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Nuclear Energy Center Site Survey Reactor Plant Considerations

May 1976

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Battelle
Pacific Northwest Laboratories

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NUCLEAR ENERGY CENTER SITE SURVEY REACTOR PLANT CONSIDERATIONS

By the Staff
of Battelle Pacific Northwest Laboratories

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May 1976

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INTRODUCTION

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TASK 1.1.2 SOCIOECONOMIC IMPACTS

INTRODUCTION

The Energy Reorganization Act of 1974 required the Nuclear Regulatory Commission (NRC) to make a nuclear energy center site survey (NECSS). The NECSS report was required to include:

1. NRC's evaluation of the results of a national survey to locate and identify possible nuclear energy center (NEC) sites, and
2. NRC's conclusions and recommendations regarding the feasibility and practicality of locating nuclear power reactors and/or other elements of the nuclear fuel cycle on nuclear energy centers.[1]

Background information for the NECSS report was developed in a series of tasks outlined in Reference 1 and subsequent additions. A number of the tasks were assigned to Battelle's Pacific Northwest Laboratories. As the study proceeded changes were made in the scopes of several tasks to accommodate new information generated in the NECSS study.[2] Those tasks which pertained to the reactor aspects of NECs are listed below:

TASK 1.1.2 SOCIOECONOMIC IMPACTS

The scope of this task was to evaluate the typical socioeconomic problems that will arise because of the magnitude of construction, the attraction of labor skills and community support functions, and the changes expected in the local fabric of society at an NEC site.

TASK 2.1.6 ENVIRONMENTAL IMPACT - REACTOR FACILITIES

The scope of this task was to evaluate the environmental impact of radioactive effluents from NECs of several geometric arrays.

TASK 2.1.11 EMERGENCY RESPONSE CAPABILITY - REACTOR FACILITIES

The scope of this task was to evaluate the effect of the NEC on the required emergency response capability for reactor facilities for accidents or threats, and compare it to dispersed sites.

TASK 2.1.12 AGING OF NECs

Evaluation of NECs with dispersed siting of reactor plants requires that the entire life cycle of both NECs and dispersed-sited plants be compared. In addition, the effect that each has on the "system" into which they become part should be examined.

The scope of this task was: 1) to identify areas in which the ageing aspects of the NECs and dispersed plants may differ, and 2) to consider in a preliminary way what these differences may entail.

TASK 2.1.13 DRY COOLED NEC

The purpose of this task was to evaluate the technical, environmental, and socioeconomic factors associated with construction and operation of a dry-cooled nuclear energy center (DCNEC). Dry-cooled centers were included as a part of the NECSS primarily because they allow increased flexibility in siting, including semi-arid and even arid areas.

The work performed under each of these tasks, as revised, is reported in the text which follows by task number.

The text for the reactor sections of the NECSS-75 report(2) was obtained in part by extracting material and data from the task writeups in this report.

REFERENCES FOR INTRODUCTION

1. Nuclear Energy Center Site Survey, NUREG-75/018, U.S. Nuclear Regulatory Commission, Office of Special Studies, March 13, 1975.

2. Nuclear Energy Center Site Survey, NUREG-001, U.S. Nuclear Regulatory Commission, Office of Special Studies, January 1976.

TASK 1.1.2

SOCIOECONOMIC IMPACTS

D. A. Summers

TASK 2.1.6 ENVIRONMENTAL IMPACTS (REACTOR FACILITIES)

TASK 1.1.2

SOCIOECONOMIC IMPACTS

The work performed under Task 1.1.2 has been reported in a separate document titled "Identification and Management of Economic and Social Impacts of Nuclear Energy Centers: A Preliminary Analysis," Human Affairs Research Centers, Pacific Northwest Division, Battelle Memorial Institute, September 1975.

TASK 2.1.6

ENVIRONMENTAL IMPACTS - REACTOR FACILITIES

J. K. Soldat

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TASK 2.1.6

ENVIRONMENTAL IMPACTS - REACTOR FACILITIES

INTRODUCTION

An important factor in the evaluation of nuclear energy centers (NEC) is a comparison of the radiological impacts from NECs with dispersed reactor plants. To assist the U.S. Nuclear Regulatory Commission's (NRC) Office of Special Studies to make the comparison, Battelle, Pacific Northwest Laboratories, calculated radiation doses for several geometric arrangements of 40-reactor NECs and for one surrogate site.

NUCLEAR ENERGY CENTER SITES

Radiation doses were calculated for several different arrangements of 40 reactors within an NEC as well as for a surrogate site. In each instance the reactors were grouped into 10 four-unit "Quads" (see Figures 1 and 2).

- Circular array with spacing (chord length) between Quads varied from 1 to 2 miles and site radius from 2 to 6 miles.
- Circular site with all 40 reactors at the center with site radii of 3.4 and 4.9 miles.
- Rectangular (linear) array with all 10 Quads in a north-south line with spacing between Quads equal to spacing between site boundary to first Quad and varied between 1 to 2 miles.
- Surrogate (hypothetical) site with 10 Quads placed realistically on an actual location (Kentucky Lake).

For each of the first three siting arrangements doses were calculated assuming that all reactors were of one type: PWR or BWR. For the surrogate site the 10 Quads contained a total of 26 PWRs and 14 BWRs.

