Vice President

Consolidated Edison Company of New York, Inc.
4 Irving Place, New York, N Y 10003
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January 20, 1977

Mr. James P. O'Reilly, Director
Region 1
Office of Inspection
U.S. Nuclear Regulatory Commission
631 Park Avenue
King of Prussia, Pennsylvania 19406

Dear Mr. O'Reilly:

On October 19, 1976, Con Edison submitted a technical report concerning an extremity exposure event which occurred on May 24, 1976 during the replacement of the fixed incore detectors at Indian Point Unit No. 2. This incident has been reanalyzed using Monte Carlo shielding techniques and detailed activation analyses. The enclosed technical report describes the methods and techniques used in this reanalysis.

Should you have any questions or wish to discuss this matter further, please call me.

Very truly yours,

William J. Cahill, Jr.

William J. Cahill, Jr.
Vice President

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EXTREMITY EXPOSURE INCIDENT DURING FIXED THIMBLE REMOVAL PROCESS - DOSE ESTIMATION USING MONTE CARLO TECHNIQUES AND DETAILED ACTIVATION ANALYSES

Summary

By letter dated October 19, 1976, Con Edison reported to the NRC, based on point kernel type shielding calculations and conservative activation analysis, that the extremity exposure incident of May 24, 1976 resulted in an estimated (gamma) radiation dose of some 7.5-9 rem to the hand of the exposed individual. Because of the inability of point kernel type methods to accurately predict gamma fluxes at distances close to the source, and the consequent uncertainty associated with use of this technique, a reanalysis of this incident was performed utilizing Monte Carlo techniques. In addition, activation analyses were performed using the Oak Ridge National Laboratory (ORNL) code ORIGEN, to estimate, as accurately as possible, the actual activation source strength of the thimble.

The (gamma) radiation dose estimated by these calculations is 10.8 rem to the hand.

Introduction

Monte Carlo calculations were selected for calculating the radiation dose per source photon because of the "exact" nature of the solution provided and the ability of this technique to consider the actual geometrical configuration of the situation. These calculations were performed for Con Edison by Mathematical Applications Group, Inc. (MAGI); a copy of the report submitted by MAGI to Con Edison is attached as Appendix 1. Source term recalculation was performed subsequent to the Monte Carlo calculations; consequently, the MAGI report presents estimation of dose on a per source photon basis by energy in addition to an estimate of the dose based on the preliminary, overly conservative source strength previously used.

The ORIGEN Code was selected for use in the activation calculations because of the suitability of this code for treating the highly time dependent irradiation history of an operating reactor and the separate presentation by source (i.e., fission products, materials of construction, or actinides) of the generated nuclides. Thus, the concentration of isotopes produced by activation of a stainless steel thimble can be listed separately from those pro-

duced in fission and directly retrieved for use in estimating gamma source strengths.

Discussion

Appendix 1 describes the model and techniques used by MAGI to perform the Monte Carlo calculations. A further description of the use of and inputs to the ORIGEN code will be presented in the section together with the details of the results obtained by merging the Monte Carlo and ORIGEN results.

A. Irradiation History

The power operating history of the Indian Point Unit No. 2 reactor was compiled from the Unit No. 2 monthly operating reports from initial power operation in 1973 to March 30, 1976, the date of shutdown for refueling. Total MWth-hrs produced during the different months were divided by the number of hours the generator was on line to obtain the average power level in thermal megawatts during the period under consideration. Offline days during an interval were considered as occurring during their actual dates, or, where more convenient, at the start of the subject interval. Outages of less than five days were not considered. Table I presents the results of this compilation, which can be seen to consist of thirty irradiation (or outage) intervals.

For purposes of providing input to ORIGEN, power levels during each interval were divided by the total charge of Uranium (87.13 metric tons) to obtain the specific power in MWth/MTU. Specific powers (in MWt/MTU) for each of the 30 intervals and the duration of each interval were provided as input to ORIGEN.

B. Materials of Thimble and Fuel

For simplicity, the material considered to be subject to activation by irradiation was the volume of a single twelve foot (= fuel stack height) length of thimble. The activity of the thimble, as calculated by ORIGEN, was divided by six to obtain the activity of a single two foot length.

Table II presents, by region, data taken from WCAP-8141 for the initial Indian Point Unit No. 2 fuel loading. These data were converted for each Uranium isotope from kg to gm-atoms per MTU and used as input to ORIGEN.

ORIGEN was used to compute the radioactivity of the irradiated thimble for the fuel composition and irradiation history outlined herein. Postirradiation properties were also computed for a decay time of 54 days after shutdown, which is when the incident occurred. Table III is a copy of part of the output of ORIGEN for the case under consideration. This table presents by isotope the activity of one twelve foot thimble length at shutdown and at times of 5.0 and 54.0 days after shutdown.

C. Calculation of Radiation Dose

Table 3 of Appendix 1 presents uncollided and total (i.e., buildup) doses in rad/hr per source γ/sec for the principal photon energies encountered. Since the relationship between dose and source γ-energy is approximately linear for the case under consideration (see Figure 2 of Appendix 1), dose rates per source γ for other energies were obtained by simple linear interpolation.

Table IV details the calculations used in arriving at a source term, S, in γ/sec for the two foot thimble length.

