than predictions due to additional shielding of the HASL P.I.C. by the turbine building operating floor. The gross difference between the GE measurement at 57.3m and the HASL measurement at 46m results because the HASL measurement was made at ground level where the cross-over steamlines are completely shielded whereas the GE measurement was made on the warehouse roof at an elevation where the steamlines are only partially shielded.

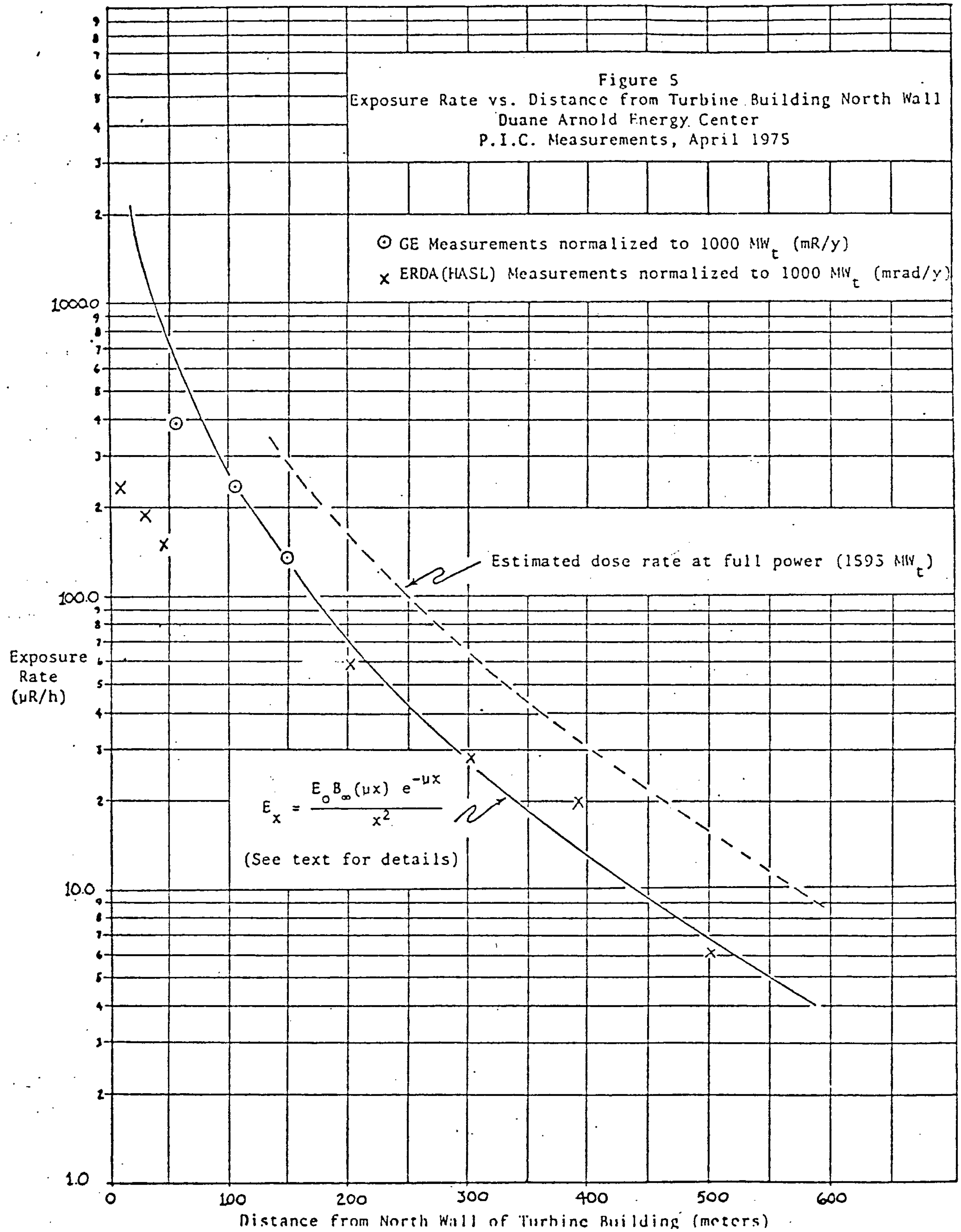

Figure 5
Exposure Rate vs. Distance from Turbine Building North Wall
Duane Arnold Energy Center
P.I.C. Measurements, April 1975
⊙ GE Measurements normalized to 1000 MWt (mR/y)
x ERDA(HASL) Measurements normalized to 1000 MWt (mrad/y)
Estimated dose rate at full power (1593 MWt)
$E_x = \frac{E_o B_\infty(\mu x)\ e^{-\mu x}}{x^2}$
(See text for details)
Exposure Rate (μR/h)
1000.0
100.0
10.0
1.0
0
100
200
300
400
500
600
Distance from North Wall of Turbine Building (meters)

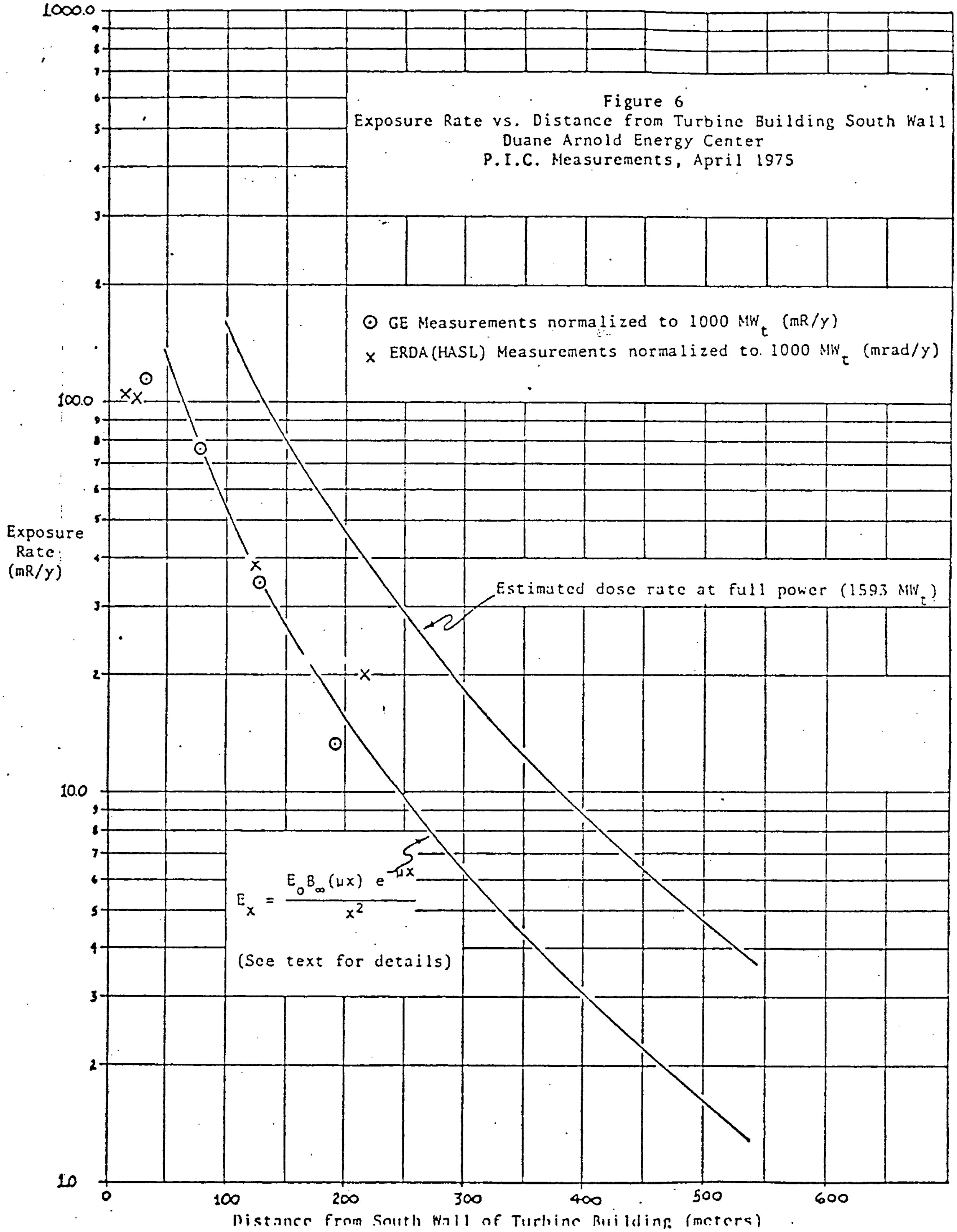

Figure 6
Exposure Rate vs. Distance from Turbine Building South Wall
Duane Arnold Energy Center
P.I.C. Measurements, April 1975
GE Measurements normalized to 1000 MWt (mR/y)
ERDA(HASL) Measurements normalized to 1000 MWt (mrad/y)
Estimated dose rate at full power (1593 MWt)
Ex = Eo B∞(μx) e^-μx / x^2
(See text for details)
Exposure Rate (mR/y)
1000.0
100.0
10.0
1.0
0
100
200
300
400
500
600
Distance from South Wall of Turbine Building (meters)

In estimating the dose in the north direction at full power, the ERDA/HASL power extrapolation value of 2.34 was used. Note that projected full power exposure rate at 500 meters is considerably higher than projected at the same distance on the east traverse.

In the southern direction, the shield walls are higher than the cross-over steamlines except for a small section in the center along the turbine-generator centerline axis and consequently the radiation fields at the same distance are considerably lower than along the northern traverse. In the calculation of the curve presented in Figure 6, a source position 49m (average centerline distance of the moisture separators from the south wall exterior) from the exterior of the south wall was used. Considering the GE measurement positions at 78.0m and 127.7m, a source strength of $1.6 \times 10^6 \frac{mR}{yr} \times m^2$ was calculated. This source strength is nearly identical to that calculated for the east traverse. Again, it is seen that the observed field measurements fit the equation satisfactorily. Since the shielding conditions are similar to those along the east traverse, a full power extrapolation value of 2.91 was used to estimate full power exposure rates.

In summary, the following observations can be made from the external P.I.C. measurements:

1. The agreement between the GE and ERDA/HASL P.I.C. measurements is excellent (within $\pm$ 10%) except in the low exposure rate region where the uncertainty is large for both groups although likely larger for the GE measurements for reasons previously discussed.

2. Excellent representation of the high exposure rate data is possible with Eqn. 1 and the extrapolation to distances where exposure rates are low and difficult to measure appears adequate and within the uncertainty of the measured values.

3. The external exposure rate versus power curve is dependent upon the source shielding configuration. This conclusion is evidenced by the difference in the 1000 MW_t to full power extrapolation factor of 2.3 (ERDA/HASL) for the north direction and 2.9 (GE) for the east direction. In the north traverse a considerable portion of the radiation field is a result of the partially unshielded cross-over steamlines.

B. Steamline Radiation Survey

Shielding design calculations for ^{16}N radiation emanating from turbine deck components require accurate source-term data. One must not only know the source-term but also the power dependence of this source-term. The steamline radiation level is due almost exclusively to ^{16}N and the power dependence of the source term may be obtained from the steamline radiation monitor readings extractable from the steamline radiation monitor stripchart recorder and the control room periodic log. Such data has been obtained at Duane Arnold during the course of this study and is presented in Table 3 and Figure 3.

