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TITLE: Determination of Reactor Building Dose Rates For Use in the Emergency Operating Procedures. (Quality)

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Objective

The objective of this calculation is to define and determine the radiation levels denoted as maximum normal and maximum safe, as shown in the Secondary Control Containment Control Emergency Operating Proceddure (EO-100/200-104). The maximum normal area radiation level is used to determine when the Secondary Containment Control Procedure is enetered. The maximum safe area radiation level is used to determine when certain operator actions should be initiated.

Methodology

There are several methods available for comparing radiation effects and several standards which may apply. For levels which effect the Emergency Operating Procedures, the judgement is that the standards should be based on site boundary dose because the concern in accidents is protecting the general population from excessive exposure to the effects of radiation.

Dispite the foregoing arguments, there still exist several standards by which Secondary Containment radiation levels could be compared. However, using good, conservative judgement, two standards are defined here which establish the maximum normal and maximum safe levels for use in the Emergency Operating Procedures.

Evaluation of Maximum Normal Radiation Limits

In order to establish the maximum normal condition, the limit determined in Reference 1 is invoked. This guide states that the site boundary at two hours due to an instantaneous release of the radioactive material under average meteorlogical conditions should be one mRem or less. In order to determine the radiological source limits, it is assumed that all of the radioactivity in the room instantaneously becomes a semi-infinite cloud source at the site boundary. The gamma dose rate at the site boundary is given as

$$D_b = 0.25 (\chi / Q) \sum Q_i E_i$$

(Reference 2, Eqn 15B-1)

where χ / Q = atmosheric dilution factor (sec/meter^3)
E_i = average gamma energy for isotope i (MeV/dis)
Q_i = source strength (Curie)
and D_b = gamma dose from semi-infinite cloud (Rem)

The average gamma energy for appropriate isotopes (Noble gasses and Iodines) are given in Reference 2, Table 15B-2. A review of this Table shows that the average energy can be approximated as 1 MeV/dis for the isotopes of interest, hence this approximation will be used for the remainder of the calculation.

The Curie source can be determined from the source strength as

$$C_i = S (\gamma / sec) / (3.7 \times 10^{10}) \text{ dis/(sec-}C_i)$$

where C_i = source strength in Curies
and S = source strength in γ / sec.

The dose equivalent from a point source can be determined from the gamma source strength (flux) as

$$D_{ps} = \frac{S \exp(-\mu x) B(\mu x)}{4 \pi R_s^2} F$$

where μ = attenuation coefficient, cm^{-1}
x = distance equivalent to sphere radius, cm
R_s = radius of sphere equivalent to room volume, cm
F = flux-to-dose conversion factor
= 1.9231×10^{-3} (mRem/hr)/(γ/m^2-sec)
(See Reference 3)

Data for Secondary Containment Room volumes are taken from Reference 4, and are reproduced in Table 1. Since larger volumes give lower allowed radioactivity concentrations and are therefore conservative, only two different volumes will be used to evaluate the radioactivity concentration limits; (1) RHR room B will be used to determine applicable limits for rooms which are internal to Secondary Containment and (2) the volume for HVAC Zone III will be used to evaluate limits for the refueling floor area. The numerical calculations are shown in the Appendix and a summary of results is presented in Table 2.

Evaluation of Maximum Safe Radiation Levels

The evaluation of Maximum Safe radiation level assumes that the radioactivity is confined locally to the room it is released in as a result of the accident. The limiting condition then becomes the dose rate at the plant site exclusion boundary, which for this case, the limits set forth in 40CFR190, 'Environmental Radiation Protection Standards for Nuclear Power Operations', will be used (Reference 5). The limits prescribed in this reference are 25 mRem to the whole body from the Uranium fuel cycle. Since the general public does have some exposure from other portions of the fuel cycle, this requirement is interpreted for the limits required here as an exclusion boundary dose of less than ten percent of the 25 mRem per year or

$$2.5 \text{ mRem / year / 8766 hours / year} = 2.852 \times 10^{-4} \text{ mRem/hr.}$$