Table V tabulates the intermediate calculations performed to merge the ORIGEN predicted source strengths with the Monte Carlo computation of dose per source photon and arrive at the total (gamma) dose to the hand. It should be noted that all isotopes having less than 0.01 Curie in the 2 foot thimble length were neglected, since they do not contribute significantly to the radiation dose received. For the same reason, the 0.143 MEV gamma emitted by Fe-59 and the 0.23 MEV (max) internal bremsstrahlung spectrum emitted by Fe-55 were also neglected. For the average burnup assembly (16,387 MWD/MTU) these calculations indicate a gamma dose of 9.64 Rem. Since burnup in the fuel assembly (E-11) containing the thimble was somewhat higher (18,340 MWD/MTU) than the core average, the estimated gamma dose to the hand, after correction for burnup, is 10.8 Rem.

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LOCATION INDIAN POINT UNIT 2.

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TABLE I

SUMMARY OF I.P.2 POWER OPERATING HISTORY 1973-1974

OD	GROSS MWt-hr	# HRS. ON OR DEF LINE	# HRS OFF OR DEF LINE	$\bar{P}$ (MWt)	$\bar{P}$ MTH	INTERVAL #
1/13/73	1,473,000	772	32.17	1908	21.90	1
12/31	0	1152	128	0	0	2
3/1/74	0	1920		0	0	
3/31	280,410	220.25	9.18	1273	14.61	3
4/10	0	240	10	0	0	4
4/30	318,226	441.	18.38	1855.	21.29	5
5/10	0	240	10	0	0	6
5/31	726,634	412.75	17.20	1760.6	20.2	7
6/30	1,312,800	595.4	24.81	2205	25.31	8
7/6	0	144	6.0	0	0	9
7/31	1,316,545	552.75	23.03	2382	27.34	10
8/6	0	144.	6.0	0	0	11
8/31	1,230,534	552.5	23.02	2227.2	25.56	12
9/30	1,235,378	580.	24.17	2130	24.45	13
10/11	0	264.	11.	0	0	14
10/31	1,279,567	453.8	20.03	2661.	30.54	15
11/30	1,427,937	630.3	26.26	2265	26.00	16
12/31	1,790,241	689.3	↓	2597	29.81	17

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TABLE I

SUMMARY OF I.P.2 POWER OPERATING HISTORY 1975

	GROSS MWh-hr	# HRS ON OR OFF LINE	# DAYS ON OR OFF LINE ↓	P. MWh	P. MTU	INTERVAL # ↓
1975	1,518,906	584.8	78.79	2597	29.81	17
5	1,603,340	616.7		2600	29.84	
	0	744.	36.0	0	0	18
	0	120.		0	0	
0	1,355,952	568.75	23.70	2384	27.36	19
31	1,814,455	683.17	58.97	2659	30.52	20
0	1,824,902	684.05		2668	30.62	
	1,641,458	628.2	26.18	2613	27.99	21
0	0	312	13.	0	0	22
	975,631	403.5	16.81	2418	2775	23
	1,459,794	651.47	27.14	2241.	25.72	24
4	0	336	14	0	0	25
11	905,306	372.53	15.52	2439	27.89	26
	1,509,221	643.83	26.83	2344	26.90	27
	1,840,706	713.43	29.73	2580.	29.61	28

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LOCATION INDIAN POINT UNIT 2.

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SUMMARY OF I.P.2 POWER OPERATING HISTORY 1976

D	GROSS MWt-hr	# HRS ON OR OFF LINE	# HRS ON OR OFF LINE	P̄ MWt	P̄ MTU		INTERVAL #
28	1,588,771	621.83	49.02	2555	29.32		29
29	1,471,068	576.25		2553	29.30		
30	1,565,758	689.25	28.72	2707	31.07		30

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LOCATION INDIAN POINT UNIT TWO

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TABLE II

INDIAN POINT UNIT 2 INITIAL FUEL LOADINGS

Loading (MT)		W/O 235U	KG/MTU U-234	MT U-234	KG/MTU U-235	KG U-235	KG/MTU U-236	MT U-236	KG/MTU U-238	MT U-238
29.58		2.21	0.12	3.55×10^{-3}	22.12	654.31	0.17	5.03×10^{-3}	977.59	28.92
28.82		2.80	0.30	5.76×10^{-3}	28.00	806.96	0.15	4.32×10^{-3}	971.64	28.02
28.73		3.30	0.30	6.62×10^{-3}	33.00	948.09	0.21	6.03×10^{-3}	965.48	27.77
87.13	MTU			17.93×10^{-3}		2.41		15.38×10^{-3}		84.71

POWER= 25.26MW, BURNUP= 16367.MWD, FLUX= 2.65E+13/CM**2-SEC

NUCLIDE RADIOACTIVITY, CURIES
BASIS = VOLUME OF ONE TWELVE FOOT THIMBLE LENGTH

		INITIAL	5. D	5Y. D
H	1	0.0	0.0	0.0
H	2	0.0	0.0	0.0
H	3	5.12E-10	5.12E-10	5.08E-10
H	4	0.0	0.0	0.0
H	5	0.0	0.0	0.0
H	6	0.0	0.0	0.0
H	7	0.0	0.0	0.0
L	6	0.0	0.0	0.0
L	7	0.0	0.0	0.0
L	8	0.0	0.0	0.0
L	9	0.0	0.0	0.0
L	10	0.0	0.0	0.0
L	11	0.0	0.0	0.0
B	10	0.0	0.0	0.0
B	11	0.0	0.0	0.0
B	12	0.0	0.0	0.0
C	12	0.0	0.0	0.0
C	13	0.0	0.0	0.0
C	14	0.0	0.0	0.0
N	13	0.0	0.0	0.0
N	14	0.0	0.0	0.0
N	15	0.0	0.0	0.0
N	16	0.0	0.0	0.0
O	16	0.0	0.0	0.0
O	17	0.0	0.0	0.0
O	18	0.0	0.0	0.0
O	19	0.0	0.0	0.0
F	19	0.0	0.0	0.0
F	20	0.0	0.0	0.0
F	20	0.0	0.0	0.0
NE	21	0.0	0.0	0.0
NE	22	0.0	0.0	0.0
NE	23	0.0	0.0	0.0
NA	22	0.0	0.0	0.0
NA	23	0.0	0.0	0.0
NA	24	0.0	0.0	0.0
MG	25	0.0	0.0	0.0
MG	26	0.0	0.0	0.0
MG	27	0.0	0.0	0.0
AL	27	0.0	0.0	0.0
AL	28	0.0	0.0	0.0
SI	28	0.0	0.0	0.0
SI	29	0.0	0.0	0.0
SI	30	0.0	0.0	0.0
SI	31	0.0	0.0	0.0
P	31	0.0	0.0	0.0
P	32	0.0	0.0	0.0
P	33	0.0	0.0	0.0

