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R. S. Boyd, ADRP, DRL
D. J. Skovholt, ADRO, DRL
L. D. Low, Director, CO
E. G. Case, Director, DRS
J. A. McBride, Director, DML

REACTOR TECHNOLOGY MEMORANDUM - CALCULATING THYROID DOSES FOR THE DBA

The enclosed RTM sets forth proposed guidelines for the model to be used in the calculation of thyroid doses from the DBA. I recommend that consideration be given to factoring these guidelines into our safety evaluations as soon as possible. Further, I would appreciate receiving any comments you care to make as a result of reviewing the RTM by September 9, 1968, in order that necessary revisions can be made promptly.

Saul Levine
Saul Levine, Assistant Director for
Reactor Technology
Division of Reactor Licensing

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Enclosure:
RTM-Calculating Thyroid Doses
for the DBA

cc w/enclosure:
P. A. Morris, Director, DRL
F. Schroeder, Deputy Director, DRL
Branch Chiefs, DRL
Asst. Directors, CO
Branch Chiefs, CO
Branch Chiefs, DRS

A/7

REACTOR TECHNOLOGY MEMORANDUM NO.

CALCULATING THYROID DOSES FOR THE DBA

I. INTRODUCTION

To assist in evaluating the consequences of the Design Basis Accident (DBA) for a construction permit, and the acceptability of a reactor site with respect to 10 CFR 100 considerations, graphs have been prepared incorporating the various factors considered in ascertaining the thyroid doses for 2 hours at the boundary of the exclusion zone, and for 30 days at the boundary of the low population zone. These graphs include the effect of power level, inventory, leakage rate, meteorology, biological factors, and distance, and may be used for estimating the magnitude of potential doses for sites with level or gently rolling topography. However, these curves should be used with caution, since they may not be applicable in situations such as a ground release level in a deep, narrow valley, or an elevated release close to a range of hills, or in certain other special cases.

This RTM will interface with others dealing with core thermal transients, fission product release and transport, iodine removal by containment sprays and recirculating filter systems, and containment leakage rate as a function of time.

To date, whole body doses from the DBA have not been controlling at any facility, since such a situation generally arises only when more than 95% of the iodines are removed by some means. Curves similar to those presented here could be prepared for calculating whole body doses, and it is anticipated that this will be done in a future RTM.

From this point, this RTM is divided into two parts: Part I deals with PWR plants, which release radioactivity from their containment systems at various points or areas on or near the surface of the containment building. Part II deals with BWR plants, which release radioactivity from their containment system primarily through a stack constructed to a height of 100 meters above site grade level. A set of curves is provided in each part which greatly simplifies the dose calculations for each. Models for the curves and detailed information concerning them are described in the appendix.

PART I

DOSE CALCULATION MODEL FOR PWR'S

I. DESCRIPTION OF THE MODEL

The evaluation model consists of curves showing the thyroid dose per megawatt of reactor power as a function of distance from the point of effluent release for exposure times of 2 hours and 30 days. Figure 1 is for PWR plants, and may also be applied with some modification to special circumstances for BWR's, which will be explained in Part II. The curve which is used with the PWR plants is marked "release affected by building wake," to indicate that the effluent is released from points close enough to the containment structure that it becomes mixed into the turbulent wake which is formed in the lee of the structure. Note that there is no provision for constricting the horizontal growth of a plume to compensate for the effect of a deep, confining valley. Such cases should be referred to Reactor Technology for evaluation.

The fission products involved in thyroid dose calculations are the 5 isotopes of iodine 131 through 135. These are assumed to exist in the reactor core at their maximum equilibrium level, a condition which is achieved in approximately 30 days of operation at a given power level. The manner in which these isotopes are assumed to migrate so as to deliver a thyroid dose to persons off-site is described in detail in the Appendix, and is outlined here.

During the course of the DBA, the iodine is released from the fuel into the containment atmosphere. It leaks from there to the outside atmosphere, where it diffuses at various rates over the total course of the accident, which is taken to be 30 days. The ground level concentrations so produced are breathed by man, and go through a metabolic process which deposits a fraction of the iodine in the thyroid gland. A radiation dose is delivered to the thyroid gland from the radiation emitted during the decay of the radioactive iodine to a stable form.

The required input data obtained from the PSAR includes the following:

1. Reactor maximum thermal power level, or "stretch" power.
2. The primary reactor containment design leak rate, as stated in the PSAR.
3. The type of reactor facility (BWR or PWR).
4. Type of containment-only the single containment is treated here.
5. Site terrain conditions.

