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**REACTOR SITING RISK COMPARISONS
RELATED TO RECOMMENDATIONS OF NUREG-0625**

by
A. W. BARSELL, F. S. DOMBEK, and D. D. ORVIS

Prepared under
Contract DE-AT03-76ET35300
for the San Francisco Operations Office
Department of Energy

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ABSTRACT

This document evaluates how implementing the remote siting recommendations for nuclear reactors (NUREG-0625) made by the Siting Policy Task Force of the U.S. Nuclear Regulatory Commission (NRC) can reduce potential public risk. The document analyzes how population density affects site-specific risk for both light water reactors (LWRs) and high-temperature gas-cooled reactors (HTGRs).

The low-density sites proposed by the Siting Policy Task Force measurably reduce acute fatalities [mostly within 8 km (5 miles)] for low probability LWR accident sequences compared to existing U.S. sites of relatively high population density. However, these low-density sites negligibly reduce corresponding latent fatalities. While low-density sites reduce individual risk due to nuclear accidents for persons near the LWR plant, they negligibly impact the overall (including non-nuclear) risk of cancer fatality. The probability is low (odds against) that even one fatality (acute or latent) would be caused by accidental release of radioactivity to a relatively dense population living within 32.2 km (20 miles) of an LWR plant operating for 40 years. In view of these results, some rethinking of the final siting rule for LWRs may be warranted.

In the HTGR, inherent characteristics, such as graphite heat capacity, materials compatibility, and the prestressed concrete reactor vessel, sufficiently delay and reduce radioactivity release so that no acute fatalities occur for any population density distribution of interest. Also, since the population distribution within 32.2 km (20 miles) has little influence on HTGR latent health effects, this report concludes that no significant safety benefit is obtained by remote siting of HTGRs. That is, the population restrictions suggested in NUREG-0625 are not needed to achieve the desired safety against Class 9 accidents. Therefore, the final siting rule should explicitly declare nonapplicability to HTGRs or other nuclear power plants

not studied in NUREG-0625 (small size plants, process heat/steam applications, etc.). The final rule should direct the NRC to evaluate siting applications for reactors other than light water cooled according to their own technical features and inherent characteristics which can potentially affect public health and safety.

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1. INTRODUCTION AND BACKGROUND

1.1. PURPOSE AND SCOPE

The Siting Policy Task Force of the U.S. Nuclear Regulatory Commission (NRC) has published its findings and recommendations to revise nuclear power plant siting regulations (NUREG-0625, Ref. 1). The Task Force siting work is one of several concurrent U.S. activities* to change the licensing regulations and practices of nuclear power reactors. While some activities have been ongoing over a number of years, they received increased impetus and priority as a result of the Three Mile Island (TMI) accident.

The experience base and technical safety characteristics of U.S. light water reactors (LWRs) underlie the principles of past and proposed siting regulations. LWR technology dominates the U.S. commercial market, focusing regulatory considerations on LWR systems and safety concerns. Thus, the Siting Policy Task Force states in their report that "the analysis in this report has been prepared based on experience with the siting of LWR plants" and "the siting principles stated in this study are not directly applicable to other types or applications of reactors (for example, gas-cooled plant and fast reactor plant)... such applications must be examined on a case-by-case basis." In practice, unique inherent safety features of other reactor types, where LWR regulations are interpreted on a "case-by-case basis," are generally not adequately considered. Consequently, this document primarily examines the potential reduction in public risk if the NUREG-0625 (Ref. 1) population density recommendations were implemented, and it presents quantitative analysis and justification that the specific

*In addition to siting policy, activities principally concern (1) introducing quantitative risk assessment methodology into the licensing process to supplement deterministic safety evaluations and (2) developing emergency plans for existing and proposed reactor sites.

numerical values that might be imposed by the revised siting regulations should be explicitly exempted for high-temperature gas-cooled reactors (HTGRs). Further, this document proposes that the language of a new siting policy should consider inherent technical features of other reactor types, rather than use nondirective phrases, such as "on a case-by-case basis."

Also, the reduced flexibility and the consideration of only electricity-generating power plants in the proposed siting policy may lead to difficulties in siting other nuclear reactors for other applications, such as heat sources for industrial complexes (process heat reactors). This document reviews the technical merits of NUREG-0625 recommendations for the nuclear industry as a whole.

1.2. BACKGROUND

U.S. reactor site criteria are embodied in 10CFR100 (Ref. 2). Formulated in 1964, these regulations predate the deployment of large commercial nuclear power plants. They contain a degree of flexibility to allow for variations and anticipated development in reactor designs and features. As reactor technology advanced and experience was gained, the need for some of the contingent tone in the present 10CFR100 diminished. Therefore, the siting principles and criteria should be reexamined in light of current knowledge.

The Siting Policy Task Force report makes nine recommendations to revise Federal Regulations and NRC practice to accomplish three expressed goals:

1. Strengthen siting as a factor in defense-in-depth by establishing site-approval requirements independent of plant design consideration.

2. Consider in siting the risk associated with accidents beyond the design basis Class 9 accidents, by establishing population density and distribution criteria.
3. Require that sites selected minimize the risk from energy generation.

The Task Force developed the bases for its recommendations after reviewing the reactor siting regulations and current NRC practice in actually interpreting and implementing the regulations. In their review of the fundamental siting regulation, 10CFR100, the Task Force concluded that current practice has seriously undermined the intent of the regulation to establish and maintain distance as an inherent safety feature in reactor siting. Further, the Task Force concluded that the flexibility written into 10CFR100 to allow for "unique or unusual features having a significant bearing on the probability or consequences of accidental release of radioactive material" and consideration of "safety features that are to be engineered into the facility" has been misinterpreted and has eroded the distance factor in exchange for improved engineered safety features. The Task Force, therefore, desires to reverse this practice.