It is also assumed that the radiation is contained in rooms that have two foot thick concrete walls, with the exception of the refueling floor where the material is contained by a steel wall of a one-quarter inch thickness. The dose at the exlusion boundary given a dose, D_w, at the outer part of the wall is

$$D_{eb} = (D_w B(\mu x) \exp (-\mu x)) / L$$

where D_{eb} = dose rate at the exlusion boundary, mRem/hr
D_w = dose rate at external wall, mRem/hr
$B(\mu x)$ = buildup factor for air = $1 + \mu x$
μ = attenuation coefficient for air, cm^{-1}
x = attenuation thickness, cm
and L = distance to the exclusion boundary, cm

A similar relationship holds for determining the dose rate at the outer wall, D_w, given the dose rate internal to the room, D_o. Thus,

$$D_w = D_o B(\mu_s x_s) \exp(-\mu_s x_s)$$

where D_o = dose rate of material internal to the room, mRem/hr
μ_s = attenuation coefficient for structure, cm^{-1}
and x_s = thickness of structure, cm

The results from this calculation are also detailed in the Appendix and the results detailed in Table 2.

Results

The results of this calculation are shown in Table 2. The calculations detailed in the Appendix show that, for Maximum Normal conditions, the refueling floor can have a maximum reading of 69 mRem/hr and the internal rooms of the reactor building can have a reading of 516.7 mRem/hr, before the Emergency Operating Procedure on Secondary Containment Control should be entered. With dose rates of 208.8 Rem/hr in an internal room and at 267.2 mRem/hr on the refueling floor, appropriate actions to minimize off-site doses should be commenced. The dose rate limits in Table 2 were determined using these calculated values as a maximum and values of 10 and 100 times the alarm limit for each room when that value was less than the maximum calculated in the Appendix.

Table 1 - Reactor Building Room Volumes

Room	Room Number	Volume, ft^3
Refuel Floor	I-500/I-810	1,365,529
RWCU Pump Room	I-502/I-503	2955 (each room)
Remote Shutdown Panel Room	I-109	3114
HPCI Room	I- 11/I-106	32112
RCIC Room	I- 12/I-103	21250
RHR Pump Room A	I- 13/I-103	54222
RHR Pump Room B	I- 14/I-104	67810

Table 2 - Radiation Limits in the Reactor Building

Room	Room Number	Max Normal Dose Rate mRem/hr	Max Safe Dose Rate Rem/hr
Spent Fuel Pool		150	0.3
Refuel Floor	I-500/I-810	50	0.3
Sample Room		50	0.5
Recirc Fan Room		50	0.5
RWCU Pump Area	I-502/I-503	50	0.5
Fuel Pool Pump Area		516	208.8
CRD HCU North		516	208.8
CRD HCU South		516	208.8
Remote S/D Room	I-109	50	0.5
HPCI Room	I- 11/I-106	300	208.8
RCIC Room	I- 12/I-107	300	208.8
RHR Pump Room A	I- 13/I-103	516	208.8
RHR Pump Room B	I- 14/I-104	516	208.8
RB Sump Room		516	208.8

Conclusions

The results of this calculation give radioactivity dose rate limits for use in the Emergency Operating Procedures at Susquehanna Steam Electric Station. The dose rate limits are based on conservative estimates of dose rate at the plant exclusion boundary and are compared to limits established for siting and operational situations, and in fact, are based on ten percent of the overall limits. Therefore, it is concluded that the Emergency Operating Procedures are now based on off-site dose limits.

References

1. NUREG-0654, 'Criteria for Preparation and Evaluation of Radiological Emergency Response Plans and Preparedness in Support of Nuclear Power Plants.'