The absolute source-term in terms of μCi/gram of steam is considerably more difficult to ascertain due to the short half-life of ^{16}N, the near impossibility of obtaining a representative steamline sample, and the inability to obtain accurate photopeak efficiency data for our gamma spectrometers in the high photon energy region. Source-term data are presently obtained indirectly from dose rate measurements made in the vicinity of the steamlines. Measurements have been cooperatively made by GE and ERDA(HASL) using eight different exposure measuring devices. The results of these measurements are presented in Figure 7. Using procedures outlived in Ref. 4, this data can be used to calculate the μCi/g of steam per

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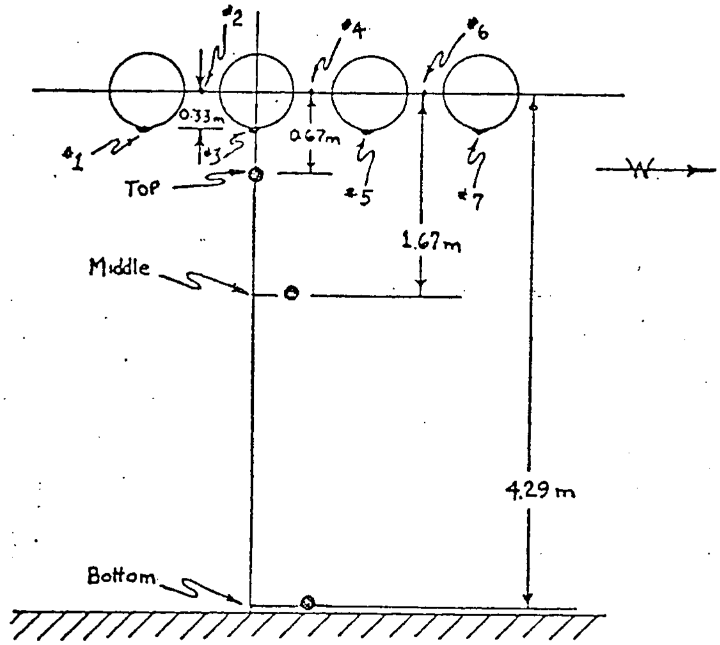
4. Rockwell, T., "Reactor Shielding Design Manual," TID-7004, Naval Reactors Branch, USAEC, March 1956.

Figure 7

Duane Arnold Energy Center

Main Steamline Survey

April 18, 1975 Reactor Power 975 MW_t



Instrument	Radiation Level (R/hr)						
	Position						
	1	2	3	4	5	6	7
Teletector	1.0	1.2	1.3	1.3	1.3	1.3	1.0
CP	-	-	1.27	-	-	-	-
PIC-6	-	-	1.7	-	-	-	-
JUNO	-	-	1.4	-	-	-	-

a. All appropriate instrument corrections have been made with the exception of the JUNO readings. The JUNO instrument was borrowed from ERDA/HASL and its calibration history is unknown.

Instrument or Detector	Radiation Level (R/hr)		
	Position		
	Top	Middle	Bottom
Teletector[a]	-	0.70	0.42
CP[a]	0.85	0.54	0.28
PIC-6[a]	1.02	0.59	0.26
JUNO[a]	1.00	0.55	0.25
Pocket Ion Chambers (GE)[b]	0.70	-	0.27
Pocket Ion Chambers (ERDA/HASL)[c]	0.65	0.36	0.19
Film (RDC/GE)[d]	0.73	0.36	0.21
TLD (RDC/GE-LiF)[d]	0.55	0.38	0.22
TLD (ERDA/HASL-LiF)[c]	0.69	0.42	0.20
TLD (ERDA/HASL - CaF_2)[c]	0.88	0.50	0.25

a. All appropriate instrument corrections have been made.

b. Uncalibrated.

c. Radiation level reported by ERDA/HASL in units of rad/hr.

d. Film and TLD's calibrated at VNC ^{60}Co facility.

mR/hr at some point distant from the steamline. These calculations will be performed by Power Plant Design.

Such calculations are difficult to perform to a high degree of accuracy due to experimental and calculational uncertainties whose magnitude are difficult to assess. One obvious uncertainty is to decide which exposure measuring device best represents the true mR/hr at the position indicated. This is a difficult question to answer because it is unlikely that any of the exposure measuring devices are correct to within $\pm$ 20%. This uncertainty is only partially a result of the problems associated with the orientation and reading of the instrument but is also related to the method and uncertainties in calibration and to the unknown spectral distribution of the radiation. As a result of pair production, multiple Compton scattering, and photopeak absorption in the steam, pipe walls, and insulation along with scattering of this primary and secondary radiation from the floors, walls, ceiling, and other components in the vicinity of the steamline, it is expected that the spectral distribution will be continuous from low energies up to the photopeak energies. Recent bench-mark experiment by Bishop, et al., on the penetration of ^{16}N radiation through various shielding materials amply support this conclusion[5,6,7]. Their results indicate that

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5. Bishop, G. B. and C. Smitton, J.Br. Nucl. Energy Soc., 14,167 (1975).
6. Smitton, C. and G. B. Bishop, J.Br. Nucl. Energy Soc., 14, 89 (1975).
7. Smitton, C. and G. B. Bishop, Nucl. Instrum. Meth., 121,41 (1974).

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the spectral distribution is a function of the thickness (number of mean free paths) and the composition of the absorber. In general, for absorber thicknesses on the order of one mean free path, the leakage spectra for 6 MeV ^{16}N gamma is predicted to be a continuous distribution containing a large fraction of the photons in the energy region below 500 keV and having a deep, broad valley between 3 and 5 MeV and rising again in the photopeak region.

The exposure measuring devices under control of GE (e.g. the Teletector, CP, PIC-6, pocket ion chambers, TLD, and Film), with exception of the pocket ion chambers, were all calibrated at the VNC ^{60}Co calibration facility. The calibration procedures are discussed in a separate report[8]. It is evident from the available

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8. Palino, G. F., "Calibration of Instruments and Dosimeters Used in ^{16}N Radiation Measurements - April 1975," NEDM-12591, in preparation.

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response functions for these detection systems, that the variation in response functions at low energy is large and is unknown for most systems above the 1.33 MeV ^{60}Co energy.

Another important consideration in interpreting detector response is the inability of most of the detectors to achieve a condition of charged particle equilibrium (CPE) in a beam of high energy photons. Photon interaction with matter is fundamentally one of ionization resulting in the production of free electrons. By charge particle equilibrium we mean that the amount of energy lost outside the detectors by electrons which originate in the detector but escape to the surroundings is exactly compensated by electrons which originate in the surrounding media and subsequently enter the detector. As long as the material surrounding the dosimeter is thicker than the range of secondary electrons, the secondary electron density as measured by the dosimeter is proportional to the photon intensity at some point within the surrounding material. As the thickness of material surrounding the active volume of the detector increases the number of gamma-ray interactions and hence secondary electrons entering the sensitive volume increases up to a thickness equivalent to the range of the secondary electrons. Hence, for thinner walls, fewer electrons enter the active volume than are leaving it and the dosimeter will read low. A thickness of 3 mm of an air equivalent absorber such as Bakelite is required for electronic equilibrium in a ^{60}Co field whereas approximately 10 mm is required for ^{16}N radiation. None of the detection systems had an air equivalent absorber of sufficient thickness to achieve electronic equilibrium in a pure ^{16}N radiation field. Fortunately, the actual field is one that is partially degraded and the thickness of plastic holder on the film and the Bakelite wall of the CP are expected to approach the condition of CPE. It is unfortunate that the observed Film readings were on the low exposure end of the calibration curve where the calibration uncertainties are large. The CP with its large volume ion chamber, relatively uniform response in the spectral region above 100 keV, and its relatively thick Bakelite wall will probably provide the most reliable values of exposure rate. The TLD (RDC/GE-LiF) results are in question due to the same reason that the Film results are in question. The results of the TLD (ERDA/HASL-LiF) are reported in units of rad/hr (e.g. absorbed dose). If CPE is achieved, the exposure is related to the absorbed dose by the expression

$$X\ (\text{mR/hr}) = \frac{K(\text{mrad/hr})}{0.869} \times \left[\frac{(\frac{\mu_{en}}{\rho})_{air}}{(\frac{\mu_{en}}{\rho})_{LiF}}\right]_{E\gamma}$$

where $\left[\frac{(\frac{\mu_{en}}{\rho})_{air}}{(\frac{\mu_{en}}{\rho})_{LiF}}\right]_{E\gamma}$ is the ratio of energy absorption coefficient (cm^2/g) for air and LiF at some specified energy $E\gamma$. Above 200 keV this ratio is near unity whereas below 200 keV the ratio decreases slowly to 0.77*. Assuming $E_\gamma \geqslant 200$ keV the exposure calculated from the ERDA/HASL LiF TLD results are lower than that measured with the CP. If we were to assume that the CP readings are correct, the difference between the CP and the LiF dosimeter can be rationalized if either of the following conditions exist:

1. CPE was not achieved for the LiF dosimeter (this will result in the TLD's reading too low); however, the disagreement will be reduced if
2. a significant low energy ($E\gamma < 200$ keV) spectral component exists (this will result in the TLD's reading too high).

*See the relative response function curves for LiF, CaF_2:Mn, and film in the instrument calibration report.

The former reason is very likely the primary contribution to this difference. Evidence for the latter effect can be noted from the much higher readings for the CaF_2:Mn TLD which has a significantly lower value for $(\mu_{en}/\rho)_{air} / (\mu_{en}/\rho)_{CaF_2:Mn}$ in the region below 200 keV.*

C. Turbine Building Survey

1. Component Survey

An extensive radiation survey was made of the turbine deck components at Duane Arnold. Such survey data are required to determine the magnitude of the source terms used in the evaluation of shielding design criteria for turbine deck components. The components surveyed included the moisture separator-reheaters, the reheater drain tanks, the low pressure stop and intermediate valves, the high pressure turbine hood, the low pressure turbine hoods, and the low pressure feedwater heaters. The results of these surveys are presented in the following figures and graphs.

In addition to the instrumental survey mentioned above, an additional comparative survey of selected turbine deck components was performed using a TLD/Film badge set and the CP instrument. The results of this survey are presented in Figure 15 and Table 6.

In perusing the data it is readily apparent that the CP readings, even after corrections for scale nonlinearity and source-CP chamber orientation, were substantially lower than the corrected readings observed using the PIC-6 or the Teletector. In considering reasons for these variations, two factors must be considered. The first factor that may be important is that the source surface to the center of the detectors active volume is different for each instrument. For the CP, using the instrument with the chamber held

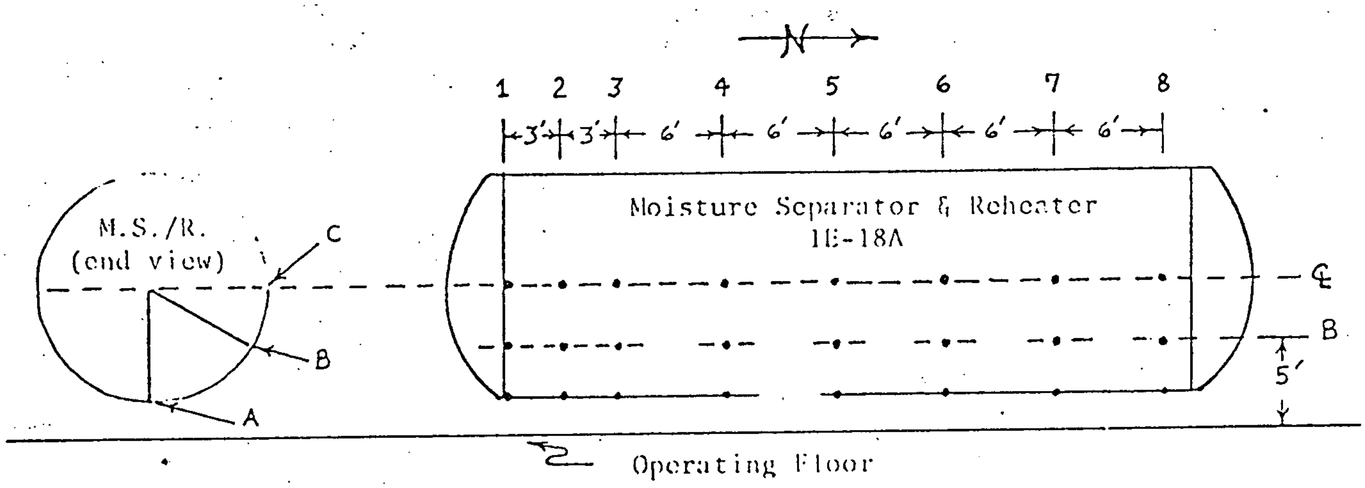
*See the relative response function curves for LiF, CaF_2:Mn, and film in the instrument calibration report.