The Siting Policy Task Force fundamentally recommends that reactor sites be sufficiently remote from population concentrations and from external hazards which might initiate accidents having significant radiological consequence. To achieve this goal, the Task Force proposes that minimum distances be established for the Exclusion Area Boundary (EAB) and Emergency Planning Zone (EPZ) for population interaction. In addition, the Task Force proposes minimum standoff distances for each of several specified external hazards. These distances are to be independent of the specific engineered safety features of the reactor under consideration. Also, maximum population densities and distributions are to be specified within the EPZ. The Task Force proposes that generic numerical values for the distances and population parameters be made part of 10CFR100 and suggests some characteristic specific values for these parameters.

2. EVALUATION OF PROPOSED SITING POLICY

2.1. PERCEIVED BENEFITS OF SITING POLICY CHANGES

The Task Force has attempted to consider all aspects of site selection, including radiological safety considerations due to airborne releases and to ground water contamination; potential accident initiation caused by hazards external to the plant, such as dams, seismic faults, transport facilities, and airports; population growth and changes in land use patterns that could affect the suitability of a site with time; the need to link site evacuations and emergency planning; and potential political jurisdictional conflicts.

To promote enhanced safety of nuclear power reactors, the Task Force has reinforced the fundamental principle of distance as an additional level of protection against the uncontrolled release of radioactivity to the public. To implement this principle, the Task Force has strived for simplicity and specificity in the regulations. This approach disregards the effectiveness of engineered safety features in preventing and mitigating postulated accidents (although, all plants are assumed to employ at least the essentially standard engineered safety features in current LWRs).

Specifically, the Task Force recommends the following: (1) an ~0.8 km (~0.5-mile) minimum distance for the reactor site boundary (the EAB) and (2) an 16.1-km (10-mile) EPZ. These recommendations expect that the minimum EAB will sufficiently protect against all design basis accidents without evacuating anyone outside the EAB. Coupled with standard engineered safety features of current plants, the minimum EAB distance was judged to sufficiently preclude doses in excess of the current 10CFR100 guidelines. The Task Force suggests that the minimum EAB distance would make specific dose limits or guidelines unnecessary.

Beyond the EAB, the proposed siting criteria protect against events beyond the design basis (so-called Class 9 accidents). Referring to the perceived intent of 10CFR100, the Task Force recommends that the EPZ and an emergency plan be established out to 16.1 km (10 miles) and, in conjunction with prescribed limits on the population density and distribution, out to ~32.2 km (~20 miles). While the changes to 10CFR100 recommended by the Task Force do not specify population parameters, the NUREG-0625 explanatory discussion suggests some values and anticipates that a study will establish a technical basis for such values. NUREG-0625 implies that an appropriate technical basis would be a generic quantitative risk evaluation for LWR Class 9 events.

One issue in the Task Force report not addressed in 10CFR100 concerns explicit protection against hazards external to the reactor site (such as explosives or toxins, large dams, seismic faults, airports, etc.) that could cause a radiological hazard. Although current regulatory practice accounts for such hazards, it has relied on engineered features, rather than separation distance, to protect against such hazards. To counter this trend, the Task Force recommends that minimum standoff distances be established for each class of external hazards. The NUREG-0625 discussion presents suggested values of 2.4 km (1.5 mile) to large propane pipelines; 0.8 km (0.5 mile) to large natural gas lines; and 8 km (5 miles) to commercial airports, light natural gas (LNG) terminals, and storage areas of large quantities of explosive or toxic materials. Clearly, the Task Force goal is to reestablish distance and to simplify site evaluation. The Task Force perspective, as stated, concerns only applying nuclear power to electric generating stations. If the recommendations were adopted, then applied to all commercial-sized reactors, they could severely limit use of nuclear fission energy for industrial applications, including the production of synthetic petrofuels. According to the U.S. Congress Conference Report, Section 108, of the NRC Authorization Bill for FY-80 (Ref. 3), new NRC policy should not foreclose the nuclear option in any region of the country.

2.2. CONSISTENCY WITH KEMENY COMMISSION AND ROGOVIN INQUIRY FINDINGS

Comments on siting practice in the report of the President's Commission on Three Mile Island (Kemeny Commission) (Ref. 4) support the Siting Policy Task Force view that the principle of remote siting has eroded. The Kemeny Commission states that siting criteria have been applied in a "strange, unnatural and round-about manner," particularly the concept of low population zone (LPZ).

The Kemeny Commission report remarks that the LPZ is supposed to be related to emergency planning considerations but notes that the size of the LPZ is based on a hypothetical accident that is assumed to deliver the "extremely high dose" of 25 rems, a dose which is "many times greater than the maximum received at TMI." The Kemeny Commission perceives the shortcomings of the LPZ selection, as implemented by 10CFR100 and regulatory practice, to be (1) yielding a very small LPZ in the range of 3.2 km (2 miles) and (2) allowing people outside the LPZ to receive a large dose if those within the LPZ receive the limit of 25 rem. The Kemeny Commission concludes that this siting practice does not relevantly protect the public and notes that the NRC had considered evacuating people out to 32.2 km (20 miles) from the reactor at one point during the TMI crisis.

The Kemeny Commission recommends (1) eliminating the LPZ concept and (2) basing siting and emergency planning on a spectrum of smaller accidents for which the level of required emergency action at various distances should be assessed. Presumably, such emergency actions could range from evacuation, to ingestion of potassium iodide tablets, to simply staying indoors for a prescribed period of time. In support of this revision of siting practice, the Kemeny Commission also recommends that more research be made into radiation health effects to provide sound public health and safety criteria.

The "Report to the Commissioners and to the Public" by the NRC Special Inquiry Group on Three Mile Island (Rogovin Inquiry) (Ref. 5) concludes the following regarding reactor siting practices:

"...this leads us to conclude that, out of an abundance of caution future reactors should be located at sites that are at least 10 miles and perhaps more from any significant center of population. In developing criteria for future siting, we believe the NRC will have to give consideration to the specific characteristics of the area that influence the effectiveness of evacuation: population density, population centers beyond the minimum distance of 10 miles..."

