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SAVANNAH RIVER REACTOR OPERATION: INDICES OF RISK FOR EMERGENCY PLANNING (U)

October 1990

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SAFETY • RESPONSIBILITY • SECURITY
SRS
SAVANNAH RIVER SITE

PREPARED FOR THE U.S. DEPARTMENT OF ENERGY UNDER CONTRACT NO. DE-AC09-89SR18035

SARM
Safety Analysis and
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by

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Savannah River Reactor Operation: Indices of Risk for Emergency Planning (U)

INTRODUCTION & SUMMARY

As Probabilistic Risk Assessment (PRA) and Severe Accident studies mature and lead to better understanding of the progression of hypothetical core melt accidents in Savannah River Site (SRS) reactors, it is necessary to periodically reexamine implications of the new source terms for neighboring offsite populations. This application considers multiple-system failure events and consequently higher radiological source terms than from normal operation or design basis accident (DBA) consideration. Measures of consequence such as constant dose vs. distance, boundary doses, and health effects to close-in populations are usually examined in this context. A set of source terms developed for the Safety Information Document[1] (SID) for support of the Reactor Operation EIS forms the basis for a revised risk evaluation discussed herein. Since a range of meteorological conditions are possible for the SRS occurring at the time of a postulated severe accident, correspondingly, there are varying magnitudes in the calculated measures of consequence. Severe reactor accident consequences therefore are reported probabilistically in a complementary cumulative distribution function (CCDF) format. The CCDF for a given consequence relates the frequency of time a level of consequence is equaled or exceeded. This study uses the CCDFs and expected values or means from CCDFs developed for the consequence measures described above to furnish additional information regarding risk of operation of the SRS K reactor. Publication of this report fulfils the request made by the Restart Office of the Department of Energy during review of the SID in February, 1990. [2]

Revision 1 to the original report[3] evaluates the sensitivity of individual risk estimates to the extent of offsite evacuation assumed from K reactor and compares these risks to the Draft DOE Safety Goals.[4] Neither this study nor the original completely substantiates the sufficiency of the current Emergency Planning Zone (EPZ). However, two principal measures (200-rem whole-body dose vs. distance and 300-rem thyroid dose vs. distance) for setting an EPZ are considered. Additional dose-at-distance calculations and consideration of design basis accidents (DBAs) would be needed to complete a re-evaluation of the current EPZ. These subject areas are not addressed in the current document.

A consequence analysis code is applied to twenty-six severe accident source terms derived from the SID Level 2 analysis. Source term frequencies, indicating expected occurrence per reactor-year, are taken from the Level 1 PRA.[5] Conditional consequences from each consequence code run are weighted by release category frequency and summed to yield exceedance frequency curves appropriate to one year of reactor operation. Risk to the in-close offsite population from SRS is presented in terms of:

- Individual risk of early fatality and latent (cancer) fatality to an offsite individual within 1.6 km and 16 km of the SRS reservation boundary, respectively;
- Constant red bone marrow dose (25 rem and 200 rem) vs. distance;
- Constant 300-rem thyroid dose vs. distance; and
- Red bone marrow dose at two radial intervals (6-7 miles) and (14-15 miles) away from K reactor.

Given the SID source terms and Level 1 PRA frequencies, the individual risk of fatality measures of consequence are below DOE Safety Goals regardless of no-evacuation, 10-mile, or 20-mile from K reactor assumption. The two dose-at-distance curves appear to decline rapidly at a distance that would tend to support the current EPZ; however additional dose CCDFs and DBA calculations are necessary before the EPZ could be judged to be within full compliance.

DISCUSSION

The commercial reactor Safety Goal policy is summarized initially. The origin of applying dose-at-distance arguments to partially defend EPZ regions around a power reactor are then covered. The corresponding DOE goal or order is discussed next. The SID source terms and Level 1 PRA frequencies are then used to evaluate K reactor operation risk to close-in populations.

Commercial Reactors

The NRC safety goals were issued in 1986.[6] These quantitative setpoints address the risk of prompt or early fatality and induced cancer (delayed) to those living near a nuclear power facility. The prompt fatality safety objective is that the risk of prompt fatality to the average individual within one mile of a plant site boundary be increased by less than 0.1% because of the possibility of nuclear plant accidents. Applying this fraction to other sources of accident death, a numerical criterion of 5×10^{-7} per year for average individual risk of early death. The NRC criterion on the latent scale is that the average risk of a cancer fatality within 10 miles of a nuclear plant boundary be less than 0.1% of the cancer fatality risk from all other causes, or 2×10^{-6} per year.

The Joint U. S. NRC and EPA Task Force on Emergency Planning in 1978 established the early rationale for a commercial reactor Emergency Planning Zone (EPZ) of 10-mile radius[7]. The Task Force identified a set of severe accidents from the WASH-1400 analysis to establish a risk profile for a representative nuclear power facility. Consequence analysis of the source terms led to three principal indices of consequence to guide the EPZ precedent setting. These were: (1) constant 200 rem whole-body dose vs. distance; (2) constant 25 rem whole-body dose vs. distance; and (3) constant 300-rem thyroid dose vs. distance. The distances shown are maxima and are a function of the meteorological conditions (wind-rose, Pasquill-Gifford stability class, and other site characteristics). For a given release, other directional sectors would see little if any airborne radioactivity; consequently cloudshine, groundshine and inhalation dose pathways would yield minimal dose .

Figure 1 shows the conditional probability of exceeding a 200-rem whole-body dose vs. distance from basis reactor used in the Task Force study. The probability is conditional on a core melt accident (frequency of 5 x 10^{-5} per reactor-year) from WASH-1400. The 200-rem dose is that at which significant early injuries would be expected to occur demanding hospitalization. Figure 2 shows the 300-rem thyroid dose counterpart to Fig. 1. Doses of 300-rem thyroid and 25-rem whole-body correspond to the Nuclear Regulatory Commission's guideline values for reactor siting in 10 CFR 100. The 200-rem whole-body dose and the 300-rem thyroid dose curves cross the ten-mile distance at conditional probabilities of 0.03 and 0.095, respectively.

Draft DOE Safety Goals and EPZ Considerations

Draft Safety Goals from the Department of Energy were last published in May, 1989.[4] The offsite goals are given in terms of individual risk within one mile and ten miles of the DOE reservation boundary for acute fatality and latent cancer fatality, respectively. Numerically, the goals are the same as those set by the NRC.

Emergency planning zone requirements were originally addressed during the preparation of the Environmental Impact Statement for the restart of L reactor.[8,9] It was determined that a maximum credible accident source term would lead to whole-body doses in excess of 5 rem at the SRS boundary in only two of sixteen sectors from K reactor, assuming 99.5% meterological conditions. Contingency planning zones were established for ten-mile radii about operating reactors at the same time. These zones were later set as EPZs to comply with commercial reactor planning practice.

DOE orders have been issued to offer sites assistance in the interpretation of maximum credible accident frequency, emergency response planning, and DOE facility preparedness.[10-13] These orders are subject to a wide range of interpretation as far as offering a procedure for developing a defensible and clear rationale for DOE reactor EPZ determination, however.

Savannah River Site EPZ and SID Source Terms

The current SRS EPZ is formed by constructing a sixteen-kilometer (10-mile) arc about each operating reactor, and defining the outer boundary to the EPZ as that part of the 360° rotation traversing offsite. Figure 3 shows the Site, the current EPZ limits, and the original EPZ developed from maximum credible accident analysis in 1983. It is observed that the EPZ based on K reactor alone encompasses offsite regions in seven of sixteen directions, S, SSW, SW, WSW, W, WNW, and NW. For three directions, ESE, SE, and SSE, P reactor would extend the EPZ further out than that dictated by K reactor siting alone. The average distance to the SRS boundary from K reactor is 9.24 miles.

The composition of the SID source terms is given in terms of early and late release fractions of the core inventory in Table 1. Early release encompasses time periods during which in-vessel release from fuel is occurring. Late releases occur upon and after breach of the primary coolant system and include revolatilization from in-vessel, fission product evolution from molten core - concrete interactions (MCCI) and release from molten fuel - coolant interactions (MFCI). More specific information on the timing, sensible energy, and release elevation of the various source terms is found in the SID.

The Savannah River Site (SRS) consequence calculations are performed with the MACCS code, Version 1.4[14,15]. MACCS is the successor to the CRAC code methodology that evolved from WASH-1400. This version of MACCS does not have the capability to calculate whole-body dose; instead red bone marrow doses (RBM) are substituted. Runkle and Ostmeyer[16] have indicated that where the whole-body dose has been used in previous evaluations, the red bone marrow dose equivalent could be used as a surrogate for the whole-body dose for internal and external exposures. Version 1.4 MACCS does have the capability to compute thyroid doses.

Comparison of the DOE Draft Goals for the 1-mile individual early fatality risk and the ten-mile individual latent cancer death risk to those calculated for K reactor operation are given in Table 2. Calculations supporting Table 2 are based on actual offsite population distributions. Conservative models for the initiation of evacuation and the effective outward speed are applied. All release categories except RC-5 and RC-7 are modeled with an evacuation start time of two hours *after the release of the first plume segment* and a speed of 2.5 miles per hour. RC-5 and RC-7 are linked to an assumed major seismic event with disruption of the transportation networks in the region surrounding the SRS. Therefore, for these cases alone, the start time is doubled and the effective evacuation speed is halved. A range of 20 miles from K reactor is involved in either evacuation. The acute fatality individual risk is markedly low due to: 1) the distance of K and P reactors from the Site boundary and 2) the rather low population immediately offsite in windrose-dominant directions. The latent fatality individual risk within ten miles of the SRS boundary is closer to the DOE safety goal, viz. 2% of the goal. The latent cancer fatality consequence is driven more by the magnitude of source terms and their frequencies, area land use, and dose criteria for interdiction. Particular emergency response plans and the reactor-to-target organ distances within the first twenty miles have limited benefit in reducing *chronic* impacts of severe accidents.