Figure 8

Moisture Separator & Reheater Survey

Duane Arnold Energy Center

April 18, 1975 ∿ 980 MW_t



Contact Instrument Reading[a] ($\frac{mR}{h}$)

Column	1	2	3	4	5	6	7	8	Survey Instrument
Row									
A (Bottom)	120	350	310	690	630	630	590	170	Teletector
B (5' Above Oper. Floor	53	170	150	300	300	280	300	80	Teletector
	44.8	174	169	280	267	262	238	110	CP-2
	64	220	210	320	310	310	320	160	PIC-6A
C (Mid-plane)	150	150	80	150	170	160	160	125	Teletector

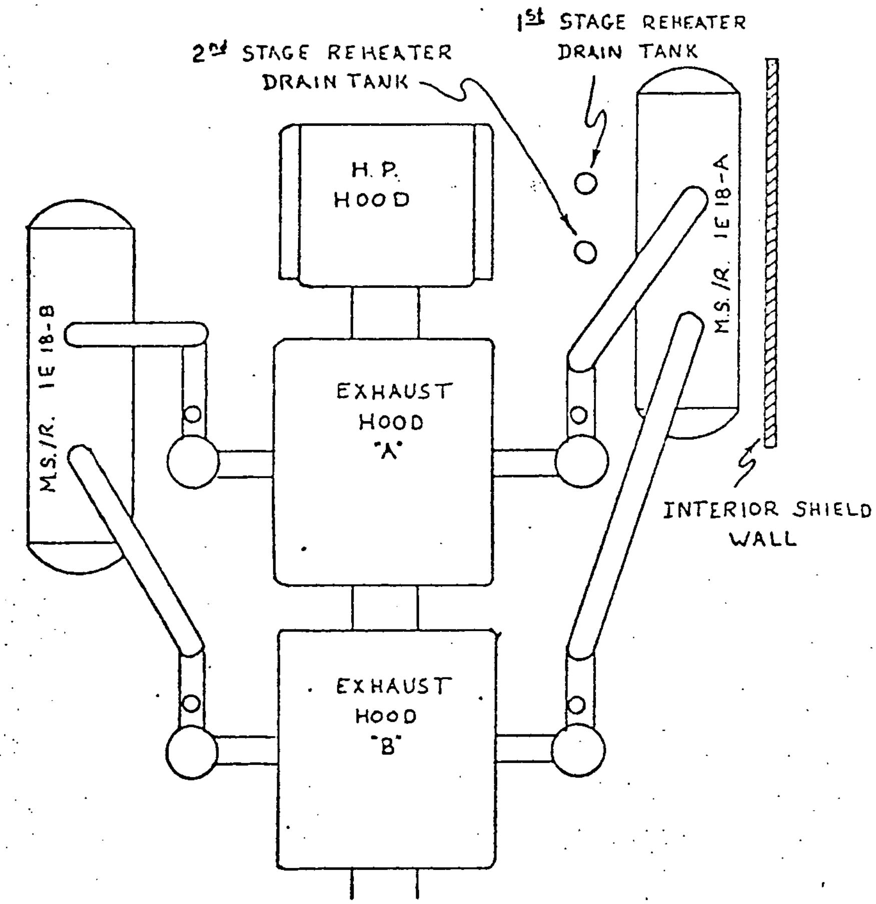
a. All appropriate instrument corrections have been made.

Figure 9

Reheater Drain Tank Survey

Duane Arnold Energy Center

April 18, 1975 ~ 980 MW_t



		Instrument Readings (Contact)[a] (mR/h)		
	Elevation	Teletector	CP	PIC-6
1st Stage Reheater Drain Tank	Top	80	-	105
	Middle	65	-	100
	Bottom	120	-	105
2nd Stage Reheater Drain Tank	Top	100	-	105
	Middle	65	92	-
	Bottom	140	85	-

a. All appropriate instrument corrections have been made.

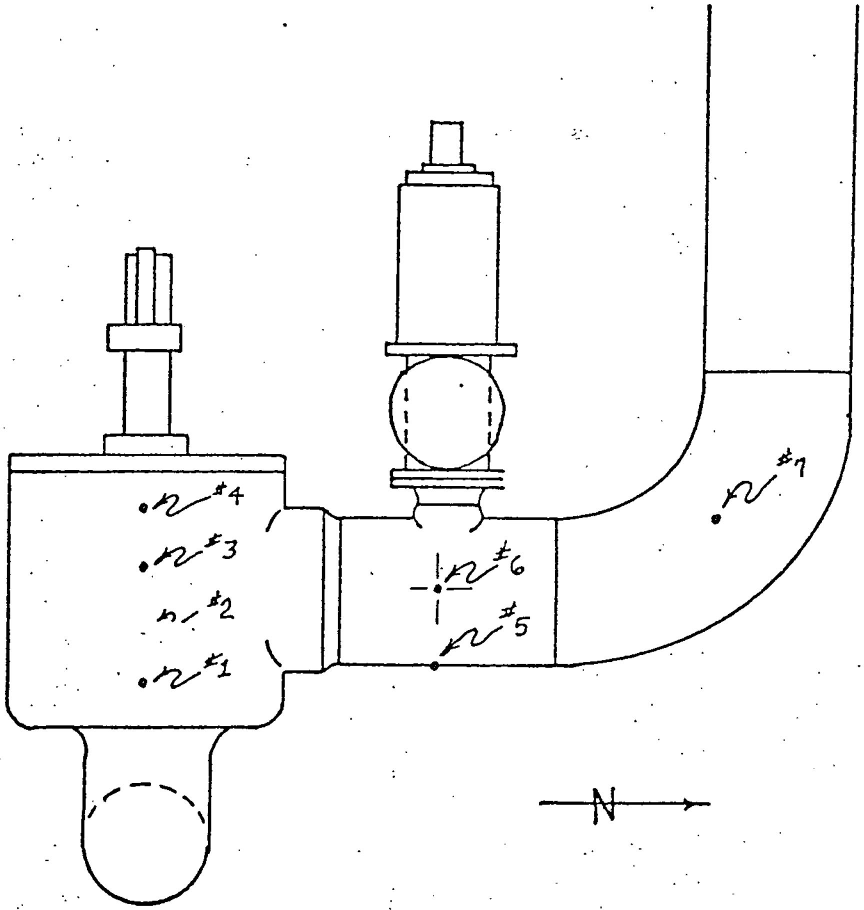
Figure 10

Stop and Intermediate Valve (CIV-1) Survey

East Side

Duane Arnold Energy Center

April 18, 1975 ~ 980 MW_t



Position Number	Instrument Readings (Contact)[a] (mR/h)		
	Teletector	CP	PIC-6
1	42	32.0	50
2	44	38.0	44
3	44	28.0	44
4	37	-	44
5	160	-	-
6	140	-	-
7	170	110	125

a. All appropriate instrument corrections have been made.

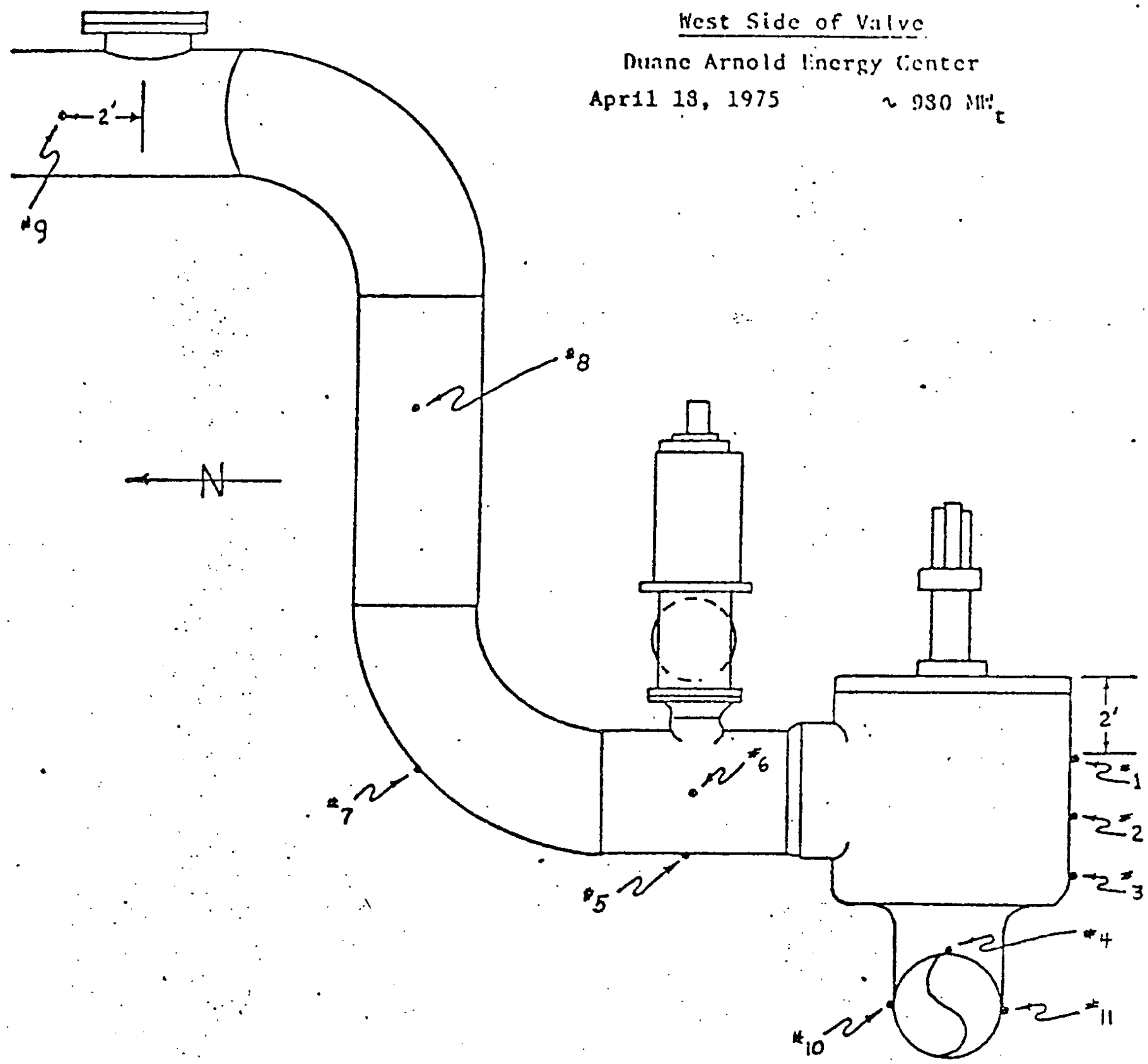
Figure 11

Stop and Intermediate Valve (CIV-1) Survey

West Side of Valve

Duane Arnold Energy Center

April 18, 1975 $\sim$ 930 MW_t



Position	Instrument Reading (Contact)[a] (mR/h) 1	2	3	4	5	6	7	8	9	10	11	Survey Instrument
	45	53	53	170	120	120	-	140	160	105	120	Teletector
	29.8	45.0	78	118	121	121	131	147	-	-	-	CP
	44	80	95	140	120	135	170	210	-	-	-	PIC-6A