Because the Rogovin Inquiry drew its technical information from sources that included the NRC staff, their views on siting were very probably influenced by some of the same individuals who participated in the Siting Policy Task Force. Therefore, this recommendation cannot be viewed as a totally independent endorsement of the Task Force policy. Nevertheless, it endorses the Kemeny Commission view that criteria be established for more remote LWR siting with specified minimum fixed distances.

2.3. CONSISTENCY WITH RECENT RISK ASSESSMENTS

In addition to WASH-1400 results (Ref. 6), more recent LWR risk assessment work (such as the German Risk Study, Ref. 7) and plant-specific risk profiles on existing U.S. LWRs (Indian Point and others) have concluded the following pertinent to the siting question:

1. A core melt does not necessarily result in large public consequences. Less than 1% of core melts result in acute fatalities. The probability of acute fatalities is thus exceedingly low.

2. Because of the above, the individual risk for acute radiation fatality to an individual living within 32.3 km (20 miles) of a nuclear power plant is completely overshadowed by other civilization-caused risks (fires, transportation accidents, etc.) and natural phenomena.
3. Individual risks of latent fatality can be somewhat greater than that of acute fatality, but siting considerations have little practical effect on curtailing latent risks, because the population affected is at distances where evacuations are impractical.
4. Differences in specific plant design features can be more important than population density with regard to the overall risk of an existing U.S. nuclear power plant. This belies the contention that current LWRs have more or less standardized engineered safety features which tend to level risk.

These conclusions are inconsistent with the foundation of NUREG-0625 (regarding the importance of remote siting and disregard of specific plant design features).

2.4. EVALUATION OF SAFETY BENEFITS TO LWR SITING

A scoping study estimated the value of the proposed NUREG-0625 population distribution controls on the probabilistic risk of nuclear power plants. The study relied on the information presented in WASH-1400 (Ref 6). Potential changes in consequences of pressurized water reactor (PWR) core melt sequences were calculated for the population distribution postulated in NUREG-0625 compared with alternate distributions. Sequence probabilities and fission product release were assumed to be fixed for the WASH-1400 PWR release categories. Site parameters were then varied in the CRAC computer program (Ref. 8), the same program used to determine consequences in WASH-1400. This program has also been employed at General Atomic (GA) for

site-specific risk assessments and to verify consequence analyses performed with the GA codes.

The study statistically examined demographic data typical of current-generation U.S. nuclear power plants. Reference 9 gives data for 104 nuclear plants in the U.S. As shown in Table 1, the 10, 50, 90, and 95 percentile population densities were established for annular rings out to 80.5 km (50 miles) radius based on the Ref. 9 data. A reference U.S. reactor site population distribution was chosen to represent a high density site in the 95th percentile class (i.e., 95% of other U.S. reactor sites have a less dense population distribution than the selected reference site). This reference site has higher population densities close to the reactor than recommended by NUREG-0625. As an illustrative example, the reference site can be associated with a sprawling dense suburban community location (somewhat like the Limerick or Bailey reactor sites, but completely hypothetical).

The study also established a population distribution consistent with Task Force recommendations. The Task Force felt that specific controls on the population living within 32.2 km (20 miles) of the reactor plant could significantly reduce the current societal risks of power plant siting from so-called Class 9 accidents. While specific population density and distribution characteristics were not established in NUREG-0625, an illustrative population control scheme proposed by the Task Force is summarized as follows:

1. From the exclusion zone to 8 km (5 miles), the population density at the beginning of reactor operation in this annulus should not exceed one half of the average population density of the region where the reactor is to be located or 39 persons/km² (100 persons/mile²), whichever is greater. The population within this annulus should not be expected to increase to more than double the original population during the life of the plant, and no more than

TABLE 1
POPULATION DISTRIBUTIONS OF ASSUMED SITES

Radial Segment [km (miles)]	Reference Populations Used in This Study [persons/km ² (persons/mile ²)]		104 U.S. Nuclear Power Plants ^(a) [persons/km ² (persons/mile ²)]			
	Reference U.S.	NUREG-0625 ^(b)	Percentile			
			10th	50th	90th	95th
0-1.6 (0-1)	586 (1500)	0	0	8 (20)	105 (270)	203 (520)
1.6-8 (1-5)	352 (900)	40 (100)	4 (10)	29 (75)	195 (500)	363 (930)
8-16.1 (5-10)	352 (900)	59 (150)	8 (20)	59 (150)	195 (500)	312 (800)
16.1-32.2 (10-20)	352 (900)	176 (450)	12 (30)	59 (150)	265 (680)	429 (1100)
32.2-80.5 (20-50)	586 (1500)	586 (1500)	13 (33)	74 (190)	371 (950)	585 (1500)

(a) From NUREG-0348, Ref. 9.

(b) Ref. 1.

one-half of the allowed number of persons in the zone should be permitted within any single 22.5-deg sector. Transients should be weighed according to their fractional occupancy within this annulus.

2. From 8 to 16.1 km (5 to 10 miles), the population density at the beginning of reactor operation in this annulus should not exceed three-quarters of the average population density of the region where the reactor is to be located, or 59 persons/km² (150 persons/mile²), whichever is greater. No more than one-half of the allowed number of persons in this annular ring should be permitted in any single 22.5-deg sector.
3. From 16.6 to 32.2 km (10 to 20 miles), the population density at the beginning of reactor operation in this annulus should not exceed twice the average population density of the region where the reactor is to be located, or 156 persons/km² (400 persons/mile²), whichever is greater. However, no more than one-half of the allowed number of persons in this annular ring should be permitted in any single 22.5-deg sector.

The Task Force felt that specific population control and limits beyond 32.2 km (20 miles) from the plant are not warranted. The study assumed the population distribution beyond 32.2 km (20 miles) to be the same as for the reference site. Table 1 presents the population model derived to correspond to the Task Force intent. As an illustrative aid, Fig. 1 presents the cumulative population in a 22.5-deg sector.