The individual risk calculations were repeated for the K reactor siting for two alternative models. In the first set, a ten-mile from K evacuation is initiated with the same timing and speed as described in the base case model. The second set of calculations assumes no evacuation whatsoever. Table 3 compares these two alternate models to the original case for early fatality and latent cancer individual risks. The early fatality risk increases from the base case to 10-mile and to no evacuation alternative models; however the point estimates are still well below the early fatality risk DOE safety goal. The mean or expected values for the latent cancer risk differ insignificantly among the base and alternate model options. Each of the three models remains only to within 2% of the latent cancer risk criterion. It is concluded that for chronic effects there is little difference in the overall collective dose to the ten-mile population among the three models, i.e. the mean or average risk is insensitive to the timing and speed chosen for these ranges of assumptions.

Population dose output is not easily interpreted for *individual* organ doses at a constant radius from the fission product release point. Instead, the approach used here is to determine the population dose to the red bone marrow in a particular radial interval, and divide that total dose by the population affected. The problem for the MACCS analyst is to determine quantitatively the reference population affected by the plume, since the code determines essentially 116 population doses* for a given source term, before weighting by meteorological bin frequency to produce the final complementary cumulative distribution function (CCDF). In the first time regime after a postulated atmospheric release, defined as the the emergency phase, the plume at one to fifteen miles downwind is assumed not likely to have broadened beyond 22.5^{o} (the width of one of the sixteen directional sectors used in the MACCS calculations). Therefore in principle, a total of 116 sector-specific reference populations for a given source term would have to be known to compute individual doses. Since it is not possible to unfold this information from MACCS, the average sector population is then appropriate as the denominator. This quantity is determined by dividing the total radial interval population by sixteen. Two radial intervals downwind of a released plume are shown in Figure 4 to illustrate the estimation procedure used. Specific calculations for the closest boundary to K reactor and the farthest boundary from K reactor are discussed in a later section.

The emergency phase portion of the accident sequence is considered for each of the twenty-six Release Categories from the April, 1990 revision of the SID. During this phase of the accident sequence, red bone marrow dose and thyroid dose are incurred via three pathways: 1) external dose due to cloudshine; 2) exposure to radionuclides on the ground (groundshine); and 3) dose from inhalation. Resuspension of radioactivity is accounted for and resultant doses through inhalation may also contribute. Water ingestion and food ingestion doses are important for an intermediate-to-long-term time perspective, but are not included during the emergency phase.

Appendix G of the Plant Vogtle Draft EIS (NUREG-1087) was used as the basis for the time period used in these calculations[17]. A seven-day period is assumed without imposed evacuation or sheltering emergency response. However, if the projected red bone marrow dose over the seven-day period exceeds 200 rem, then the people in the affected grid elements would be

*The MACCS calculations reported here use Latin Hypercube Sampling of meteorological conditions contained in one year of SRS-specific data. Twenty-nine bins are used describing stability, wind, occurrence of rain, and wind slowdown conditions. Four samples are drawn per bin:

29 Bins x 4 Start times per bin = 116 start times.

relocated after a ground exposure of 24 hours. Both seven-day and 24-hour periods begin when the fission product plume reaches the grid elements in question.

The lower of the three curves in Figure 5 shows the exceedance frequency for the 200-rem red bone marrow dose vs. distance. The conditional probabilities for the 26 SID release categories have been weighted by the respective release category frequency (Table 4), summed, and plotted as Figure 5. For Figure 6, the exceedance frequency of Figure 5 is divided by the total core melt frequency of 1.96×10^{-4} per reactor-year to yield the CCDF in terms of conditional probability, i.e., probability, given that a core melt accident has occurred (frequency of 1.96×10^{-4} per reactor-year). Again, the 200-rem red bone marrow curve is the lowermost of the three curves. At the 0.03 conditional probability point on Figure 5, the distance is approximately 7 miles. Since the red bone marrow dose will be somewhat less than the whole-body dose for the same distance, one interpretation is that the 200-rem whole-body dose would intersect the distance abscissa at approximately ten miles. Moreover, it may be inferred that the spectrum of SID source terms produces no compelling argument to shift current EPZs to greater distances.

The middle of the three curves in Figures 5 and 6 show the same indices for the 300-rem thyroid dose. The equivalent procedure is used as for the 200-rem dose. The 0.095 conditional probability on Figure 6 intersects the distance at 8.5 miles.

The 200-rem red bone marrow dose CCDF and the 300-rem thyroid CCDF in Figure 6 show higher conditional probabilities in the near-field, i.e. 0.1 to 2 miles from the release point, than analogous plots given in the WASH-1400 based Figures 1 and 2. This feature is due to the ground- and roof-level source terms that dominate release categories RC-5 through RC-8a (seismic-driven) and RC-9 through RC-11a (steam explosion-driven). The lower elevation releases are relatively broad plumes that typically occupy more than several compass directions at the point of emission. Additionally, the meteorogical conditions will tend to be less dispersive at 10 m elevation as compared to 62 m (the height of the reactor stack). The net effect is to increase the conditional probability of receiving threshold doses more than may be predicted from one 22.5° sector alone. Source terms modeled in release categories 1 through 4d are primarily stack level elevations; plotting the conditional probability of a 300-rem thyroid dose for example yields a similar value at two miles to that shown in the NUREG-0396 report (Figure I-13, P(2 miles) ~ 0.13).

The uppermost curves in Figures 5 and 6 are the results of the 25-rem red bone marrow calculations. These CCDFs are determined in the same manner as the 200-rem red bone marrow.

Figure 5A compares the exceedance frequency for the 200-rem red bone marrow to the NUREG-0396 commercial plant curve. Risk differences in the eight to fifteen mile range for the two studies are insignificant.

Figure 6 curves are similar qualitatively to those presented in the NUREG-0396 study. The SRS conditional probabilities at a radius of ten miles are lower than the WASH-1400 derived values, however beyond ten miles the decline is less pronounced. There does not appear to be sufficient differences in the principal indices of risk to modify the current EPZ, viz. to distances greater or less than ten miles from K reactor. The current setpoint is sufficient from the current severe accident perspective. Of course, maximum credible accident assessments are needed to fully assess the sufficiency of the EPZ. Such assessments are outside the scope of the current study.

Figures 5 and 6 are conservative in the predicted distances, viz. component source terms may have plume segments of from a few minutes to nearly ten hours in length. Each segment transports with invariant wind conditions, i. e. the weather present at the start of the release persists throughout the duration of the plume. Clearly, this assumption will tend to break down for longer duration plume segments. The overall effect in calculations of this nature is to broadcast radioactive material to larger distances in one direction than would be expected realistically.

Of perhaps greater importance is the potential for misinterpretation of these curves and the dose for constant-distance CCDFs addressed in the following section. This study does not give the frequency or conditional probability of an **individual** exceeding the indicated exposure; rather the curves give the frequency or conditional probability of exceeding the exposure anywhere on the circumference at a given distance.

Dose at SRS Boundary

The red bone marrow dose for the DOE reservation (SRS boundary) was also requested in CCDF format[2]. The boundary from K reactor ranges from ~6 miles distant (West) to 14-15 miles distant (North-by-Northeast). Therefore red bone marrow doses in two rings are calculated: 1) the dose 6-to-7 miles from K reactor; and 2) the dose 14-to-15 miles from K reactor. The ten-mile dose curve should be bounded by these two computations. In all cases, the MACCS code will calculate 116 population doses, based on a random sampling of "start times", occurring over one calendar year, for an assumed atmospheric release. The population doses may be related to an individual dose by dividing by the average sector populations discussed earlier.

For the 6 to 7 mile distance from K reactor calculation, the offsite population is essentially zero. Thus, the population dose if computed with these data would be zero as well. The calculations were performed instead with an installed population of 100 people in each of the sixteen compass sectors. Once the population dose CCDF is output from MACCS, it is divided by 100 to provide an approximate individual dose.

The offsite database shows a population total of 2671 for the 14 to 15 mile interval; the divisor for 14-to-15 mile population dose is then 2671 ÷ 16 = 167.

Using a windrose-weighted population average for the sixteen sectors results in changing the 14-to-15 mile population denominator insignificantly, or from 167 to 169.

The twenty-six SID release categories are included in the overall exceedance frequency plot (Figure 7) for the 6-to-7 mile average individual dose. The procedure is identical to that employed for the Figure 5 CCDF. The 14-to-15 mile average dose band is shown as the lower curve in Figure 7.

The SID core melt frequency of 1.96 x 10^{-4} per reactor-year is divided into the exceedance frequency CCDFs from Figure 7 to yield exceedance probability CCDFs for the 6-to-7 mile and 14-to-15 mile bands shown in Figure 8. The latter figure indicates that a 200-rem red bone marrow dose would be exceeded during a core melt accident 2 times out of 100 somewhere in the six-to-seven mile band. The conditional probability would drop to less than 3 times out of 1000 for the 14-to-15 mile band. If the one-sector assumption is maintained, then the conditional probability of exceeding a 200-rem bone marrow dose by an **individual** would be lower by a factor of sixteen. This reduction follows from the one chance in sixteen of the wind direction being in the sector in which the individual is located.