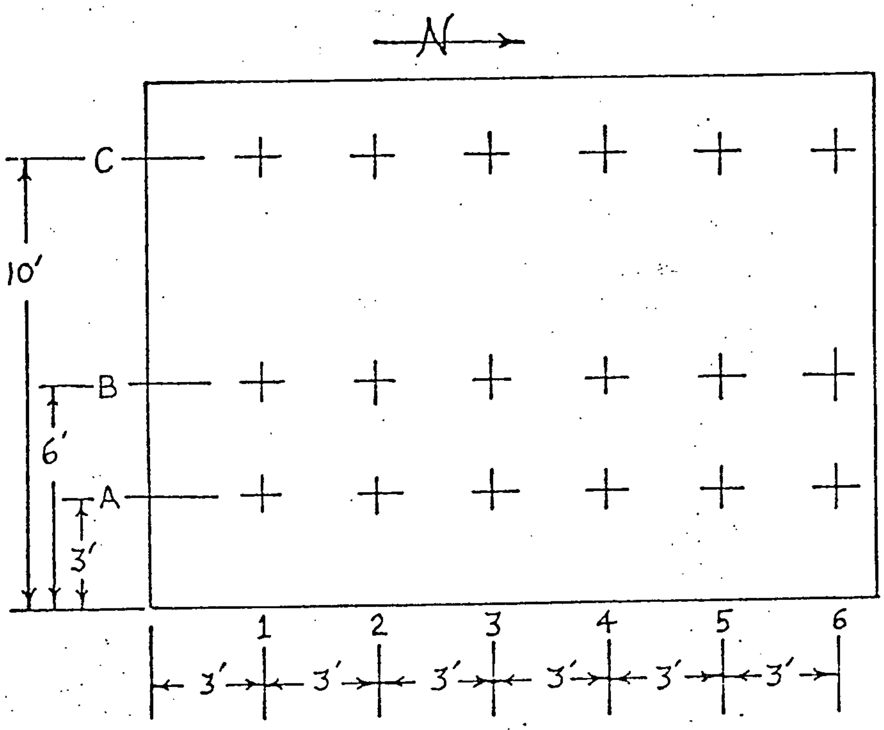
a. All appropriate instrument corrections have been made.

Figure 12

Survey of East Face of High Pressure Hood

Duane Arnold Energy Center

April 18, 1975 ~ 980 MW_t



Row	Instrument Reading (Contact)[a] (mR/h) — Columns: 1	2	3	4	5	6	Survey Instrument
C	140	-	135	135	140	120	Teletector
B	105	200	220	260	260	160	Teletector
	141	194	194	220	235	125	CP
	146	220	230	280	310	160	PIC-6
A	-	125	180	250	240	125	Teletector
	113	174	208	254	235	131	CP
	106	200	280	280	240	160	PIC-6

Note: Teletector reading on top of south end of hood was 90 mR/hr. On the top surface in the middle of the hood the Teletector read 140 mR/hr.

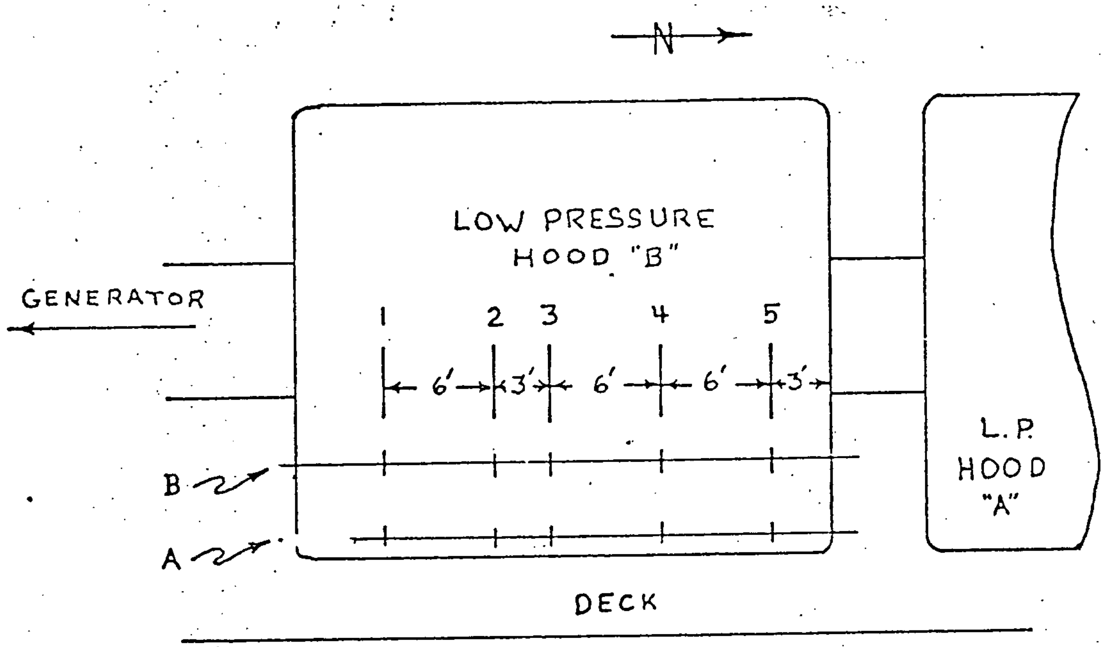
a. All appropriate instrument corrections have been made.

Figure 13

Low Pressure Turbine Survey - Hood "B"

Duane Arnold Energy Center

April 18, 1975 ~ 980 MW_t



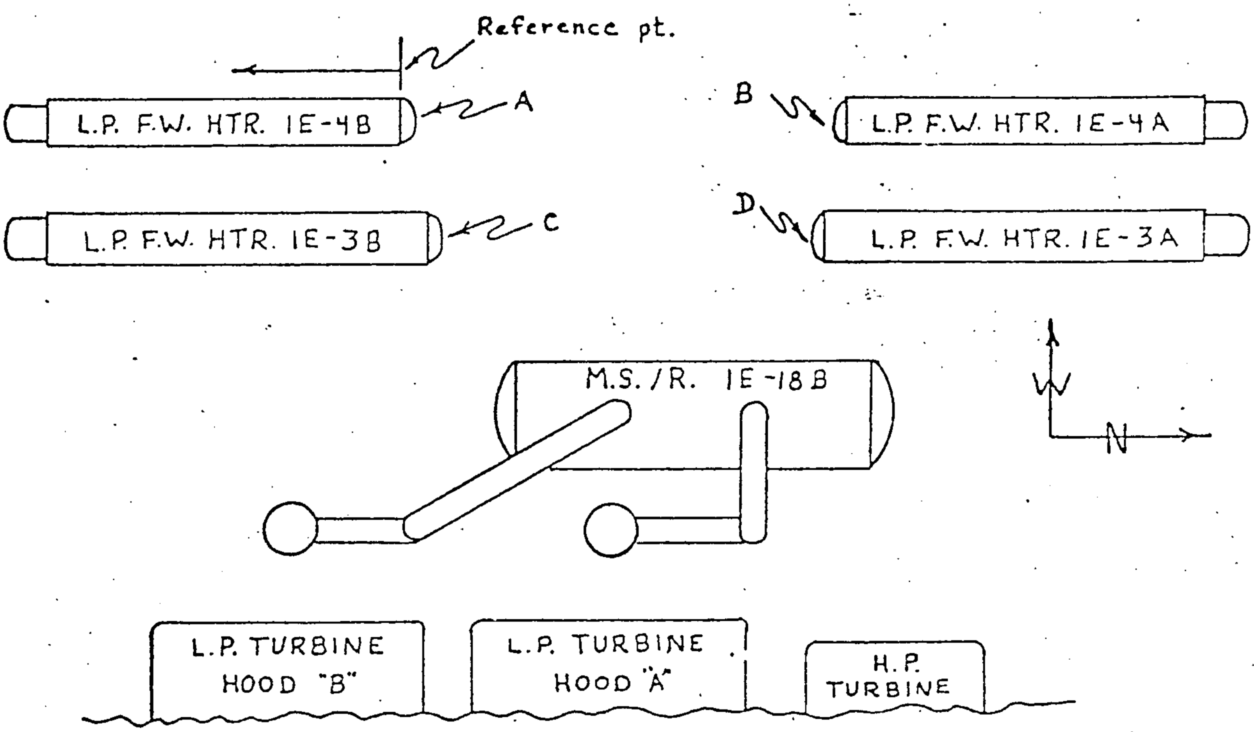
Row	Instrument Readings (Contact)[a] (mR/h) Column 1	2	3	4	5	Survey Instrument
A (1' above deck)	45 24.5 35	50 32.2 28	50 31.5 55	87 33.2 56	42 30.5 28	Teletector CP PIC-6A
B (6' above deck)	39 22.8 36	41 26.3 39	31 18.5 32	43 30.0 44	41 30.5 44	Teletector CP PIC-6A

a. All appropriate instrument corrections have been made.

Figure 14
Low Pressure Feedwater Heater - 4A Survey

Duane Arnold Energy Center

April 18, 1975 ∿ 980 MW_t



	Instrument Readings (Contact)[a] (mR/h)		
Distance from Reference Point (ft.)	Teletector	CP	PIC-6
0	66	100	130
3	160	140	180
9	220	209	260
15	105	105	125
21	32	32.0	54
27	48	14.1	23
33	13	11.1	14
39	13	6.8	13
42	0.4	1.5	1.0
A*	-	128	-
B*	-	50	-
C*	-	120	-
D*	-	107	-
*Center axis-end on.			

a. All appropriate instrument corrections have been made.