For both study sites, the population density at distances greater than 80.5 km (50 miles) was assigned a value of 195 persons/km² (500 persons/mile²). This population density was derived by scaling the current U.S. average population density within 112.7 km (70 miles) of nuclear power plants (Ref. 5), 117 persons/km² (300 persons/mile²), to the year 2000.

Fig. 1. Population distributions for assumed sites

The NUREG-0625 site is essentially a moderately populated U.S. site in the 0 to 32.2 km (0 to 20 mile) near-site population segment that has been nonmechanistically adjusted to conform with the intent of NUREG-0625. Therefore, comparisons between the reference U.S. and NUREG-0625 sites will measure the potential of the Task Force guidelines to modify consequences. Additionally, the severe reference site (95th percentile) selected will likely more dramatically demonstrate consequence changes due to implementing the Task Force recommendations than would typical existing nuclear reactor sites.

WASH-1400 (Ref. 6) used a series of six broad types of representative composite reactor sites to characterize the first 100 U.S. reactor plants. A computer file described one year of hourly recorded meteorological data for each composite site. This data file represented actual measured meteorological data for a composite site, which was representative of the prevailing meteorology of the constituent sites within the composite.

The meteorological data set, representative of the Northeast River Valley composite site in WASH-1400, applied in all the study accident consequence estimates. Recognizably, using a fixed set of meteorological data for multiple sites is a simplification, justifiable only to isolate the parametric effect of population density distribution. For an actual site, the specific land topology and weather patterns, combined with the population distribution, may significantly affect the consequence assessment, evacuation plans, and evacuation routes. This study assumed the WASH-1400 evacuation model. Thus, consequence trends and comparisons, rather than absolute magnitudes, are of interest in the study results.

Table 2 summarizes the study analysis assumptions and parameter values employed to determine the impact of NUREG-0625 population control. The parameters were intended to be as consistent as possible with WASH-1400 methodology. Table 2 notes deviations, where present. It calculates consequences for activity releases of each release category, considering the occurrence of the categories. Table 3 summarizes fission product releases.

TABLE 2
SUMMARY OF MODELS AND PARAMETER VALUES USED IN CRAC COMPUTER PROGRAM ANALYSIS^(a)

<u>Parameter</u>	<u>WASH-1400 (Ref. 6)</u>	<u>This Study</u>
Releases from containment	Core melt and design basis accident, PWR and BWR release categories.	PWR core melt release categories.
Reactor site specification	Six composite reactor sites each representative of the climatic and topographic features of the first 100 reactors in the U.S. by 1985.	NUREG-0625 (Ref. 1) and reference U.S. site (Ref. 9).
Topographic data, land use character	Characteristic of the reactor sites within each composite site grouping, 16 sections per site examined.	Topography representative of the State of New York.
Meteorological definition	91 stratified weather samples examined for each composite site/release category combination.	91 stratified weather samples for composite site 1, Northeast River Valley.
Evacuation model	Evacuation to a distance of 40 km (25 miles) downwind in a 45-deg sector. Additional evacuation upwind to a radial distance of 8 km (5 miles). Velocity of evacuations used; 0, 1.9, and 11.3 km/h (0, 1.2, and 7.0 mph) at respective probability of occurrence of 30, 40, and 30%.	Same except single evacuation speed of 1.9 km/h (1.2 mph) assumed.
Integration distance for consequence assessment	805 km (500 miles), with any remaining material [after 805 km (500 miles) transport] uniformly deposited in the 805 to 3219 km (500 to 2000 miles) radial segment.	Same

^(a) Model description and parameters for economic effects, land interdiction and decontamination, individual doses, and population health effects are presented in WASH-1400 (Ref. 6) and are taken to be the same in this study.

TABLE 3
SUMMARY OF FISSION PRODUCT RELEASE FOR PWR RELEASE CATEGORIES (Ref. 6)

Release Category	Probability per Reactor-Yr	Time of Release (h)	Duration of Release (h)	Warning Time for Evacuation (h)	Elevation of Release [m (ft)]	Containment Energy Release [10^6 W (10^6 Btu/h)]	Fraction of Core Inventory Released							
							Xe-Kr	CH ₃ I	I ₂	Cs-Rb	Te-Sb	Ba-Sr	Ru	La
1	9×10^{-7}	2.5	0.5	1.0	25 (82)	156 (530)	0.9	6×10^{-3}	0.7	0.4	0.4	0.05	0.4	3×10^{-3}
2	8×10^{-6}	2.5	0.5	1.0	0	51 (170)	0.9	7×10^{-3}	0.7	0.5	0.3	0.06	0.02	4×10^{-3}
3	4×10^{-6}	5.0	1.5	2.0	0	1.8 (6)	0.8	6×10^{-3}	0.2	0.2	0.3	0.02	0.03	3×10^{-3}
4	5×10^{-7}	2.0	3.0	2.0	0	0.3 (1)	0.6	2×10^{-3}	0.09	0.04	0.03	5×10^{-3}	3×10^{-3}	4×10^{-4}
5	7×10^{-7}	2.0	4.0	1.0	0	0.09 (0.3)	0.3	2×10^{-3}	0.03	9×10^{-3}	5×10^{-3}	1×10^{-3}	6×10^{-4}	7×10^{-5}
6	6×10^{-6}	12.0	10.0	1.0	0	N/A	0.3	2×10^{-3}	8×10^{-4}	8×10^{-4}	1×10^{-3}	9×10^{-5}	7×10^{-5}	1×10^{-5}
7	4×10^{-5}	10.0	10.0	1.0	0	N/A	6×10^{-3}	2×10^{-5}	2×10^{-5}	1×10^{-5}	2×10^{-5}	1×10^{-6}	1×10^{-6}	2×10^{-7}
8	4×10^{-5}	0.5	0.5	N/A	0	N/A	2×10^{-3}	5×10^{-6}	1×10^{-4}	5×10^{-4}	1×10^{-6}	1×10^{-8}	0	0
9	4×10^{-4}	0.5	0.5	N/A	0	N/A	3×10^{-6}	7×10^{-9}	1×10^{-7}	6×10^{-7}	1×10^{-9}	1×10^{-11}	0	0