2. Susquehanna Steam Electric Station, Final Safety Analysis Report.

3. Lamarsh, J. R.,'Introduction to Nuclear Engineering', Second Edition, Addison-Wesley, Reading, Mass., 1983, Chapter 10 and Tables.

4. Letter from J. G. Refling to W. A. Deluca, PLI-66641, dated 1/28/91.

5. U. S. Government Code Of Federal Regulations, 40CFR190 'Environmental Radiation Protection Standards for Nuclear Power Operations'.

APPENDIX

Numerical Calculations

Maximum Normal Evaluation Calculation

Data

Room Volume (RHR room B) = $67810\ ft^3$
Attenuation Coefficient for air = $8.22 \times 10^{-5}\ cm^{-1}$
Attenuation Coefficient for concrete = $0.1476\ cm^{-1}$
Attenuation Coefficient for steel = $0.4494\ cm^{-1}$
χ / Q = $2.1 \times 10^{-5}\ sec / m^3$

Therefore $$R_s = \left(\frac{3V}{4\pi} \right)^{1/3} = \left(\frac{3 \times 67810}{4 \times \pi} \right)^{1/3}$$

$$= 25.3\ ft = 771\ cm$$

Distance to Exclusion Boundary = 600 yards = 54864 cm

Case I: Evaluation Against NUREG-0654

For this case, the offsite dose rate at the Exclusion Boundary is limited to less than 0.1×25 mRem/yr = 2.852×10^{-4} mRem/hr.

a. Internal Volume

The limit on number of Curies in the room is

$$C_i = D_{eb} / \{ (0.25)(\chi / Q)(E_o) \} .$$

$$C_i = 54.3 \text{ Curies}$$

The source strength is then

$$S = 3.7 \times 10^{10}\ C_i = 2.01 \times 10^{12}\ (\gamma / sec)$$

The room point source is then

$$D_{ps} = \frac{S \exp(-\mu x) B(\mu x)}{4 \pi R_s^2} F$$

$$D_{ps} = \frac{(2.01 \times 10^{12})(0.939)(1.0634)}{(4 \times 3.14159)(771)^2} (1.9231 \times 10^{-3})$$

$$D_{ps} = \underline{516.7\ mRem / hr}$$

b. Refueling Floor Volume

For the refueling floor, the volume is 1,365,529 ft^3. Therefore,

$$R_s = \left(\frac{3 \times 1365529}{4 \times \pi} \right)^{1/3} = 68.8 \text{ ft} = 2098 \text{ cm.}$$

For the refueling floor, the source strength is the same as determined in part a. Therefore, the point source limit for the refueling floor is

$$D_{ps} = \frac{(2.01 \times 10^{12})(0.842)(1.173)}{(4 \times 3.14159)(2098)^2} (1.9231 \times 10^{-3})$$

D_{ps} = 69.0 mRem / hr

Maximum Safe Calculation

Case II: Evaluation Against 40CFR190

For this case, it is assumed that two feet (60.96 cm) of concrete shields the internal rooms from the environment. The refueling floor is shielded from the environment by steel with a thickness of 1/4 inch. Other data for this case is presented in Case I.

a. Internal Rooms

The dose at the Exclusion Boundary is again taken to be 1/10 of the limit of 25 mRem/yr or 2.852×10^{-4} mRem/hr. Therefore, the dose rate outside of the wall containing the radioactivity is

$$D_w = \frac{L \times D_{eb}}{B(\mu x) \exp(-\mu x)}$$

$$D_w = \frac{54864 \times 2.852 \times 10^{-4}}{B(8.22 \times 10^{-5} \times 54864) \exp(-(8.22 \times 10^{-5})(54864))}$$

D_w = 258.2 mRem/hr

The dose rate on the inside of the room is then

$$D_o = \frac{D_{eb}}{B(\mu_c x_c) \exp(-\mu_c x_c)}$$

$$D_O = \frac{258.2}{B((0.1476)(60.96))\ \exp(-(0.1476)(60.96))}$$

D_O = 208800 mRem/hr = 208.8 Rem/hr

b. Refueling Floor

For this case, the dose rate at the outside wall is the same as in Case a. The dose rate on the inside of the room, based on steel shielding of thickness 1/4 inch (0.635 cm), is then

$$D_O = \frac{258.2}{B((0.4494)(0.635))\ \exp(-(0.4494)(0.635))}$$

D_O = 267.2 mRem/hr.

