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Licensing and Accident Reviews for an HNEC

R. G. Clark

September 1978

Prepared for the U.S. Department of Energy
under Contract EY-76-C-06-1830

Pacific Northwest Laboratory
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Pacific Northwest Laboratory
Richland, Washington 99352

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SUMMARY

An examination of the different criteria in the Code of Federal Regulation (CFR) particularly Chapter 10, the Regulatory Guides of the Nuclear Regulatory Commission (NRC), the Standard Work Plan Reviews, some specific standards and public correspondence of the Advisory Committee for Reactor Safety (ACRS), current proposed legislation, and reviews of several generic studies of nuclear energy centers did not reveal any areas where the concept of a nuclear energy center at Hanford would be limited by technical concerns. Rules or regulations or formal official guidance that address specifically Nuclear Energy Centers, however, do not exist. Such regulations and guidance will apparently be developed and promulgated following informal and preliminary petitions to the regulatory bodies requesting an energy center per se. Current practice does include siting up to several power plants at a single site, referred to as multiple-unit sites with up to four power reactors located at one site. Preliminary planning has included five units in two groups, one of two and the other of three, which are rather widely separated. The latter may be of interest to a nuclear energy center at Hanford, because of the distances at Hanford that are available to separate the sites. Regulations and guides that direct current practice in siting multiple-units at one location may be adequate to address most if not all of the considerations for siting required for the concept of twenty units at Hanford located at five sites, each of which would contain three to five power generating reactors. The technical studies completed in support of the concept of an HNEC have analyzed many of the key licensing issues that would normally be associated with the siting of several thermal nuclear power plants at one location. To contribute to these, an analysis of the effects of a class nine accident at one unit on the other power reactors at an HNEC was completed. Some perspective relative to other similarly improbable events was gained in this analysis. In part because of the distances available between sites at Hanford, the consequences of a class nine accident onsite can be assessed to be less probable than the consequences from ashfalls from volcanic activity in the Cascades and significantly less probable than the consequences from earthquakes for which designs and procedures have been developed. Consequences here are measured in losses of electrical generating capacity.

INTRODUCTION

The purpose of this review was to identify siting or other concerns that may indicate limitations on the ability to license a nuclear energy center at Hanford.

Several studies on nuclear energy centers have been completed and some have included licensing (regulatory) aspects of siting nuclear power centers.[1-3] This review however, was primarily to identify any limitations that may affect licensing specifically at an HNEC.

The scope included examining existing criteria for siting nuclear facilities, including single reactor and multireactor (multi-unit) sites. To fill a void in other analyses and to gain some perspective on another impact of an HNEC, the scope was extended to analyze the consequences within the HNEC, of a class nine accident at a unit at one site. A predictive model utilized in this analysis was developed from meteorological parameters based on thirty years of meteorological records[4] at Hanford.

From this analysis, additional perspective was developed on the relative severity of the effects of rare events, both man made and from unstable conditions in nature, on the operation of (and the ability to license) an energy center at Hanford (HNEC).

Further insights on the unique siting characteristics of an HNEC have resulted from such perspectives.

LICENSING REVIEW

This evaluation consists of reviews of appropriate parts of Volume 10 (and others) of the Federal Code, the current Regulatory guides, the Standard Review Plans (NUREG 0075), the Proposed Standard Review Plans for EIS (NUREG 0098), appropriate published correspondence on multiple siting from the Advisory Committee on Reactor Safety, the prior reviews on nuclear energy centers and the related studies completed for the concept of a nuclear energy center at Hanford. Each was reviewed to identify possible areas of constraints or support for an HNEC.

The current status of regulations on nuclear energy centers is perhaps best summarized by a part of a recent revision to Regulatory Guide 4.11, Terrestrial Environmental Studies for Nuclear Power Stations, Rev 1, August 1977.

In the introduction of this guide the following appears:

> * | This guide is intended to reflect current practice, i.e., the siting of up to several power plants at a single site. Prior consultation with the staff is recommended if larger-scale "Energy Centers" are contemplated.
>
> *Lines indicate substantive changes from previous issue.

Groups in the regulatory body, the Nuclear Regulatory Commission, apparently are not now considering the preparation of codes and guides directed to larger scale Energy Centers.[a] Codes and guides have increasingly noted however, siting several power plants at a single site (multi-unit sites) (see Appendix A.)

Although four units at a site have been the most for which approval has been sought of NRC and others such as the state agencies, the regulations

(a) The Tyronne Energy Park in Dunn County, Wisconsin, which was recently issued a construction permit by NRC, is not to be identified as an energy center. The park connotation results from the aesthetic features planned for this site which is to contain one (perhaps two eventually) power units.

and guides do not specifically limit the number of units at a site to four. Presumably, if all of the existing regulations and guides were satisfied, more than four units may be acceptable.

Present planning for which construction permits have been sought has included two stations of two units and three units each located about twenty-five miles apart.[a] The siting issues here may be of interest to an HNEC because of the distances available between some sites at Hanford. Figure 2 (see page 14), indicates the general layout of these sites at Hanford and the table gives the approximate distances between the proposed sites.

A recent review examined the expansion potential for existing nuclear power station sites.[5] An interesting concept of mini NECs was developed in this analysis. Thus the potential for developing essentially a small NEC might exist utilizing the criteria in existing codes and guides. Hanford was rated as having the potential to expand from the existing three to a large nuclear energy center. This backdoor approach to an energy center was not defended in another recent review largely because of the absence, in this approach, of long-range planning which was deemed essential.[6] Parenthetically, the observation was made that presently organized utilities, institutions, and political entities are not capable of handling and evaluating the long-term planning and firm commitments of the large resources required for (twenty unit) NECs.

Whatever other reservations may exist concerning a large NEC (twenty units) at Hanford, siting criteria that would limit licensing the proposed units do not at this time appear to include limiting restraints.

(a) Duke Power Company, Perkins and Catawba sites in South Carolina

REVIEW OF THE FEDERAL CODES

No regulations in the federal code currently address nuclear energy centers per se.

Limitations on annual dose equivalents from exposure to radiation and on quantities of radioactive material released from the entire fuel cycle have been imposed by EPA.[a] These latter restrictions as they may affect an HNEC are addressed in a supporting document.[b]

Regulations that bear on siting and safety where several thermal nuclear power plants may be located on one site are reviewed in Appendix A. As above, none appear to be limiting to the concept of an HNEC, but of course none are directed specifically to nuclear energy centers.

REVIEW OF THE REGULATORY GUIDES

By definition, "Regulatory Guides are issued to describe ... methods acceptable to the NRC staff implementing ... regulations ... to provide guidance to applicants." The Guides are not substitutes for regulations (as contained in the Federal Codes for example) and compliance with them is not required. However, they are generally closely followed. More recent guides provide input relating to multi-unit sites. None of these guides issued so far would appear to deny an HNEC. The results of this analysis are tabulated in Appendix B. Two other documents were included in this part of the review; namely, the Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants, NUREG-75/087 and Draft, Environmental Standard Review Plans for the Environmental Review of Construction Permit Applications for Nuclear Power Plants, NUREG-0158 Parts 1, 2 and 3. Both were prepared as internal working documents for the NRC staff, prepared by this staff for the purpose of improving the quality and uniformity of the reviews undertaken by NRC. They make reference to the appropriate codes and

(a) Title 40 Code of Federal Regulations, Part 190, "Environmental Radiation Protection Standards for Nuclear Power Operations," Federal Register, Vol. 42 (No. 9), pp. 2858-2861, January 13, 1977.
(b) Radiological Studies, J. K. Soldat.

guides where sharing of services among units or where more than one unit may be located at a site. No additional insights or guidance on multi-unit siting is contained in these documents.