References 6 and 8 extensively describe the consequence model employed in the CRAC code, which is only summarized here. Figure 2 schematically represents the functional features of the CRAC consequence model. The CRAC code requires input on the timing and quantity of radioactive material released to the environment and a description of the accident conditions. The code models the atmospheric dispersion of released material to downwind locations in the surrounding population and computes the resulting doses from radioactivity in the air and on the ground. Accident mitigation features, such as near-site evacuation to reduce early exposure to the passing cloud, interdiction of food stuffs, and decontamination to reduce long-term chronic effects, are modeled as described in WASH-1400. The CRAC code produces consequences in the form of acute and latent health effects and property damage cost. The CRAC code is felt to be the most complete and comprehensive assessment tool developed to date for realistically assessing LWR reactor accident consequences.

This study infers the resulting impact of proposed NUREG-0625 population distribution and density control on the accident risks of nuclear power plants by comparing CRAC estimates of accident risks for the reference U.S. site (Ref. 9) to accident risks similarly calculated for the NUREG-0625 site. The accident consequences felt to be most responsive to population control were (1) early acute fatalities and (2) latent cancer fatalities. This study employs these consequence units.*

Figure 3 plots the PWR acute fatalities for the study sites. These results suggest that NUREG-0625 guidance can significantly affect near-site-related health effects at low accident frequencies. Approximately a factor of eight reduction (at conditional probability of occurrence of 1×10^{-7} reactor-year⁻¹) in acute fatalities is obtained by modifying the 0 to

* Other consequence units, such as topography-related concerns (relocation and decontamination area or total property damage), early illness, thyroid nodules, or generic effects, might also have been estimated and compared in this study. However, the character of the population-related effects are judged to be satisfactorily shown with the two indices chosen.

Fig. 2. Schematic outline of consequence model employed in CRAC code

Fig. 3. Cumulative probability distribution for acute fatalities over a spectrum of PWR accidents

32.2 km (0 to 20 mile) population density of the reference site to conform to the intent of NUREG-0625.

Figure 4 presents the estimated PWR latent cancer fatalities for this study. No detectable difference is observed between the reference U.S. site and the site with NUREG-0625 controls. This is because PWR latent effects occur primarily at distances greater than 32.2 km (20 miles). Figure 5 displays the parametric results, showing that, depending on the site examined, 97% to 99% of the total LWR latent cancer fatalities occur at distances greater than 32.2 km (20 miles). This implies that population control in the 0 to 32.2 km to (0 to 20 mile) segment of the LWR does little to modify latent consequences.

The average individual risk within 32.2 km (20 miles) of an LWR plant can be calculated from Figs. 3 through 5 by summing the 0 to 32.2 km (0 to 20) mile radius fatality risk and dividing by the resident population within 32.2 km (20 miles). For the reference U.S. site, the average individual risk of acute fatality due to nuclear plant accidents is extremely low, 9×10^{-11} /person/year. The average individual risk for the NUREG-0625 site is about three times lower. This is because within the 0 to 32.2 km (0 to 20 mile) NUREG-0625 site population, relatively fewer people are located at distances 0 to 8 km (0 to 5 miles), where most acute fatalities would have occurred. But even for the reference U.S. site, the average individual risk of acute fatality is 20 times lower than the average individual risk of latent fatality (2×10^{-9}), which is unaffected by the 0 to 32.2 km (0 to 20 mile) population distribution. Thus, while the NUREG-0625 site population restrictions reduce the average individual risk of acute fatality (by a factor of three compared to the reference U.S. site), the benefit regarding overall individual risk reduction is questionable because the larger risk of latent cancer* is unchanged.

*

To address the benefit of reducing acute versus latent fatalities, a quantitative model is needed for acute versus latent fatality comparisons; this is beyond the scope of this report.

Fig. 4. Cumulative probability distribution for latent fatalities over a spectrum of PWR accidents

Fig.*5. Cumulative latent health effects versus distance from the reactor plant (PWR 2 release category)

Figures 5 and 6 present the distribution of individual risk due to acute and latent fatalities for PWR accidents. Individual risk for acute fatalities becomes relatively small after ~8 km (~5 miles), while the latent health effect risk drops off much more gradually. Localization of the acute health effects is due to the distinct threshold dose required to cause such effects. Compared to individual risk of cancer fatalities due to non-nuclear causes (Refs. 6, 7), the nuclear risk for individuals is negligible everywhere.

In addition to individual risk, the societal risk for the total population within 32.2 km (20 miles) of a nuclear plant due to plant accidents is small compared to risks of spontaneous cancer fatality due to non-nuclear causes, even for most densely populated existing U.S. sites. According to current average U.S. statistics (Ref. 6), about 800 and 1900 persons living within 0 to 32.2 km (0 to 20 miles) of the NUREG-0625 and reference U.S. sites, respectively, would contract fatal cancer each year (incidence rate of 17 cases per 10,000 persons). In contrast, the probability is low that even one fatality of any kind would be incurred due to accidents over the entire 40-year operational life of an LWR on the reference U.S. site. Thus, on a probabilistic basis, a remote reactor siting [even down to zero people within 32.2 km (20 miles)] gives low benefit in terms of lives-saved statistics.

Fig. 6. Mean individual risks for persons living in the vicinity of a PWR versus distance from the plant for the U.S. reference site over a spectrum of PWR accidents

3. IMPLICATIONS OF PROPOSED SITING POLICY ON HTGR SITING

The proposed NUREG-0625 guidance on population density distribution, as stated, applies only to LWR sites; however, its potential to change HTGR accident risk should be examined and quantified.