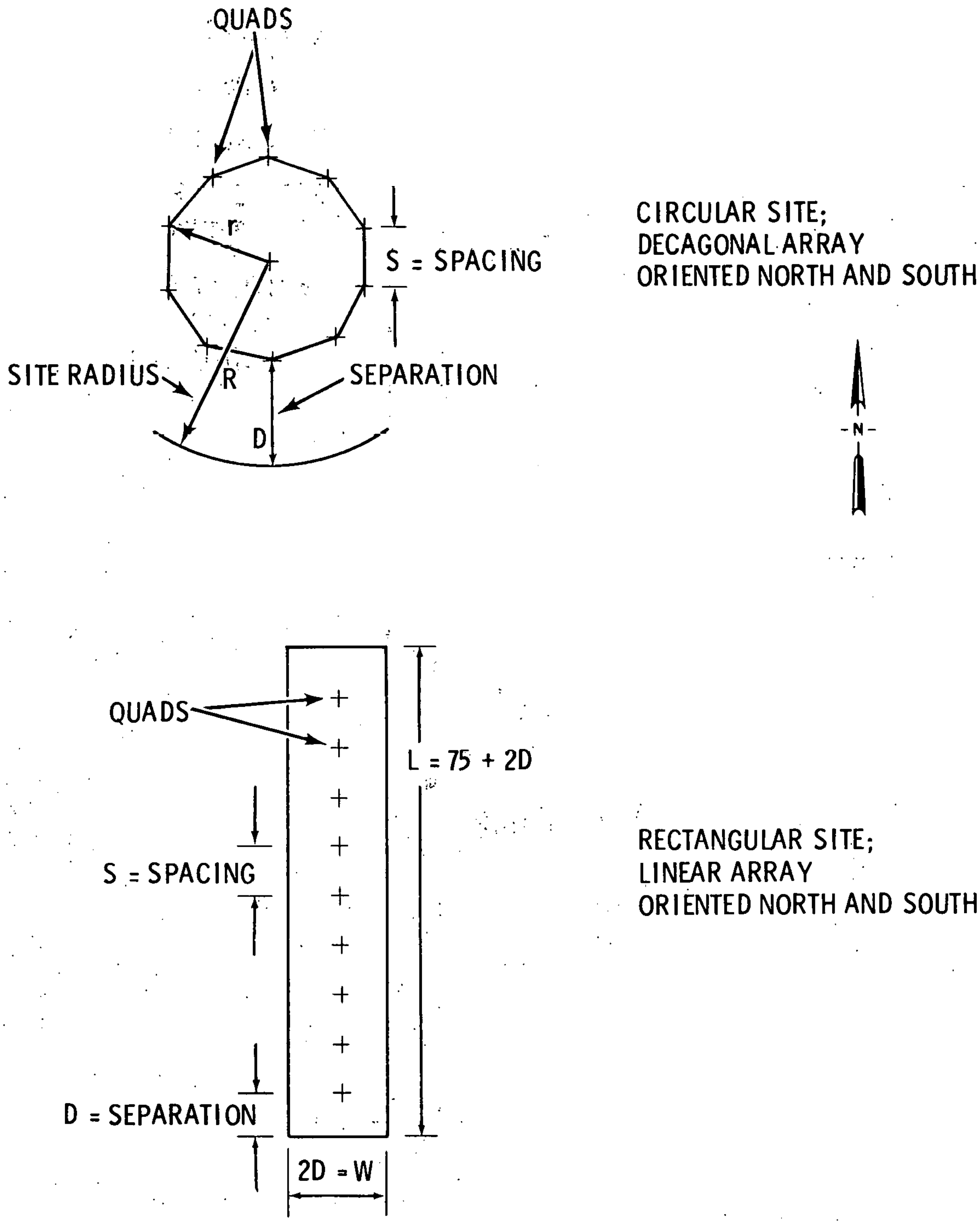

FIGURE 1. Generic Site Arrangements 40-Unit NEC

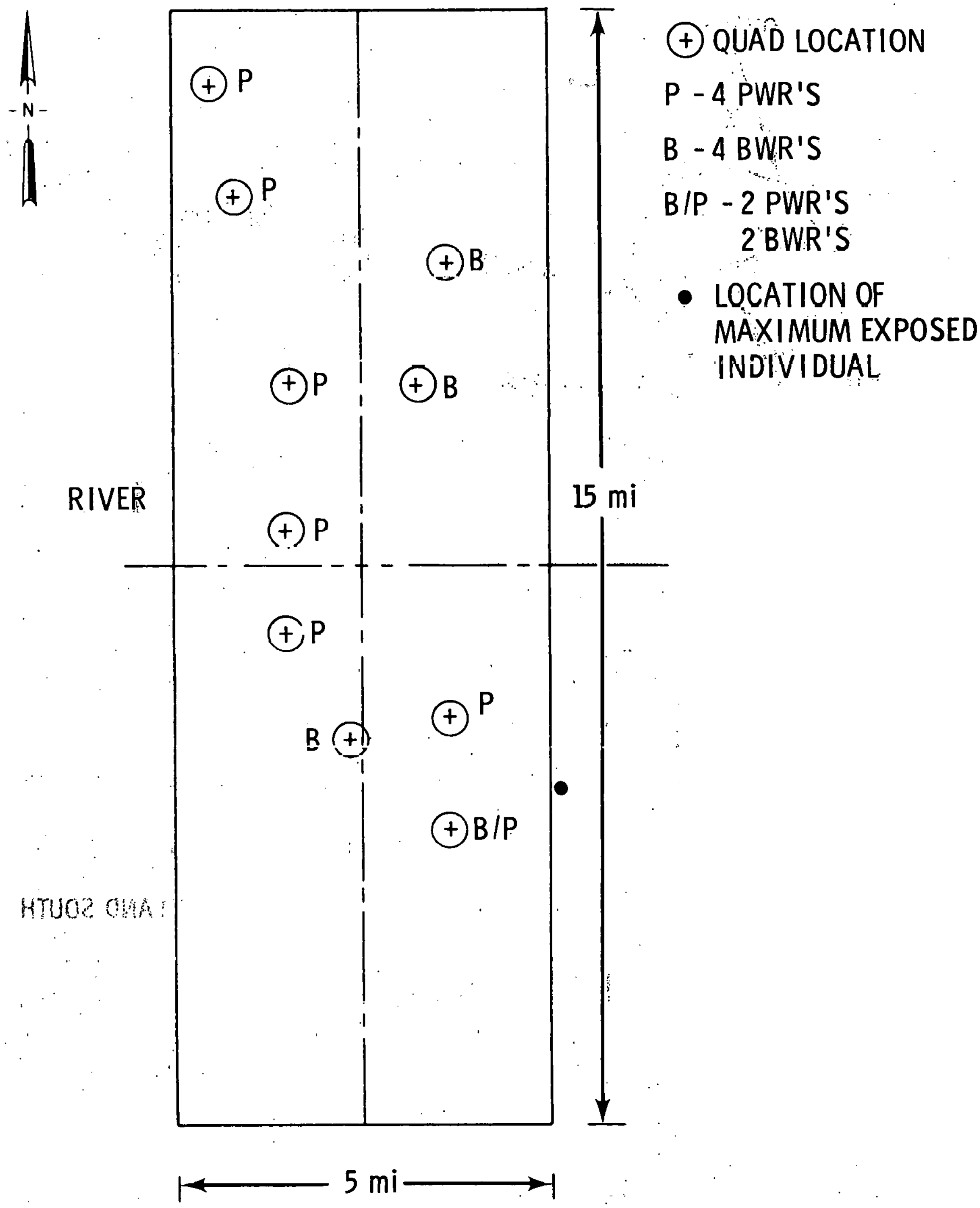

FIGURE 2. Kentucky Lake Surrogate Site Arrangement

METEOROLOGY

PNL used two sets of meteorology. The first set was from the Belafonte reactor site[1] with the wind directions rotated to match the prevailing winds at a "surrogate" (Kentucky Lake) site.[2] With this rotation the prevailing wind and the maximum atmospheric dispersion factor ($\overline{\chi}/Q'$) were in the southerly direction from the release points. The second meteorology site was the "river" meteorology from WASH-1258.[3] External dose calculations were made using the rotated Belafonte meteorology; external doses and thyroid doses were calculated from the river meteorology. A description of the entire dose calculation scheme, including the river meteorology, was given in a companion document, BNWL-B-456.[4]

A plot of annual average atmospheric dispersion factors ($\overline{\chi}/Q'$) from a vent release versus distance (along the average sector) for the river site is given in Figure 3. Table 1 lists the relative value of $\overline{\chi}/Q'$ in sectors other than the average, arranged so that the maximum value of 2.5 times the average lies in the southerly direction.