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TABLE 1.
SID SOURCE TERMS BY RELEASE CATEGORY

RC-1 RELEASE FRACTIONS FOR RELEASE GROUPS (FRACTION OF MARK 22 INVENTORY)

GROUP:	Xe/Kr	I	Cs	Te	Sr	Ru	La	Ce	Ba	T
EARLY	.999	1.3E-5	1.3E-5	1.3E-5	1.1E-5	-	-	-	7.8E-6	0.999
LATE	1.5E-3	9.8E-8	3.9E-8	-	9.39E-5	-	-	-	6.25E-5	1.5E-3
TOTAL	1.000	1.3E-5	1.3E-5	1.3E-5	1.0E-4	-	-	-	7.0E-5	1.000

RC-1A RELEASE FRACTIONS FOR RELEASE GROUPS (FRACTION OF MARK 22 INVENTORY)

GROUP:	Xe/Kr	I	Cs	Te	Sr	Ru	La	Ce	Ba	T
EARLY	.999	1.3E-5	1.3E-5	1.3E-5	1.1E-5	-	-	-	7.8E-6	0.999
LATE	1.5E-3	3.35E-2	3.85E-8	-	9.39E-5	-	-	-	6.25E-5	1.5E-3
TOTAL	1.000	3.35E-2	1.3E-5	1.3E-5	1.0E-4	-	-	-	7.0E-5	1.000

RC-2 RELEASE FRACTIONS FOR RELEASE GROUPS (FRACTION OF MARK 22 INVENTORY)

GROUP:	Xe/Kr	I	Cs	Te	Sr	Ru	La	Ce	Ba	T
EARLY	1.000	4.98E-2	3.59E-4	2.92E-4	3.57E-4	-	-	-	2.33E-4	1.000
LATE	-	2.97E-2	8.51E-6	3.42E-6	1.16E-5	-	-	-	7.59E-6	-
TOTAL	1.000	7.95E-2	3.67E-4	2.95E-4	3.68E-4	-	-	-	2.41E-4	1.000

RC-2A RELEASE FRACTIONS FOR RELEASE GROUPS (FRACTION OF MARK 22 INVENTORY)

GROUP:	Xe/Kr	I	Cs	Te	Sr	Ru	La	Ce	Ba	T
EARLY	1.000	4.98E-2	3.59E-4	2.92E-4	3.57E-4	-	-	-	2.33E-4	1.000
LATE	-	9.38E-1	8.51E-6	3.42E-6	1.16E-5	-	-	-	7.59E-6	-
TOTAL	1.000	9.88E-1	3.67E-4	2.95E-4	3.68E-4	-	-	-	2.41E-4	1.000

RC-2B RELEASE FRACTIONS FOR RELEASE GROUPS (FRACTION OF MARK 22 INVENTORY)

GROUP:	Xe/Kr	I	Cs	Te	Sr	Ru	La	Ce	Ba	T
EARLY	1.000	4.98E-2	3.59E-4	2.92E-4	3.57E-4	-	-	-	2.33E-4	1.000
LATE	-	9.38E-1	7.13E-1	2.89E-1	1.16E-5	-	-	-	7.59E-6	-
TOTAL	1.000	9.88E-1	7.13E-1	2.89E-1	3.68E-4	-	-	-	2.41E-4	1.000

RC-3 RELEASE FRACTIONS FOR RELEASE GROUPS (FRACTION OF MARK 22 INVENTORY)

GROUP:	Xe/Kr	I	Cs	Te	Sr	Ru	La	Ce	Ba	T
EARLY	1.00	1.83E-4	9.28E-5	4.82E-5	1.99E-4	-	-	-	1.29E-4	1.000
LATE	-	4.01E-5	-	-	4.63E-6	-	-	-	3.05E-6	-
TOTAL	1.00	2.23E-4	9.28E-5	4.82E-5	2.03E-4	-	-	-	1.32E-4	1.000

RC-3A RELEASE FRACTIONS FOR RELEASE GROUPS (FRACTION OF MARK 22 INVENTORY)

GROUP:	Xe/Kr	I	Cs	Te	Sr	Ru	La	Ce	Ba	T
EARLY	1.00	1.83E-4	9.28E-5	4.82E-5	2.03E-4	-	-	-	1.32E-4	1.000
LATE	-	2.80E-1	-	-	-	-	-	-	-	-
TOTAL	1.00	2.80E-1	9.28E-5	4.82E-5	2.03E-4	-	-	-	1.32E-4	1.000

TABLE 1. (Continued-1)
SID SOURCE TERMS BY RELEASE CATEGORY

RC-4 RELEASE FRACTIONS FOR RELEASE GROUPS (FRACTION OF MARK 22 INVENTORY)

GROUP:	Xe/Kr	I	Cs	Te	Sr	Ru	La	Ce	Ba	T
EARLY	0.950	1.15E-3	1.4E-4	1.35E-4	8.8E-5	3.5E-5	3.5E-5	3.5E-5	2.1E-5	0.950
LATE	0.050	3.2E-2	8.5E-5	4.2E-5	2.2E-4	8.8E-5	8.8E-5	8.8E-5	5.7E-5	0.050
TOTAL	1.000	3.31E-2	2.25E-4	1.77E-4	3.08E-4	1.23E-4	1.23E-4	1.23E-4	7.8E-5	1.000

RC-4A RELEASE FRACTIONS FOR RELEASE GROUPS (FRACTION OF MARK 22 INVENTORY)

GROUP:	Xe/Kr	I	Cs	Te	Sr	Ru	La	Ce	Ba	T
EARLY	0.950	1.15E-3	1.4E-4	1.35E-4	8.8E-5	3.5E-5	3.5E-5	3.5E-5	2.1E-5	0.950
LATE	0.050	6.61E-1	8.5E-5	4.2E-5	2.2E-4	8.8E-5	8.8E-5	8.8E-5	5.7E-5	0.050
TOTAL	1.000	6.62E-1	2.25E-4	1.77E-4	3.08E-4	1.23E-4	1.23E-4	1.23E-4	7.8E-5	1.000

RC-4B RELEASE FRACTIONS FOR RELEASE GROUPS (FRACTION OF MARK 22 INVENTORY)

GROUP:	Xe/Kr	I	Cs	Te	Sr	Ru	La	Ce	Ba	T
EARLY	0.950	1.15E-3	1.4E-4	1.35E-4	8.8E-5	3.5E-5	3.5E-5	3.5E-5	2.1E-5	0.950
LATE	0.050	6.58E-1	4.3E-1	1.7E-1	2.2E-4	8.8E-5	8.8E-5	8.8E-5	5.7E-5	0.050
TOTAL	1.000	6.59E-1	4.3E-1	1.7E-1	3.08E-4	1.23E-4	1.23E-4	1.23E-4	7.8E-5	1.000

RC-4C RELEASE FRACTIONS FOR RELEASE GROUPS (FRACTION OF MARK 22 INVENTORY)

GROUP:	Xe/Kr	I	Cs	Te	Sr	Ru	La	Ce	Ba	T
EARLY	0.950	1.15E-3	1.4E-4	1.35E-4	6.6E-5	2.6E-5	2.6E-5	2.6E-5	1.6E-5	0.950
LATE	0.050	3.2E-2	8.5E-5	4.2E-5	4.1E-6	1.6E-6	1.6E-6	1.6E-6	6.0E-6	0.050
TOTAL	1.000	3.31E-2	2.25E-4	1.77E-4	7.0E-5	2.8E-5	2.8E-5	2.8E-5	2.2E-5	1.000

RC-4D RELEASE FRACTIONS FOR RELEASE GROUPS (FRACTION OF MARK 22 INVENTORY)

GROUP:	Xe/Kr	I	Cs	Te	Sr	Ru	La	Ce	Ba	T
EARLY	0.950	1.15E-3	1.4E-4	1.35E-4	6.6E-5	2.6E-5	2.6E-5	2.6E-5	1.58E-5	0.950
LATE	0.050	6.61E-1	8.5E-5	4.2E-5	4.1E-6	1.6E-6	1.6E-6	1.6E-6	1.1E-6	0.050
TOTAL	1.000	6.62E-1	2.25E-4	1.77E-4	7.0E5	2.76E-5	2.76E-5	2.76E-5	1.69E-5	1.000

RC-5 RELEASE FRACTIONS FOR RELEASE GROUPS (FRACTION OF MARK 22 INVENTORY)

GROUP:	Xe/Kr	I	Cs	Te	Sr	Ru	La	Ce	Ba	T
EARLY	0.957	7.58E-1	4.64E-1	4.24E-1	2.80E-1	0.00	0.0	0.0	1.81E-1	0.957
LATE	4.28E-2	1.81E-1	1.90E-1	1.06E-1	4.02E-1	0.00	0.0	0.0	2.32E-1	4.28E-2
TOTAL	1.000	9.39E-1	6.54E-1	5.30E-1	6.82E-1	0.00	0.0	0.0	4.13E-1	1.000

RC-5A RELEASE FRACTIONS FOR RELEASE GROUPS (FRACTION OF MARK 22 INVENTORY)

GROUP:	Xe/Kr	I	Cs	Te	Sr	Ru	La	Ce	Ba	T
EARLY	0.957	7.58E-1	4.64E-1	4.24E-1	2.94E-1	1.0E-2	1.0E-2	1.0E-2	1.91E-1	0.957
LATE	4.28E-2	1.81E-1	1.90E-1	1.06E-1	4.02E-1	0.00	0.0	0.0	2.32E-1	4.28E-2
TOTAL	1.000	9.39E-1	6.54E-1	5.30E-1	6.97E-1	1.0E-2	1.0E-2	1.0E-2	4.23E-1	1.000

TABLE 1. (Continued-2)
SID SOURCE TERMS BY RELEASE CATEGORY

RC-6 RELEASE FRACTIONS FOR RELEASE GROUPS (FRACTION OF MARK 22 INVENTORY)