Maximum Normal Operating Radiation Level

The BWR EPG identifies three criteria that must be satisfied to properly define this entry condition / action level:

A. Like all other entry conditions to secondary containment control, this entry must take into consideration the adverse effects on equipment operability in the SC and conditions directly challenging SC integrity. An area radiation level above its MNO level is an indication that water from a primary system may be discharging into SC. (See BWR EPG Appendix B pgs B-8-7 and B-8-8.)

B. This level must be the highest value of radiation expected to occur during normal plant operating conditions with all directly associated support and control systems functioning properly. (See BWR EPG Appendix B pg B-3-9.)

C. In general, all entry condition setpoints must be simple, operationally significant, unambiguous, readily identifiable, and familiar to the plant operators.

The manner in which the value of 1 R/hr meets criteria A can be demonstrated by examining the purpose of the Secondary Containment Control procedure. There are four purposes:

1. Protect equipment in SC: 1 R/hr is orders of magnitude below a radiation level expected to cause equipment operability concerns based on FSAR analyses.

2. Limit radioactivity release to the SC: By definition, any radiation level in SC above or below 1 R/hr could be indication that a release to SC has occurred.

3. Maintain SC integrity: 1 R/hr is orders of magnitude below a radiation level that could affect SC integrity.

4. Limit radioactivity release from SC: Engineering analysis has shown that 1 R/hr assures the exposure at the site boundary is significantly below that which would approach technical specification limits (3.11.2.2a).

Criteria B is satisfied by comparing the value of 1 R/hr to the reactor building ARM alarm setpoints. The highest value of radiation expected during normal plant operation is reflected in these setpoints. 1 R/hr bounds all reactor building ARM setpoints thus permitting a graded procedural response to off-normal events. Response to ARM alarms is governed by alarm response and off-normal procedures. When actions in these procedures fail to reduce increasing SC radiation level, entry to the emergency operating procedure is appropriate.

In order to meet criteria C, the value of 1 R/hr has been rounded to the nearest whole Rem above the ARM alarm setpoint. This ensures a simple, unambiguous, readily identifiable entry condition and action level is used.

Enclosure

SC/R-2 IS ANY AREA RAD LEVEL > MAX NORMAL
(SC/R-1)

Table SC-3

SC Area	#	ARM Channel Description	Max Normal (R/hr)	Max Safe (R/hr)
818 ft el	14 or 47 15,42 or 49	Spent Fuel Pool Refuel Floor	1	10
779 ft el*	11 12	Sample Station Room Recirc Fan Room	1	100
749 ft el North	8 or 52	RWCU Pump Area	1	100
749 ft el South	10 or 54	Fuel Pool Pump Area (hallway near instrument rack)	1	100
719 ft el	5 or 50	CRD HCU North	1	100
719 ft el	6 or 51	CRD HCU South	1	100
683 ft el	(None)	(None)	1	100
670 ft el	16 or 53	Access to Remote S/D Room	1	10
645 ft el (HPCI Room and Core Spray B)	3 or 48	HPCI Equipment Area	1	100
645 ft el	2 or 57	RCIC Equipment Area	1	100
645 ft el	1 or 56	RHR Pump Room B	1	100
645 ft el	25 or 55	RHR Pump Room A	1	100
645 ft el** (Sump Room and Core Spray A)	4	RB Sump Room	1	100

* Highest ARM indication = 100mr/hr
** Highest ARM indication = 1R/hr
Secondary Containment Radiation