The principal assumptions made in this evaluation model are given below:

1. Twenty-five percent of the total iodine inventory in the core is available for leakage from the primary containment.

2. The containment leaks at its design value for the first 24 hours. Then, to account for pressure reduction due to containment sprays and heat transfer to structural parts, the rate is reduced to 45% of its initial value for the duration of the accident (30 days).

3. The leakage occurs at or near enough to the ground that it is mixed into the turbulent wake in the lee of the building.

4. Correction may be made for the additional dispersion produced by the turbulent wake of the building. The curves provided contain a representative correction factor which is appropriate for most reactor facilities, and is justifiable from presently available data. The appendix provides detailed information concerning this.

5. No filtration occurs as the material passes through the walls of the containment building.

6. Credit for cleanup by containment sprays or recirculating filter systems may be taken, although it is not incorporated into the curves provided. Evaluation of such credit should be done with the help of Reactor Technology, as noted below.

7. A complete atmospheric diffusion model for the ground release case is incorporated into the curves, as described in the Appendix, and in RTM . The model changes with time to form a conservative estimate of changes which typically occur in the atmosphere over long periods of time. Requests from applicants to use less conservative conditions should be referred to Reactor Technology for evaluation

8. No correction is made for depletion of the plume due to deposition of iodine on the ground, or for radioactive decay in transit. Both of these are relatively small effects with the model used, especially for doses at the site boundary.

9. Decay during holdup in the containment is accounted for, since this is a major effect during the 30-day period, and forms part of the basis for considering the accident ended at that time (all the iodine has decayed).

10. For the first 8 hours, the breathing rate is taken as 3.47×10^{-4} cubic meters per second. After that, until the end of the accident, the rate is taken as 2.32×10^{-4} cubic meters per second. Both values are found in ICRP recommendations.

11. The ICRP recommended values of uptake fraction, effective energy, decay rate, and thyroid mass are used to calculate dose conversion factors. Parameter values and equations are given in the Appendix.