NUCLIDE RADIOACTIVITY, CURIES
BASIS = VOLUME OF ONE TWELVE FOOT THIMBLE LENGTH

	INITIAL	[illegible] D	[illegible] D
F [illegible]	0.0	0.0	0.0
[illegible]	0.0	0.0	0.0
[illegible] 33	0.0	0.0	0.0
[illegible]	0.0	0.0	0.0
[illegible]	0.0	0.0	0.0
[illegible] 35	0.0	0.0	0.0
[illegible] 37	0.0	0.0	0.0
CL [illegible]	0.0	0.0	0.0
CL [illegible]	0.0	0.0	0.0
CL [illegible]	0.0	0.0	0.0
CL [illegible]	0.0	0.0	0.0
AR [illegible]	0.0	0.0	0.0
AR [illegible]	0.0	0.0	0.0
AR [illegible]	0.0	0.0	0.0
AR [illegible]	0.0	0.0	0.0
AR [illegible]	0.0	0.0	0.0
K [illegible]	7.93E-14	1.44E-33	0.0
K [illegible]	0.0	0.0	0.0
K [illegible]	0.0	0.0	0.0
K [illegible]	0.0	0.0	0.0
K [illegible]	2.57E-17	-1.47E-17	0.0
K [illegible]	8.21E-22	8.21E-22	1.29E-37
[illegible]	1.81E-13	0.0	0.0
CA [illegible]	0.0	0.0	0.0
CA [illegible]	0.0	0.0	0.0
CA [illegible]	0.0	0.0	0.0
CA [illegible]	0.0	0.0	0.0
CA [illegible]	0.0	0.0	0.0
CA 47	1.10E-12	1.00E-12	6.76E-13
CA 48	0.0	0.0	0.0
CA 49	1.28E-09	5.94E-10	3.29E-13
CA 49	0.0	0.0	0.0
CA 49	0.0	0.0	0.0
SC [illegible]	0.0	0.0	0.0
SC [illegible]	4.53E-15	4.49E-15	2.99E-15
SC 47	6.48E-06	2.35E-06	1.19E-10
SC 48	8.02E-06	1.21E-06	1.05E-14
SC 49	1.50E-05	0.0	0.0
SC 50	1.53E-07	0.0	0.0
TI [illegible]	0.0	0.0	0.0
TI 47	0.0	0.0	0.0
TI 48	0.0	0.0	0.0
TI [illegible]	0.0	0.0	0.0
TI [illegible]	0.0	0.0	0.0
TI 51	4.63E-05	0.0	0.0
V [illegible]	0.0	0.0	0.0
V 50	0.0	0.0	0.0
V 51	0.0	0.0	0.0
V 52	6.08E+00	0.0	0.0
V 53	3.65E-02	0.0	0.0
V 54	3.65E-04	0.0	0.0
CR 50	0.0	0.0	0.0

POWER= 25.50MW, BURNUP= 1.387.MWD, FLUX= 2.35E+13N/CM**2-SEC

NUCLIDE RADIOACTIVITY, CURIES
BASIS = VOLUME OF ONE TWELVE FOOT THIMBLE LENGTH

	INITIAL	2. 0	54. 0
CS 51	8.37E+02	7.34E+02	2.18E+02
CS 52	0.0	0.0	0.0
CS 53	0.0	0.0	0.0
CS 54	0.0	0.0	0.0
CS 55	1.17E+01	0.0	0.0
BA 54	3.40E+01	3.36E+01	3.00E+01
BA 55	0.0	0.0	0.0
BA 56	1.97E+01	1.96E-13	0.0
BA 57	1.38E-01	0.0	0.0
BA 58	4.64E-04	0.0	0.0
LA 54	0.0	0.0	0.0
LA 55	2.26E+02	2.27E+02	2.19E+02
LA 56	0.0	0.0	0.0
LA 57	0.0	0.0	0.0
LA 58	0.0	0.0	0.0
LA 59	2.55E+01	2.54E+01	1.10E+01
CE 58M	0.0	0.0	0.0
CE 56	1.05E+02	1.03E+02	8.40E+01
CE 57	0.0	0.0	0.0
CE 60M	1.33E+02	0.0	0.0
CE 60	4.15E+01	4.15E+01	4.08E+01
CE 61	1.43E+00	0.0	0.0
CE 62	8.00E-05	0.0	0.0
PR 58	0.0	0.0	0.0
PR 59	2.54E-02	2.54E-02	2.54E-02
PR 60	0.0	0.0	0.0
PR 61	0.0	0.0	0.0
PR 62	0.0	0.0	0.0
PR 63	4.01E+00	4.01E+00	4.01E+00
PR 64	0.0	0.0	0.0
PR 65	1.13E+01	6.77E-14	0.0
CE 62	0.0	0.0	0.0
CE 63	0.0	0.0	0.0
CE 64	1.03E-03	2.41E-05	0.0
CE 65	0.0	0.0	0.0
CE 66	3.64E-02	0.0	0.0
ND 63	0.0	0.0	0.0
ND 64	0.0	0.0	0.0
ND 65	5.38E-07	5.30E-07	4.62E-07
ND 66	0.0	0.0	0.0
ND 67	0.0	0.0	0.0
ND 68	0.0	0.0	0.0
ND 69M	0.0	0.0	0.0
ND 69	0.0	0.0	0.0
ND 70	0.0	0.0	0.0
ND 71M	0.0	0.0	0.0
ND 71	0.0	0.0	0.0
PM 69	0.0	0.0	0.0
PM 70	0.0	0.0	0.0
PM 71	0.0	0.0	0.0
PM 72	0.0	0.0	0.0
PM 73	0.0	0.0	0.0