TABLE 1. Relative Atmospheric Dispersion Factors Versus Direction

Direction from Facility	Relative $\overline{\chi}/Q'$
N	0.55
NNE	0.60
NE	0.65
ENE	0.70
E	0.75
ESE	1.0
SE	1.3
SSE	1.5
S	2.5 (maximum)
SSW	1.5
SW	1.3
WSW	1.0
W	0.75
WNW	0.70
NW	0.65
NNW	0.60
Average	1.0

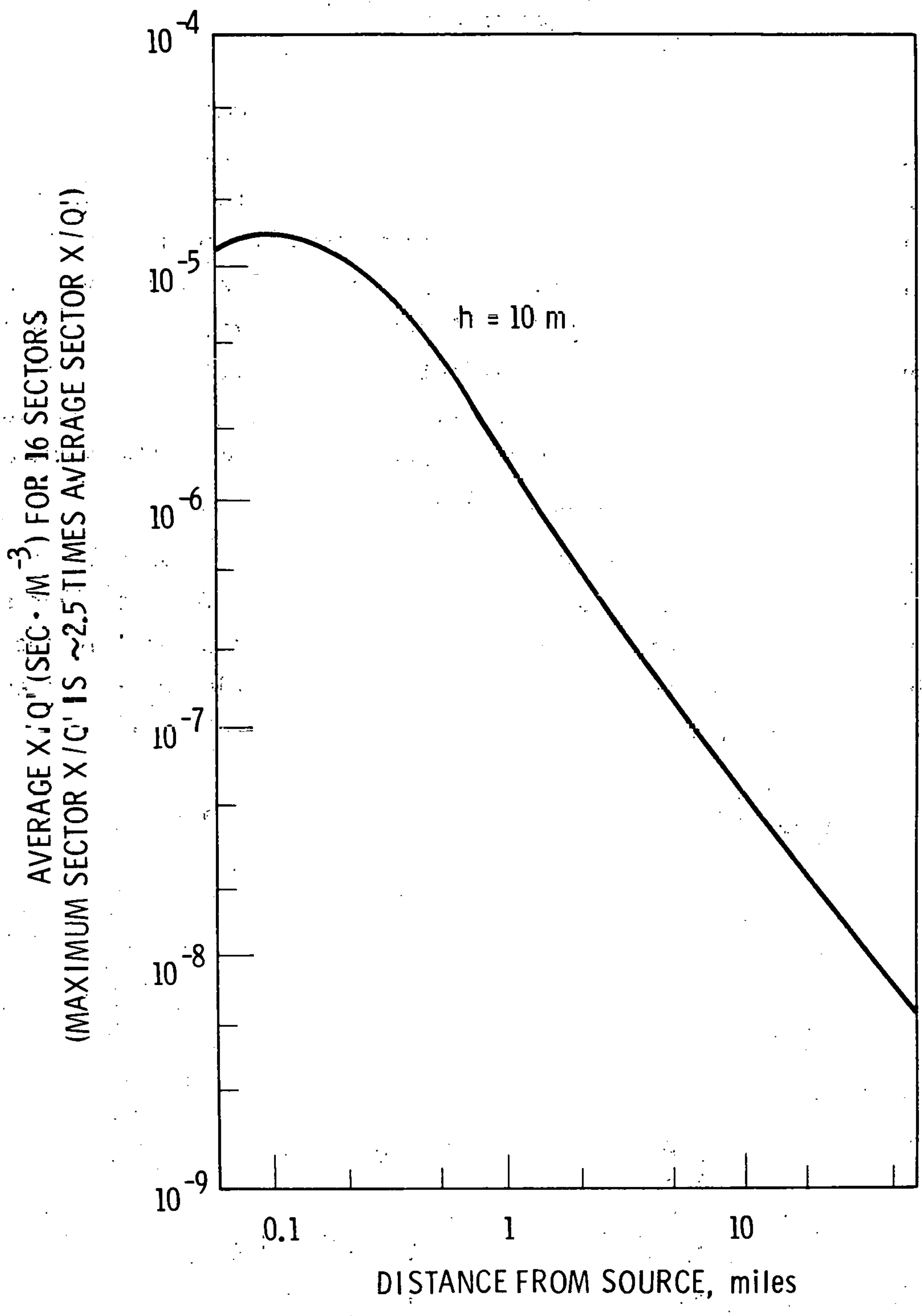

FIGURE 3. Atmospheric Dispersion - "River Site" (After Figure 6B-1, pp. 6B-43, WASH-1258)(3)

DOSE CALCULATIONS

For the first three types of sites the principal item of interest was how the external dose to the maximally exposed individual varied with reactor type (PWR or BWR), reactor spacing and site dimensions. For the surrogate site doses were calculated for all significant airborne exposure pathways to both the maximum individual at the site boundary and the population out to 50 miles.

When the reactors were of all one type, the summation of the atmospheric dispersion factors from each of the 40 sources could be used with the quantities of radionuclides released from one unit to calculate doses to the maximum individual or the population.

The Quads for the surrogate site had different release rates, depending on whether they contained four PWRs, four BWRs or two of each type of reactor. For this site a computer program, MUSIC, was developed which permitted siting the reactor Quads and the exposure persons on a grid and calculating the direction and distance between each Quad and the person exposed. The distance information was then used to address a curve fit to Figure 3 and then the direction was used to find the appropriate ratio from Table 1. Once the ($\overline{\chi}/Q'$) was defined for a Quad, the dose from that Quad was calculated and stored both as dose versus radionuclide and total.

After dose calculations for all 10 Quads were completed, the program summed up the total doses from all 10 Quads for each nuclide and the grand total dose. The program also calculated the summation of all ten $\overline{\chi}/Q'$ values to assist in selection of the probable location of maximum exposure (The program MUSIC is further described in Appendix A.)

GASEOUS EFFLUENT RELEASES

The radionuclides released with the gaseous effluents from a NEC were defined by NRC and are listed in Table 2. No releases of ^{3}H or ^{14}C were specified in this original list. These two nuclides were added later and a separate dose calculation performed (see section "Doses from ^{3}H and ^{14}C" for further detail).

TABLE 2. Radionuclides Released with Gaseous Effluents at the NEC (Ci/yr)

Nuclide	Ci/yr/Unit BWR	Ci/yr/Unit PWR	Ci/yr for 40 Units At Reference Site[a]
Kr-83M	8.4	2.4	1.8(+2)
Kr-85M	1.3(+2)	1.4(+1)	2.2(+3)
Kr-85	8.3(+2)	1.0(+3)	1.87(+3)
Kr-87	4.3(+1)	7.2	7.9(+2)
Kr-88	5.3(+1)	2.4(+1)	1.4(+3)
Kr-89	1.9(+2)	---	2.7(+3)
Xe-131M	5.8 (+1)	6.7(+1)	2.6(+3)
Xe-133M	---	2.9(+1)	7.5(+2)
Xe-133	3.8(+3)	2.8(+3)	1.3(+5)
Xe-135M	6.0(+1)	1.2	8.7(+2)
Xe-135	4.9(+2)	4.1(+1)	7.9(+3)
Xe-137	3.1(+2)	1.2	4.4(+3)
Xe-138	2.4(+2)	6.0	3.5(+3)
I-131	5.8(-2)	5.8(-2)	2.3
I-133	4.1(-2)	4.1(-2)	1.6
TOTAL	6,200	4,000	191,000

(a) Total released from 14 BWRs and 26 PWRs.

DOSE CONVERSION FACTORS

The factors for converting air concentrations of various radionuclides to radiation dose are listed in Tables 3 and 4 along with those originally used by NRC for similar dose calculations.