OTHER REVIEWS

In response to a request from the NRC staff, the Advisory Committee on Reactor Safeguards recommended in December of 1975 several criteria in current siting policies be considered.(7) One of the recommendations noted that studies may be needed on the short- and long-term consequences of a major accident in a nuclear installation on other operations at a multi-unit site such as a nuclear power park. Included in the closure was another recommendation that attention should also be given to the development of additional criteria for sites containing more than one reactor or nuclear facility. Recent guides and regulations have noted criteria for multi-unit sites. As noted above--none so far have been restrictive to the concept of an HNEC.

THE RADIOLOGICAL CONSEQUENCES OF CLASS NINE ACCIDENT AT HNEC

This analysis is based on a meteorological model developed in one of the HNEC conceptual studies.[4] This model uses 30 years or more of meteorological records at Hanford from which some expectations of the frequency of occurrence (probability) of different meteorological parameters have been developed. These parameters include for example, prevailing wind directions, average wind speeds, atmospheric stability, the height of the mixing layer and others.

To these parameters are added an expected plume width, a deposition velocity to account for depositing material released in the accident and the assumption that essentially all of the release occurs over 0.5 hours. This model, when superimposed on the layout of the five quads on the site of the HNEC, predicts in a probabilistic manner, the effects of accident releases from a unit in any one quad on the remaining reactors at the HNEC. The model thus yields the conditional probabilities of M quads being involved with different levels of air concentrations or surface depositions of radioactive material, given that a class nine accident has occurred at a reactor in one of them. The following two tables developed from that report show these results. Notice, for example, that for all normalized concentrations in both tables, the probability of the reactors in the same quad being involved is 1.0 (a certainty) according to this model. The probability, for example, of three or more quads being involved with a normalized air concentration of 1×10^{-7} is 0.07 (0.066) (Table 1).

Similarly for ground deposition as shown in Table 2. Note that the concentrations (left column) are given in terms of normalized surface concentrations. As an example, for concentrations equal to or greater than $1 \times 10^{-8}\ m^{-2}$, the conditional probability that at least two quads are contaminated is 0.05 (0.046) given that an accident occurs.

The result of only four quads of the five proposed being involved is a limitation of the models, orientation of clusters and wind direction classes. The probability of the fifth quad (16-20 reactors) being involved, while extremely low, must be considered possible.

TABLE 1. Conditional Probability that at Least M Quads Would be Involved[(a)] Following an Accident at an HNEC.

Normalized Air Concentration, s/m^3	Same Quad	Number of Quads ≥2	≥3	≥4
1.00×10^{-5}	1.000			
4.64×10^{-6}	1.000	0.046		
4.64×10^{-7}	1.000	0.069	0.011	
2.15×10^{-7}	1.000	0.126	0.030	
1.00×10^{-7}	1.000	0.158	0.066	0.018
4.64×10^{-8}	1.000	0.172	0.085	0.023
2.15×10^{-8}	1.000	0.182	0.090	0.024
1.00×10^{-8}	1.000	0.188	0.095	0.025
>0	1.000	0.194	0.108	0.030

(a) Involvement is defined by normalized air concentration equal to or greater than tabled value.

The full development of the consequences requires a description of a source term and a method to convert the involvement in normalized concentrations to corresponding levels of dose. Figure 1 illustrates the procedure used.

As indicated by Figure 1, the source term was taken from the Reactor Safety Study.[(8)] Any of the accidents involving the core that were identified in that study could be used to develop subsequent potential doses at other reactor sites from a) the passing cloud immediately following the accident; and b) ground level contamination during the period following deposition. Table 3 summarizes these accidents and the release mechanisms involved. For this analysis, the class nine accident identified as release category PWR-2 was selected. This was judged to be about as probable as any other event. It also postulates as great or greater quantities of radioactive material released as in any other accident for a ground level release. It can be considered as worst case. The tabulation of radionuclides released in this event are given in Tables 4 and 5. From these tabulations, the appropriate nuclides were

TABLE 2. Conditional Probability that at Least M Quads Would be Involved[a] Following an Accident at an HNEC.

Normalized Surface Concentration, s/m^3	Same Quad	Number of Quads ≥ 2	≥ 3	≥ 4
1.00×10^{-7}	1.000			
4.64×10^{-8}	1.000	0.006		
2.15×10^{-8}	1.000	0.021		
1.00×10^{-8}	1.000	0.046		
4.64×10^{-9}	1.000	0.069	0.011	
2.15×10^{-9}	1.000	0.126	0.030	
1.00×10^{-9}	1.000	0.158	0.066	0.018
4.64×10^{-10}	1.000	0.172	0.085	0.023
2.15×10^{-10}	1.000	0.182	0.090	0.024
1.00×10^{-10}	1.000	0.188	0.095	0.025
>0	1.000	0.194	0.108	0.030

(a) Involvement is defined by normalized surface concentration equal to or greater than tabled value.

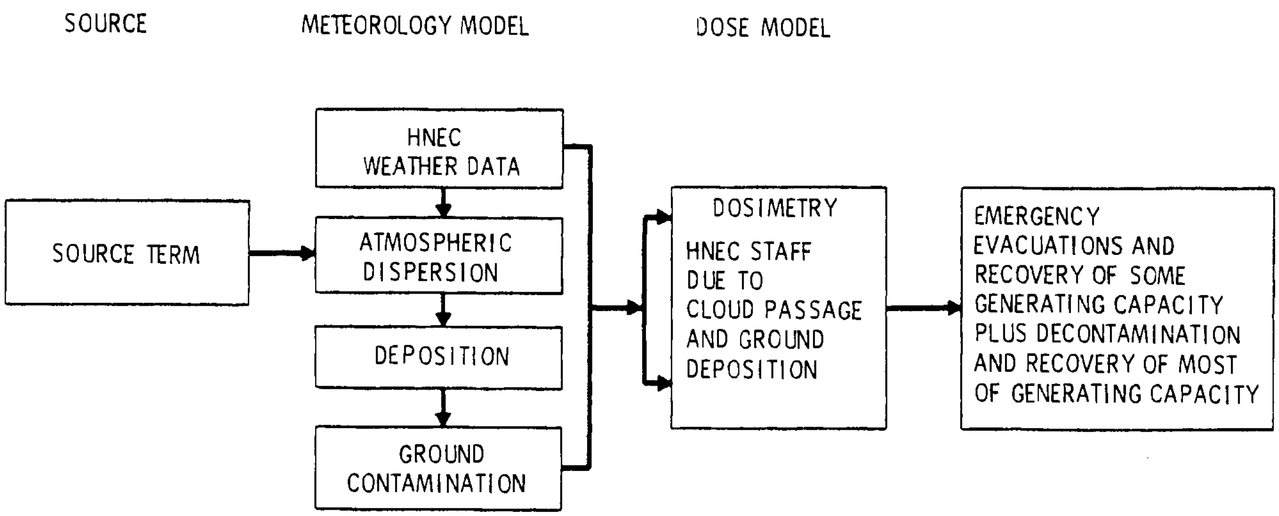


FIGURE 1. Schematic Outline of Consequence Model Radioactivity Release

TABLE 3. Release Categories Following Reactor Accidents Involving Core[a]

	Pressurized Water Reactors
PWR 1	Steam explosion due to molten UO_2 falling into water followed by missile rupturing containment.
PWR 2	Core melt and failure of radioactivity removal systems followed by rupture of containment.
PWR 3	Similar to PWR 1 and 2 but involves partial success of radioactivity removal systems.
PWR 4	Core melt with containment not fully isolated, containment radioactivity removal systems have failed.
PWR 5	Similar to PWR 4 except removal systems operative.
PWR 6	Core melt through bottom, above ground containment intact. Radioactivity removal systems inoperative.
PWR 7	Similar to PWR 6 except radioactivity removal system operating.
PWR 8	Core doesn't melt, release of activity in the gaps of fuel rods, containment fails to isolate properly.
PWR 9	Similar to PWR 8, except containment isolates correctly.
	Boiling Water Reactors
BWR 1	Similar to PWR 1
BWR 2	Core melt after containment over pressure rupture caused by loss of decay heat removal systems, limited deposition of radioactive materials. Release directly to atmosphere.
BWR 3	Similar to BWR 2 except material released through the reactor building to the atmosphere.
BWR 4	Core melt, containment fails to operate properly and the leakage is enough to prevent containment over pressure rupture.
BWR 5	Core does not melt, but activity is released from the gap of the fuel rods. Activity passes through reactor building gas treatment system and is released to the atmosphere through a tall stack.