Figure 15

Duane Arnold Energy Center

TLD-FILM-CP Turbine Bldg. Component Surv

April 19, 1975

Reactor Power -- 860 $\pm$ 5 MW_t

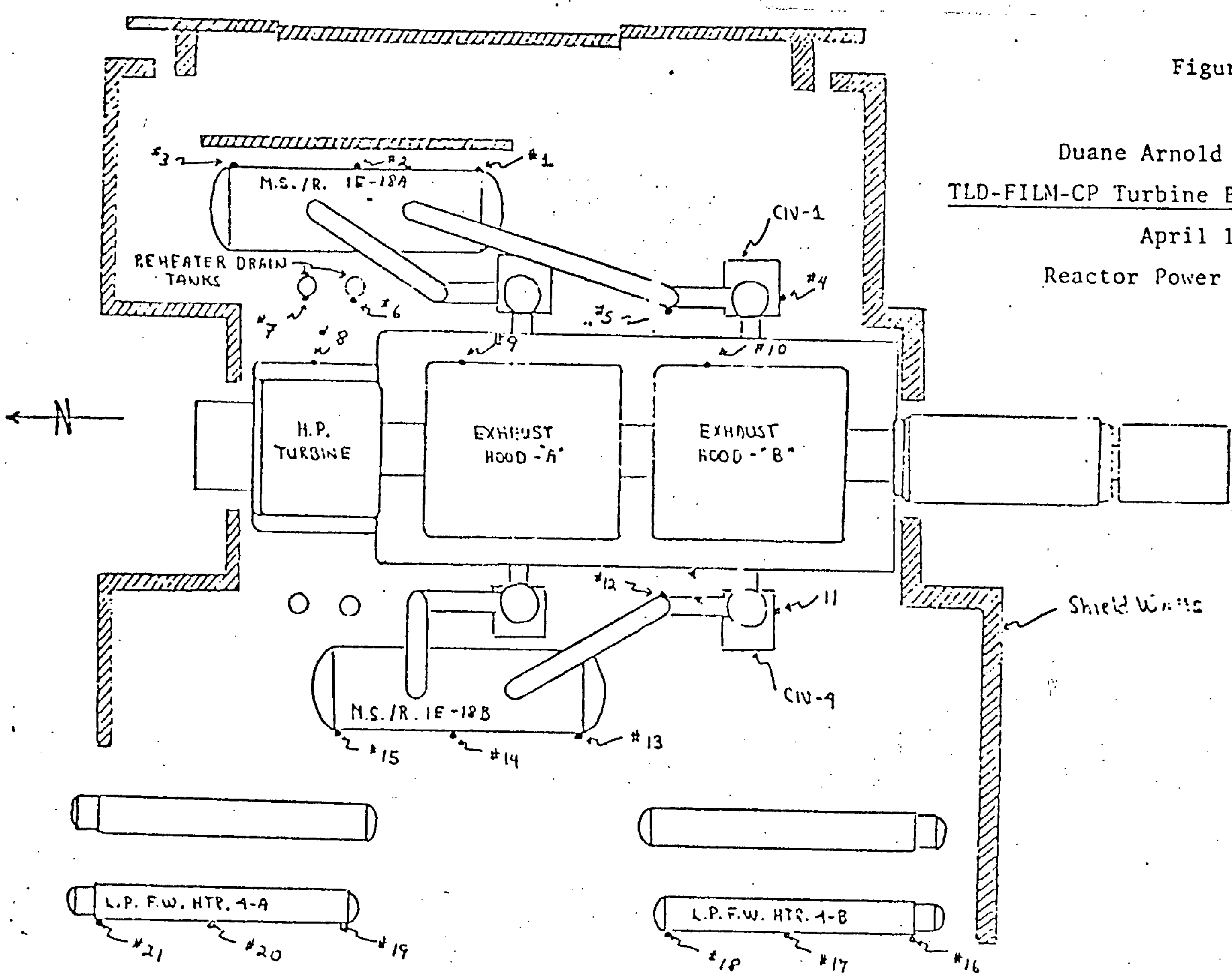


TABLE 6

DUANE ARNOLD ENERGY CENTER

TLD-FILM-CP Turbine Building Component Survey

Date : April 19, 1975

Reactor Power: 860 ± 5 MW_t

Survey Location Number	Location	Exposure Rate (mR/hr)		
		TLD[a]	FILM[a]	CP[b]
1	M.S.&R. 1E-18A. SE corner at midplane.	47	52	54
2	M.S.&R. 1E-18A. Center of E side at midplane.	74	74	88
3	M.S.&R. 1E-18A. NE corner at midplane.	35	45	45
4	Stop & Intermediate Valve (CIV-1). Send about midplane of central casing.	0	15	17
5	Exhaust Hood "B" Steamline. W side at center of vertical run.	63	77	63
6	2nd Stage Reheater Drain Tank. W side at mid-height.	43	38	50
7	1st Stage Reheater Drain Tank. W side at mid-height.	38	39	45
8	H.P. Turbine. Center of E face.	86	95	107
9	Exhaust Hood "A". 1.8m south of NE corner and 1.0m above deck.	33	29	33
10	Exhaust Hood "B". 2.2m south of NE corner and 1.0m above deck.	23	24	23
11	Stop & Intermediate Valve (CIV-4) S end about midplane of Central casing.	0	18	23
12	Exhaust Hood "B" Steamline. E side at center of vertical run.	72	80	80
13	M.S.&R. 1E-18B. SW corner at midplane.	69	64	75
14	M.S.&R. 1E-18B. Center of W side at midplane.	76	85	92
15	M.S.&R. 1E-18B. NW corner at midplane.	49	57	60
16	L.P.F.W. Htr. 4-B. SW corner at midplane.	0	0	1.2
17	L.P.F.W. Htr. 4-B. Center of W side at midplane.	33	29	29
18	L.P.F.W. Htr. 4-B. NW corner at midplane.	55	64	70
19	L.P.F.W. Htr. 4-A. SW corner at midplane.	27	21	33
20	L.P.F.W. Htr. 4-A. Center of W side at midplane.	0	9	12.7
21	L.P.F.W. Htr. 4-A. NW corner at midplane.	0	0	5-15

a. The RDC (Radiation Detection Corp., Sunnyvale, CA) TLD's (LiF)/Film badge sets were calibrated with ^{60}Co direct radiation at the VNC calibration facility.

b. All appropriate instrument corrections have been made.

parallel to the source, this distance is 7.7 cm whereas it is 1.0 cm for the PIC-6 and 1.3 cm for the Teletector. Although the differences in these distances may not be important for large sources such as the moisture separator-reheater, calculations presented by Burns, et al.[9], indicate that the exposure rate for smaller sources changes dramatically

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9. Burns, L.S., D. W. Jeter, and K. W. McCausland, Radiation Dose Rates in the Turbine Building at Partial Power Loads, APED-5731, General Electric Co., 1968.

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in the region under consideration (e.g. 0-10 cm). The calculated dose-rate distance effect are sufficient to account for a portion of the relative instrument responses. Since the center of ionization is not at the center of the active volume when these instruments are used for contact measurements, a general rule of thumb in data interpretation is that the reference distance to use is 2/3 the surface to center of detector active volume distance.

The second factor which may contribute to the differences observed is the fact that the low energy response function for the three instruments are significantly different. It is apparent from our previous discussion that there is a large low energy spectral component in the shielding degraded ^{16}N spectrum. This low energy component may be the principal factor responsible for the observed differences in instrument response.

In general, when the instruments are used in a relatively homogeneous field of shielding degraded ^{16}N radiation the CP readings are lower than those observed for the PIC-6 or Teletector. This observation is consistent with previous ^{16}N instrument response studies at Dresden-3 and Oyster Creek[10] where it was found that the

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10. Helmholz, H. R., D. Dutina, and R. S. Gilbert, N-16 Radiation Studies at the Oyster Creek Nuclear Power Station, October-November, 1973, NEDM-24184, General Electric Co., Jan. 1974.

CP agreed well with the reference instrument, a #552 Condenser R Meter probe, whereas the PIC-6 and Teletector readings were consistently biased high. The CP instrument response is considered by the authors to better represent the actual exposure rate at the position surveyed irrespective of the spectral distribution.

An opportunity arose during this study to partially evaluate the performance of a commercial TLD/Film service*. The TLD/Film badge used consisted of a conventional film badge with two LiF powder

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*Radiation Detection Co. (RDC), Sunnyvale, CA

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capsules mounted directly behind the film in the badge. During the initial stages of this study, it was not apparent to the authors the level of TLD and Film exposure required by the commercial service to read the exposure with a reasonable degree of precision, and since many of the TLD measurements were made in conjunction with those of ERDA/HASL all exposures were matched to needs. Subsequent to the study it was ascertained that exposures of the RDC's TLD in excess of 100 mR were required to obtain a precision of ± 10%. Between 10 and 100 mR the reported precision is ± 10 mR. The latter level of precision is unacceptable. Unfortunately, the exposure times used in the TLD/Film survey of turbine deck components was approximately one hour and as a result many of the dosimeters were exposed in the region between 10 and 100 mR. However, the Film precision is reportedly better than the TLD precision in this low exposure region. Even though the precision is low, it is apparent from Table 6 that the agreement between the TLD's, the Film, and the CP instrument is satisfactory. Similar type studies at Cooper Nuclear Power Station† where exposures were considerably higher and the precision of the measurement greater, indicated that the CP response is bias high relative to the Film or TLD. The reason for this bias may be

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† Palino, G. F. and H. R. Helmholz, "^{16}N Radiation Measurements at Cooper Nuclear Power Station-April 1975," NEDM-12592, General Electric Co., August 1975.

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a result of the inability of the TLD/Film combination badge to achieve CPE.

In the use of LiF TLD's it is necessary to prevent the temperature of the dosimeter from rising above 100°F since temperature fading of the phosphorescent signal can occur. Most turbine buildings are warm and the surface temperatures of many of the components are in excess of 100°F. For this reason during each measurement the TLD/Film packets were enclosed in plastic and placed in a styrafoam cup filled with ice. The cup was covered on top with plastic to prevent spillage during transfer and the complete unit was taped to the component where the exposure rate was measured. It is estimated that the source surface to detector distance is approximately 2.5 cm.

The great advantage of the TLD/Film combination is that the system is passive so that during the measurement personnel need not receive excessive exposure. This is especially important in the vicinity of the steamlines and the moisture separators. The TLD/Film combination can also be useful in measuring doses at positions difficult to reach with a survey instrument such as the surface dose along exterior walls of the turbine building.

The principal difficulty in the use of the TLD/Film combination is that exposures in excess of 100 mR are required to achieve a reasonable level of precision. Depending on the component surveyed, this may require exposure periods significantly in excess of one hour. During such long exposures the reactor power may vary and problems may be encountered in maintaining TLD and Film temperatures below 100°F. In most situations the CP is an adequate alternative to using the TLD/Film combination.

2. Surveys of Shield Walls

A survey grid was established on the outside of the inner shield wall that is located next to and east of M.S./R. 1E-18A. The shield wall is 25' 6" high and 18" thick and is constructed of solid concrete blocks. Detector response readings were taken along the survey grid using the Teletector, CP, and PIC-6. The results of this survey are presented in Figure 16. It is to be noted that in this low exposure rate region the instrument responses vary greatly although the trend of the CP to read lower than the PIC-6 or Teletector still is evident. The shield wall is definitely effective in reducing the radiation exposure in the eastwardly direction.

The interior of the east exterior shield wall was also surveyed and the results are presented in Figure 17. The instrument readings taken in the shadow of the inner shield wall are as expected quite low (0.5 - 2.0 mR/hr) but the observed exposure rate readings not in the shadow of this wall show significant fields due to the direct line radiation from the cross-over steamlines, the rear section of the M.S./R., intercept valves, and low pressure turbine.