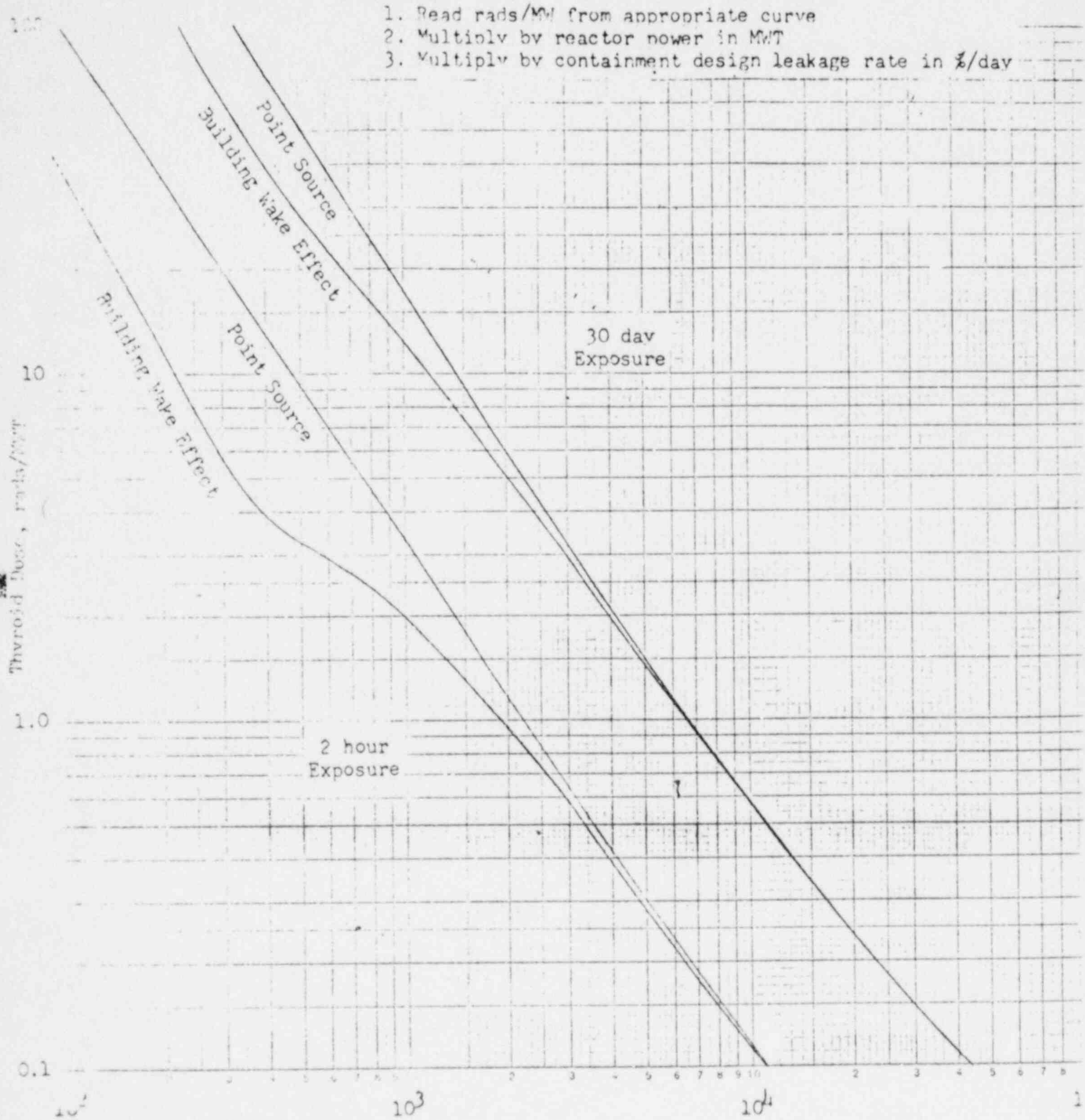
Thyroid Doses, Rads/MW

for ground level releases

from Design Basis Accidents

Directions:

1. Read rads/MW from appropriate curve
2. Multiply by reactor power in MWT
3. Multiply by containment design leakage rate in %/day



Distance from Reactor Building in Meters

Figure 1--PWR's

PART II

DOSE CALCULATION FOR BWR's

I. DESCRIPTION OF THE MODEL

The evaluation model consists of curves showing the thyroid dose per megawatt of reactor power as a function of distance from the point of effluent release for exposure times of 2 hours and 30 days. Figure 2 provides the doses for BWR plants, where the releases take place from a structural stack 100 meters high, with adjustments for differences in postulated diffusion conditions for inland and seacoast locations. Note that there is no provision for handling situations where the proposed stack height, or the effective stack (after correction for plume rise or terrain conditions) is different from 100 meters. However, an estimate of the maximum possible dose value for such conditions (assuming the effective stack height is zero) may be obtained by using the curve labeled "release from a point source" in Figure 1 for PWR's, and dividing the result by 10 to account for the fact that the release is reduced by passing it through a filter. Likewise, there is no provision for constricting the horizontal growth of a plume in a deep, confining valley location. Such cases should be referred to Reactor Technology for evaluation.

The fission products involved in thyroid dose calculations are the 5 isotopes of iodine 131 through 135. These are assumed to exist in the reactor core at their maximum equilibrium level, a condition which is achieved in approximately 30 days of operation at a given power level. The manner in which these isotopes are assumed to migrate so as to deliver a thyroid dose to persons off-site is described in detail in the Appendix, and is outlined here.

During the course of the DBA, the iodine is released from the fuel into the containment atmosphere. It leaks from there to the outside atmosphere, where it diffuses at various rates over the total course of the accident, which is taken to be 30 days. The ground level concentrations so produced are breathed by man, and go through a metabolic process which deposits a fraction of the iodine in the thyroid gland. A radiation dose is delivered to the thyroid gland from the radiation emitted during the decay of the radioactive iodine to a stable form.

The required input data obtained from the PSAR includes the following:

1. The reactor maximum thermal power level, or "stretch" power.

2. The primary reactor containment design leak rate, as stated in the PSAR.

3. The type of reactor facility (BWR or PWR).

4. Type of containment-only the type with vapor suppression, reactor building and emergency exhaust system with filter and stack is treated below.

5. Site terrain conditions, and location with respect to large bodies of water.

The principal assumptions made in this evaluation model are given below:

1. Twenty-five percent of the total iodine inventory in the core is available for leakage from the primary containment.

2. The primary containment leaks at its design value for the first 24 hours. Then to account for pressure reduction due to containment cooling systems and heat transfer to structural parts, the rate is reduced to 45% of the initial value for the duration of the accident (30 days).

3. Leakage from the primary containment passes directly to the emergency exhaust system without mixing in the reactor building atmosphere.

4. This system removes 90% of the iodine, and releases it to the atmosphere from the top of a stack constructed to a height of 100 meters above site grade.