(a) From Reference 8

TABLE 4. Initial Activity of Radionuclides in the Nuclear Reactor Core at the Time of the Hypothetical Accident (Reference 8)

No.	Radionuclide	Radioactive Inventory Source (curies x 10^{-8})	Half-Life (days)
1	Cobalt-58	0.0078	71.0
2	Cobalt-60	0.0029	1,920
3	Krypton-85	0.0056	3,950
4	Krypton-85m	0.24	0.183
5	Krypton-87	0.47	0.0528
6	Krypton-88	0.68	0.117
7	Rubidium-86	0.00026	18.7
8	Strontium-89	0.94	52.1
9	Strontium-90	0.037	11,030
10	Strontium-91	1.1	0.403
11	Yttrium-90	0.039	2.67
12	Yttrium-91	1.2	59.0
13	Zirconium-95	1.5	65.2
14	Zirconium-97	1.5	0.71
15	Niobium-95	1.5	35.0
16	Molybdenum-99	1.6	2.8
17	Technetium-99m	1.4	0.25
18	Ruthenium-103	1.1	39.5
19	Ruthenium-105	0.72	0.185
20	Ruthenium-106	0.25	366
21	Rhodium-105	0.49	1.50
22	Tellurium-127	0.059	0.391
23	Tellurium-127m	0.011	109
24	Tellurium-129	0.31	0.048
25	Tellurium-129m	0.053	0.340
26	Tellurium-131m	0.13	1.25
27	Tellurium-132	1.2	3.25
28	Antimony-127	0.061	3.88
29	Antimony-129	0.33	0.179
30	Iodine-131	0.85	8.05
31	Iodine-132	1.2	0.0958
32	Iodine-133	1.7	0.875
33	Iodine-134	1.9	0.0366
34	Iodine-135	1.5	0.280
35	Xenon-133	1.7	5.28
36	Xenon-135	0.34	0.384
37	Cesium-134	0.075	750
38	Cesium-136	0.030	13.0
39	Cesium-137	0.047	11,000
40	Barium-140	1.6	12.8
41	Lanthanum-140	1.6	1.67
42	Cerium-141	1.5	32.3
43	Cerium-143	1.3	1.38
44	Cerium-144	0.85	284
45	Praseodymium-143	1.3	13.7
46	Neodymium-147	0.60	11.1
47	Neptunium-239	16.4	2.35
48	Plutonium-238	0.00057	32,500
49	Plutonium-239	0.00021	8.9×10^6
50	Plutonium-240	0.00021	2.4×10^6
51	Plutonium-241	0.034	5,350
52	Americium-241	0.000017	1.5×10^5
53	Curium-242	0.0050	163
54	Curium-244	0.00023	6,630

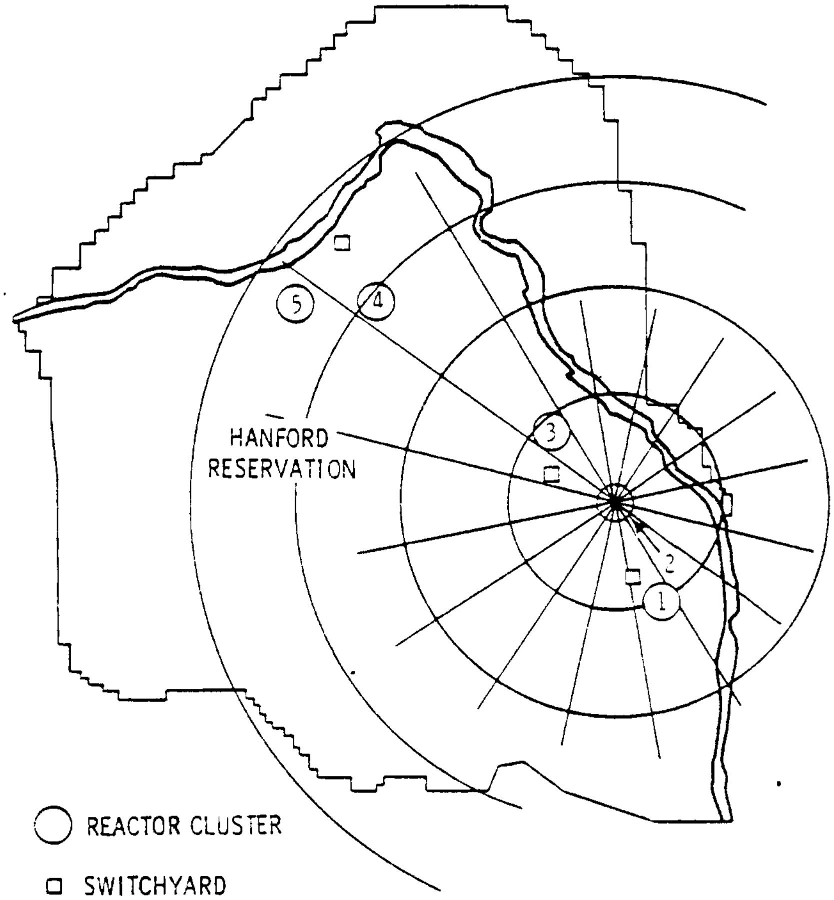
TABLE 5. Parameters of Releases Following Reactor Accidents Involving Core[a]

Release Category	Probability per Reactor Year	Release Duration (Hr)	Warning Time (Hr)	Fraction of Core Inventory Released			
				Xe-Kr	I	Cs-Rb	Ba-Sr
PWR 1	$9x10^{-7}$	0.5	1.0	0.9	0.7	0.4	0.05
PWR 2	$8x10^{-6}$	0.5	1.0	0.9	0.7	0.5	0.06
PWR 3	$4x10^{-6}$	1.5	2.0	0.8	0.2	0.2	0.02
PWR 4	$5x10^{-7}$	3.0	2.0	0.6	0.09	0.04	$5x10^{-3}$
PWR 5	$7x10^{-7}$	4.0	1.0	0.3	0.03	$9x10^{-3}$	$1x10^{-3}$
PWR 6	$6x10^{-6}$	10.0	1.0	0.3	$8x10^{-4}$	$8x10^{-4}$	$9x10^{-5}$
PWR 7	$4x10^{-5}$	10.0	1.0	$6x10^{-3}$	$2x10^{-5}$	$1x10^{-5}$	$1x10^{-6}$
PWR 8	$4x10^{-5}$	0.5	N/A	$2x10^{-3}$	$1x10^{-4}$	$5x10^{-4}$	$1x10^{-3}$
PWR 9	$4x10^{-4}$	0.5	N/A	$3x10^{-6}$	$1x10^{-7}$	$6x10^{-7}$	$1x10^{-11}$
BWR 1	$1x10^{-6}$	2.0	1.5	1.0	0.4	0.4	0.05
BWR 2	$6x10^{-6}$	3.0	2.0	1.0	0.9	0.5	0.1
BWR 3	$2x10^{-5}$	3.0	2.0	1.0	0.1	0.1	0.01
BWR 4	$2x10^{-6}$	2.0	2.0	0.6	$8x10^{-4}$	$5x10^{-3}$	$6x10^{-4}$
BWR 5	$1x10^{-4}$	5.0	N/A	$5x10^{-4}$	$6x10^{-11}$	$4x10^{-9}$	$8x10^{-14}$

(a) From Reference 8, Table 5.1

selected as principal contributors to a dose at other reactor sites from air submersion and from ground deposition.

The HNEC meteorological model assumed that the containment breach resulted in a source 100 meters wide which spread downwind over 22-1/2° as it moved out from the point of release. Figure 2 illustrates one such release at cluster 2 with clusters 3 and 4 shown within a 22-1/2° sector downwind.