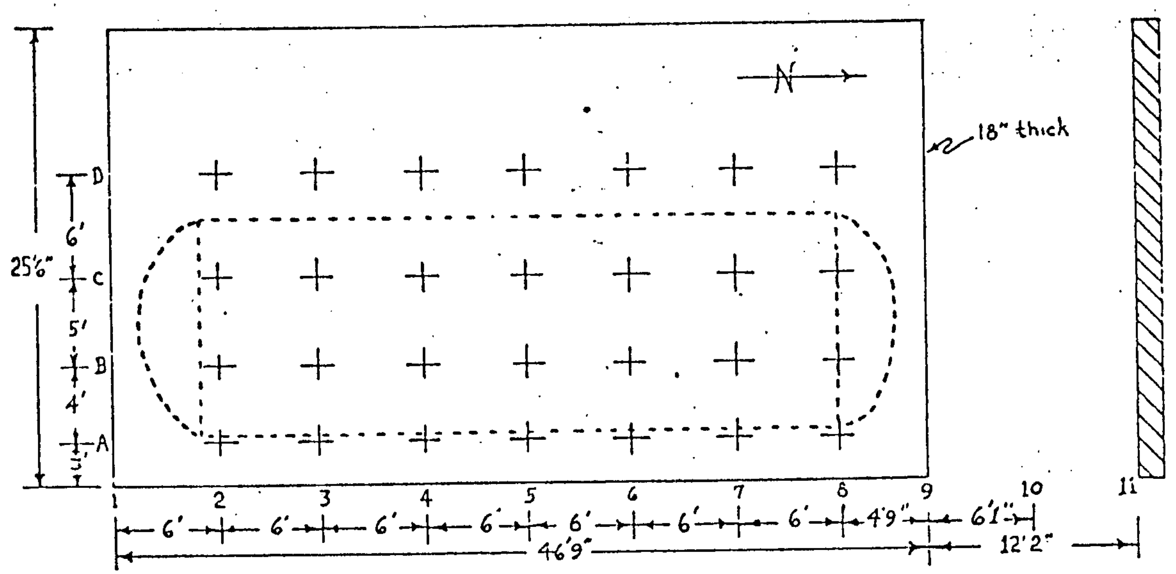
Detailed comparison radiation measurements were performed by GE and ERDA(HASL) at three positions on the turbine deck floor (see Table 7). Two of these positions were south of the south edge of the inner shield wall in a region of direct ^{16}N radiation whereas the third measurement was taken in a highly shielding degraded field at the base of the outside of the inner shield wall. All of the varied measurement techniques agree within $\pm$ 20%. Interestingly, it appears from the ERDA/HASL data that the CaF_2:Mn dosimeter response relative to LiF was essentially the same in the relatively direct ^{16}N field as in the shielding degraded field. This observation is unexpected. The shielding degraded spectrum is expected to have a considerable low energy spectral component in the region where the CaF_2 response function is larger than that for LiF. In the mid-energy region above 0.5 MeV the response of the two TLD's are quite similar but in the high energy region near 6 MeV the CaF_2 response is slightly greater than that of LiF.

Figure 16

Duane Arnold Energy Center

East Face of Inner Shield Wall

April 18, 1975 A 980 MW_t



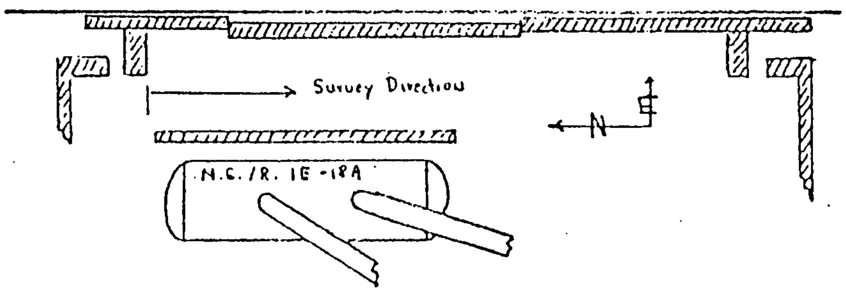
Row	Contact Instrument Readings (mR/h)[a]											Survey Instrument
	Columns											
	1	2	3	4	5	6	7	8	9	10	11	
D	4.7	1.2	1.2	1.2	1.2	2.7	1.2	0.7	0.7	19	-	Teletector
C	8.7	1.2	3.4	3.4	3.4	3.4	2.7	0.8	2.7	22	-	Teletector
B	5.2	3.8	6.1	6.1	6.1	6.1	5.2	3.4	3.4	23	-	Teletector
	4.3	2.1	3.8	4.3	3.9	3.8	3.2	1.8	2.0	14.9	12.1	CP
	5.2	2.5	5.3	5.3	5.1	4.9	3.9	1.8	2.1	23	-	PIC-6A
A	6.1	2.5	4.4	8.0	6.6	7.0	2.7	1.2	2.1	23	-	Teletector
	3.4	1.7	3.0	4.6	3.9	4.8	2.0	1.0	2.3	14.4	11.6	CP
	3.7	1.4	3.5	4.8	4.1	4.0	2.0	1.2	2.5	13	12	PIC-6A

Figure 17

East Shield Wall Survey

Duane Arnold Energy Center

April 18, 1975 ~ 980 MW_t



Contact Instrument Readings (mR/h)[a]

Height Above Deck (ft.)	Distance from NE Portal Wall (see above figure) (feet)															Survey Instrument
	6	12	18	24	30	36	42	48	54	60	66	72	78	84	87	
3	0.8	0.8	2.1	1.6	2.2	2.5	3.4	3.8	6.1	9.0	7.0	7.5	7.0	6.1	6.1	Teletector
	0.2	0.7	0.6	1.0	1.1	1.5	1.8	2.1	2.8	3.9	4.2	4.6	4.8	4.9	4.7	CP
	<1	<1	1.1	1.1	1.2	1.7	1.9	2.9	3.2	4.3	4.5	3.4	4.1	3.6	3.4	PIC-6
7	2.1	1.2	2.1	2.1	3.0	3.0	3.0	5.0	6.1	6.1	8.8	10.0	8.8	8.8	8.8	Teletector
	0.2	0.5	1.0	1.4	1.7	1.7	1.2	2.2	3.0	4.1	6.7	6.2	6.7	6.8	5.5	CP
	1.2	1.2	1.7	1.8	2.1	2.2	3.2	1.1	5.2	9.3	6.7	7.4	8.0	7.1	6.7	PIC-6
12	1.2	0.5	2.1	3.2	2.1	3.4	4.7	6.6	8.5	11.6	11.6	12.6	11.6	10.0	7.5	Teletector
18	0.6	0.8	0.8	2.1	2.7	3.4	4.5	6.9	9.8	13.1	13.1	12.5	12.5	11.7	8.5	Teletector

a. All appropriate instrument corrections have been made.

TABLE 7

GE - ERDA(HASL) TLD/FILM COMPARISON STUDY

Turbine Deck - Duane Arnold Energy Center

April 18-19, 1975

Location and/or Description of Exposure	Date-Time	GE Results[a]		ERDA(HASL) Results[c]		
		GE Calib. RDC Film (mR/hr)	GE Calib.[b] RDC TLD (LiF) (mR/hr)	LiF (mrad/hr)	CaF_2:Mn (mrad/hr)	P.I.C. (mR/hr)
HASL sample designation A, C. Intercomparison of TLD response to direct ^{16}N radiation. Samples placed on turbine deck floor approx. 0.6m south of the south end of the inner shield wall.[d,e]	4/18/75 1032-1415	19.8	17.8	15.6	20.0	16.6
HASL sample designation B, D. Intercomparison of TLD response to direct ^{16}N radiation. Sample placed on turbine deck floor approx. 4m south of samples A and C.[d,f]	4/18/75 1032-1415	16.8	18.4	13.4	16.9	14.8
HASL sample designation E. Intercomparison of TLD response to degraded ^{16}N radiation. Samples placed on turbine deck against and directly east of the inner shield wall centerline.[g]	4/18/75 1415 - 4/19/75 1132	2.2	2.4	1.71	2.10	1.99

a. Film and TLD's calibrated at VNC ^{60}Co facility. Exposures were determined by concurrent exposure of RDC TLD-film badge and the Condenser R-Meter probe #552.

b. Radiation Detection Co. (RDC), Sunnyvale, CA calibration and precision statement for TLD's.

Calibration based on exposure of controls to Cs-137 corrected to a Co-60 equivalent.

Precision:		
	10mR to 100mR	- better than ± 10mR
	100mR to 1R	- better than ± 10%
	Greater than 1R	- better than ± 5%

c. See Appendix A.

d. Reactor power during the experiment averaged 982 MW_t. Power level varied from 979 to 985 MW_t.

e. CP reading 10cm above this sample position was 21.5 mR/hr. The uncalibrated personnel pocket ion chamber #6401 indicated 88.5 mR total exposure (exposure rate 23.8 mR/hr).

f. CP reading 10cm above this sample position was 18.2 mR/hr. The uncalibrated personnel pocket ion chamber #8786 indicated 67.0 mR total exposure (exposure rate 18.0 mR/hr).

g. The reactor power level for the exposure interval (21.28 hr) varied between 505 MW_t and 1006 MW_t with an average hourly value of 805 MW_t.

3. Roof Survey

An extensive survey of the turbine building roof using the CP, PIC-6, and Teletector along with a partial Teletector survey of the east turbine building wall has been performed at Duane Arnold. The results of the survey are presented in Table 8 and the survey grid and relative placements of the major turbine deck components are represented in Figure 18. Measurements were taken at an elevation of 3' above the roof surface every 10' along the designated traverses. A partial survey of the east wall at elevations 7' and 14' 6" below the roof surface was made using the Teletector. There is no overhead shielding of the turbine deck components with exception of the roof structure.

The CP readings have been graphically represented in Figures 19A and 19B. In these figures the center position of the major turbine deck components have been located. The highest radiation field is located along the turbine generator centerline traverse at a position just south of the center of the M.S./R. 1E-18B in an area where the cross-over steamlines may contribute significantly. The observed dips in the radiation fields occur at positions corresponding to measurement points in the shadow of the roof beam supports. It is interesting to note that the readings along the west roof edge are significantly higher than along the east roof. The difference may be attributed to lack of an inner shield wall on M.S./R. 1E-18B and due to the presence of the L.P. F.W. heaters on the west side of the turbine deck.

TABLE 8

Duane Arnold Energy Center

Turbine Roof and East Wall Survey

April 17, 1975 Reactor Power ~ 1100 MW_t

Instrument Reading (mR/h)[a]

Row	Survey Instruments	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200
		Distance from North Wall of Turbine Building (See Figure) (feet)																				
A	Teletector	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	CP	0.8	1.3	1.3	1.8	2.8	3.5	5.2	6.1	7.0	8.5	8.5	8.5	7.8	6.1	5.7	4.7	3.4	3.0	1.8	1.7	1.3
	PIC-6	1.0	1.4	1.7	2.3	3.6	4.8	7.3	9	11	11	11	12	11	10	9	7.2	4.8	4.0	2.8	2.0	1.7
B	Teletector	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	CP	0.9	0.9	1.1	2.7	3.8	5.2	7.8	9.0	11.8	13.8	12.4	13.6	12.8	7.5	9.4	8.5	5.2	4.8	3.8	1.9	1.7
	PIC-6	1.1	1.1	1.4	3.3	4.8	5.7	11	12	17	19	17	19	18	10	13	11	6.2	5.8	4.5	2.1	1.8
C	Teletector	1.2	-	3.7	-	9.1	-	17	-	26	-	26	-	28	-	22	-	12	-	8.4	-	5.1
	CP	1.3	1.7	2.1	4.3	4.8	4.3	8.9	12.1	13.8	16.6	16.6	17.5	18.4	14.5	15.0	12.8	8.2	7.8	6.3	3.7	2.5
	PIC-6	1.5	-	2.7	-	6.8	-	14.1	-	24	-	23	-	24	-	19	-	10.0	-	7.0	-	3.8
D	Teletector	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	CP	0.8	1.0	1.3	2.8	3.5	4.3	7.2	9.4	12.0	13.3	13.0	14.7	14.7	9.9	10.4	9.7	6.6	6.1	5.2	2.8	2.5
	PIC-6	1.1	1.3	1.6	3.8	4.3	5.8	10	12	18	20	19	23	23	13	16	14	8.6	8.6	6.2	3.2	3.1
E	Teletector	-	1.0	1.5	2.9	2.9	4.3	6.1	5.2	7.0	8.0	7.0	8.0	8.0	5.2	6.6	6.1	3.4	4.4	4.3	1.7	2.5
	CP	-	0.4	0.8	1.7	1.8	2.2	3.4	3.4	4.3	5.7	5.2	5.3	6.1	3.6	4.4	4.7	2.6	2.5	2.4	1.8	1.3
	PIC-6	-	<1	1.1	2.2	2.1	2.3	4.3	4.6	6.2	7.5	6.2	7.5	8.4	4.1	6.2	6.2	3.1	3.4	3.0	1.5	1.6
F[b]	Teletector	-	-	-	-	7.3	-	-	10	-	-	13	-	-	-	14	-	-	-	-	-	-
	CP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	PIC-6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
G[b]	Teletector	-	-	-	3.4	4.3	2.5	6.6	6.9	8	9	11	11	11	6.9	11	11	7.5	6.9	-	-	-
	CP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	PIC-6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

a. The measurements were made at a height ~ 3' above roof surface with the exception of the traverses F and G which are contact readings along the east wall. All appropriate instrument corrections have been made.