GROUP:	Xe/Kr	I	Cs	Te	Sr	Ru	La	Ce	Ba	T
EARLY	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LATE	1.00	5.0E-1	5.5E-3	8.7E-3	6.7E-2	0.0	0.0	0.0	7.1E-2	1.00
TOTAL	1.00	5.0E-1	5.5E-3	8.7E-3	6.7E-2	0.00	0.00	0.00	7.1E-2	1.00

RC-6A RELEASE FRACTIONS FOR RELEASE GROUPS (FRACTION OF MARK 22 INVENTORY)

GROUP:	Xe/Kr	I	Cs	Te	Sr	Ru	La	Ce	Ba	T
EARLY	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LATE	1.00	5.0E-1	5.5E-3	8.7E-3	6.7E-2	0.0	0.0	0.0	7.1E-2	1.00
TOTAL	1.00	5.0E-1	5.5E-3	8.7E-3	6.7E-2	0.00	0.00	0.00	7.1E-2	1.00

RC-7 RELEASE FRACTIONS FOR RELEASE GROUPS (FRACTION OF MARK 22 INVENTORY)

GROUP:	Xe/Kr	I	Cs	Te	Sr	Ru	La	Ce	Ba	T
EARLY	0.244	2.5E-3	2.3E-3	2.2E-3	1.1E-3	0.00	0.00	0.00	9.0E-4	0.244
LATE	0.756	2.3E-3	3.5E-3	3.4E-3	0.234	0.0	0.0	0.0	0.151	0.756
TOTAL	1.000	4.8E-3	5.8E-3	5.6E-3	0.235	0.00	0.00	0.00	0.152	1.000

RC-7A RELEASE FRACTIONS FOR RELEASE GROUPS (FRACTION OF MARK 22 INVENTORY)

GROUP:	Xe/Kr	I	Cs	Te	Sr	Ru	La	Ce	Ba	T
EARLY	0.244	2.5E-3	2.3E-3	2.2E-3	1.1E-3	0.00	0.00	0.00	9.0E-4	0.244
LATE	0.756	2.3E-3	3.5E-3	3.4E-3	1.2E-3	0.0	0.0	0.0	1.2E-3	0.756
TOTAL	1.000	4.8E-3	5.8E-3	5.6E-3	2.3E-3	0.00	0.00	0.00	2.1E-3	1.000

RC-8 RELEASE FRACTIONS FOR RELEASE GROUPS (FRACTION OF MARK 22 INVENTORY)

GROUP:	Xe/Kr	I	Cs	Te	Sr	Ru	La	Ce	Ba	T
EARLY	0.154	1.89E-3	1.84E-3	1.84E-3	6.53E-2	0.0	0.0	0.0	4.41E-2	0.154
LATE	8.46E-1	5.90E-3	5.90E-3	5.90E-3	0.170	0.0	0.0	0.0	0.112	0.846
TOTAL	1.000	7.79E-3	7.74E-3	7.74E-3	0.235	0.0	0.0	0.0	0.156	1.000

RC-8A RELEASE FRACTIONS FOR RELEASE GROUPS (FRACTION OF MARK 22 INVENTORY)

GROUP:	Xe/Kr	I	Cs	Te	Sr	Ru	La	Ce	Ba	T
EARLY	0.154	1.89E-3	1.84E-3	1.84E-3	9.21E-4	0.0	0.0	0.0	7.39E-4	0.154
LATE	8.46E-1	5.90E-3	5.90E-3	5.90E-3	2.93E-3	0.00	0.00	0.00	2.35E-3	0.846
TOTAL	1.000	7.79E-3	7.74E-3	7.74E-3	3.85E-3	0.00	0.00	0.00	3.09E-3	1.000

TABLE 1. (Continued-3)
SID SOURCE TERMS BY RELEASE CATEGORY

RC-9 RELEASE FRACTIONS FOR RELEASE GROUPS (FRACTION OF MARK 22 INVENTORY)

GROUP:	Xe/Kr	I	Cs	Te	Sr	Ru	La	Ce	Ba	T
EARLY	0.9492	1.7E-3	1.0E-3	1.01E-3	1.3E-3	7.9E-3	7.9E-3	7.9E-3	2.2E-3	0.9492
LATE	0.0508	3.37E-2	1.60E-2	7.40E-3	1.28E-1	9.26E-4	9.26E-4	9.26E-4	0.08	0.0508
TOTAL	1.00	3.53E-2	1.70E-2	8.42E-3	1.30E-1	8.83E-3	8.83E-3	8.83E-3	8.16E-2	1.00

RC-9A RELEASE FRACTIONS FOR RELEASE GROUPS (FRACTION OF MARK 22 INVENTORY)

GROUP:	Xe/Kr	I	Cs	Te	Sr	Ru	La	Ce	Ba	T
EARLY	0.9492	1.7E-3	1.0E-3	1.10E-3	1.3E-3	7.9E-3	7.9E-3	7.9E-3	2.2E-3	0.9492
LATE	0.0508	3.37E-2	1.60E-2	7.40E-3	0.0	9.26E-4	9.26E-4	9.26E-4	0.0	0.0508
TOTAL	1.00	3.53E-2	1.70E-2	8.42E-3	1.29E-3	8.83E-3	8.83E-3	8.83E-3	2.2E-3	1.00

RC-10 RELEASE FRACTIONS FOR RELEASE GROUPS (FRACTION OF MARK 22 INVENTORY)

GROUP:	Xe/Kr	I	Cs	Te	Sr	Ru	La	Ce	Ba	T
EARLY	0.949	2.2E-4	2.2E-4	2.2E-4	1.0E-4	0.0	0.0	0.0	2.6E-5	0.949
LATE	0.051	7.48E-1	4.52E-1	0.201	0.745	8.8E-3	8.8E-3	8.8E-3	0.302	0.051
TOTAL	1.000	0.748	0.452	0.201	0.745	8.8E-3	8.8E-3	8.8E-3	0.302	1.000

RC-10A RELEASE FRACTIONS FOR RELEASE GROUPS (FRACTION OF MARK 22 INVENTORY)

GROUP:	Xe/Kr	I	Cs	Te	Sr	Ru	La	Ce	Ba	T
EARLY	0.949	2.2E-4	2.2E-4	2.2E-4	1.0E-4	0.0	0.0	0.0	2.6E-5	0.949
LATE	0.051	7.48E-1	4.52E-1	0.201	1.71E-2	8.8E-3	8.8E-3	8.8E-3	1.90E-2	0.051
TOTAL	1.000	0.748	0.452	0.201	1.72E-2	8.8E-3	8.8E-3	8.8E-3	1.90E-2	1.000

RC-11 RELEASE FRACTIONS FOR RELEASE GROUPS (FRACTION OF MARK 22 INVENTORY)

GROUP:	Xe/Kr	I	Cs	Te	Sr	Ru	La	Ce	Ba	T
EARLY	0.791	4.8E-5	8.4E-5	8.3E-5	4.2E-5	0.0	0.0	0.0	2.6E-5	0.791
LATE	0.209	0.650	3.62E-1	1.91E-1	0.391	8.8E-3	8.8E-3	8.8E-3	0.250	0.209
TOTAL	1.000	0.650	0.362	0.191	0.391	8.8E-3	8.8E-3	8.8E-3	0.250	1.000

RC-11A RELEASE FRACTIONS FOR RELEASE GROUPS (FRACTION OF MARK 22 INVENTORY)

GROUP:	Xe/Kr	I	Cs	Te	Sr	Ru	La	Ce	Ba	T
EARLY	0.791	4.8E-5	8.4E-5	8.3E-5	4.2E-5	0.0	0.0	0.0	2.6E-5	0.791
LATE	0.209	0.650	3.62E-1	1.91E-1	1.21E-2	8.8E-3	8.8E-3	8.8E-3	1.61E-2	0.209
TOTAL	1.000	0.650	0.362	0.191	1.21E-2	8.8E-3	8.8E-3	8.8E-3	1.61E-2	1.000

TABLE 2.
COMPARISON AGAINST DOE DRAFT SAFETY GOALS
(OFFSITE INDIVIDUAL RISK - DRAFT MAY, 1989)

Basis: 26 Release Categories Analyzed in the April, 1990 Safety Information Document

Risk Category	DOE Safety Goal (risk/reactor-y)	SRS, per Reactor (risk/reactor-y)*	SRS SID/DOE Goal, (%)
Offsite Acute Fatality			
Within 10 miles of K reactor	---	6.3×10^{-10}	---
1 mile from DOE reservation boundary, **K reactor** source term	4.0×10^{-7}	5.9×10^{-11}	0.015
Offsite Latent Cancer Fatality			
10 miles from DOE reservation boundary, **K reactor** source term	2.0×10^{-6}	3.4×10^{-8}	1.7

* 1. Accounts for 1980 population distribution; multipy by 1.137 to estimate 1990 patterns.
2. Assumes 20-mile evacuation from K reactor beginning at 2 hours after the release of the first plume segment at an effective speed of 2.5 miles per hour for all release categories except for RC-5 and RC-7..