Cluster No.	2	3	4	5
1	5.4 (3.36)	12.9 (8.02)	25.5 (15.85)	28.3 (17.59)
2		7.5 (4.66)	20.4 (12.68)	23.4 (14.54)
3			13.1 (8.14)	16.5 (10.25)
4				4.0 (2.99)

FIGURE 2. Sites and Areas Involved in Radioactive Release at HNEC Example: Release at cluster 2, with distances between clusters tabulated in kilometers (miles).

DEVELOPMENT OF THE DOSE DUE TO AIR SUBMERSION (PASSING CLOUD)

Source Conversion

The radionuclides given in Table 4 were submitted to the model for dose estimates which converted these radioactive species into external total body dose,[9] in units of rem/(sec/m^3) as a function of time.

These calculated doses, normalized to a time integrated air concentration of 1.0 sec/m^3 by the SUBDOSA model are given in Table 6. Note that for the first 1000 seconds following the release, the values are constant and that after 20,000 seconds, they have decreased only by about 57% to 8 x 10^7 rem/(sec/m^3). The time becomes a factor in recognizing distances the cloud would travel. If an average wind speed of 2 to 3 m/sec during the incident was developed from historical records, then the above tabulation for the first 1000 seconds accounts for the same dose factor for up to 2 to 3 kilometers from the accident site. The meteorological model further reduces this source term with depletion of the cloud contents by fallout along the way.

As an example, for the first 2000 seconds, the probability of different doses involving two or more quads can be immediately determined.

$$D_{(0\text{-}2000\ \mathrm{sec})} = X/Q\ (s/m^3)^a \times \mathrm{rem}/(\mathrm{sec}/m^3)^b$$

a - from Table 1

b - from Table 6

Assume from Table 1, a normalized air concentration of 1 x 10^{-7} (s/m^3). Using the dose in rem/(s/m^3) up to the first 2000 seconds from Table 6, the result is:

$$D_{0\text{-}2000\ \mathrm{sec}}(\mathrm{in\ rem}) = 1 \times 10^{-7}\ (s/m^3) \times 1.3 \times 10^8\ \mathrm{rem}/(s/m^3)$$

$$= 13\ \mathrm{rem}$$

TABLE 6. External Total-Body Dose for Accident PWR-2

Time, seconds	Total-Body Dose,(*) rem/(sec/m^3)
0	1.4×10^8
100	1.4×10^8
200	1.4×10^8
500	1.4×10^8
1,000	1.4×10^8
2,000	1.3×10^8
5,000	1.2×10^8
10,000	1.0×10^8
20,000	8.0×10^7

(*) SUBDOSA Model[9]

Assuming a shielding factor of 0.2[8] for those inside (in a control room for instance), the resulting dose is 2.6 rem received from the overhead cloud during its half hour passing. The probabilities of two or more quads receiving this dose is the same as given in Table 2 for $\geq$2 quads involved with this level (1×10^{-7} sec/m^3) of normalized air concentration. Table 1 then can be reconstructed in terms of dose, as shown in Table 7. Note that the left-hand column is now in terms of dose. If 2 to 3 m/s of wind speed is assumed, only these units close enough to be enveloped during the 2000 seconds or less of cloud travel are included in this table.

The model predicts that the dose accumulated in control rooms in the same quad as the affected reactor will vary from 280 rem to 0.130 rem. This range includes the heaviest concentrations considered plausible and are worst case conditions. Emergency procedures that are commensurate with risk will have to be in place to shut down the reactors and evacuate the personnel. The probability of the event, a loss of a full core, is once in about every 6000 years (1.4×10^{-6}).

TABLE 7. Conditional Probability that Personnel in at Least 2, 3, or 4 Quads Would Experience the Computed Radiation Doses from the Passing Cloud Following a Release from a Reactor Accident at an HNEC (The first 2000 seconds)

Radiation Dose in Rem, Assuming Shielding Factor of 0.2	Conditional Probabilities of at Least 2 Quads Being Exposed, Same	≥2
280	1.000	-
130	1.000	0.01
60	1.000	0.02
28	1.000	0.05
13	1.000	0.07
6	1.000	0.13
2.8	1.000	0.16
1.3	1.000	0.17
0.6	1.000	0.18
0.28	1.000	0.19
0.13	1.000	0.19

The actual probabilities of M or more quads being involved in any release is obtained by factoring in the conditional probability of a reactor accident of this type occurring; namely,

Pa = P (actual) = N x P(1) where

N = Number of reactors at the site

P(1) = probability of this type of accident for one reactor = 8×10^{-6}/reactor year (Table 5)

P(A) = $20 \times 1 \times 10^{-6}$/reactor year

P(A) = 1.6×10^{-4}/reactor year

Thus, if each of the conditional probabilities given in Table 7 were multiplied by 1.6×10^{-4}, the result would be a tabulation in actual probabilities for M or more quads having the associated doses from a passing cloud.

In this manner the actual probabilities of M or more quads being involved with different dose levels due to the passage of the cloud are developed from Table 1 and given in Tables C-1 through C-5 in Appendix C.

The actual probabilities of three or more reactors in the same quad as the accident with different dose levels due to the passage of the cloud are developed as a special case and are given in Table C-1.

The exposures vary with the times shown after the accident due to the rapid decay of some radionuclides and due to depletion of the cloud due to fallout. The probabilities of the nearest reactors (same quad) being involved with substantial doses is the same as the probability of the accident, 1×10^{-4}/ reactor/yr. If an accident does occur, the probability is high that the reactors in the nearest quad will be heavily involved. The probability of at least ≥3 quads (thirteen reactors or more) being involved is significantly less and for all 5 quads (twenty reactors) the occurrence is possible but its probability vanishingly low.

DEVELOPMENT OF DOSE RATES DUE TO DEPOSITION

The exposure due to deposition (fallout) is calculated in terms of a dose rate where the exposure from the passing cloud (air submersion) was estimated in total dose in rem that resulted during the half hour passage of the cloud. The dose rates of interest are those within a reactor building, control room for example, from ground contamination outside. The radionuclides used to develop dose rates from ground contamination are taken from the reference study.[(3)] This selection was based on the radioactive half-life and the type and the energy of the emitted radiation which are important to external exposure from ground deposition. These selected nuclides were divided into two groups according to half-life as shown in the following Table 9. Section I of the table lists the relatively long-lived species; the contribution from these to the radiation level is essentially constant over the time period of interest here; namely, approximately sixty days. Section II contains the short-lived species whose contribution will decrease over the times of interest, some very rapidly.

TABLE 8. Radionuclides Used for Ground Deposition (WASH-1400, Appendix VI, 8.3.1.2)

Section I: Long-Term Isotopes Used, Where $e^{-\lambda t} \approx 1$		Section II: Shorter-Term Isotopes	
Species	Half-Life Days	Species	Half-Life Days
^{137}Cs	1100	^{136}Cs	13
^{134}Cs	750	^{131}I	8.05
^{106}Ru	366	^{103}Ru	39.5
^{60}Co	1920	^{97}Zr	0.71
^{58}Co	71	^{95}Nb	35
^{95}Zr	65		

Source Conversion

Converting the radioactivity from the above species to dose rates was done as follows:

$$DR = DF \times D/Q \times S \times e^{-\lambda t}$$

DR = Dose Rate, mrem/hr

DR = Dose Factor, a value in mrem/hr/pCi/m^2 - (Reference, Nuclear Regulatory Guide 109, page 1.109-41, Table E-6 Whole body dose from surface contamination in pCi/m^2.)

D/Q = Normalized surface concentration (1/m^2) as a function of Hanford meteorology--Reference 4, or see Table 2 of this report.

S = Source term, given in pCi for each isotope, Reference Tables 4 and 5.

$e^{-\lambda t}$ = Correction for radioactive decay.