POWER= 25.58MW, BURNUP= 16387.MWD, FLUX= 2.64E+13N/CM**2-SEC

NUCLIDE RADIOACTIVITY, CURIES
BASIS = VOLUME OF ONE TWELVE FOOT THIMBLE LENGTH

	INITIAL	5. D	54. D
SR 89	0.0	0.0	0.0
SR 90	0.0	0.0	0.0
SR 91	0.0	0.0	0.0
Y 90M	0.0	0.0	0.0
Y 90	0.0	0.0	0.0
Y 91M	0.0	0.0	0.0
Y 91	0.0	0.0	0.0
ZR 90	0.0	0.0	0.0
ZR 91	0.0	0.0	0.0
ZR 92	0.0	0.0	0.0
ZR 93	0.0	0.0	0.0
ZR 95	0.0	0.0	0.0
ZR 96	0.0	0.0	0.0
NB 92	0.0	0.0	0.0
NB 93M	0.0	0.0	0.0
NB 95	0.0	0.0	0.0
NB 96	0.0	0.0	0.0
NB 97	0.0	0.0	0.0
MO 96	0.0	0.0	0.0
MO 97	0.0	0.0	0.0
MO 98	0.0	0.0	0.0
MO 99	0.0	0.0	0.0
MO100	0.0	0.0	0.0
MO101	0.0	0.0	0.0
TC 99M	0.0	0.0	0.0
TC 99	0.0	0.0	0.0
TC101	0.0	0.0	0.0
RU101	0.0	0.0	0.0
CD115M	0.0	0.0	0.0
CD115	0.0	0.0	0.0
CD119M	0.0	0.0	0.0
CD119	0.0	0.0	0.0
CD121	0.0	0.0	0.0
IN113	0.0	0.0	0.0
IN115M	0.0	0.0	0.0
IN119	0.0	0.0	0.0
IN121M	0.0	0.0	0.0
IN121	0.0	0.0	0.0
SN113	0.0	0.0	0.0
SN115	0.0	0.0	0.0
SN116	0.0	0.0	0.0
SN117M	0.0	0.0	0.0

POWER= 25.50MW, BURNUP= 16587.9MD, FLUX= 2.64E+13N/CM**2-SEC

NUCLIDE RADIOACTIVITY, CURIES
BASIS = VOLUME OF ONE TWELVE FOOT THIMBLE LENGTH

	INITIAL	5. D	54. D
SB117	0.0	0.0	0.0
SB118	0.0	0.0	0.0
SB118M	0.0	0.0	0.0
SB119	0.0	0.0	0.0
SB120	0.0	0.0	0.0
SB120M	0.0	0.0	0.0
SB121	0.0	0.0	0.0
SB122	0.0	0.0	0.0
SB122M	0.0	0.0	0.0
SB123	0.0	0.0	0.0
SB124	0.0	0.0	0.0
SB124M	0.0	0.0	0.0
SB125	0.0	0.0	0.0
TE121	0.0	0.0	0.0
TE123	0.0	0.0	0.0
TE123M	0.0	0.0	0.0
TE125	0.0	0.0	0.0
TE125M	0.0	0.0	0.0
TE127	0.0	0.0	0.0
TE127M	0.0	0.0	0.0
TE128	0.0	0.0	0.0
TE129	0.0	0.0	0.0
TE129M	0.0	0.0	0.0
TE130	0.0	0.0	0.0
TE131	0.0	0.0	0.0
TE131M	0.0	0.0	0.0
TE132	0.0	0.0	0.0
I131	0.0	0.0	0.0
I132	0.0	0.0	0.0
I133	0.0	0.0	0.0
I134	0.0	0.0	0.0
I135	0.0	0.0	0.0
XE131M	0.0	0.0	0.0
XE133	0.0	0.0	0.0
XE133M	0.0	0.0	0.0
XE135	0.0	0.0	0.0
XE135M	0.0	0.0	0.0
XE137	0.0	0.0	0.0
XE138	0.0	0.0	0.0
CS134	0.0	0.0	0.0
CS135	0.0	0.0	0.0
CS136	0.0	0.0	0.0
CS137	0.0	0.0	0.0
CS138	0.0	0.0	0.0
TOTAL	1.46E+03	1.17E+03	5.87E+02

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LOCATION INDIAN POINT UNIT 2.