3.1. INHERENT HTGR SAFETY FEATURES

Since safety was emphasized throughout the design evolution of gas-cooled reactors, HTGRs have a high degree of inherent safety. These inherent HTGR features act as the first lines of defense to retain the inventory of radioactivity and to maintain the integrity of the containment barriers. Table 4 illustrates the inherent safety contribution of each HTGR essential design feature over a wide spectrum of postulated accident conditions.

3.1.1. Graphite Core with Refractory Fuel

The HTGR core is constructed entirely of ceramic materials which maintain their integrity even at extreme temperatures. This integrity contributes to large safety margins between normal operating temperatures and damage limits. The core structure weighs almost 1.4 million kg (3 million lb); the associated heat capacity and a low power density insure that reactor temperature transients proceed very gradually in response to disturbances. Coated particle fuel imbedded in the core graphite can retain fission products even in the unexpected event of a sustained interruption in core cooling capability. The slow thermal response also provides for a more forgiving reactor, since ample time is available to prevent transients from progressing into major accidents. In the extremely rare event that all means of core cooling are lost indefinitely, the core cannot melt down, and the remaining inherent features preclude the rapid release of large quantities of radioactivity.

TABLE 4
SAFETY SIGNIFICANCE OF KEY INHERENT FEATURES

<u>Inherent Feature</u>	<u>Relevant Properties</u>	<u>Safety Significance</u>
Coated particle fuel	Ceramic material	Maintains integrity at very high temperatures.
	Small diameter	Small temperature rise across fuel.
	Multiple "pressure vessels"	High retention of radioactivity; slow controlled release under no cooling conditions.
Graphite core	High Heat capacity/low power density	Slow response to temperature transients, ample time for prevention and mitigation of accidents.
	Does not melt	No "China Syndrome" type of considerations.
	Ceramic material	Maintains strength at very high temperatures.
Helium coolant	Single phase	No boiling, bubbles, liquid level or pump cavitation; coolant injection systems not required.
	Neutronically inert	No reactivity effects.
	Chemically inert	No chemical reactions with fuel or other reactor components.
	Low stored energy	Enhanced containment effectiveness, need for containment heat removal system.
PCRV and associated liner	Structurally redundant	High level of integrity (failure of individual structural measures inconsequential).
	Concrete cooling requirement	Independent heat removal capability.
	Massive robust structure	Heat retention of radioactivity, massive containment heat barrier.
	Integral arrangement	Primary system pipe/duct ruptures eliminated. Air ingress potential limited to containment volume.

3.1.2. Helium Primary Coolant

Helium gas, which is noncondensable over the whole HTGR temperature range always totally occupies its space and, so confined, obeys one unique and linear temperature-pressure relationship. Because no liquid-gas interface need be considered, a single unambiguous signal (pressure) determines the coolant location. Thus, rapid depressurization can be accommodated without concern for such consequences as void formation, local core dryout, and cavitation of pumps, as would be the case with liquids confined at temperatures above their atmospheric boiling point.

The working pressure required for gas-cooled reactors is typically much below that needed to adequately pressurize a water coolant. This feature enables sufficient core cooling to be readily provided for the HTGR even at atmospheric pressure. In this sense, HTGRs can be claimed to be immune to the so-called loss of coolant accident (LOCA), obviating the need for coolant injection systems. Hence, only decay heat need be removed to provide adequate cooling, simplifying the cooling system design. These simplifications in the design requirements make quick operator decisions or prompt actions unnecessary to maintain adequate cooling.

Helium is inert, which means it cannot react chemically with other materials, such as fuel cladding or core structural components. At TMI, uncovering the core and subsequent fuel cladding heatup caused the zirconium-water chemical reaction that apparently damaged the fuel rods and extensively liberated hydrogen gas. The hydrogen bubble that formed complicated subsequent efforts to cool the core.

3.1.3. Prestressed Concrete

The HTGR utilizes a prestressed concrete reactor vessel (PCRv). This large passive structure encloses the entire primary coolant system, including the reactor core and all steam generation equipment. High strength in the PCRv is provided by redundant axial and circumferential steel tendons

that prestress the concrete in compression so that cracks which might occur are self-sealing. The shielding afforded by the concrete prevents neutron embrittlement in the load-bearing tendons. The functions of sealing and load carrying are separated by a steel liner, which is always in compression, further limiting the possibilities for fault propagation. During postulated core heatup accidents, the PCRV retards the transport of fission products to the containment building and protects the containment from the degrading effects of reactor decay heat. These characteristics contribute to the long time-scale of accident progression and provide for exceptional radioactivity retention.

The effectiveness of the HTGR inherent safety features are exploited by compatible engineered safety features. One such engineered feature is a dedicated, fully redundant decay-heat-removal system, which is separate from and independent of the power conversion system. This system is distinct from an LWR emergency cooling system in that heat can be adequately removed after a postulated leak in the primary coolant boundary without needing coolant injection. A second inherent safety feature is a containment structure to prevent the release of any radioactivity which may escape the primary coolant boundary.

Inherent HTGR safety features provide two basic improvements over LWRs: (1) greater retention of fission products by plant barriers (this is especially true for relatively nonvolatile, long-lived, biologically hazardous isotopes) and (2) extended time for release and associated profound effects on operator control and off-site evacuation.

3.2. EVALUATION OF SITING POLICY IMPACT ON HTGR SAFETY

The Accident Initiation and Progression Analysis (AIPA) applied probabilistic risk analysis (PRA) methodology to the HTGR (Ref. 10). Using event tree/fault tree techniques similar to those used in WASH-1400 (Ref. 6), AIPA evaluated the HTGR system response to a wide spectrum of initiating events, considering inherent and engineered safety features.