For example, the contribution of the dose rate from ^{137}Cs on contaminated ground was determined by

$$DR_{137} = DF \times D/Q \times S \times e^{-\lambda t}$$
$$= 4.2 \times 10^{-9} \times D/Q \times 23.5 \times 10^{17} \times 1$$

$$DR_{137} = 98.7 \times 10^{8} \times D/Q \text{ (mrem/hr-m}^2\text{) (D/Q values as in Table 2)}$$

Table 9 summarizes these results for all of the nuclides involved in a dose rate from ground contamination.

TABLE 9. Development of Dose Rate Factors for Both Long-Term and Short-Term Isotopes

Nuclide	$T^{1/2} > 60$ days Dose mrem/hr-m^2 x 10^9	Nuclide	Dose mrem/hr-m^2 x 10^9 $T^{1/2} > 60$ days (at T = 0)
^{137}Cs	10.04	^{136}Cs	22.5
^{134}Cs	45.0	^{131}I	166.6
^{95}Z	3.0	^{103}Ru	7.92
^{106}Ru	0.75	^{97}Zr	3.3
^{60}Co	0.10	^{95}Nb	3.06
^{58}Co	0.11	TOTAL	203.4×10^9 at T = 0
TOTAL	59×10^9		

From the above, the nuclides with the shorter half lives contribute the major portion of the dose rate immediately after the passage of the cloud.

Shortly after twenty-one days, the contribution from the longer half-life nuclides becomes predominant. Table 10 illustrates this.

TABLE 10. Dose Rates in $mrem/hr\text{-}m^2$ as a Function of Time

Elapsed Time, Days	Contribution from Shorter Half-Life Nuclides, $mrem/hr\text{-}m^2 \times 10^9$	Total Longer[a] plus Shorter Half-Life Material, $mrem/hr\text{-}m^2 \times 10^9$
0	203.4	262.4
7	144.6	199.8
14	93.7	152.7
21	62.4	121.4
30	42.2	101.2
45	24.6	83.6
60	16.7	75.7
90	9.1	68.1
120	5.1	64.1

(a) Longer life nuclides contribute essentially a constant 59 $mrem/hr\text{-}m^2 \times 10^9$

The information from the Total column in the above summary, when multiplied by the appropriate normalized concentrations given in Table 2 will yield dose rates at the selected days after the accident.

Then, the conditional probabilities result that these dose rates would occur to those standing on the ground outside of the reactor buildings in at least M quads, assuming that an accident occurs at one unit.

Shielding factors from uneven ground (0.7) and a windowless building (0.2) would reduce the dose rates to those inside by a factor of 0.14. A conservative estimate of attenuation of the dose due to distance from the source to those inside is estimated to be another 0.7. A more realistic attenuation factor would be greater by at least a factor of 10. But, to be conservative, a total shielding factor of just 0.1 is thus assumed (0.7 x 0.2 x 0.7). A further significant reduction of the source level from the most preliminary decontamination efforts is also not included. It was assumed, however, that intake ventilation filtering systems functioned as designed with no radioactive material entering the facilities to contribute to dose levels inside.

As an example, the dose rate inside a building after fourteen days, assuming an involvement outside of 1 x 10^{-8} (m^{-2}) (Table 3) would be as follows:

$$DR_{14} = 1 \times 10^{-8} \ m^{-2} \times 93.7 \times 10^{9} \ mrem/hr\text{-}m^{2} \times 10^{-1} = 93.7 \ mrem/hr$$

The probability of at least two quads having this dose rate would be obtained from Table 2 at the involvement level of 1 x 10^{-8} m^{-2}.

A new set of tables developed from Table 2 but expressed in terms of dose rates at several finite times following the accident is given in Appendix C.

CONCLUSIONS - ACCIDENT REVIEW

The results are given in terms of the most probable involvements based on several assumptions in meteorology.(4) For the dose within buildings due to a passing cloud, lethal doses are not predicted for any who remain inside during the passage; but these doses are, however, for the reactors in the same and next quads as the accident, substantial. If any are caught outside and remain submersed in the cloud for the time estimated for it to pass, a lethal dose is predicted. Emergency procedures for this low probability event, once about every 6000 years, can be expected to be in place to prevent this. These procedures would be essentially the same as required for other accidents involving a reactor core. Most of these would not result in accidental releases, but full-scale emergency procedures would be constantly available if needed. For the reactors more distant from the accident, the times available to take proper action prior to arrival of the cloud and the much lower doses that occur, result in no real threat to personnel assuming proper actions are taken. From contaminated ground from fallout at reactor sites near the accident, the dose rates are predicted to be significant for the greater releases. Substantial decontamination efforts are predicted to be required to restore nearby reactors to operating status. For example, surface dose rates of about 75 mrem/hr outside (7.5 mrem/hr inside) are estimated to be possible for at least fifteen reactors although 50 times less probable than the accident itself. Manageable dose rates however result even in the worst predicted case. Some reduction will occur as the radionuclides decay with time, but the real reductions in dose rates in reasonable time periods will result only from decontaminating each affected site.

The risk of this event when the consequences are loss of generating capability, compare favorably with rare natural events. It was shown that a loss of generating capacity from a class nine accident at an HNEC is less likely than a loss of generating capacity from an ashfall from volcanic activity in the Cascades and significantly less likely than a loss of generating capacity from an Operating Basis Earthquake.[10] See Appendix D.

In this review, numerically conservative values of dose and dose rates were developed and meteorology parameters specific to Hanford were used. This analysis while adequate to indicate probable exposures and consequences, is not a detailed safety analysis. Such an analysis would be a subject for further development of the HNEC concept.

Finally, the probability of occurrence of the accident selected as the example in this review from the reference report;[8] namely, the PRW-2, is used throughout as single valued. At best, it is an estimate with some error bounds which if developed in the reference report were not given. Knowing the conservatism that was used in that report to develop the estimate, it seems plausible to accept it as a reasonable approximation. As such, it is utilized here to make comparisons with estimates of the frequency of occurrence of other rare events to provide perspective among them. This procedure was used knowing that estimating the frequency of occurrence of any rare event is an uncertain process.

ACKNOWLEDGMENT

The assistance of D. L. Strenge, C. A. Baker and J. K. Soldat in the estimations of dose and of J. V. Ramsdell in meteorology are gratefully acknowledged.

REFERENCES

1. USNRC Office of Special Studies, Nuclear Energy Center Site Survey-1975, NUREG-0001 (NECSS-75), Vol. 1, January 1976.

2. United States Atomic Energy Commission, Evaluation of Nuclear Energy Centers, Vol. 2, Appendix 10, Regulatory Aspects of Siting Nuclear Power Centers, WASH-1288, January 31, 1974.

3. Nuclear Energy Center, Site Survey, Reactor Plant Considerations BNWL-B-457, May 1976.

4. J. V. Ramsdell and S. I. Diebel, Meteorological Evaluation of Multiple Reactor Contamination Probabilities for an HNEC, PNL-2452, UC-80, March 1978.

5. D. F. Cope and H. F. Bauman, Expansion Potential for Existing Nuclear Power Station Sites, ORNL/TM-5927, November 1977.

6. The Institutional Aspects of the Energy Centers Concept, ANE-3086-1, by a Panel of The National Academy of Public Administration, March 1977.

7. Letter Report Review of Siting Policies for Licensing Nuclear Facilities, Dr. William Kerr, Chairman, to L. V. Gossick, Executive Director of Operations, USNRC, December 10, 1975.

8. Reactor Safety Study, WASH-1400, NUREG-75/014, USNRC, October 1975.

9. SUBDOSA, BNWL-B-351, D. L. Strenge, E. C. Watson, and J. R. Houston, June 1975, A Computer Program for Calculating External Doses from Accidental Atmospheric Releases of Radionuclides, ERDA Report, Battelle PNL MTIS, June 1975.

10. R. G. Clark and W. J. Dowis, Reliability of Generation at a Hanford Nuclear Energy Center (HNEC), PNL-2474, UC-80, December 1977.