TABLE 3.
COMPARISON AGAINST DOE DRAFT SAFETY GOALS AND ALTERNATIVE EVACUATION MODELS

Basis: 26 Release Categories Analyzed in the April, 1990 Safety Information Document

Risk Category	DOE Safety Goal (risk/reactor-y)	SRS, per Reactor (risk/reactor-y)*	SRS SID/DOE Goal, (%)
Offsite Acute Fatality 1 mile from DOE reservation boundary, **K reactor** source term			
Base Case Evacuation[1,2]	4.0×10^{-7}	5.88×10^{-11}	0.015
10-mile Evacuation[1,3]		1.87×10^{-10}	0.047
No Evacuation[1,4]		5.80×10^{-10}	0.145
Offsite Latent Fatality 10 miles from DOE reservation boundary, **K reactor** source term			
Base Case Evacuation[1,2]	2.0×10^{-6}	3.4×10^{-8}	1.70
10-mile Evacuation[1,3]		3.4×10^{-8}	1.70
No Evacuation[1,4]		3.4×10^{-8}	1.70

* 1. Accounts for 1980 population distribution; multipy by 1.137 to estimate 1990 patterns.
2. Assumes 20-mile evacuation from K reactor beginning at 2 hours after the release of the first plume segment at an effective speed of 2.5 miles per hour for all release categories except for RC-5 and RC-7. For these 2 RCs, the time is 4 hours and the speed is 1.25 mph.
3. Assumes 10-mile evacuation from K reactor beginning at 2 hours after the release of the first plume segment at an effective speed of 2.5 miles per hour for all release categories except for RC-5 and RC-7. For these 2 RCs, the time is 4 hours and the speed is 1.25 mph.
4. Stationary offsite population - no evacuation assumed.

TABLE 4.
RELEASE CATEGORY FREQUENCIES
APRIL, 1990 SAFETY INFORMATION DOCUMENT

Release Category	Frequency (per reactor year)
1	3.576E-05
1A	1.879E-07
2	1.161E-05
2A	1.014E-07
2B	1.623E-06
3	3.433E-05
3A	4.230E-07
4	1.313E-05
4A	1.146E-07
4B	4.937E-08
4C	1.585E-06
4D	1.383E-08
5	2.360E-06
5A	5.005E-07
6	2.210E-05
6A	1.050E-05
7	4.340E-07
7A	2.366E-06
8	4.759E-06
8A	2.594E-05
9	7.250E-07
9A	2.151E-05
10	6.555E-07
10A	2.483E-07
11	2.123E-06
11A	4.113E-06
TOTAL	1.96E-04

FIGURE 1.
CONDITIONAL PROBABILITY OF EXCEEDING 200 rem WHOLE BODY DOSE VERSUS DISTANCE
(NUREG-0396)

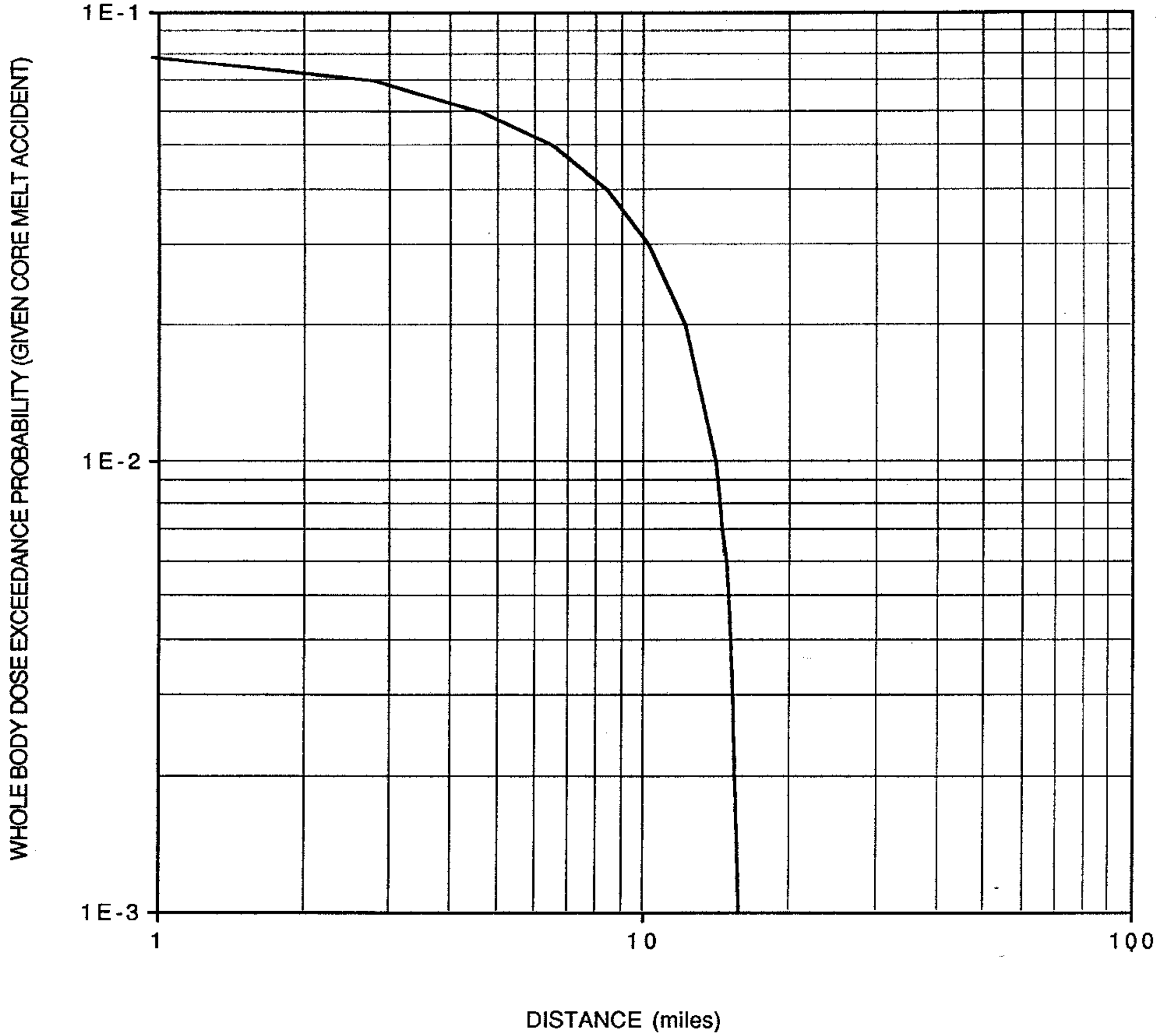


FIGURE 2
CONDITIONAL PROBABILITY OF EXCEEDING 300 rem THYROID DOSE VERSUS DISTANCE
(NUREG-0396)