TABLE IV

SOURCE TERM CALCULATIONS USING ORIGEN ACTIVITY ESTIMATES

NUCLIDE	$\frac{C_i}{12'}$	$\frac{C_i}{2'}$	E_β (MEV/γ)	$\bar{f}$ (γ/dis)	A (dis/sec)	S (γ/sec)
51	218.	36.33	0.32	0.09	1.34×10^{12}	1.21×10^{11}
54	30.0	5.0	0.835	1.0	1.85×10^{11}	1.85×10^{11}
89	11.0	1.83	0.192	0.028	6.77×10^{10}	1.90×10^{9}
	↓	↓	1.095	0.56	↓	3.79×10^{10}
			1.292	0.44		2.98×10^{10}
	64.0	10.67	0.511	0.30	3.95×10^{11}	1.19×10^{11}
	↓	↓	0.810	0.99	↓	3.91×10^{11}
			0.865	0.014		5.53×10^{9}
			1.67	0.006		2.37×10^{9}
	40.8	6.8	1.172	1.0	2.52×10^{11}	2.52×10^{11}
	↓	↓	1.332	1.0	↓	2.52×10^{11}
3	4.01	0.668	No γ	No γ	2.47×10^{10}	No γ

DATA SHEET

PREPARED BY

SUBJECT

DATE 1/10/77

LOCAT POINT BEACH UNIT 2.

TABLE V

DOSE ESTIMATION FROM MERGER OF MONTE CARLO AND ORIGEN RESULTS

LOC	E_γ (MEV/γ)	S * (γ/sec)	$\left(\frac{R/Hr}{\gamma/sec}\right)$ **	D_R (R/HR)	D_S (R/10 sec)
-57	0.32	1.21×10^{11}	3.33×10^{-12}	101.40	0.282
-54	0.835	1.55×10^{11}	2.66×10^{-9}	418.10	1.16
-59	0.192	1.93×10^{9}	4.8×10^{-10}	0.912	2.53×10^{-3}
	1.095	3.77×10^{9}	2.91×10^{-9}	110.29	0.306
	1.292	2.83×10^{9}	3.92×10^{-9}	101.92	0.283
-58	0.511	1.19×10^{11}	6.44×10^{-9}	171.36	0.476
	0.810	3.91×10^{11}	2.30×10^{-9}	830.20	2.309
	0.865	5.53×10^{9}	2.23×10^{-9}	12.33	0.034
	1.67	2.37×10^{9}	4.32×10^{-9}	10.24	0.028
-60	1.172	2.52×10^{11}	3.07×10^{-9}	773.64	2.149
	1.332	2.52×10^{11}	3.62×10^{-9}	912.24	2.534
				3472.6 R/HR	9.64 R/10 sec

Boundary Correction

$D_S = 9.64 + \frac{18.3\%}{100\%} \Rightarrow D_S = 11.4$ R/...

* Derived from ORIGEN Computation (see Table IV)

** Results of Monte Carlo Computation (see Table 3 of MAGI Report)

APPENDIX 1

MATHEMATICAL APPLICATIONS GROUP, INC.
3 WESTCHESTER PLAZA
ELMSFORD, N.Y. 10523
TEL. (914) 592 • 4646

December 29, 1976
M-8276
P-7145

Mr. Kenneth Eccleston
Nuclear Engineering Subsection
Nuclear and Emission Control
Engineering Department
Consolidated Edison Co. of N. Y., Inc.
4 Irving Place
New York, N. Y. 10003

Dear Mr. Eccleston:

Enclosed please find the final report summarizing the calculational program performed by MAGI under Consolidated Edison Company purchase order #6-8208.

Please contact me if there are any questions concerning the report or if I can be of further assistance.

Very truly yours,

Martin O. Cohen

Martin O. Cohen
Manager
Nuclear Applications

MOC/ae
Enc.

MAGI PROJECT 7145

DOSE DELIVERED TO THE HAND

OF

ON

24 MAY 1976

Mathematical Applications Group, Inc.
3 Westchester Plaza
Elmsford, New York, N. Y. 10523

1. INTRODUCTION

Mathematical Applications Group, Inc. (MAGI) has performed a series of Monte Carlo calculations for the Consolidated Edison Company (Con Ed), to assess the biological dose delivered to the hand of during the incident of 24 May 1976 at the Indian Point No. 2 facility.

The sections which follow describe the calculations performed and the results achieved.

2. GEOMETRIC CONFIGURATION

The geometry used in the Monte Carlo calculations was as shown in Figure 1.

A stainless steel rod (OD=.385", ID=.268") protrudes 2' from a water bath. At the 1' level, the rod is surrounded by a gloved hand. The hand is 4" high (OD=3", ID=.4546") and is completely enclosed by the glove which is .0348" thick.

The hand is assumed to be tissue. The final results are not sensitive to the dimensions of the hand, since the hand is "optically thin"; i.e., doubling the hand volume would essentially double the neutron path lengths (and thus the flux) thereby leaving the energy deposition per unit volume unchanged. The glove has no appreciable effect upon the gamma radiation and has only the slight geometric effect of displacing the hand by 0.0348" from the rod. For convenience, the glove was given the same chemical composition as water.

The atomic concentrations of the stainless steel rod and the hand are given in Table 1.