REFERENCES NOT CITED

Nuclear Siting and Licensing Act of 1978, S-2775; H.R. 11704, The several purposes of the Act include Standardized Facility Design, Site Banks Permits (one or more), Congressional Record--Senate, March 21, 1978.

Cope, David F. and Howard F. Bauman, Utility Survey on Nuclear Power Plant, Siting and Nuclear Energy Centers, ORNL/TM-5928, August 1977.

Early Site Reviews for Nuclear Power Facilities NUREG-0180, USNRC, Office of Standards Development, February 1978. (Same Title--NUREG-0068, December 1976.)

APPENDIX A

REVIEW OF FEDERAL REGULATIONS

APPENDIX A

REVIEW OF THE FEDERAL CODES

The Code of Federal Regulations 10 CFR, particularly Parts 50 and 100, contain sections that may affect but apparently not limit the concept of an HNEC. Appendix A of 10 CFR 50, General Design Criteria for Nuclear Power Plants, includes a few criteria that impact multi-unit stations more or less directly. These criteria are quite general however, and, as currently issued are not limiting for multi-unit sites at an HNEC. The following summarizes these specific criteria which impact multi-unit stations.

No.	Title	Impact
5	Sharing of Structures Systems and Components	For systems involving safety. designs for sharing must not impair ability to perform their safety functions including an accident in one and an orderly shutdown and cool down in remaining units.
17	Electric Power Systems	Perhaps the most detailed of these design criteria and including offsite power requirements for safety functions. Offsite power criteria will affect multi-unit siting.
18	Inspection and Testing of Electric Power Systems	Designs must allow testing and transfer of power including offsite power systems.
34	Residual Heat Removal	Criteria included for offsite power to provide necessary safety functions.
44	Cooling Water	Criteria included for offsite power to transfer heat load to ultimate heat sink.

Other examples of the need to satisfy these basic design criteria in 10 CFR 50 may develop if multi-unit sites come into being and a pooling among stations of equipment, manpower, or services may be proposed.

A recent addition to 10 CFR 50, paragraph 34,[a] relative to maintaining integrity of structures, systems, and components important to safety during construction at multi-unit sites would not impact the HNEC concept. It is unlikely that construction underway on reactor operation at one multi-unit station is likely to affect construction or operation at another multi-unit station at an HNEC.

Part 100 of 10 CFR, Reactor Site Criteria, includes criteria for consideration for siting multiple reactor facilities. The criteria in this Code that relate most to an HNEC are those that limit radioactive effluents from all LWRs at a site. As above, as can be determined from just a concept of an HNEC, the impact of these criteria have been reviewed and not found limiting in other sections of the conceptual study including the radiological section.

The Environmental Protection Agency (EPA) issued new regulations consisting of the addition of a new Subchapter F and Part 190, in January 1977.[b] These give environmental radiation protection standards for nuclear power operations.

In the discussion of major issues that had been raised during the comment period, some conclusions were made by EPA regarding the impact on the new standards of multi-unit sites.

The Agency inferred that multi-unit sites closer than ten miles may require special attention during licensing and that for sites containing up to five reactors, conformance to criteria in 10 CFR 50, Appendix I, by these multi-unit stations should provide reasonable assurance of compliance with these new EPA standards. Considering the long distance from any multi-unit site at Hanford to the nearest populated zone, the conclusion relating to the ten miles between sites does not appear to be limiting to the HNEC concept. The conclusion is not however a part of the Federal Code.

(a) Federal Register, Vol. 43, No. 135, Thursday, July 14, 1977.

(b) Federal Register, Vol. 42, No. 9, Thursday, January 13, 1977.

APPENDIX B

REVIEW OF REGULATORY GUIDES

APPENDIX B

REVIEW OF REGULATORY GUIDES

None of the current regulatory guides are directed to energy centers as indicated in the text. Moreover not much guidance for energy centers specifically can be inferred from those guides which mention siting multi-unit stations.

However, the concept of several multi-unit sites at an HNEC, developed sequentially as separate stations, is interesting largely because of the land areas available for siting, low population zones plus other technical and environmental features unique to an HNEC that are described elsewhere in these analyses. This concept was included during the following review of the Regulatory Guides.

Regulatory Guide No.	Title	Synopsis
1.6	Independence Between Redundant Standby (Onsite) Power Sources and Between Their Distribution Systems	Matter of nearby hydroelectric, nuclear or fossil units as standby power sources at multiple-unit sites to be evaluated on individual case basis.
1.27	Ultimate Heat Sink	In a multi-unit station, safety design precludes more than one reactor unit in accident condition at one time - "an ultimate heat sink complex serving multiple units should be capable...cooling all units it serves." This subject was addressed in this review.[a]
1.32	Criteria for Safety-Related Electric Power systems for Nuclear Power Systems	Some electrical systems are forbidden to be shared by multi-unit stations but is not limiting to HNEC in current designs.
1.75	Physical Independence of Electrical Systems	Not applicable to concerns for multi-unit installation.

(a) Heat Sink Management Studies, L. D. Kannberg.

Regulatory Guide No.	Title	Synopsis
1.81	Shared Emergency and Shutdown Systems for Multi-Unit Nuclear Power Plants	Provides guidance only to a multi-unit station and sharing of systems and components onsite of multi-unit stations.
1.91	Availability of Electric Power Sources	Relative to offsite power source, operating guidance is given when one is lost. Availability of adequate offsite backup power for an HNEC can be met but many more stations may depend on its reliability to always provide two operating sources, for each reactor in the several quads at an HNEC HNEC.
1.109	Calculation of Annual Doses to Man from Routine Releases of Reactor Effluents for Evaluating Compliance with 10 CFR 50, Appendix I.	
1.111	Methods for Estimating Atmospheric Transport and Dispersion of Gaseous Effluents in Routine Releases from Light-Water-Cooled Reactors.	These are guides to implement (in part) Appendix I, 10 CFR 50
1.112	Calculation of Releases of Radioactive Materials in Gaseous and Liquid Effluents from Light-Water-Cooled Power Reactors.	
1.113	Estimating Aquatic Dispersion of Effluents from Accidental and Routine Reactor Releases for the Purpose of Implementing Appendix I.	

There are other guides that will relate to the existence of multi-unit stations. Emergency Plans, Regulatory Guide 101, will have to be cognizant of the presence of multi-unit stations and include their presence.

Nearby multi-unit stations may be supportive of each other in emergency planning perhaps and certainly in the pooling of efforts to maintain industrial security Regulatory Guide 1.17, Protection of Nuclear Power Plants Against Sabotage. Some existing requirements can be reinforced by the presence of multi-unit stations at an HNEC.

APPENDIX C

AIR SUBMERSION AND GROUND DEPOSITION

APPENDIX C

AIR SUBMERSION AND GROUND DEPOSITION

TABLE C-1. Probability x 10^{-4} that at Least M Reactors in the Same Quad as the Accident Would be Involved. Involvement is defined as the dose received inside a reactor building, as indicated in Column 1, from the passage of the radioactive cloud 1000 seconds after a release.

Rem	Number of Reactors 3	4	5
280	1.6	1.4	0.5
130	1.6	1.4	0.4
60	1.6	1.4	0.4
28	1.6	1.4	0.5
13	1.6	1.4	0.5
6	1.6	1.4	0.6
2.8	1.6	1.4	0.6
1.3	1.6	1.4	0.6
0.6	1.6	1.4	0.7
0.3	1.6	1.4	0.7
>0	1.6	1.4	0.7

Example--The probability of at least five reactors (if the quad has five) receiving 6 rem within 1000 seconds (approximately 17 minutes) after a release at another reactor is 6 x 10^{-5} (0.6 x 1 x 10^{-4}) per reactor year, a frequency of once about every 16,000 years. This table is a special case in estimating doses within a quad. For up to 1000 seconds and more following an accident, the only quad involved is the one containing the reactor having the accident.