5. No ground level leakage from the reactor building is assumed in this model, although exfiltration should be looked at separately with the help of Reactor Technology.

6. A complete atmospheric diffusion model for the elevated (stack) release case is incorporated into the curves, as described in the Appendix, and in RTM . The model changes with time to form a conservative estimate of changes which typically occur in the atmosphere over long periods of time. Requests from applicants to use less conservative conditions should be referred to Reactor Technology for evaluation.

7. No correction is made for depletion of the plume due to deposition of iodine on the ground, or for radioactive decay in transit. Both of these are relatively small effects with the model used, especially for doses at the site boundary.

8. Decay during holdup in the containment is accounted for, since this is a major effect during the 30-day period, and forms part of the basis for considering the accident ended at that time (all of the iodine has decayed).

9. For the first 8 hours, the breathing rate is taken as 3.47×10^{-4} cubic meters per second. After that, until the end of the accident, the rate is taken as 2.32×10^{-4} cubic meters per second. Both values are found in ICRP recommendations.

10. The ICRP recommended values of uptake fraction, effective energy, decay rate, and thyroid mass are used to calculate dose conversion factors. Parameter values and equations are given in the Appendix.

Thyroid Doses, Rads/MW

for releases from 100-meter stacks

from Design Basis Accidents

Directions:

1. Read rads/MW from Appropriate curve
2. Multiply by reactor power in MWT
3. Multiply by containment design leakage rate in %/day