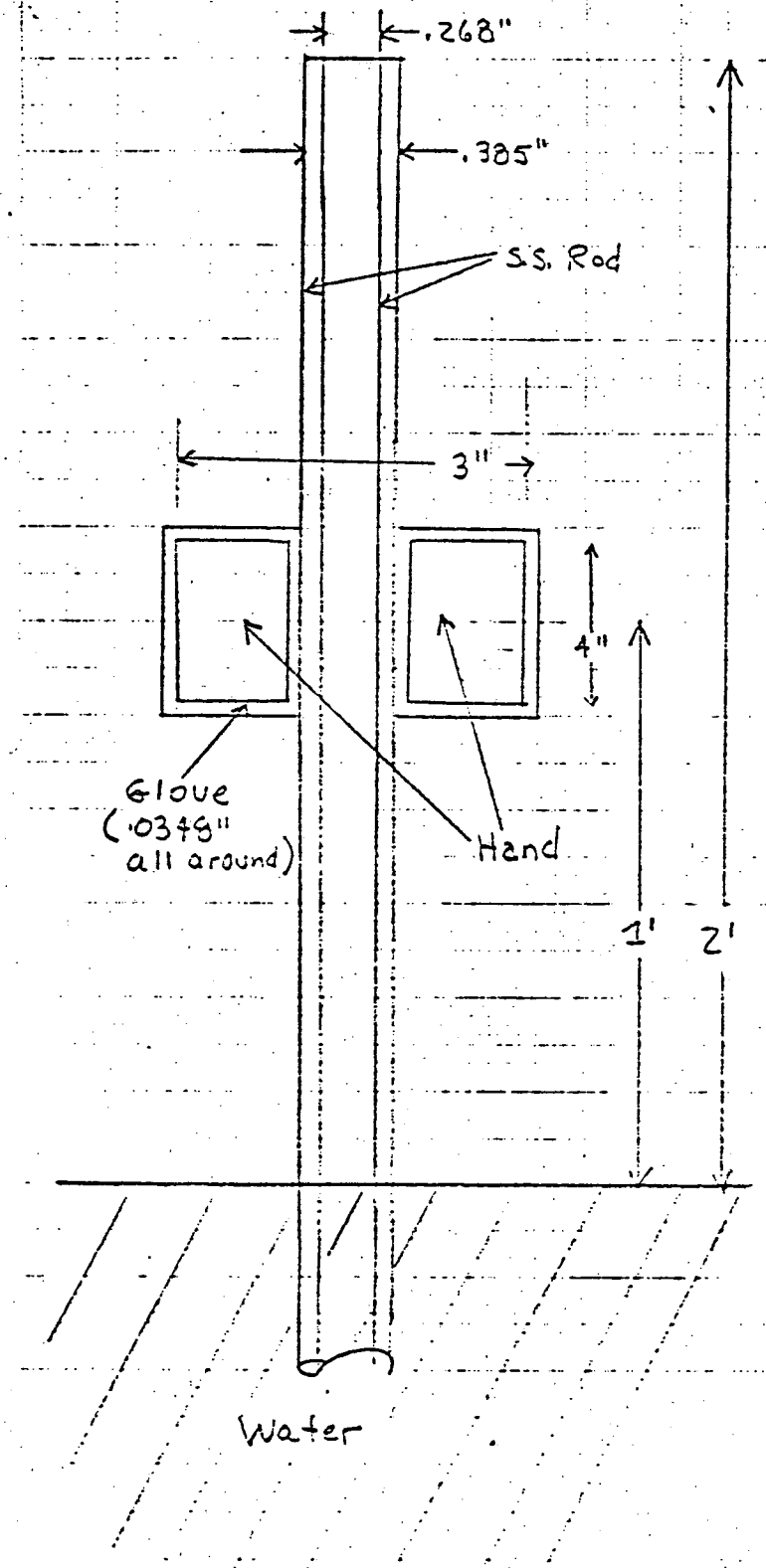


Figure 1

GEOMETRIC CONFIGURATION
(not to scale)

TABLE 1

ATOMIC CONCENTRATIONS

MATERIAL	NUCLIDE	ATOMIC DENSITY (atoms/barn·cm)
Stainless Steel	Iron	0.06175
Stainless Steel	Chromium	0.01676
Stainless Steel	Nickel	0.00882
Tissue	Hydrogen	0.0598
Tissue	Oxygen	0.0245
Tissue	Carbon	0.00903
Tissue	Nitrogen	0.00129

3. GAMMA RADIATION SOURCES

It was assumed that the rod was uniformly radioactive. Nine prominent gamma ray lines were identified by Con Ed and these are displayed in Table 2 along with preliminary estimates of the source strength terms (also provided by Con Ed).

Since the source strengths were provided on a preliminary basis only, separate Monte Carlo calculations (see below) were performed for each gamma ray line and the results which were obtained were on a per source particle basis. Subsequently, these results were each folded with the corresponding source strengths, and then summed over all nine lines, to obtain the estimate of the dose to the hand.

TABLE 2

GAMMA RAY SOURCES

GAMMA RAY LINE (MeV)	RADIOACTIVE ISOTOPE	SOURCE STRENGTH* (MeV/cm-sec)
0.19	Fe-59	5.51 + 7**
0.32	Cr-51	1.31 + 10
0.511	Co-58	2.09 + 10
0.81	Co-58	1.11 + 11
1.10	Fe-59	6.07 + 9
1.17	Co-60	1.18 + 10
1.29	Fe-59	5.37 + 9
1.33	Co-60	1.34 + 10
1.64	Co-58	1.12 + 9

*At time 5 days after shutdown

**Read: 5.51×10^7

4. MONTE CARLO CALCULATIONS

Separate calculations were performed with the SAM-CE Monte Carlo code[1] for each of the nine identified gamma ray lines. In order to speed convergence of the Monte Carlo calculations, spatial and angular importance sampling were employed to emphasize those gamma ray histories which intercept the hand.

SAM-CE calculated the flux in the hand, as a function of energy, and then applied an energy-dependent gamma flux-to-tissue dose conversion factor[2] to obtain tissue dose. Both uncollided and total doses were determined for each gamma ray line. The statistical uncertainty of the results were approximately ±5%.

The results are given for each line, in Table 3. They are also plotted, for both uncollided and total dose, in Figure 2 wherein a simple linear relationship between dose and source energy is clearly visible. This will eliminate the need for additional Monte Carlo calculations should other prominent gamma ray lines be identified in the future.