TABLE 3. Comparison of Radiation Dose Factors for External Exposure (mrem/yr per pCi/m^3)[a]

	Total Body		Skin	
Nuclide	BNW	NRC[5]	BNW	NRC[a]
^{83M}Kr	8.77E-7	1.21E-5	3.59E-5	1.93E-5
^{85M}Kr	1.14E-3	1.17E-3	2.81E-3	2.69E-3
^{85}Kr	1.93E-5	1.61E-5	1.40E-3	1.36E-3
^{87}Kr	1.14E-2	5.92E-3	2.37E-2	1.59E-2
^{88}Kr	1.84E-2[b]	1.47E-2	4.12E-2[b]	1.76E-2
^{89}Kr	1.96E-2	1.66E-2	3.30E-2	2.74E-2
^{131M}Xe	1.40E-4	9.15E-5	6.22E-4	6.32E-4
^{133M}Xe	3.59E-4	2.51E-4	1.31E-3	1.32E-3
^{133}Xe	2.19E-4	2.94E-4	6.05E-4	6.59E-4
^{135M}Xe	3.07E-3	3.12E-3	4.38E-3	4.07E-3
^{135}Xe	1.84E-3	1.81E-3	4.30E-3	3.78E-3
^{137}Xe	1.05E-3	1.4 E-3	1.58E-2	1.38E-2
^{138}Xe	2.63E-2[c]	8.83E-3	4.21E-2[c]	1.33E-2

(a) Exposed 24 hr/day, 365 day/yr
(b) Includes radiations from ^{88}Rb daughter
(c) Includes radiations from ^{138}Cs daughter

Except for ^{83M}Kr there are no significant differences between the dose factors for noble gases from air submersion.[a]

At the suggestion of NRC personnel, PNL used the radioiodine dose factors from Regulatory Guide 1.42, REV 1, March 1974,[5] as shown in Table 4. The values used by the Radiological Assessment Branch (RAB) in similar

(a) Later recalculation of the air submersion dose factors by PNL has reduced the differences even further except for the ^{83M}Kr skin dose factor.

TABLE 4. Comparison of Thyroid Dose Conversion Factors (mrem/yr per pCi/m^3)

Pathways	Nuclide	Adult: Regulatory Guide(a)	Adult: NRC(b)	Child: Regulatory Guide(a)	Child: NRC(b)
Inhalation(c)	I-131	13	10	15	15
	I-133	3.1	2.5	3.8	3.8
Milk(d):					
Cow	I-131	400	---	3,630	3,630
	I-133	16	---	67	67
Goat	I-131	---	---	18,300	18,300
	I-133	---	---	340	340
Vegetables	I-131	49(e)	10	---	---
	I-133	2.0	0.35	---	---

(a) From Regulatory Guide 1.42, March 1974,[5] and used in the calculations performed by BNW.
(b) Listed in Reference 6. Basis not given; might include 50% reduction for losses in preparation and average diet of 7.5 kg/3 months
(c) Breathing rate 3.0 m^3/day child, 20 m^3/day adult.
(d) 12 months' grazing season; 1 ℓ/day of cow's milk, 0.7 ℓ/day of goat's milk.
(e) Based on Maximum Individual consumption of 18 kg of vegetables over a 3-month period.

calculations are shown for comparison. The reasons for the small differences in adult inhalation dose factors or for the large differences in adult vegetation ingestion dose factors are not known. It is possible that the NRC vegetation values were for an average adult diet and might include factors for radioactive decay and/or losses in home preparation.

EFFECT OF REACTOR SITING ON OFFSITE DOSE COMMITMENT

The annual radiation doses to the total body of a maximally exposed individual from noble gases were calculated for various linear and circular site arrangements using the release rates listed in Table 2 and the dose factors listed in Table 3; the parameters related to site arrangement were defined in Figure 1. The results for the various sets of calculations are presented in Table 5 through 8.

In addition to the total-body dose calculations, the thyroid dose to a 1-yr old infant consuming milk produced at various distances from a single reactor was calculated. The release rates were 0.058 Ci/yr ^{131}I and 0.051 Ci per year ^{133}I and, again, the dose factors used were those given in Table 4. Iodine depletion factors versus distances were taken from Regulatory Guide 1.42.[5] The results are listed in Table 9.

TABLE 5. Total-Body Dose Rates at Various Distances from a Single Cluster of Power Reactors in the Direction of Maximum Atmospheric Dispersion[a] (mrem/yr)[b]

Number of Reactors	Distance from Source (miles)						
	0.5	1.0	2.0	3.0	4.0	5.0	7.5
				PWRs Only			
1	0.538	0.176	0.054	0.028	0.018	0.013	0.007
4	2.15	0.70	0.217	0.111	0.070	0.050	0.027
40	21.51	7.05	2.166	1.109	0.702	0.499	0.273
				BWRs Only			
1	4.60	1.15	0.249	0.101	0.055	0.035	0.017
4	18.39	4.58	1.00	0.40	0.22	0.14	0.069
40	183.87	45.84	9.98	4.04	2.19	1.41	0.69

(a) Using river site meteorology from WASH-1258[3] this is the southerly direction.
(b) Dose from submersion in plume of noble gases calculated from release rates in Table 2 and dose factors in Table 3.

TABLE 6. Total-Body Dose Rates for Various Site Dimensions of a Linear Array of 40 Power Reactors (mrem/yr)[a]

Distance (D) from Site Boundary(mi.) to Nearest Quad	PWRs Only: Case 1 Quad Spacing S=1 mile	PWRs Only: Case 2 Quad Spacing S=1.5 miles	PWRs Only: Case 3 Quad Spacing S= 2 miles	BWRs Only: Case 1 Quad Spacing S=1 mile	BWRs Only: Case 2 Quad Spacing S=1.5 miles	BWRs Only: Case 3 Quad Spacing S=2 miles
0.5	2.95	2.62	2.47	21.7	20.1	19.4
1.0	1.29	1.08	0.97	6.68	5.79	5.38
2.0	0.60	0.48	0.42	2.14	1.74	1.53
3.0	0.39	0.32	0.27	1.17	0.94	0.81
4.0	0.29	0.24	0.20	0.80	0.64	0.55
5.0	0.23	0.19	0.17	0.60	0.49	0.42
(At Site Center)	(3.41)	(1.80)	(1.12)	(26.0)	(11.7)	(6.42)

(a) Dose from submersion in plume of noble gases calculated using release rates in Table 2 and dose factors in Table 3.

TABLE 7. Total-Body Dose Rates for Various Dimensions of a Circular Array[a] of 40 Power Reactors (mrem/yr)[b]

Distance(D) to Nearest Quad	PWRs Only: Case 1 Quad Spacing S=1 Mile	PWRs Only: Case 2 Quad Spacing S=1.5 Miles	PWRs Only: Case 3 Quad Spacing S=2 Miles	BWRs Only: Case 1 Quad Spacing S=1 Mile	BWRs Only: Case 2 Quad Spacing S=1.5 Miles	BWRs Only: Case 3 Quad Spacing S= 2 Miles
0.5	3.19	2.75	2.51	23.48	20.87	19.66
1.0	1.44	1.18	1.04	7.74	6.38	5.73
2.0	0.74	0.57	0.46	2.78	2.14	1.74
3.0	0.47	0.39	0.32	1.46	1.20	0.99
4.0	0.33	0.29	0.25	0.94	0.79	0.69
5.0	0.29	0.22	0.20	0.78	0.59	0.52
7.5	0.21	0.16	0.13	0.52	0.40	0.31
(At Site Center)[c]	(1.39)	(0.70)	(0.44)	(7.37)	(2.97)	(1.57)

(a) Oriented north and south.
(b) Dose from submersion in plume of noble gases calculated using release rates in *Table 2 and dose factors in Table 3.*
(c) Distance from site center to nearest Quad is radius(r) of array. For Case 1, r=1.62 miles; for Case 2, r=2.43 miles; for Case 3, r=3.24 miles. Site radius (R) equals radius (r) of array plus distance (D) to nearest Quad.