TABLE C-2. Probability x 10^{-4} that at Least 2 Quads Would be Involved Following an Accident at an HNEC. Involvement is defined as the dose received inside a reactor building, as indicated in Column 1, from the passage of the radioactive cloud 2000 seconds (33 minutes) after a release.

Rem	Probability $\geq$2 Quads
260	0.01
120	0.03
56	0.07
26	0.07
12	0.11
5.6	0.20
2.6	0.25
1.2	0.28
0.6	0.29
0.1	0.3
>0	0.31

Example--The useful probabilities here are those associated with $\geq$2 quads as the cloud moving at 2 to 3 m/sec could reach quads adjacent to the accident site. A dose of 5.6 rem would affect at least 2 quads with a probability of 2 x 10^{-5} or with a frequency of once about every 50,000 years. The error band in the probability estimate may be 2 or 5 or even 10 times lower. The corresponding frequency may be once every 5,000 years. The conclusions are not changed however. The range of dose expected would extend from 120 to 0.1 rem.

TABLE C-3. Probability x 10^{-4} that at Least M Quads Would be Involved Following an Accident at an HNEC. Involvement is defined as the dose received inside a reactor building, as indicated in Column 1, from the passage of the radioactive cloud 5000 seconds (1 hr, 23 min) after a release.

Rem	Probability ≥2 Quads	≥3 Quads	≥4 Quads
240			
111	0.1		
52	0.3		
24	0.07		
11	0.11	0.02	
5.2	0.20	0.05	
2.4	0.25	0.11	
1.1	0.28	0.14	
0.5	0.29	0.14	
0.2	0.3	0.15	
>0	0.31	0.17	

The elapsed time is sufficient to involve at least 13 reactors. (≥3 quads)

Example--The probability of at least 3 quads (≥13 reactors) receiving 5.2 rem is 5 x 10^{-6} (1 x 10^{-4} x 0.05) a frequency of once about every 200,000 years.

TABLE C-4. Probability x 10^{-4} that at Least M Quads Would be Involved Following an Accident at an HNEC. Involvement is defined as the dose received inside a reactor building, as indicated in Column 1, from the passage of the radioactive cloud 10,000 seconds (2 hr, 46 min) after a release

	Probability		
Rem	≥2 Quads	≥3 Quads	≥4 Quads
200			
93	0.01		
43	0.03		
20	0.07		
9.3	0.11	0.02	
4.3	0.20	0.05	
2.0	0.25	0.11	0.03
0.9	0.28	0.14	0.14
0.4	0.29	0.14	0.04
0.2	0.3	0.15	0.04
>0	0.31	0.17	0.05

The elapsed time is sufficient at wind speeds of 2 to 3 m/sec for the cloud to reach the quad containing a fifteenth reactor.

Example--The probability of a dose of 2 rem in at least 4 quads (15 reactors) is 3×10^{-6} ($3 \times 10^{-2} \times 10^{-4}$) or once about every 330,000 years. It is about 50 times less probable at HNEC for at least 15 reactors to have this dose as as it is for reactors in the same quad as the accident to have the dose. (1.6/0.03 = 50).

TABLE C-5. Probability x 10^{-4} that at Least M Quads Would be Involved Following an Accident at an HNEC. Involvement is defined as the dose received inside a reactor building, as indicated in Column 1, from the passage of the radioactive cloud 20,000 seconds (5 hr, 33 min) after a release

	Probability		
Rem	≥2 Quads	≥3 Quads	≥4 Quads
160			
74	0.01		
34	0.03		
16	0.07		
7.4	0.11	0.02	
3.4	0.20	0.05	
1.6	0.25	0.11	0.03
0.7	0.28	0.14	0.14
0.3	0.29	0.14	0.04
0.2	0.3	0.15	0.04
>0	0.31	0.17	0.05

Example--As in the case of the release after 10,000 seconds the probability of at least 4 quads (≥15 reactors) receiving a dose of 1.6 rem is 3.0 x 10^{-6}, about once every 330,000 years.

TABLE C-6. Probability x 10^{-4} that at Least M Quads Would be Involved Following an Accident at an HNEC. Involvement is defined as the dose rates inside reactor building from ground contamination outside on same day as the accident.

Dose Rate	Probability			
	Same Quad	≥2 Quads	≥3 Quads	≥4 Quads
2.62 rem/hr	1.6			
1.2 rem/hr	1.6	0.01		
0.56 rem/hr	1.6	0.03		
262 mrem/hr	1.6	0.07		
120 mrem/hr	1.6	0.11	0.02	
56 mrem/hr	1.6	0.20	0.05	
26 mrem/hr	1.6	0.25	0.11	0.03
12 mrem/hr	1.6	0.28	0.14	0.04
7 mrem/hr	1.6	0.29	0.14	0.04
3 mrem/hr	1.6	0.3	0.15	0.04
>0 mrem/hr	1.6	0.31	0.17	0.05

Example--On the same day of the accident, the probability of at least 3 quads having 56 mrem/hr within the reactor building is 5×10^{-6}, i.e., at a frequency of once about every 200,000 years.

TABLE C-7. Probability x 10^{-4} that at Least M Quads Would be Involved Following an Accident at an HNEC. Involvement is defined as the dose rates inside reactor building following the accident by 7 days

Dose Rate	Probability			
	Same Quad	≥2 Quads	≥3 Quads	≥4 Quads
2.0 rem/hr	1.6			
0.93 rem/hr	1.6	0.01		
0.43 rem/hr	1.6	0.03		
200 mrem/hr	1.6	0.07		
93 mrem/hr	1.6	0.11	0.02	
43 mrem/hr	1.6	0.20	0.05	
20 mrem/hr	1.6	0.25	0.11	0.03
9 mrem/hr	1.6	0.28	0.14	0.04
4 mrem/hr	1.6	0.29	0.14	0.04
2 mrem/hr	1.6	0.3	0.15	0.04
>0 mrem/hr	1.6	0.31	0.17	0.05

Example--The probability of at least 4 quads having 20 mrem/hr inside the buildings 7 days after the accident is 3 x 10^{-6}, or once about every 333,000 years.

TABLE C-8. Probability x 10^{-4} that at Least M Quads Would be Involved Following an Accident at an HNEC. Involvement is defined as the dose rates inside reactor building following the accident by 14 days.

Dose Rate	Probability			
	Same Quad	≥2 Quads	≥3 Quads	≥4 Quads
1.5 rem/hr	1.6			
0.71 rem/hr	1.6	0.01		
0.329 rem/hr	1.6	0.03		
150 mrem/hr	1.6	0.07		
71 mrem/hr	1.6	0.11	0.02	
33 mrem/hr	1.6	0.20	0.05	
15 mrem/hr	1.6	0.25	0.11	0.03
7 mrem/hr	1.6	0.28	0.14	0.04
3 mrem/hr	1.6	0.29	0.14	0.04
1.5 mrem/hr	1.6	0.3	0.15	0.04
>0 mrem/hr	1.6	0.31	0.17	0.05

Example--The probability of at least 4 quads (≥15 reactors) having a 15 mrem/hr dose rate inside the building after 14 days is 3 x 10^{-6}, or about once every 333,000 years.

TABLE C-9. Probability x 10^{-4} that at Least M Quads Would be Involved Following an Accident at an HNEC. Involvement is defined as the dose rates inside reactor building following the the accident by 30 days.

Dose Rate	Probability			
	Same Quad	≥2 Quads	≥3 Quads	≥4 Quads
1 rem/hr	1.6			
470 mrem/hr	1.6	0.01		
218 mrem/hr	1.6	0.03		
100 mrem/hr	1.6	0.07		
47 mrem/hr	1.6	0.11	0.02	
22 mrem/hr	1.6	0.20	0.05	
10 mrem/hr	1.6	0.25	0.11	0.03
4.7 mrem/hr	1.6	0.28	0.14	0.04
2.2 mrem/hr	1.6	0.29	0.14	0.04
1.0 mrem/hr	1.6	0.3	0.15	0.04
>0 mrem/hr	1.6	0.31	0.17	0.05

Example--The probability of at least 2 quads (≥7 reactors) having 10 mrem/hr inside the reactor building 30 days after the accident is 2.5 x 10^{-5}, or about once every 40,000 years.