TABLE 3

MONTE CARLO RESULTS

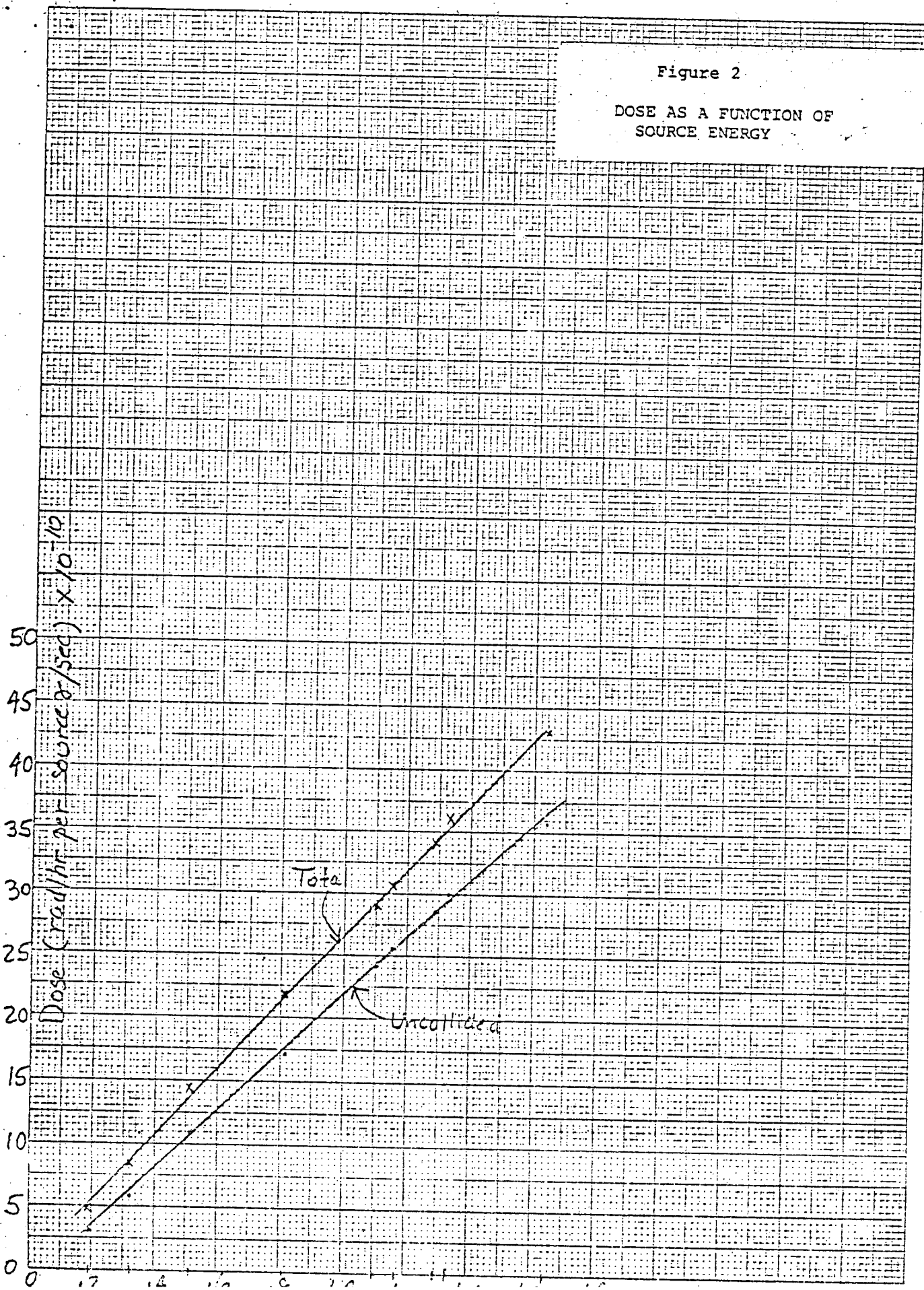
GAMMA RAY LINE (MeV)	DOSE (rad/hr per sourceγ/sec)* Uncollided	Total	RATIO: Uncollided-to-Total
0.19	.301 -9 (5)**	.480 -9 (6)	.63
0.32	.567 -9 (4)	.838 -9 (5)	.68
0.511	.110 -9 (4)	.144 -8 (4)	.76
0.81	.173 -8 (5)	.220 -8 (5)	.79
1.10	.242 -8 (5)	.291 -8 (5)	.83
1.17	.257 -8 (5)	.307 -8 (6)	.84
1.29	.286 -8 (5)	.342 -8 (5)	.82
1.33	.300 -8 (5)	.362 -8 (5)	.83
1.64	.358 -8 (4)	.432 -8 (4)	.83

*Note: Divide by 3600 sec/hr to obtain dose in units of rad/source γ as in Table 4.

**Read: $0.301 \times 10^{-9} \pm 5\%$

Figure 2

DOSE AS A FUNCTION OF SOURCE ENERGY



5. DETERMINATION OF THE HAND DOSE

The source strengths provided by Con Ed, S_ℓ, are in units of MeV/cm·sec at time 5 days after shutdown. These can be converted to the ten-second source strengths, $S_{10\text{-sec}}$ (γ particles), at time 54 days, as follows:

1) Radioactive Decay - The half-life in days, $T_{1/2}$, is given in Table 4 for each line. These are related to the decay constant, λ (days^{-1}) by $\lambda = \ell n\ (2)/T_{1/2}$. The relative source strength at time 54 days is then:

$$S_\ell(54 \text{ days}) = S_\ell(5 \text{ days}) \cdot \exp[-\lambda(54-5)]$$

2) Particle Emission - The conversion of source strength from MeV to source particles is accomplished by a simple $(E_0)^{-1}$ conversion factor, where E_0 is the source energy in MeV.