TABLE 8. Total-Body Dose Rates for Various Dimensions of a Circular Array[a] of 40 Power Reactors (mrem/yr)[b]

Site Radius (R) (miles)	Case 1 Quad Spacing S=1 mile	Case 2 Quad Spacing S=1.5 miles	Case 3 Quad Spacing S=2 miles	Distance (D) to Nearest Quad (miles) Case 1	Case 2	Case 3
			PWRs ONLY			
2.0	2.06	----	----	0.68	----	----
2.8	----	1.08	----	----	0.90	----
3.0	0.89	----	----	1.5	1.0	----
3.6	----	----	0.70	2.1	1.5	1.1
4.0	0.51	0.58	0.66	2.5	1.9	1.4
5.0	0.42	0.38	0.42	3.5	2.8	2.2
6.0	----	----	0.30	4.5	3.8	3.1
7.5	0.28	0.23	----	6.0	5.3	4.6
8.0	----	----	0.18	6.3	5.8	5.1
(At Site Center)	(1.18)	(0.60)	(0.37)	r =(1.62)	(2.43)	(3.24)
			BWRs ONLY			
2.0	13.2	----	----	0.68	----	----
2.8	----	6.00	----	----	0.90	----
3.0	3.85	----	----	1.5	1.0	----
3.6	----	----	3.56	2.1	1.5	1.1
4.0	1.73	2.27	3.06	2.5	1.9	1.4
5.0	1.26	1.20	1.54	3.5	2.8	2.2
6.0	----	----	0.90	4.5	3.8	3.1
7.5	0.60	0.59	----	6.0	5.3	4.6
8.0	----	----	0.46	6.3	5.8	5.1
(At Site Center)	(6.09)	(2.45)	(1.30)	r =(1.62)	(2.43)	(3.24)

(a) Oriented east-west; for this orientation formula in footnote "c" in Table 7 does not apply.
(b) Dose from submersion in plume of noble gases calculated from release rates in Table 2 and dose factors in Table 3.

TABLE 9. Infant Thyroid Dose Rate Versus Distance from a Single Reactor in the Maximum (South) Sector (mrem/yr)

Distance (miles)	Depletion Factor	Thyroid Dose Rate[a]
0.5	0.967	77
1.0	0.936	26
2.0	0.880	8.0
3.0	0.832	4.1
4.0	0.790	2.6
5.0	0.752	1.8
7.5	0.677	0.94

(a) Doses were calculated using release rates of ^{131}I and ^{133}I given in Table 2, dose factors given in Table 4 and iodine depletion factors from Regulatory Guide 1.42.[5]

SURROGATE (KENTUCKY LAKE) SITE

Dose calculations were performed for the maximally exposed individual at the site boundary of the NECSS-75 "surrogate" Kentucky Lake site (Figure 2). External doses to skin and total body from air submersion, and thyroid doses from inhalation and ingestion were calculated for the infant and the adult. Two locations were chosen: 1) one on the center of the southern boundary (the direction of the prevailing wind), and 2) one on the southern part of the eastern boundary where the highest air concentrations actually occur. The results of these calculations are summarized in Table 10.

Total doses (man-rem/yr) to the population of 3.5×10^6 persons assumed to live within 50 miles of the surrogate site were also calculated for the same pathways. The results are listed in Table 11. The average per capita dose rate obtained by dividing the total man-rem values by the total population are also listed in Table 11.

TABLE 10. Maximum Individual Dose Rates at Site Boundary of Surrogate (Kentucky Lake) Site (mrem/yr)[a]

Organ	Pathway	South[b] Child	South[b] Adult	Southeast[c] Child	Southeast[c] Adult
Skin	Plume	1.2	1.2	2.1	2.1
Total Body	Plume	0.36	0.36	0.67	0.67
Thyroid	Plume	(0.36)[d]	(0.36)	(0.67)	(0.67)
Thyroid	Diet	55.3	7.66	86.4	12.0
Thyroid	Inhalation	0.3	0.22	0.4	0.3
Thyroid	Total	56	8.2	87	13

(a) Dose rates calculated from release rates in Table 2 and dose factors in Tables 3 and 4.
(b) South sector at site boundary.
(c) Southeast sector - highest χ/X' at site boundary.
(d) ( ) indicates internal dose from external exposure.

TABLE 11. Dose Rates to the Population at a Hypothetical Site with 40 Reactors at the Center[a,b]

Nuclides	Population Dose Rate (man-rem/yr)			Average Dose Rate Per Person (mrem/yr)		
	Skin	Total Body	Thyroid[c]	Skin	Total Body	Thyroid[c]
Noble Gases	190	72	72	0.05	0.02	0.02
I-131	---	---	318	---	---	0.09
I-133	---	---	6.7	---	---	0.002
TOTAL	190	72	400	0.05	0.02	0.11

(a) Doses calculated from release rates in Table 2 and dose factors in Tables 3 and 4.

(b) Circular site with a 5-mile radius with 3.5×10^6 people within 50 miles.

(c) Including cloud depletion factor of 0.5 and doses from diet and inhalation.

DOSES FROM ^{3}H AND ^{14}C

In addition to the radiation doses previously discussed the NRC requested that PNL calculate doses to the maximally exposed individual and to the 50-mile population from release of ^{3}H and ^{14}C to the air at the surrogate NEC site. The release rates specified by NRC and the calculated maximum offsite air concentrations are given in Table 12.

TABLE 12. Release Rates and Maximum Offsite Air Concentrations of ^{3}H and ^{14}C at the 40-Reactor Surrogate NEC Site, (Ci/yr)

Nuclide	Ci/yr			pCi/m^3 (b)
	PWR	BWR	NEC (a)	
H-3	1100	43	29,200	317
C-14	8	9	234	3.38

(a) Total from 26 PWRs plus 14 BWRs

(b) Maximum concentration at the site boundary occurs in a southeast direction from the site center.

The dietary assumptions used to calculate the doses are listed in Table 13. The breathing rate assumed for calculations of inhalation dose was 20 m^3/day. For total population (man-rem) dose, 3.5 x 10^6 persons were assumed to reside within 50 miles of the site.

The dose calculations involved the assumption of instantaneous mixing of the ^{3}H and ^{14}C with the stable elements H and C in the atmosphere around the site. The concentrations of stable elements were based on average air concentrations of 8 ml H_2O/m^3 air and 320 ppm CO_2. The resulting specific activities of ^{3}H and ^{14}C in air were then assumed to occur in the first portion of the human food chain, i.e., plant material. The total radionuclide intake by man and animals was then calculated on the basis of the concentrations in plants.