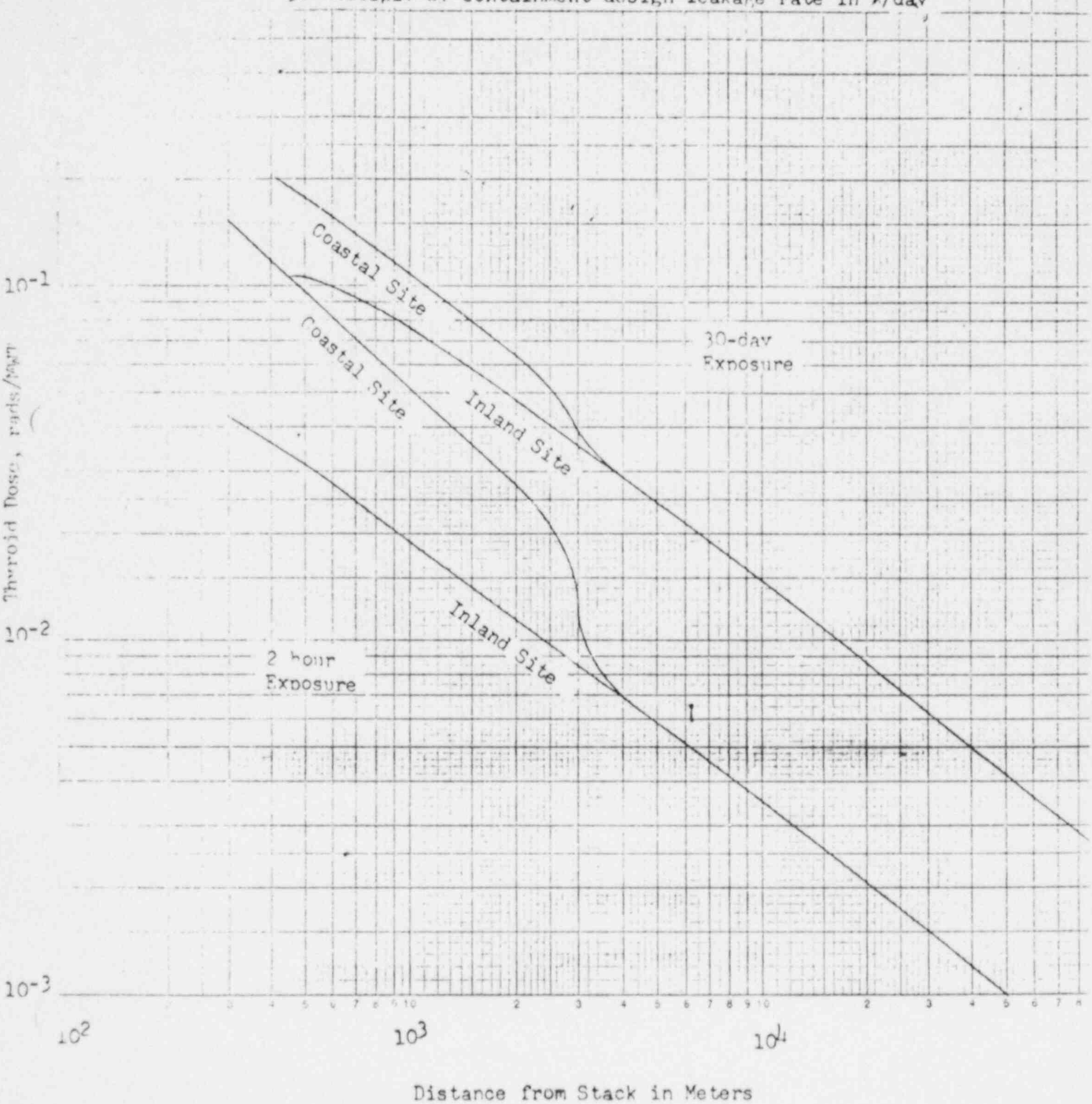


Figure 2--BWR's

PART III

EVALUATION PROCEDURES

1. Doses for a two hour exposure are evaluated at the nearest site boundary.

   1.1 Determine the shortest distance from the release point (edge of the reactor building, or top of the stack) to the edge of the exclusion area which the applicant has demonstrated is available.

   1.2 From Figure 1 or 2, as appropriate, read the value of rads/Mw at this distance from the appropriate 2 hour exposure curve.

   1.3 Multiply this result by the reactor power level in Mwt and by the primary containment leakage rate to obtain the thyroid dose for a 2 hour exposure.

   1.4 If this result is greater than 300 rads, a dose reduction factor (DRF) is needed as determined by: DRF=calculated dose/300. This reduction is obtained by chemical sprays, charcoal filters, or other means for removing iodine from the containment atmosphere. Assistance in evaluating possible dose reduction mechanisms will be provided by Reactor Technology.

2. Doses for a 30 day exposure are evaluated at the low population distance.

   2.1 Determine the radius of the low population zone by consultation with Reactor Technology, or by following the procedure in a future RTM on this subject.

   2.2 From Figure 1 or 2, as appropriate, read the value of rads/Mw at this distance from the appropriate 30-day exposure curve.

   2.3 Multiply this result by the reactor power level in Mwt and by the design value of primary containment leakage rate to obtain the thyroid dose for a 30 day exposure.

   2.4 If this result is greater than 300 rads, further study should be requested from Reactor Technology to determine what corrective action can be taken.

PART IV

APPENDIXES

A. DERIVATION OF IODINE SOURCE STRENGTH

1. The core inventory may be determined by utilizing fission yields for uranium [1,2] and calculating the inventory in curies by the appropriate equations and conversion factors, or it may be obtained directly from other references.[3]

2. Some of this iodine inventory diffuses out of the fuel and resides in the clad gap during operation, while the remainder is contained within the fuel pellet.[4] During the DBA, the clad ruptures and releases all the gap activity very early in the transient. Soon after this, it is assumed that additional fission product inventory is also released from fuel due to overheating. The total iodine release from the fuel is 50%[5]. After this iodine is released from the fuel it passes into the containment atmosphere, with an attendant deposition of one-half of it in the process. Consequently, 25% of the core inventory of iodine is assumed to be available in the containment atmosphere initially for leakage.

B. CALCULATION OF INTEGRATED LEAKAGE AS A FUNCTION OF TIME

1. Reactor Technology and Reactor Standards have written other reports dealing with the change of containment pressure with time[6], and the dependence of leak rate on containment pressure.[7]

2. Rather than using the overly-conservative "square wave" approach, in which the leak rate is assumed constant for duration of the accident, we have assumed that it is constant at its maximum value for the first 24 hours, which appears to be a reasonably conservative estimate of the maximum time that the pressure can be expected to be appreciably above its long-term "base value." The latter is set by the effects of long term energy sources and additions of non-condensibles, and is assumed to produce a leak rate of 45% of the design value.

C. CORRECTION FOR BUILDING WAKE EFFECT

1. A number of authors[8,9] have put forth various empirical equations to account for the very rapid dilution of effluent that takes place when it mixes into the turbulent wake which exists most of the time on the lee side of the building. We have chosen the most conservative one of these, although in many cases the differences are only few percent. The equation used in this RTM is:[8]

$$X/Q = 1/u \; (\;{}_{y}\;\;{}_{z} + cA)$$

where:

X is the effluent concentration, units/cubic meter

Q is the effluent leakage rate, units/second

y is the horizontal standard deviation (dimension) of the of the effluent plume, meters

z is the vertical standard deviation of the plume, meters

A is the minimum cross-sectional area of the reactor building, square meters

c is an empirical constant, which is assumed to be 1/2

u is the wind speed, meters/second.