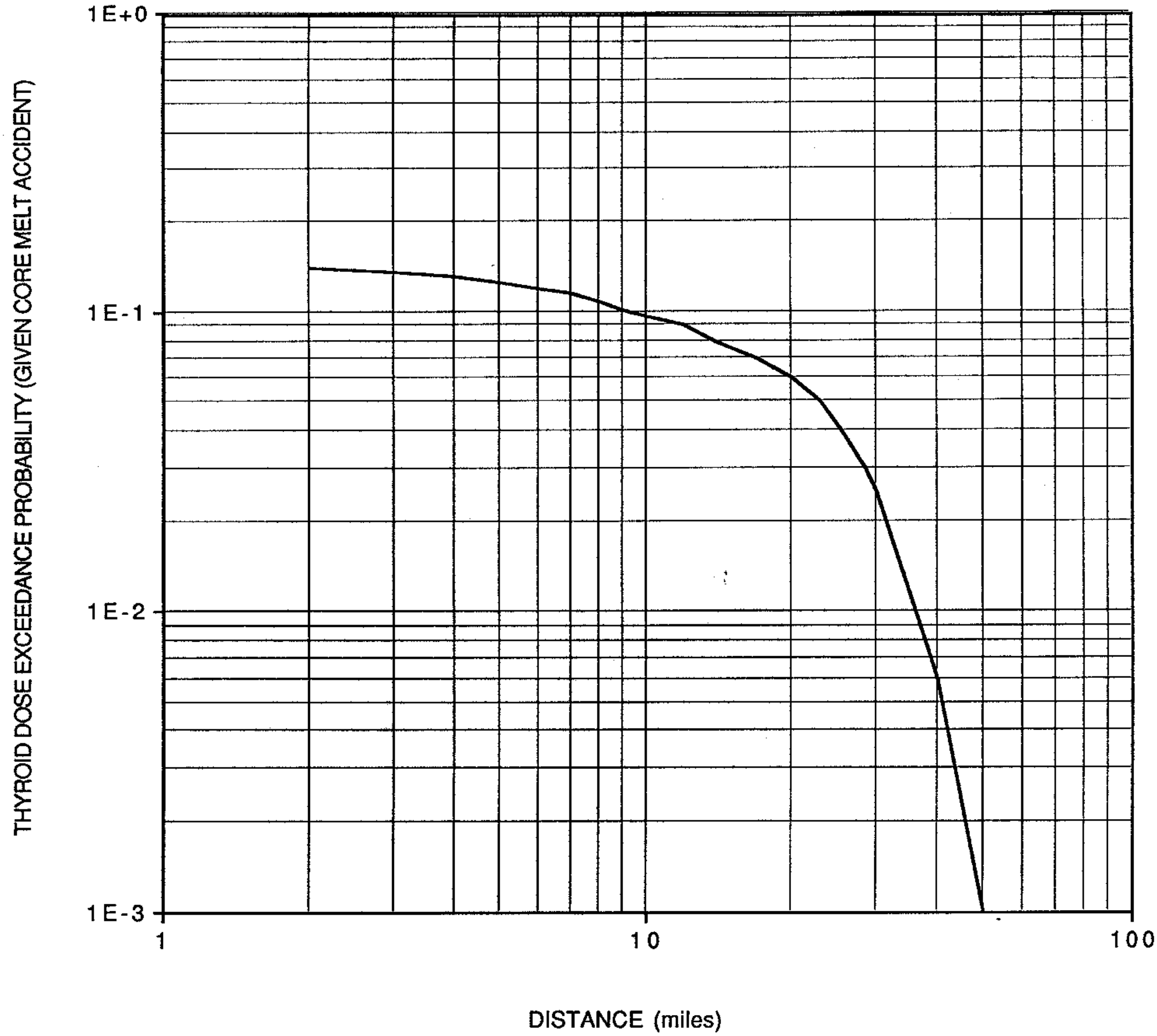
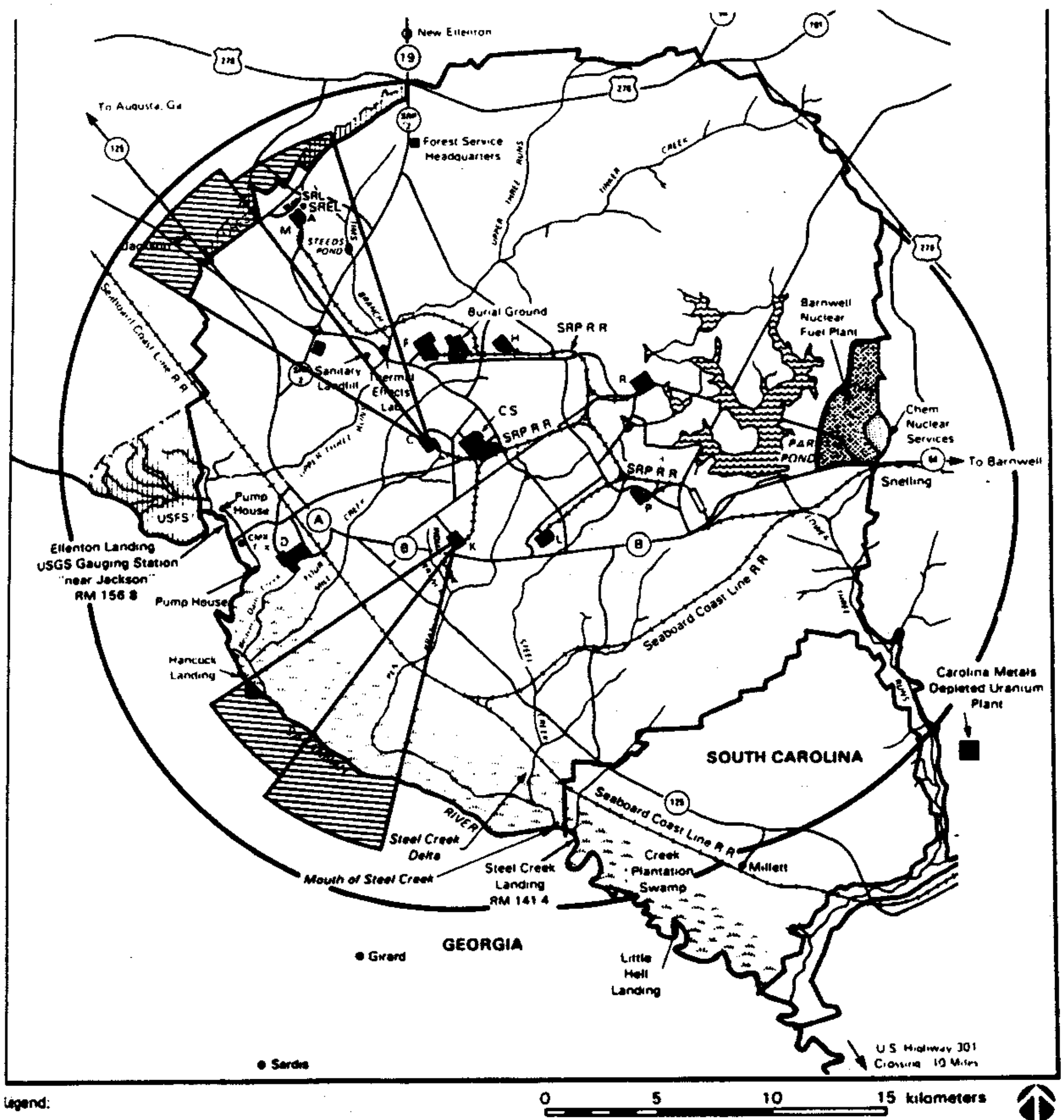


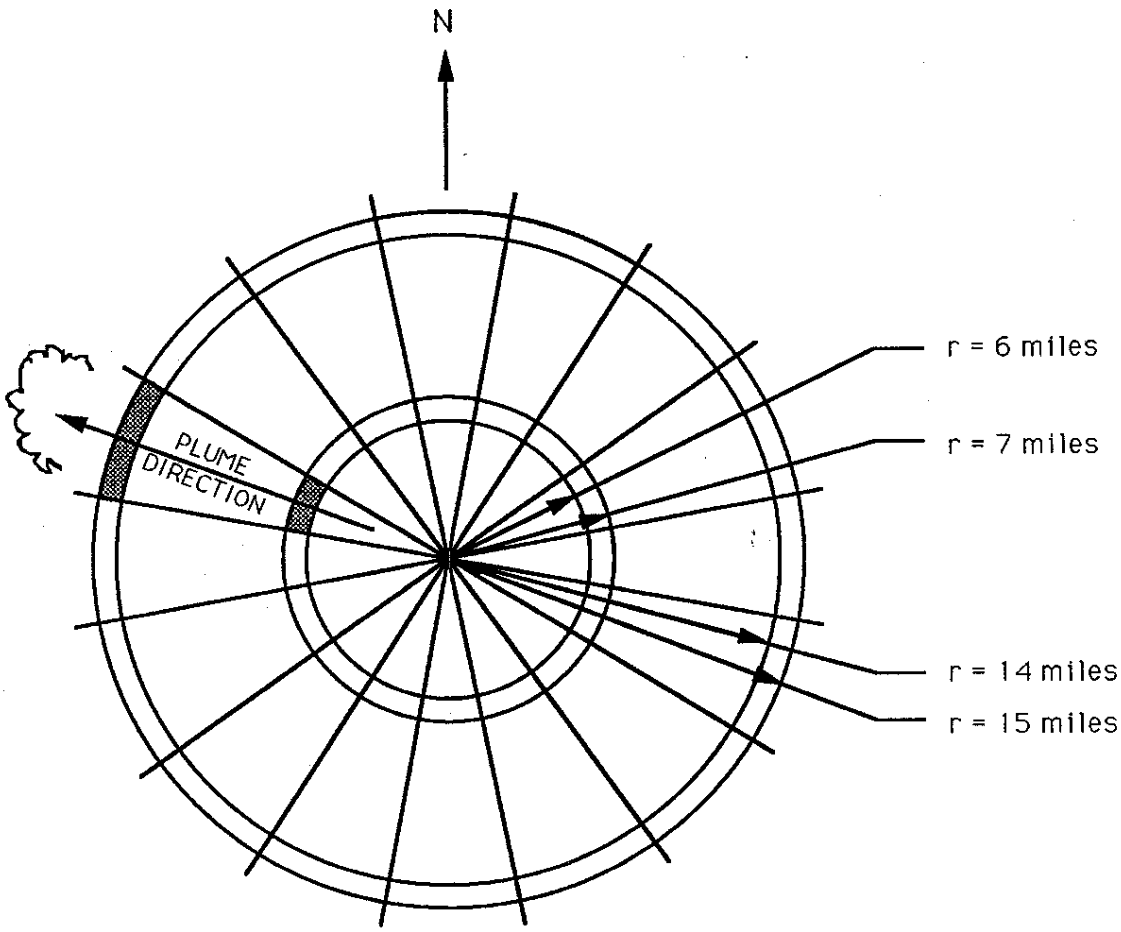
FIGURE 3.
CURRENT EMERGENCY PLANNING ZONE - SAVANNAH RIVER SITE



Legend:

- Preliminary Planning Zone (from maximum credible accident analysis)
- Preliminary Planning Zone (16-kilometer radius about each operating reactor)

FIGURE 4.
RBM DOSE AT SPECIFIC RADIAL INTERVALS



ASSUMPTION

$$\text{AFFECTED 6 - 7 mile POPULATION} = \frac{\text{TOTAL 6 - 7 mile POPULATION}}{16}$$

$$\text{AFFECTED 14 - 15 mile POPULATION} = \frac{\text{TOTAL 14 - 15 mile POPULATION}}{16}$$