TABLE 13. Exposure Assumptions Used in Calculating Radiation Doses to the Average Individual at the NEC Surrogate Site

Food Pathway

Food	Consumption (kg/yr)[a]	Fraction Locally Produced
Leafy Vegetables	30	0.5
Other Above Ground Vegetables	23	0.5
Potatoes	65	0.5
Root Vegetables	11	0.5
Berries	3.9	0.5
Melons	5.2	0.5
Orchard Fruit	33	0.5
Wheat	47	0.5
Other Grain	12	0.5
Milk	100	9/12 (grazing season)
Beef	40	1.0
Pork	40	1.0
Poultry	20	1.0

(a) The leafy vegetables and milk categories are those selected by the NRC; the other categories were derived from NRC diet by prorating 200 kg/yr of fruits and other vegetables into the eight categories shown and 100 kg/yr of meat into the three categories shown.

Doses calculated for the bone and total body of a maximally exposed person at the site boundary and for the 50-mile population are listed in Table 14. The doses to other internal organs, such as thyroid, liver, kidney, lung and GI tract, were not listed in the table, since they are identical to those shown for the total body.

The individual doses from ^{3}H and ^{14}C are about one-half to two-thirds of those previously calculated by RAB/NRC, principally because of the differences in the meteorology data employed.

TABLE 14. 50-Year Dose Commitment from ^3H and ^{14}C Released to the Atmosphere at the 40 Reactor NEC Surrogate Site

Nuclide	Pathway	Total Body[a]	Bone
	Average Individual at Site Boundary, mrem		
^3H	Inhalation[c]	0.50	----
	Diet	0.77	----
	TOTAL	1.3	----
^{14}C	Inhalation[c]	0.010	0.047
	Diet	4.1	18.0
	TOTAL	4.1	18.0
	Population Within 50 Miles, man-rem[b]		
^3H	Inhalation[c]	80	----
	Diet	120	----
	TOTAL	200	----
^{14}C	Inhalation[c]	1.8	8.3
	Diet	725	3180
	TOTAL	730	3190

(a) Based on NRC average diets.

(b) Assuming $3.5x10^6$ people live within 50 miles of the surrogate site.

(c) Includes transpiration.

APPENDIX A

DETAILED EXPLANATION OF MUSIC

APPENDIX A

DETAILED EXPLANATION OF MUSIC

A program, MUSIC, was written in the Computer Sciences Corporation's BASIC interactive computer language for operation on an IBM 1108 computer to facilitate calculation of composite radiation doses from multiple sources of gaseous effluents with identical meteorology. The program uses an x-y grid coordinate system for reactor location and points of interest (e.g., maximum individual, site boundary, etc).

Input coordinates for a specific point are requested from the user by the program which then calculates the distance, atmospheric dispersion factor ($\overline{\chi}/Q'$) and dose from all sources to the point specified. The distance is calculated from

$$d_i = [(x_o - x_i)^2 + (y_o - y_i)^2]^{1/2}$$

where:

d_i is the distance between the i^{th} source location and the point of exposure,

x_o, y_o are the x and y coordinates of the point of exposure, and

x_i, y_i are the x and y coordinates of source location i.

The value of $\overline{\chi}/Q'$ is then calculated using the distance as an input value into an exponential polynomial fit of the χ/Q, given in Figure 3, and taken from WASH-1258[(3)] for a river site.

Direction is then determined by:

$$\theta = \arctan \frac{y_o - y_i}{x_o - x_i}$$

where

θ is the principal angle between the east/west direction and the line between the points o and i.

The relationship of θ to compass direction is determined from program logic by examination of the algebraic signs on both Δx and Δy and the magnitude of θ. The relative dispersion factors listed in Table 1 are then matched to the compass direction. Multiplication of the relative dispersion factor times the average annual atmospheric dispersion factor calculated from the distance yields a value of $\overline{\chi}/Q'$ which is specific for the particular source point (x_i,y_i) and exposure point (x_o,y_o).

Using this specific value of $\overline{\chi}/Q'$ and the effluent release data (previously input), the program calculates the external radiation doses to skin and total body at the point of exposure from an internal data file of dose factors. The calculated doses from each nuclide released are stored separately as is the total dose from all nuclides released at that specific source.

The program proceeds to the next source where the procedure is repeated. After all source locations have been addressed, the accumulated dose per nuclide from all sources combined is output as is the total dose from all sources at the site. A diagram of the data flow for the program is given in Figure A-1.

TASK 2.1.1.1 EMERGENCY RESPONSE
CAPABILITY (NUCLEAR ENERGY CENTERS)