To achieve a greater simplicity for the dose calculation, the value for A has been inserted into the calculations, 20,000 square feet, or 1860 square meters. This is a representative value which is typical of most reactor facilities, except those with ice condenser containment, and at the same time does not result in excessive credit being given for the effect, as determined by measurements.[10]

2. In the case of very small sites, this correction factor should be applied with care, since some measurements indicate that the concentration reduction obtained by this effect may be limited to approximately a factor of 4.[10] Such a limitation has been incorporated into the curves in Figure 1.

D. ATMOSPHERIC DISPERSION AS A FUNCTION OF TIME

1. The general equation for atmospheric dispersion, attributed to Pasquill is:

$$X/Q - 1/u \quad \sigma_y \sigma_z$$

where the variables are as defined above. This equation can be modified to account for additional diffusion which will take place when dispersion conditions improve from the poor conditions which are assumed to exist at the time of accident. Ground level and stack release conditions are discussed separately.

2. For ground level releases, it is assumed that for the first 8 hours following an accident the wind will blow in a uniform direction at an average speed of 1 meter/second (2.24 mph). Atmospheric dispersion is poor, being characterized by inversion conditions presented by the Pasquill "Type F." For the period from 8 to 24 hours, diffusion conditions are assumed to remain the same, but the wind direction varies so that the plume is spread uniformly over a 22.5° sector (the plume itself is approximately 6° wide). From 1 to 4 days, a stagnation period is assumed with low wind speeds and neutral to stable diffusion conditions. The plume is assumed to remain in the same 22-1/2° sector. From 4 to 30 days, more favorable atmospheric diffusion conditions are assumed, with increased wind speed, and the plume is assumed to remain in the same 22.5° sector only 1/3 of the time.

3. For the stack releases, it is much more difficult to define comparably conservative conditions. What is normally termed better dispersion conditions spread the plume more rapidly, but this causes it to come into contact with the ground closer to the stack, which produces higher concentrations that if the ground contact had been made at a greater distance. Consequently, to properly estimate conditions at any given distance, an envelope of all possible dispersion conditions is constructed. Using this technique, it is assumed that for the first 8 hours the wind speed is 1 meter/second, and the wind direction is constant, so that concentrations may be calculated from the envelope. As in the case of ground level release, the only change made for the period from 8 to 24 hours is to spread the plume uniformly over a 22.5° sector, conservatively limiting the reduction due to this effect to a factor of 5. From 1 to 4 days, an envelope of various conservative combinations of diffusion conditions is assumed, and with low wind speeds the plume is spread over the same sector. From 4 to 30 days, the plume is assumed to remain the same 22.5° sector only 1/3 of the time, as above.

4. Stack releases also have a special situation caused by a change in diffusion conditions, which can cause the plume to be brought down to the ground suddenly so as to produce much higher concentrations than would exist during any other condition. This transient condition is called fumigation, and is assumed to occur for a period of 1/2 hour at the beginning of the accident at inland sites. A more complicated situation can cause the same condition to exist for a period of 2 hours or more at seacoast locations. Both of these situations are included in the curves provided in Figure 2.

E. BREATHING RATES FOR DOSE RECEPTORS

1. For the first 8 hours, the breathing rate is taken as 3.47×10^{-4} cubic meters/second, which is the rate recommended by the ICRP[1] for the active portion of the day.

2. For all times after 8 hours, the breathing rate is taken as 2.32×10^{-4} cubic meters/second, which is the rate recommended by the ICRP for the daily average.

F. CONVERSION FACTORS FROM IODINE CURIES TO THYROID DOSE

1. The basic equation [13] for this conversion is:

$$D = 73.8 \; (C \, f_a \, E \, T \, 1/2) \; /m$$

where:

D is the thyroid dose due to the iodine inhaled, rads/uc

C is the number of microcuries of iodine inhaled

f_a is the fraction of inhaled iodine reaching the thyroid gland (23%).

E is the average effective energy of radiation from each iodine isotope, in MeV.

T 1/2 is the effective half-life of each iodine isotope in days, including radioactive and biological decay.

m is the mass of the thyroid gland (20 grams).

All numerical values involved in the dose conversion factors have been published by the ICRP[12].

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