FIGURE 5
FREQUENCY OF EXCEEDING DOSE VERSUS DISTANCE

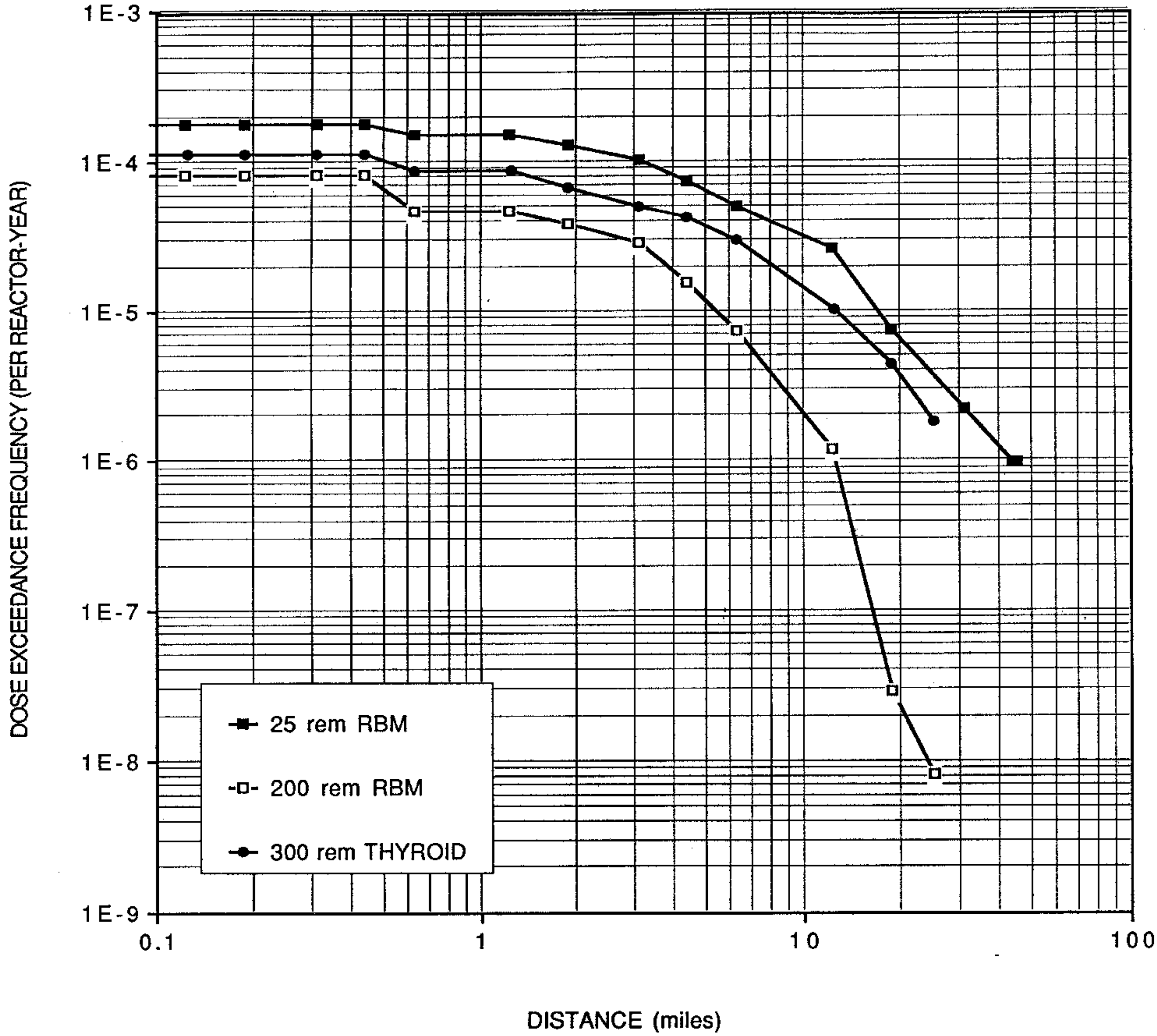


FIGURE 5A.
FREQUENCY OF EXCEEDING 200 REM RBM DOSE VERSUS DISTANCE

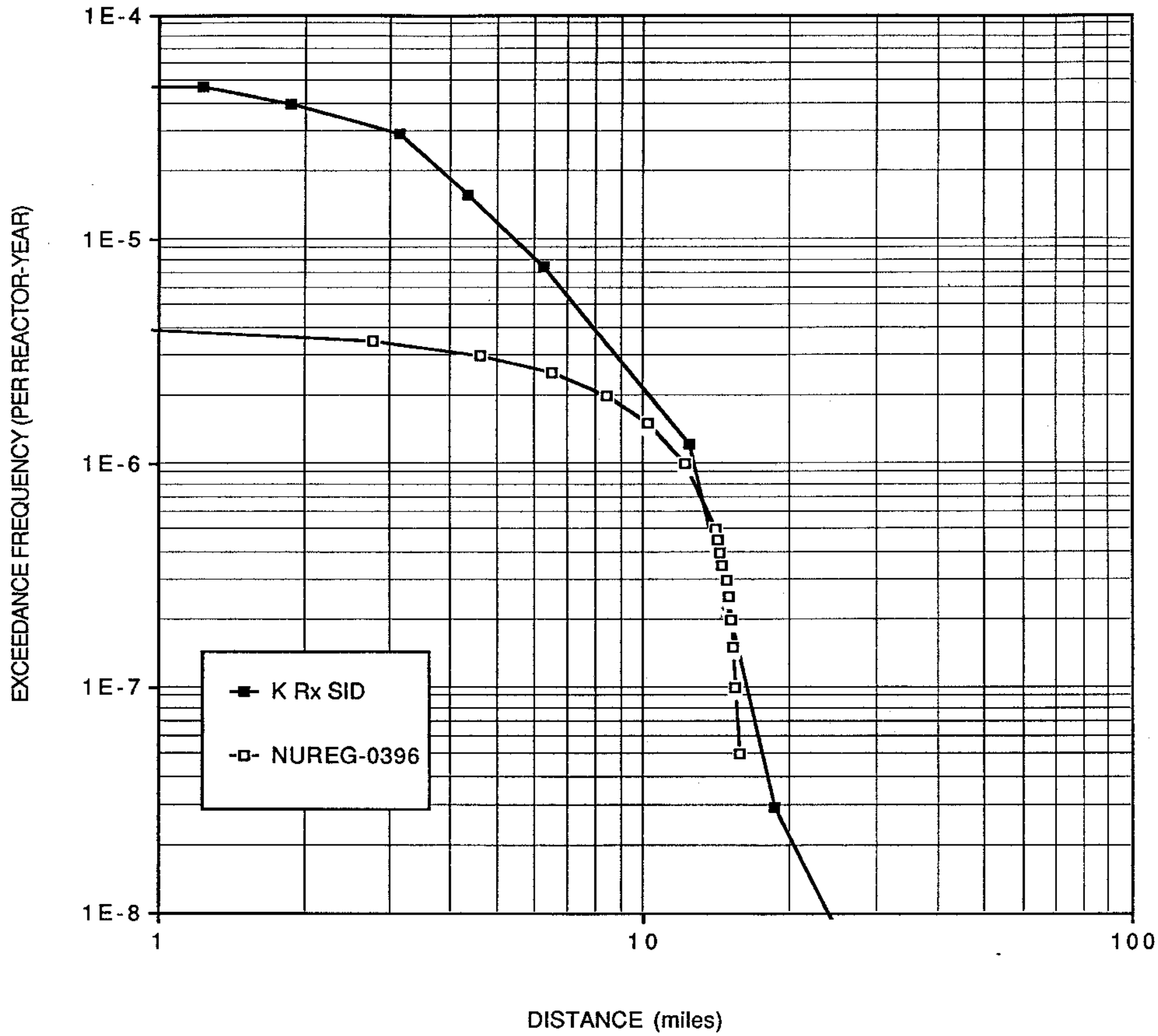


FIGURE 6.
PROBABILITY OF EXCEEDING DOSE VERSUS DISTANCE

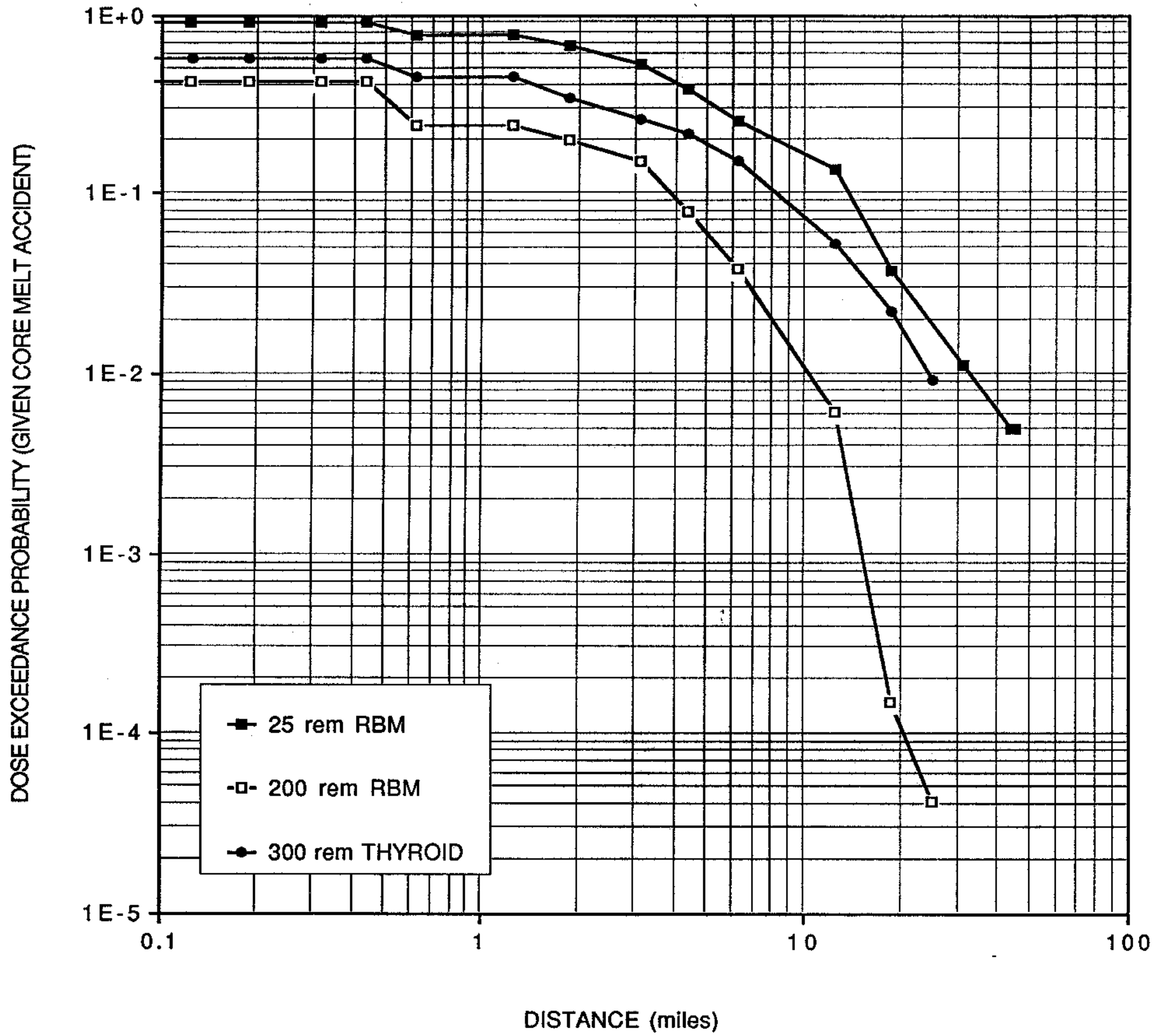


FIGURE 7.
EXCEEDANCE FREQUENCY VERSUS RED BONE MARROW DOSE (rem)