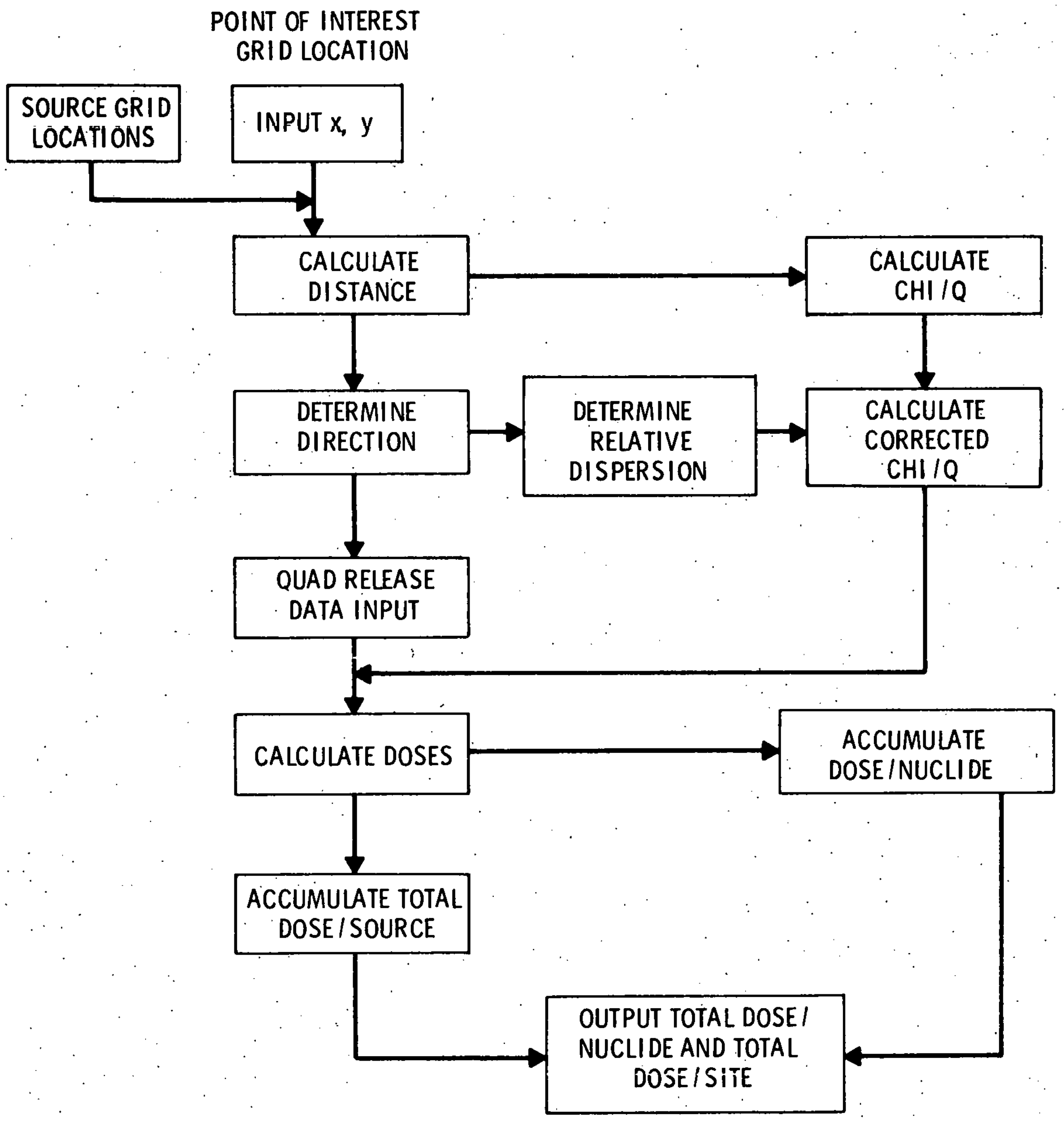

FIGURE A-1. Data Flow for MUSIC

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TASK 2.1.11

EMERGENCY RESPONSE CAPABILITY (NUCLEAR ENERGY CENTERS)

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CONTENTS FOR TASK 2.1.11

TASK 2.1.11

EMERGENCY RESPONSE CAPABILITY (NUCLEAR ENERGY CENTERS)

INTRODUCTION

One aspect in the evaluation of dispersed reactor siting and nuclear energy center (NEC) siting is their response to emergencies. Emergencies might range from very serious power plant accidents to more routine needs for ambulance or fire service. For this report the emergency response capability is primarily evaluated for the former, which is defined to include a radiological risk to the health and safety of a nearby population during the first hours following a very serious accident. Such an accident will require the evacuation of the nearby population (or a portion of it) since this is the most effective protective measure for the general public.[1,2] Thus, the comparative evaluation weighs heavily on the relative ability of the two concepts to respond to emergency evacuations.

There are several factors that can be evaluated to give a measure of this effectiveness. These factors include:

- Site Factor - Site area, population distribution, and availability of specialized manpower are aspects of this factor.
- Radiological Factor - Offsite radiation monitoring capability and availability of health physics personnel are aspects of this factor.
- Meteorological Factor - A key aspect in an emergency evacuation of the public is predicting the likely path of the radioactive plume that would be emitted in the assumed accident. This in turn depends heavily on the availability of meteorological information, codes, and skilled personnel.
- Related Services Factor - Fire protection, dosimetry, medical, and ambulance services are aspects of this factor.

The comparison of emergency response capability is based on one NEC containing 40 reactors versus ten Quads of four reactors each. It is assumed that the same amount of funds are allocated to the two cases for emergency response capability purposes. Further, the assumption is made that evacuation of the public may be required and is a prime factor of concern in the assessment of emergency response capability factors. The basic resources projected for the NEC are estimated to be available at no additional cost per facility. No projections of savings is considered.

SUMMARY AND CONCLUSIONS

A summary of the advantages and disadvantages of the NEC case when compared to the dispersed case (Base Case) for each of the four general factors is listed in Table 1.

TABLE 1. Advantages and Disadvantages of the NEC

Advantages	Disadvantages
SITE RELATED FACTORS	
Site Area	
Population located farther from reactors	None
Population dose in accident reduced	
Population and Individual Risk	
Lower total population at risk	Greater individual risk for nearby residents
Better information to public	Construction force onsite for longer period of time
Fewer required sites may permit lower population density	
Emergency Plans	
More comprehensive plan	None
More comprehensive practice exercises	
Less total governmental agencies involved	
More training possible	
Communications	
None	None
Manpower	
Substantial numbers of additional trained emergency team members	None
Additional health physics personnel	
Large total operations force	
RADIOLOGICAL FACTORS	
Event Detection	
None	None

(Effluent monitoring and in-plant area monitoring instrumentation would be no different in the two cases)

TABLE 1. (contd)

Advantages	Disadvantages
RADIOLOGICAL FACTORS (contd)	
Environs	
Monitoring instrumentation both onsite and offsite could provide better information at the NEC	None
Health physics personnel from other reactors at the NEC could be of substantial aid in coping with an emergency	
METEOROLOGICAL	
Onsite meteorological specialists	None
Minicomputer data analysis	
Improved description of plume location at distance beyond 5 miles	
RELATED SERVICES	
Fire Protection	
Onsite professional industrial fire protection service	None
Probable more rapid response	
Dosimetry Services	
Additional professional personnel specializing in environmental analysis	None
Additional instrumentation for backup of emergency events	
Rapid internal and external occupational dose assessment	
MEDICAL SERVICE	
Assigned full-time industrial physicians	None
Fewer total offsite hospital and medical personnel involved	
AMBULANCE SERVICE	
None	None

(In-plant ambulance service would improve response for operational personnel but have no effect on general population)

The four general factors examined for emergency response capability affecting the general public residing near power reactor sites are all found to favor the NEC case when compared to the dispersed case (an equivalent number of reactors in dispersed Quad sites). The two cases examined are rated equal in terms of communications, ambulance service, and event or accident detection. There does appear to be some disadvantage to the NEC case in terms of greater risk for individuals residing near NECs and the long-term presence of a construction work force. However, this is not considered to be a major problem in emergency response. All other factors examined show an advantage to the NEC case. It appears that the promptness and effectiveness of the emergency response could be judged significantly greater in the NEC case than in the dispersed case.

As previously discussed, evacuation of the population was singled out as a prime factor for mitigating accident consequences to the population residing near a nuclear site. The emergency response evacuation capability of an NEC when compared to the dispersed case are as follows:

- The larger site area of the NEC tends to provide greater distance to the population permitting more time before evacuation, fewer numbers evacuated, lower probable total dose.
- The smaller number of NEC sites may permit location in areas of lower population density permitting superior evacuation information dissemination.
- Emergency plans at the NEC may: 1) be more comprehensive, 2) include more training, 3) have fewer agencies involved (lessening communications problems), and 4) more detailed practice exercises ensuring a more probable timely evacuation of the public when compared to ten dispersed sites.
- The availability of additional trained manpower at the NEC will tend to expedite evacuation.
- Radiological monitoring systems in the environs and additional health physics personnel at the NEC will tend to permit more rapid and exact delineation of the area requiring evacuation.
- Meteorological instrumentation and specialist availability at the NEC will tend to permit rapid evaluation of the area requiring initial evacuation and provide rapid updating as meteorological conditions change.

DESCRIPTION OF CASES

The Base Case is the four-reactor cluster (Quad), located at one site. This is the maximum number of power reactors currently in the licensing stage or being built at the single site. The relevant emergency response characteristics of the dispersed Quad site were characterized by examination of Preliminary Safety Analysis Reports and Final Safety Analysis Reports or other emergency plans for nine[3-9] power reactor sites: Hartsville, Trojan, Oconee 1, 2, and 3, Turkey Point, St. Lucie, Browns Ferry, Sequoyah, Dresden, and Quad Cities. The NEC is assumed to consist of ten four-reactor clusters located on a single site. The assumption developed for the Base Case and projected for the NEC are shown in Table 2.