3) Total Length - Mulitplication by 60.96 cm (2 feet) converts the source strengths from a per centimeter basis to a total length basis.

4) Irradiation Time - It is conservatively assumed that the rod and hand were in the position of Figure 1 during the entire 10 second interval*. Hence, the source strengths per sec are converted to 10-second source strengths by a multiplication factor of 10.

Combining items 1-4, above, the source terms are obtained by:

$$S_{10\text{-sec}}(\text{source photons}) = \frac{S_\ell x e^{-49\lambda}}{E_0} \times 609.6$$

The results are given in Table 4. (The customary unit of biological dose, the rem, is used, where one rad of gamma radiation corresponds to a biological dose of one rem[3]. Hence the rad-to-rem conversion factor is unity).

Table 4 shows that the total 10-second dose to the hand, based upon the preliminary source strengths provided by Con Ed is ∿54 rem. The 0.81 MeV line from Co-58 dominates the problem, accounting for ∿59% of the total dose to the hand.

*Actually, during this 10 second period, the 2 foot section of originally exposed rod was being shoved under water, with the hand probably reaching the water level after about 5 seconds. This will be examined below.

TABLE 4

DOSE TO HAND

GAMMA RAY LINE (MeV)	DOSE PER SOURCE γ (rem/source γ)	$T_{1/2}$ (days)	λ (day^{-1})	$\frac{609.6e^{-49\lambda}}{E_0}$ (cm·sec/MeV)	S_ℓ (MeV/cm·sec)	$S_{10\text{-sec}}$ (source γ)	DOSE TO HAND (rem)
.19	1.33 -13*	44.6	.01554	1498.	5.51 + 7	8.25 + 10	0.01
.32	2.33 -13	27.7	.02502	559.	1.37 + 10	7.66 + 12	1.78
.511	4.00 -13	71.3	.00972	741.	2.09 + 10	1.55 + 13	6.19
.81	6.11 -13	71.3	.00972	467.	1.11 + 11	5.18 + 13	31.67
1.10	8.08 -13	44.6	.01554	259.	6.07 + 9	1.57 + 12	1.27
1.17	8.53 -13	5.27 years	3.60×10^{-4}	512.	1.18 + 10	6.04 + 12	5.15
1.29	9.50 -13	44.6	.01554	221.	5.37 + 9	1.19 + 12	1.13
1.33	1.006 -12	5.27 years	3.60×10^{-4}	450.	1.34 + 10	6.03 + 12	6.07
1.64	1.20 -12	71.3	.00972	231.	1.12 + 9	2.59 + 11	.31

*Read: 1.33×10^{-13}

TOTAL DOSE = 53.58 rem

6. SOURCE GEOMETRIC CONFIGURATION

In order to assess the degree of conservatism provided by assuming that the rod and hand were in the position of Figure 1 for the entire 10 second period, a second set of calculations were run for the point in the time history when the lower part of the hand reached the water level (i.e., the rod protruded 1'2" from the water bath). The results are displayed in Table 5.

It is seen that the dose contributions from the gamma lines below 1 MeV are essentially unchanged. For these softer gamma rays most of the contribution is from the 4" section held by the hand. For the source energies above 1 MeV, lateral contributions (i.e., from other parts of the rod) contribute to the total dose and these are significantly attenuated by the presence of more water.

However, when the results are combined with the preliminary source strengths and summed over all nine gamma lines, the net effect of lowering the rod is a small decrease in the hand dose rate by a factor of $\sim 50.3/53.6 = 0.94$.

If it is assumed that at the end of the ten second period (rod completely under all water) the dose has decreased by an additional factor of 0.94, then the dose at this time would be $\sim$47.2 rem.

Therefore, the best estimate of the 10 second hand dose is of the order of 50 rem. This result can be refined with improved estimates of the source strengths of the identified gamma rays lines.

TABLE 5

EFFECT OF ROD POSITION ON HAND DOSE

GAMMA RAY LINE (MeV)	DOSE (rad/hr per sourceγ/sec) ROD 2' ABOVE WATER	ROD 1'2" ABOVE WATER
0.19	.480 -9 (6)*	.475 -9 (7)
0.32	.838 -9 (5)	.877 -9 (6)
0.511	.144 -8 (4)	.151 -8 (5)
0.81	.220 -8 (5)	.205 -8 (8)
1.10	.291 -8 (5)	.271 -8 (5)
1.17	.307 -8 (6)	.289 -8 (5)
1.29	.342 -8 (5)	.292 -8 (5)
1.33	.362 -8 (5)	.305 -8 (6)
1.64	.432 -8 (4)	.390 -8 (6)
HAND DOSE (Calculations not shown)	53.6 rem	50.3 rem

*Read: $0.480 \times 10^{-9} \pm 6\%$

REFERENCES

1. M. O. Cohen, et al., "SAM-CE: A Three Dimensional Monte Carlo Code for the Solution of the Forward Neutron and Forward and Adjoint Gamma Ray Transport Equations - Revision D", MR-7021, Rev. D (Oct. 1975).

2. B. J. Henderson, "Conversion of Neutron or Gamma Ray Flux to Absorbed Dose Rate", XDC 59-8-179, p. 18 (Aug. 1959).

3. H. Goldstein, "Fundamental Aspects of Reactor Shielding", Addison-Wesley Publishing Co., Inc., p. 27 (1959).