b. For the F traverse the survey was made at a position 7' below roof level. For the G traverse the survey was made at a position 14' 6" below roof level

Figure 18

Duane Arnold Energy Center

Turbine Roof and East Wall Survey

April 17, 1975 · Reactor Power ~ 1100 MW_t

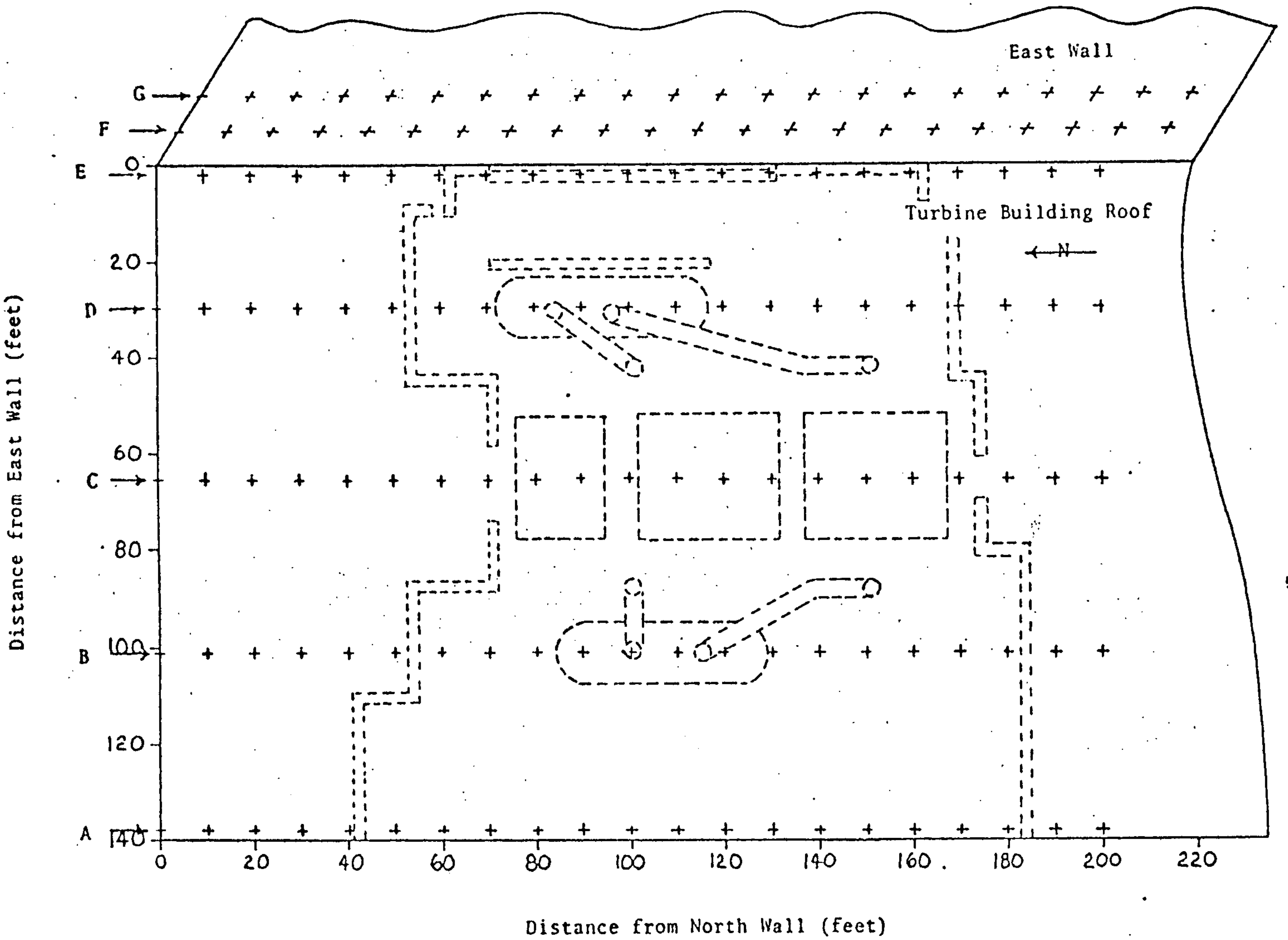


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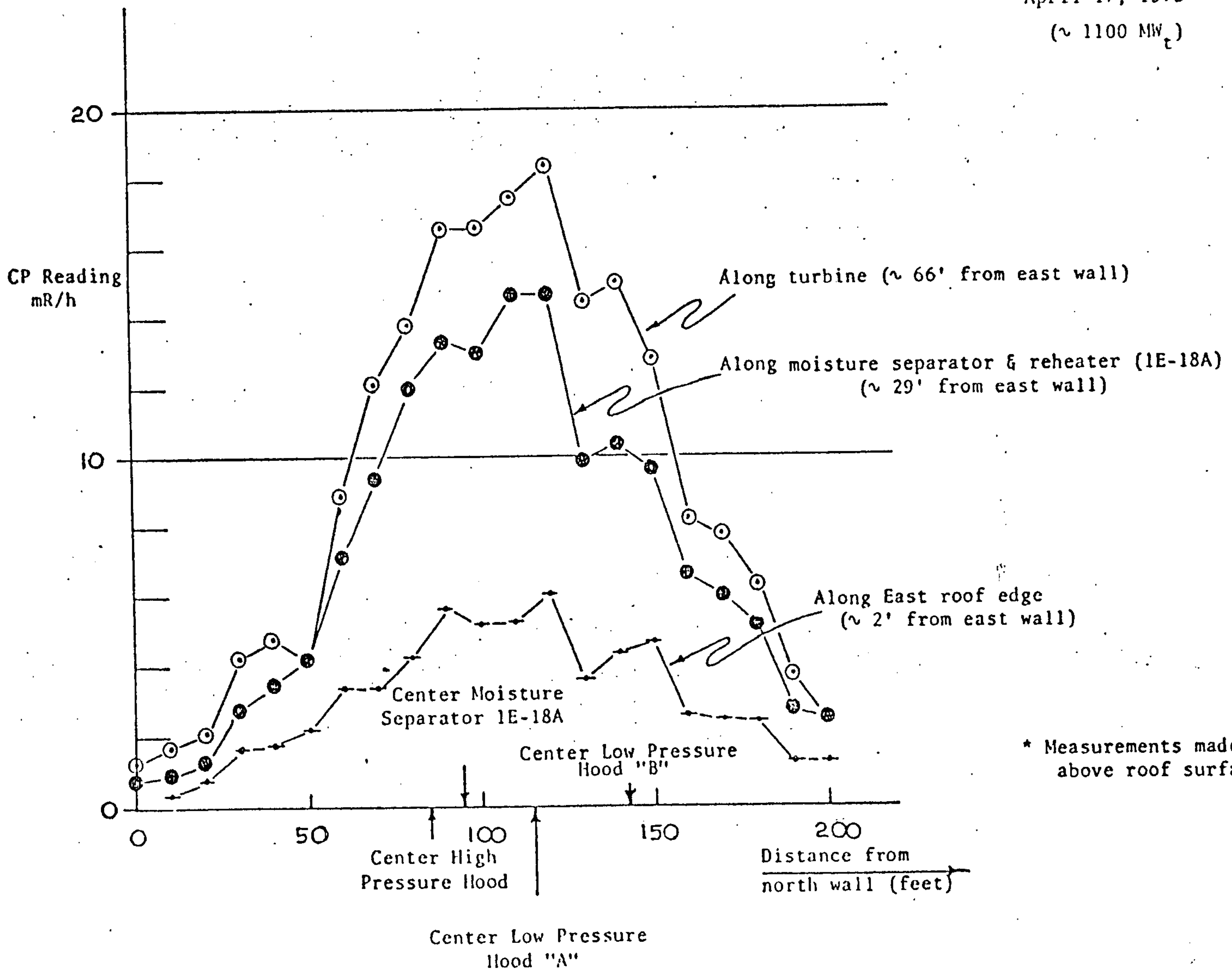
Figure 19A

Duane Arnold Energy Center

Turbine Building Roof*

April 17, 1975

(~ 1100 MW_t)



* Measurements made ~ 3' above roof surface

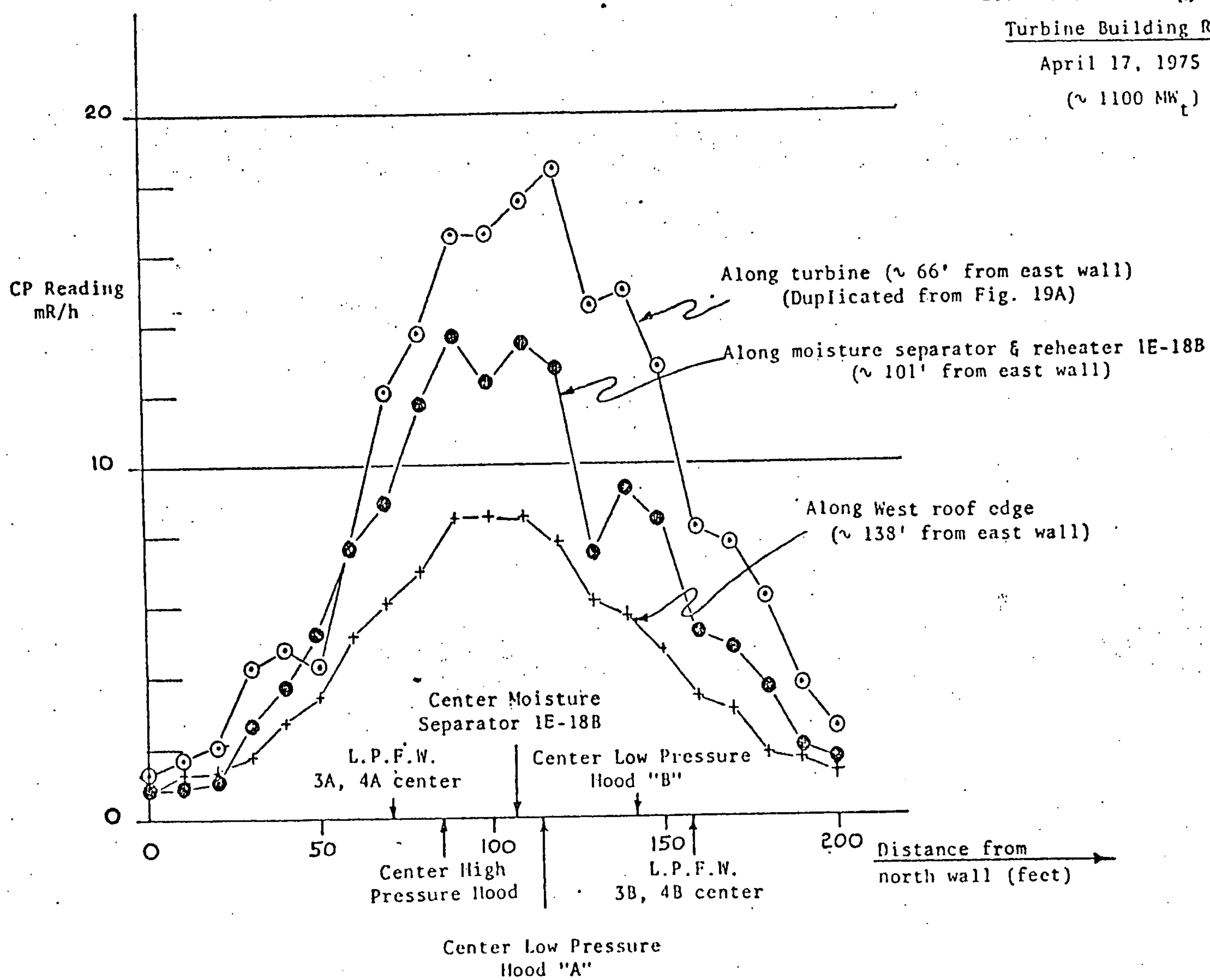
Figure 19B

Duane Arnold Energy Center

Turbine Building Roof

April 17, 1975

(~ 1100 MW_t)