Several peer groups, including the German KFA/GRS group,^{*} reviewed the AIPA study results. Also, KFA supplemented AIPA with quantitative risk assessments for the HTGR on German sites with high population densities (Ref. 11). By and large, these peer reviews and additional analyses support the AIPA results. One of the most significant results is that HTGR accidents produce no acute fatalities in the population distributions of the composite sites (WASH-1400) analyzed, even for low probability core heatup sequences. The HTGR health effect risk thus stems totally from latent effects.

The present study builds upon the AIPA study; it performs a scoping analysis, similar to that in Section 2.4, on the effect of near-site, population densities on the public risk of an HTGR. CRAC code consequence calculations were made for HTGR fission product release categories given in Ref. 10. In that report, six core heatup (risk dominating event) release categories were defined (see Table 5). The CRAC code analysis, as defined in Ref. 10, considered time and magnitude of radioactivity release and occurrence frequency for each category. The site population distribution was varied. An HTGR-specific evacuation model was developed as described below. Table 2 gives the other CRAC code models and parameter values assumed. The CRAC code gave cumulative probability distributions on HTGR accident fatalities for the selected sites.

Three site population distributions were evaluated: (1) the reference U.S. site, (2) the NUREG-0625 site, and (3) a hypothetical urban site with a denser population than any existing reactor site. This third site development was intended to obtain parametric results over a wider range by maximizing the foreseeable population in the near [0 to 32.2 km (0 to 20 mile)], intermediate [32.2 to 80.5 km (20 to 50 mile)], and far [80.5 to 805 km (50 to 500 mile)] fields surrounding a highly urbanized reactor placement.

^{*} Kernforschungsanlage (KFA)/Gesellschaft für Reaktorsicherheit (GRS).

TABLE 5
HTGR RELEASE CATEGORY CHARACTERISTICS, CORE HEATUP SCENARIOS (Ref. 10)

Core Heatup Release Category	Probability per Reactor-Yr	Time of Release (h)	Duration of Release (h)	Warning Time for Evacuation (h)	Fraction of Core Inventory Released						
					Xe-Kr	I ₂	Cs-Rb	Te-Sb	Ba-Sr	Ru	La
1	6×10^{-9}	35	To 30 days	1.0	0.2	9×10^{-3}	2×10^{-6}	8×10^{-4}	2×10^{-7}	0	6×10^{-7}
2	5×10^{-8}	143	To 30 days	1.0	0.5	5×10^{-3}	6×10^{-4}	9×10^{-5}	4×10^{-5}	3×10^{-7}	2×10^{-6}
3	4×10^{-7}	238	To 30 days	1.0	0.3	3×10^{-3}	1×10^{-5}	2×10^{-5}	2×10^{-8}	0	6×10^{-9}
4	8×10^{-7}	212	To 30 days	1.0	0.4	4×10^{-4}	6×10^{-5}	8×10^{-7}	8×10^{-6}	2×10^{-7}	4×10^{-7}
5	6×10^{-6}	307	To 30 days	1.0	0.2	2×10^{-4}	3×10^{-7}	2×10^{-7}	2×10^{-8}	0	0
6	3×10^{-5}	35	To 30 days	1.0	3×10^{-3}	6×10^{-7}	0	1×10^{-7}	0	0	0

Reactor accident consequence determinations with this site bound the upper magnitude of population effects on reactor siting.

The population distribution for the hypothetical urban site was comprised as follows:

1. The population density for the 0 to 32.2 km (0 to 20 mile) segment of the urban site was that of the proposed BASF/Ludwigshaven urban German site (Ref. 11) adjusted to the year 2000.
2. The 32.2 to 80.5 km (20 to 50 mile) segment of the hypothetical urban site used the estimated year 2000 Indian Point population distribution.
3. The remaining 80.5 to 805 km (50 to 500 mile) radial segment was assigned a fixed population density of 195 persons/km² (500 persons/mile²). Table 6 gives the urban site population density distribution used for this analysis.

The HTGR evacuation model employed in this study departs significantly from the evacuation models utilized for the LWR accident sequence of WASH-1400. Inherent safety features of the HTGR ensure a slow progression of HTGR fission product release to the environment (none occurring with warning times of less than ~24 h, thereby ensuring enough time for complete evacuation). Additionally, the relatively low magnitude of biologically hazardous fission products released allows for orderly and complete evacuation from a smaller distance than anticipated for LWRs.

The HTGR evacuation model employed in the analysis assumes total evacuation of the population to the LPZ boundary distance of 2.5 km (1.6 miles). This represents a departure from WASH-1400 evacuation models which account for evacuations to 40.2 km (25 miles). The HTGR evacuation model is conservative in a sense in that it may tend to predict marginally higher

TABLE 6
URBAN SITE POPULATION DISTRIBUTION ASSUMED IN THIS STUDY

Radial Segment [km (miles)]	Urban Site(a) Population Density [persons/kg ² (persons/mile ²)]	Factor Increase Over NUREG-0625 (b) Site Population Density
0-1.6 (0-1)	156 (400)	Similar
1.6-8 (1-5)	2734 (7000)	8
8-16.1 (5-10)	977 (2500)	3
16.1-32.2 (10-20)	664 (1700)	2
32.2-80.5 (20-50)	~1172 (~3000)	2
Av 0-80.5 (0-50)	1172 (3000)	2

(a) Ref. 11.

(b) Ref. 1.

latent fatalities than if the evacuation was affected to 40.2 km (25 miles), as in the LWR model. However, as will be shown later, HTGR scenarios with a 2.5 km (1.6 miles) evacuation distance do not produce acute fatalities. (Presumably, acute fatalities would be the prime reason for an evacuation contingency.) In summary, the resultant HTGR evacuation model was deemed to be realistic and responsive to expected HTGR accident scenarios.