TABLE C-10. Probability x 10^{-4} that at Least M Quads Would be Involved Following an Accident at an HNEC. Involvement is defined as the dose rates inside reactor building following the accident by 60 days.

Dose Rate	Probability			
	Same Quad	≥2 Quads	≥3 Quads	≥4 Quads
757 mrem/hr	1.6			
351 mrem/hr	1.6	0.01		
163 mrem/hr	1.6	0.03		
75.7 mrem/hr	1.6	0.07		
35.1 mrem/hr	1.6	0.11	0.02	
16.3 mrem/hr	1.6	0.20	0.05	
7.6 mrem/hr	1.6	0.25	0.11	0.03
3.5 mrem/hr	1.6	0.28	0.14	0.04
1.6 mrem/hr	1.6	0.29	0.14	0.04
0.8 mrem/hr	1.6	0.3	0.15	0.04
>0 mrem/hr	1.6	0.31	0.17	0.05

Example--The probability of at least 3 quads (≥11 reactors) having 7-1/2 mrem/hr inside the reactor building 60 days after the accident is 1.1 x 10^{-5}, or at a frequency of once about every 90,000 years.

APPENDIX D

EVALUATION OF THE CONSEQUENCES

APPENDIX D

EVALUATION OF THE CONSEQUENCES

One of the predictable consequences of a class nine accident at an HNEC is loss of generating capacity for finite periods of time following the accident.

Estimates of the consequences have been predicted based on several assumptions. All twenty of the projected reactors are in place. At any one time at least four are down for refueling or maintenance. Emergency procedures in place at the time of the accident may force every reactor to shut down at least to hot standby. After two days as an average, all units not affected or affected only to low levels of contamination are back in service. Some units may be back in service within hours while others destined to early return to service may take longer.

Using these assumptions, maximum and minimum probable losses of generating capacity were developed. The results are given in the following tables.

TABLE D-1. Maximum Outage Occurence. Energy generation loss from 16 units out of service due to the accident for the indicated lengths of time.

Time Required to Decontaminate, days	Outage Description	Generation Loss, GW-hr
45	5 Unit Site (includes site of accident)--all units up at time of accident	6480[a]
15	4 Unit Adjacent Quad All units up	1728
10	4 Unit Quad Beyond All units up	1152
7	4 Unit Quad beyond the above 3 of 4 units up	605
		9965

(a) 6480 GW-hr = 45 days x 24 hr/day x 1.2 GW/unit x 5 units.

In a similar manner, the total generation loss for the different involvement of the reactors was determined. Involvement included both number of quads involved plus the maximum and minimum of reactors involved in one of the quads, with all units up at the time of the accident. The variability of involvement is assumed to be a result of an arbitrary wind direction and orientation of the reactors.

TABLE D-2. Summary of Energy Generation Loss

Number of Quads Involved	Maximum Loss, GW-hr	Minimum Loss, GW-hr	Probability of Occurrence in Units of 10^{-4}
4	19.1	2709	0.04
3	17.6	2708	0.11
2	14.5	2593	0.25
1	9.5	2016	1.6

The probability of occurrence, column four in Table 6 was obtained from a table essentially equal to Table C-9 but computed for a 45-day decay period. The data from Table D-2 is shown in graphical form in Figure 3. The capacity, in gigawatts shown as the abscissa, refers to the amount of generating capctity lost from the various quads depending on their involvement. The lower ordinate gives the corresponding energy generation loss in gigawatt-hours (GW-hr). The upper coordinate gives the probabilities that are associated with different capacity loss (quads involved).

The dotted horizontal line assumes a fixed probability of loss of any amount of capacity due to administrative procedures that force an extended shutdown of all units at an HNEC if an accident occurs. The top curve is the expected probabilities assuming only administrative procedures permit those reactors not involved to continue service after a brief interpretation.

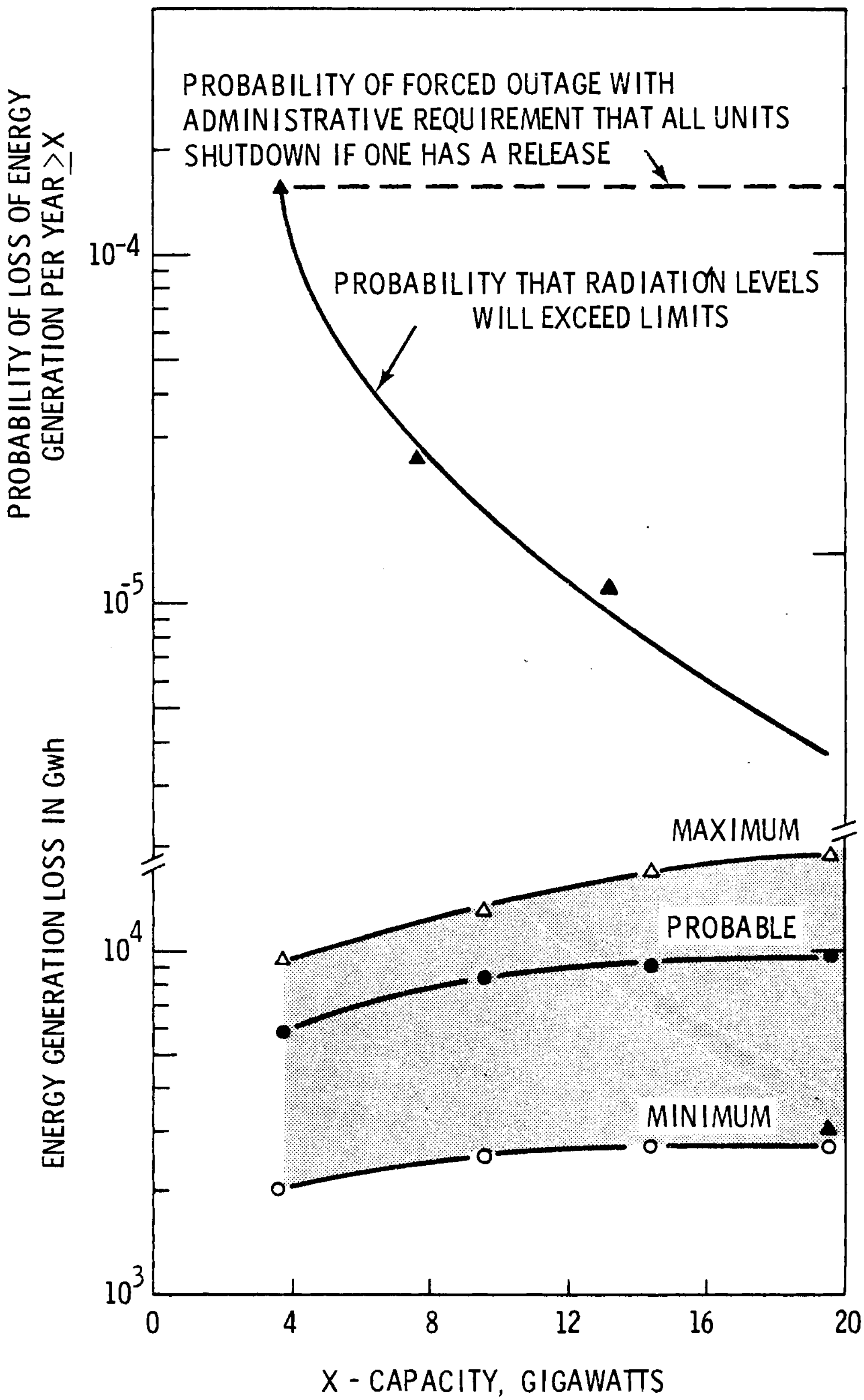


FIGURE 3. Energy Generation Loss

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Research Institute
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Tom Cole
Oak Ridge National Laboratory
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