ACKNOWLEDGMENTS

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The authors would also like to express their appreciation to the ERDA/HASL team (W. Lowder, P. Raft, G. Burke, and M. Boyl) for their invaluable collaborative effort in the environmental radiation measurement program and for the instrument and TLD intercomparison measurements. Their measurement data and the many hours of useful discussions of measurement techniques and data interpretation were instrumental in the interpretation of our (GE) data and in the preparation of this report.

APPENDIX A

RECEIVED
JUN 16 1975
H. R. HELMHOLZ

^{16}N Radiation Survey at the Duane Arnold Energy Center Unit 1, April 16-20, 1975

Arnold is a load-following 1600 MWt nuclear power plant that was operating between 35 and 75% power during the survey. Power control was accomplished by recirculation flow adjustments, with few rod movements. Field measurements were necessarily made at different times, and, therefore, at different power levels. Normalization to a constant power (1000 MWt) was accomplished by relating all measurements to the simultaneous readings of a continuously-monitoring ionization chamber placed about 50 meters north of the turbine building. The ^{16}N levels at maximum power would be about a factor of two higher (2.34 x, if no rod adjustments were necessary).

The ^{16}N levels at the outdoor locations listed in the table were inferred by subtracting a cosmic ray background of 3.9 μR/h from the total ion chamber reading and inferring the gamma background from the indicated spectrometric measurements or from ion chamber readings after plant shutdown on 4/19. The distances given are referred to the respective walls of the turbine building. The center line of the turbine axis is 19m inside the east wall, and the centers of the moisture separators are 31 and 36 in. from the north wall and 9 and 30m from the east wall, respectively.

The difference between the two dose profiles shown in the figure can be partly explained by the different spectral shapes in the two directions. Significant 6.13 MeV total absorption peaks were noted at the northerly locations, indicating possibly incomplete line-of-sight shielding from turbine room sources. Some primary photons were noted in the easterly direction, but to a much lesser extent. The relative hardness of the Arnold spectra relative to those obtained at Oyster Creek (no side shielding of turbine building) can be roughly quantitated as follows: the total energy deposited in the 4 x 4 - in. NaI detector by ^{16}N photons producing counts above 3.4 MeV per unit air dose rate (μrad/h) was 1.43 GeV/min at Oyster Creek, 0.86 GeV/min at Arnold (north), and 0.34 GeV/min at Arnold (east), all at ~ 300 meters from the turbine building.

Also tabulated are in-plant intercomparisons of the responses of several types of dosimeters. The measurement under the steam lines and on the turbine room floor involve exposures to fields with differing spectra. A very strong high energy component would be expected at all but the last turbine room measurement, which was made behind concrete shielding. No power level normalization was done for these readings, except to correct the large ion chamber readings to render them consistent with the mean power level of the exposure period for the passive detectors.

Survey Data - Arnold Plant

Distance (meters)	Detector	Gamma Air Dose Rate ("μR"/h) ^{40}K	u	Th	^{137}Cs	Total	^{16}N	1000 MWt ^{16}N Dose (mrad/y)
East Axis								
11	IC					44.1	41.9	260
56	IC					50.4	48:	298
68	IC					31.5	29.2	193
80	IC					20.4	18.1	115
95	IC					15.8	13.4	88
134	IC					11.2	7.9	52
	Ge(Li)	1.7	0.7	1.0	0.02	(3.4)	-	
	NaI	1.4	0.7	0.9	-	(3.1)	-	
165	IC					8.3	5.6	37
	NaI	1.4	0.5	0.7	-	(2.7)	-	
229	IC					6.4	2.7	18
	Ge(Li)	1.6	0.9	1.1	0.1	(3.7)	-	
288	IC					5.9	2.0	13
	Ge(Li)	1.6	0.9	1.3	0.2	(4.0)		
	NaI	1.5	1.0	1.2	-	(3.8)		
457	IC					4.6	1.0	6.7
	Ge(Li)	1.7	0.8	1.1	0.2	(3.8)		
	NaI	1.4	0.6	1.1	0.2	(3.3)		
488	IC					4.5	0.7:	5:

Distance (meters)	Detector	Gamma Air Dose Rate ("μR"/h) ^{40}K	u	Th	^{137}Cs	Total	^{16}N	1000 MWt ^{16}N Dose (mrad/y)
North Axis								
9	IC					30.5	~ 28	235
30	IC					24.8	22.5	189
46	IC					21.3	19.0	150
201	IC					7.1	5.1	59
	Ge(Li)	0.9	0.7	0.5	~ 0	(2.1)		
	NaI	0.7	0.4	0.5	-	(1.6)		
302	IC					6.2	2.5	28
	Ge(Li)	1.6	1.0	1.3	0.1	(3.9)		
	NaI	1.3	0.6	1.1	-	(3.1)		
347	IC					6.0	-	-
393	IC					6.0	1.7:	20
	NaI	1.6	0.9	1.4	-	(4.0)		
503	IC					5.7	0.5	6
	Ge(Li)	1.8	1.6	1.8	0.1	(5.2)		
South Axis								
13	IC					8.0	5:	106:
23	IC					11.4	8:	104:
123	IC					6.6	3:	38:
217	IC					4.9	1.6	20
	Ge(Li)	1.6	1.0	0.8	~ 0	(3.4)		
	NaI	1.7	0.6	0.6	-	(3.0)		

In-Plant Intercomparison Data - Arnold

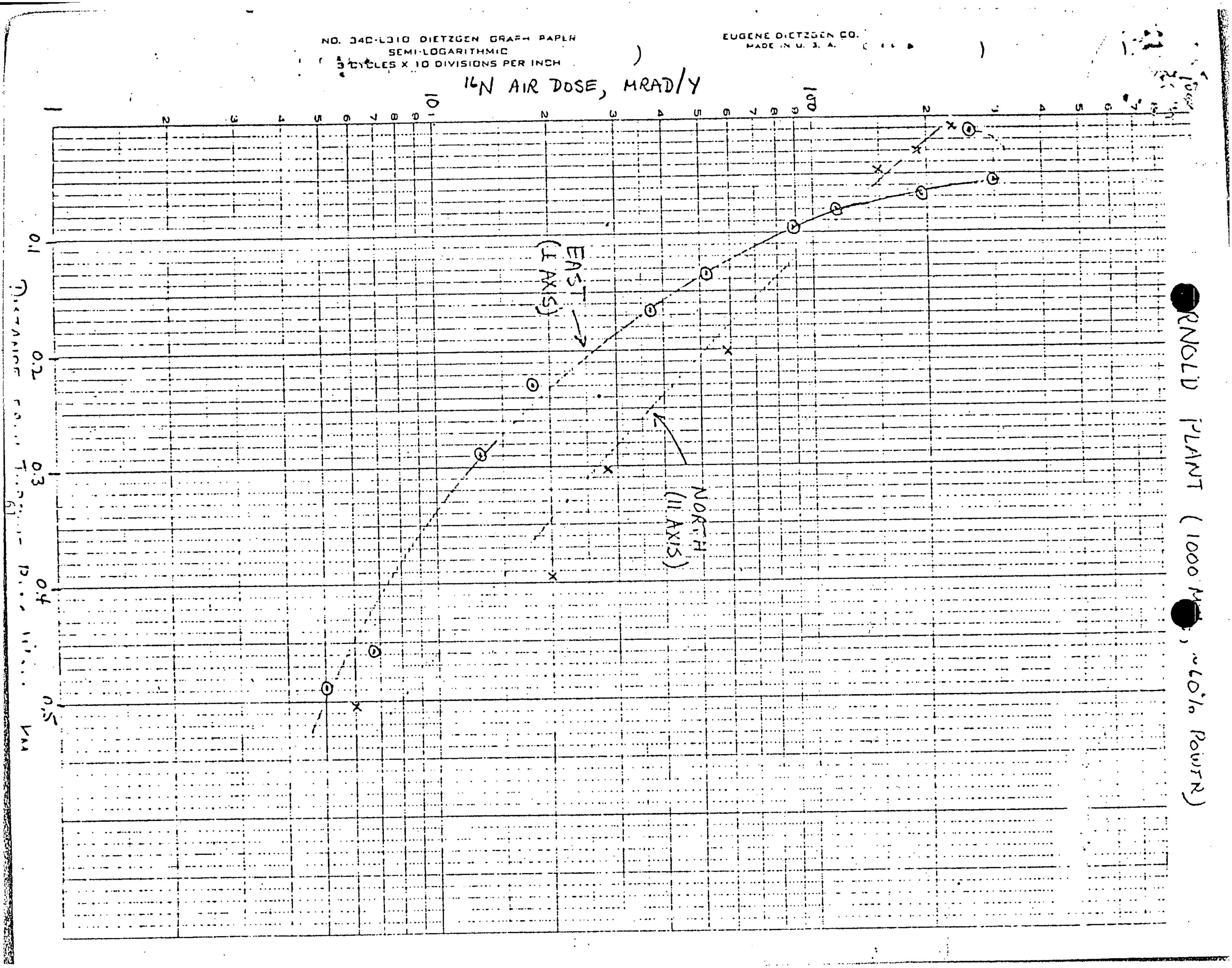
^{16}N Dose Rate (mrad/h)

Location \ Detector	LiF	CaF_2:Mn	Pocket Ion Chamber	HASL † Ion Chamber
Steam Lines				
Floor	202	248	190	
Middle (50" from lines)	421	504	360	
Top (10.5" from lines)	689	877	650	
Turbine Floor				
A,C *	15.6	20.0	14	16.6
B,D *	13.4	16.9	12	14.8
E **	1.71	2.10		1.99

* Locations A,C and B,D were in direct line with the moisture separators.

** Location E was behind an ~ 18" concrete shielding wall next to the moisture separator.

† Ion chamber dose rates are normalized for the average power level during the TLD-pocket chamber measurement periods.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PLANT
POWER)