The CRAC code results show that the HTGR accidents result in no acute fatalities for any of the population distributions analyzed in this study, including the urban site. This striking finding is attributable to the inherent safety features of the HTGR concept, which limit the magnitude of radioactivity release and extend the time of release. The magnitudes are such that potentially lethal concentrations of radioactive material only occur within 1 or 2 km (0.6 to 1.2 miles) of the plant, if at all, even for severe weather cases calculated in the CRAC code results. In addition to having few or no people affected in the short distance, the short evacuation radius makes the evacuation more effective. Also, the extended time between accident recognition and radiological dose commitment affords time for population alert and transportation and, thus, effective evacuation.

Figure 7 presents CRAC code results for latent cancer fatalities. The HTGR-related latent cancer fatalities appear to be a very weak function of the near-site [0 to 32.2 km (0 to 20 mile)] population controls proposed by NUREG-0625. For example, the reference U.S. site latent consequences are slightly higher (30%) than the NUREG-0625 site at a probability level of 10^{-7} reactor-year⁻¹. However, at this probability, considerably higher levels of safety are afforded by the HTGR than for the LWR for all sites considered, including the urban site.

The latent effects versus distance profile is more localized in the HTGR than in the accident scenarios considered in the formulation of NUREG-0625, tending to produce latent consequences over a correspondingly smaller radius. Figure 8 presents the results of a parametric study estimating the

Fig. 7. Latent cancer fatalities due to a spectrum of HTGR accidents for different population distributions

Fig. 8. Relative fraction of total latent fatalities as a function of distance over a spectrum of HTGR accidents

cumulative latent cancer fatalities with radial distance from the reactor site. The calculation was performed for a single, severe release category to maximize latent cancer consequences. Results are sufficiently representative to illustrate the consequence versus distance trends. For the reference U.S. site, 45% of the HTGR latent cancer consequences occur at distances greater than 80.5 km (50 miles) [as compared to PWR effects of 78% at distances greater than 80.5 km (50 miles)]. This demonstrates the lower magnitudes of fission product release and corresponding low latent effects for the HTGR.

These results show that inherent safety can be achieved in ways other than site isolation. The HTGR inherent features achieve greater safety benefits than intended by the proposed isolated siting policy, regardless of population density. Consequently, the HTGR accident risk is hardly affected by remote siting. This same conclusion was reached in Ref. 12 based on accident consequence considerations. That paper examines possible methods for reducing consequences, including remote siting, and discusses advantages of inherent features for this purpose. It points out that the much longer radioactivity release time enables effective evacuation or countermeasures, if required, for HTGR Class 9 accidents; remote siting adds little safety benefit.

4. CONCLUSIONS AND RECOMMENDATIONS

This study indicates that severe LWR core melt events analyzed in WASH-1400 (Ref. 2) pose risk of acute fatalities only to the population immediately around the plant [within ~8 km (~5 miles)] rather than the 32.2 km (20 mile) zone of control recommended by NUREG-0625. Also, extending the control zone to 32.2 km (20 miles) negligibly affects societal risk due to latent fatalities. The magnitude of societal risk due to LWR-accident-caused fatalities of any kind is so low compared to non-nuclear-caused fatalities that restrictions beyond current siting practice questionably reduce public risk overall. In any case, the maximum benefit seems to be achieved by population restrictions within ~8 km (~5 miles); beyond that distance, returns diminish. Thus, some modification of the NUREG-0625 proposals for LWRs may be warranted.

The HTGR inherent and passive safety features limit radiological consequences such that no acute fatalities are calculated even for severe core heatup accidents. While latent health effects are somewhat more localized than in PWR calculations, population restrictions within 32.2 km (20 miles) for the HTGR give little benefit. The HTGR overall societal risk is calculated to be well below that which could be achieved by proposed NUREG-0625 policy for LWRs.

This study concludes that the new siting policy should contain explicit language excluding HTGRs from its scope of coverage. Siting of reactor types not considered in NUREG-0625 should be based on their own technical features and inherent characteristics which can potentially affect public health and safety. Such reactor types should also include small size reactors and reactors for process heat/steam applications.

5. REFERENCES

1. "Report of the Siting Policy Task Force," USNRC, Office of Nuclear Reactor Regulation, Report, NUREG-0625, August 1979.
2. "Reactor Site Criteria," in Code of Federal Regulations, Title 10, Part 100, January 1974, pp. 413-423.
3. "Joint Explanatory Statement of the Committee on the Conference, Authorized Appropriations to the Nuclear Regulatory Commission," Conference Report 96-1070, House of Representatives, 96th Congress, 2nd Session, June 4, 1980.
4. Kemeny, J. G., et al., "Report of the President's Commission on the Accident at Three Mile Island," Washington, D.C., October 1979.
5. Rogovin, M., et al., "Three Mile Island: A Report to the Commissioners and to the Public," USNRC, Special Inquiry Group, Report, v. I, February 1980.
6. "Reactor Safety Study: As Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants," USNRC Report WASH-1400, October 1975 (NUREG-75/014).
7. "The German Risk Study, Summary," German Federal Ministry of Research and Technology Report, Gesellschaft für Reaktorsicherheit, August 15, 1979.
8. "Calculations of Reactor Accident Consequences - CRAC Computer Code User's Manual," USNRC Report (Draft), February 1977.
9. Bunch, D., et al., "Demographic Statistics Pertaining to Nuclear Power Reactor Sites," USNRC Report NUREG-0348, November 1979.
10. "HTGR Accident Initiation and Progression Analysis, Status Report, Phase II Risk Assessment," DOE Report GA-A15000, General Atomic Company, April 1978.
11. "Safety Study of an HTR Concept Sited in Germany," Germany Federal Ministry of the Interior Report, Kernforschungsanlage Jülich, GmbH, Institute for Reactor Safety, and Gesellschaft für Reaktorsicherheit, to be published.

12. Cave, L., R. Holmes, and P. Holmes," The Implications of Using Consequences as a Criterion for Reactor Design," UCLA Technical Report UCLA-ENG-7875, October 1978.

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SAN DIEGO, CALIFORNIA 92138