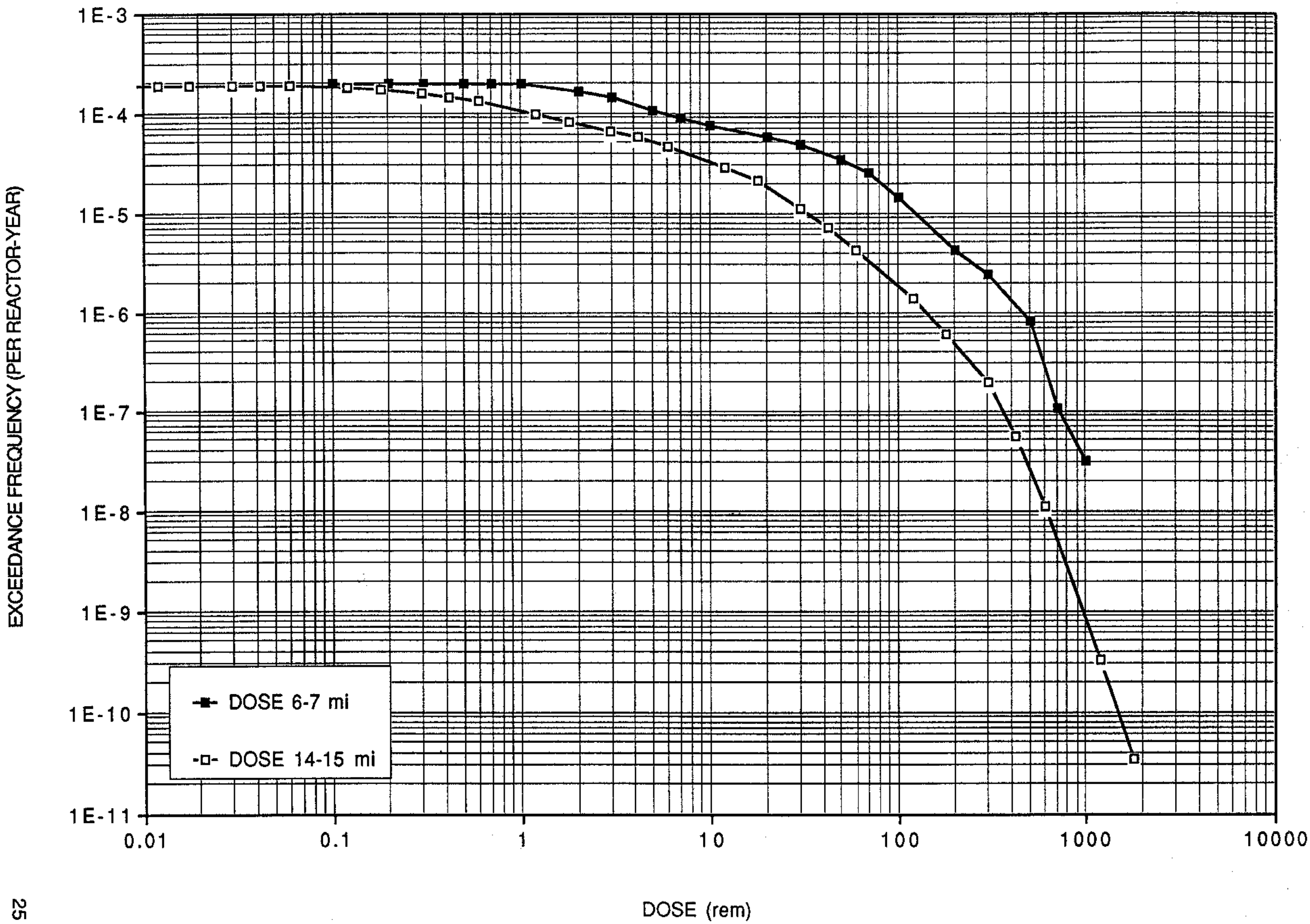
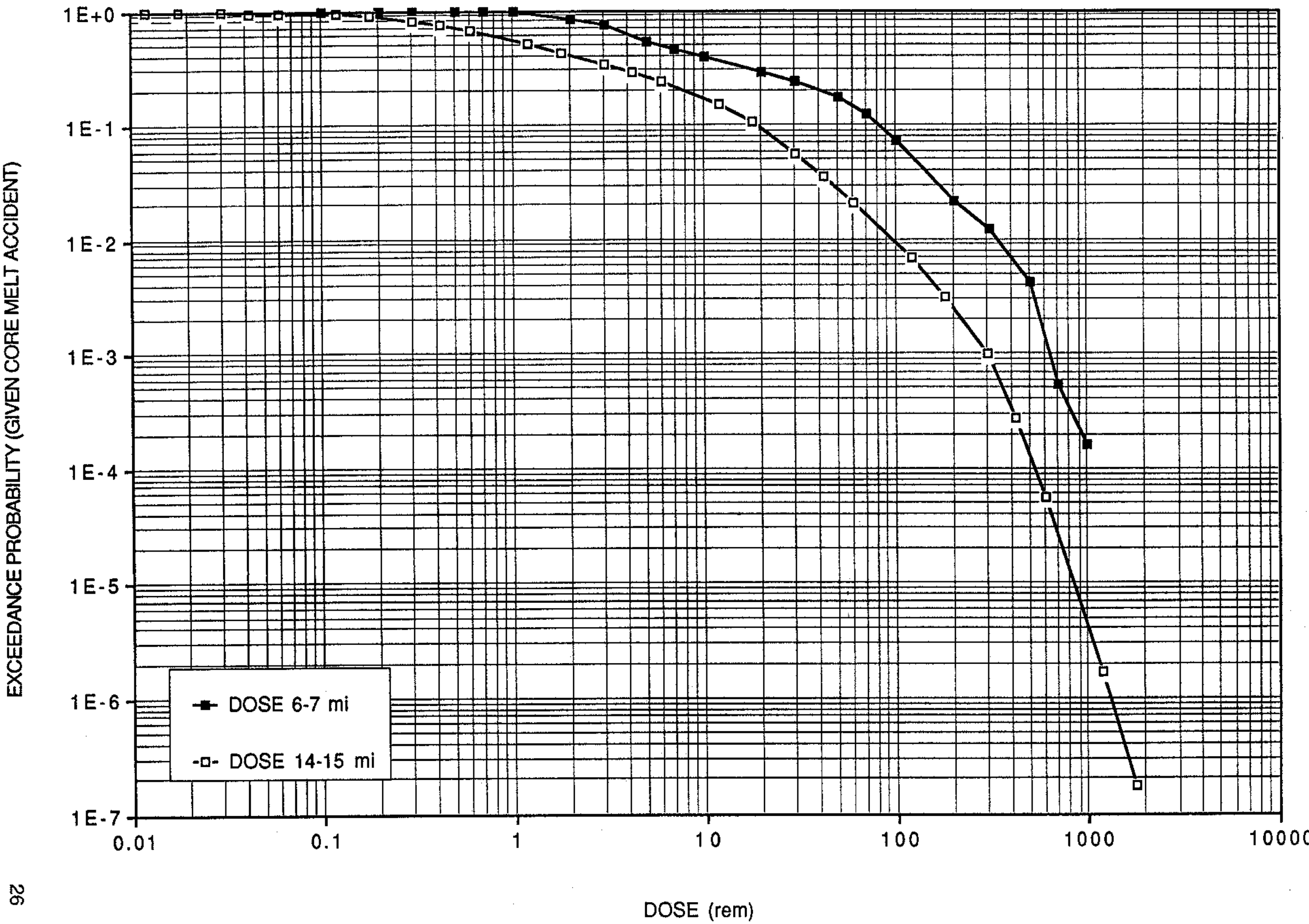


FIGURE 8.
EXCEEDANCE PROBABILITY VERSUS RED BONE MARROW DOSE (rem)



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Indices of Risk for Emergency Planning (U)

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December 13, 1990

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Ms. W. F. Perrin, Technical Information Officer
U. S. Department of Energy
Savannah River Operations Office
Aiken, SC 29801

Dear Ms. Perrin:

REQUEST FOR APPROVAL TO RELEASE SCIENTIFIC/TECHNICAL INFORMATION

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[signature] WSRC Technical Information Manager
J. A. Duschinski

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WSRC-RP-90-348, REV 1, "SAVANNAH RIVER REACTOR OPERATIONS: INDICES OF RISK FOR EMERGENCY PLANNING (U)," By K. R. O'Kula and J. M. East.

A report being sent to OSTI for distribution to the general public.

Technical questions pertaining to the contents of this document should be addressed to the author(s) or

D. D. Sharp, Manager
Reactor Safety Research
Savannah River Site

Questions concerning processing of this document should be addressed to the WSRC Technical Information Manager, 5-3992 or 5-2646.

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AUTHORS
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