TABLE 2. Assumptions for Comparison of Base Case and NEC

Assumption	Base Case	NEC
Reactor (number)	4	40
Capacity (MWe)	4,800	48,000
Site Area (mi^2)	1.5 → 5	75
Site Boundary (miles)	0.5 → 1.25	1.25
Operations Personnel	420	4,200
Emergency Staff	110	1,000
Meteorology		
Main Tower	1	1
Auxiliary Towers	1	20 - 24
Radiation Instrumentation		
Environs		
Air Monitors (telemetered)		
Onsite	2	20
Within 10 Miles	4	40
Remote (not telemetered)	2	20
TLDs		
Onsite	25	250
Offsite	3	30

COMPARISON OF CASES

The accident assumption is made that evacuation of the public may be required and is a prime factor of concern in the assessment of emergency response capability factors. This assumption must be considered when each factor in the two cases is compared.

The assumed Base Case is discussed initially for each emergency factor and then extrapolated in a linear fashion to the NEC for this assessment. Then the relative advantages or disadvantages for the two cases are pointed out. The Quad and NEC are compared, as are ten dispersed Quads and the NEC when considered pertinent to the evaluation.

SITE RELATED FACTORS

Site Area

The site area for the Base Case Quad is assumed to be 5 miles^2. The distance from the reactors to the site boundaries in the reactor sites varied from 0.5 to 1.25 miles; most sites had the shorter distance of 0.5 miles. The site with the maximum distance to the site boundary was the Carolina Power and Light Company four-reactor complex named Shearon Harris. Extrapolation to the 10-Quad NEC, with a reasonable spacing of Quads and the spacings considered part of a dedicated site, implies a site area of about 75 miles^2 with 1.25 miles the nearest distance to the site boundary for any Quad.

Emergency response effects related to the site area favor the NEC, since some of the reactors would be as far as 8 to 10 miles from the nearest population in an accident situation affecting the population near the site. The greater the distance to the population, more time would be available for emergency response actions at the NEC. In some instances the greater distance would require no action from the public since dispersion and deposition of a release could reduce the consequences. In any event the population dose could be substantially reduced for many of the 10 Quads located at an NEC.

The advantages and disadvantages of the site area for the NEC are:

- Advantages to NEC
  - Population located farther from reactors
  - Population dose in accident reduced
- Disadvantage to NEC
  - None

Population and Individual Risk

According to WASH-1400 (Rasmussen Report)[10] the cumulative population averaged for 66 sites is 11,000 at 5 miles; 49,000 at 10 miles; 228,000 at 20 miles; and 800,000 at 30 miles. Currently, licensing requires a low population zone around a reactor site with more dense population permitted at a distance. In actual practice among sites examined, the cumulative population varies by factors of 10^3 at 20 miles.

The ten dispersed sites would affect ten different population groups or approximately ten times the population around an NEC. Utilizing ten dispersed sites could result in somewhat less risk to a much larger population.

Considering the low probability of an accident involving the population (10^{-7} to 10^{-9}),[10] there would be little or no advantage in spreading the risk over a larger population. Considering emergency response, the smaller total population involved around an NEC could be an advantage in: 1) planning for possible evacuation, 2) informing the population of emergency procedures, and perhaps 3) involving the public in practice emergency exercises. Since there would be a limited number of NECs across the country, the NEC may possibly be sited in more remote areas of lower total population than a corresponding number of dispersed sites.

Based solely on the greater number of reactors present, individual risk or risk to a critical population could be ten times greater near an NEC than at a dispersed site. Vector analysis using distance to reactor, typical meteorology and wind speed indicate that the risk to an individual or critical population (see Appendix C) near the site boundary would be much less, perhaps 2.5 times greater for an NEC than for a Base Case site. Whatever the increased risk, it seems small when considering accidents with probabilities in the 10^{-7} to 10^{-9} range as suggested in WASH-1400[10] as accidents with population effects.

The construction force (thousands of people) present during building of the NEC may be considered part of the critical population. The construction force constitutes a disadvantage to the NEC in terms of possible effects during the initial emergency but the force would be available as manpower for recovery action. Evacuation of the construction force from the site would be rapid since the population is administratively organized and transportation will be readily available.

The advantages and disadvantages of the NEC concerning population and individual risk are:

- Advantages to NEC
  - Lower total population at risk
  - Possible better information to public
  - Fewer required sites may permit lower density population
- Disadvantages to NEC
  - Greater individual risk
  - Construction force onsite

Emergency Plans

Licensing regulations currently require formulation of comprehensive emergency plans for each reactor facility. The plans must be complete and must include all necessary written agreements for contracted services such as medical, ambulance, fire, and dosimetry. In addition, the plans must include the agreements with County, State, and Federal agencies that are actively involved in emergency response actions. These plans must contain a description of an organization that is established to cope with an emergency, including lines of authority, and the responsibilities and duties of various emergency team members. The specific plan for an NEC, which may involve more segments of local government, could be complex; however, some single power reactor sites also affect more than one state and county in each state. An advantage of the NEC compared to the dispersed site in execution of emergency plans is that only one plan is needed compared with ten plans for the equivalent dispersed sites. As a result:

- Some savings may be possible in development of the specific plans.
- Only one group of offsite local government and other services would be needed.
- Concentrated effort in emergency planning, exercises and training sessions at the NEC should clearly provide a substantially superior response if an accident occurs.

The NEC has a substantial advantage over the dispersed site in terms of emergency plan because of the possible emergency exercises and training sessions and fewer total people and governmental agencies involved.

Communications

Communication channels at a typical reactor are relatively complete. For example, onsite public address systems are used extensively and commercial and leased telephone services are used. Many facilities also employ company microwave telephone service and short-wave radio base stations are used along with portable sets. The "beeper" of a radiopaging system may also be used to alert key people. The NEC would have all of these systems and may have staff concerned specifically with communications. Communications between Quad sites at the NEC would be necessary in an emergency, adding another layer of communication effort. However, a significant advantage or disadvantage is not apparent for the NEC in terms of communications on the site.

A weakness in communications to the responsible State authorities appeared in most emergency plans that were examined. The telephone numbers of State officials and alternates are listed in all plans, but if telephone service is lost, no alternate communication channels are indicated.

If additional communications capability were desirable, the most logical method that could also increase quality of response, timeliness of response and redundancy in several other areas may be a remote control center that would be established for all facilities at the NEC. This remote control center would be used in addition to control centers required by each facility at the site and could be located at some point that is accessible to both facility and governmental agencies (perhaps at a county sheriff's office, state police, or some other local governmental or private location continuously manned). Redundant communications with all parties concerned with emergencies affecting offsite action would be established which could include radio links to state officials. No significant communications advantage or disadvantage is indicated for the NEC case.

Manpower

Based on analysis of emergency plans for several Quad reactor facilities, it is assumed that at a minimum the plant personnel listed in Table 3 would be trained to specifically cope with a radiological emergency at each Quad site. These personnel form the basic pool of human resource emergency response capability. The total operating force at each Quad is estimated to be about 400 (about 4,000 for an NEC). All of these personnel will receive some training in the emergency plan as a license condition; they would then form a pool of knowledgeable personnel from which additional support could be drawn.

TABLE 3. Minimum Trained Plant Personnel

Personnel	Minimum Number
Plant Management (Sr. Operator's License)	26
Health Physics Supervisors	2
Health Physics Technicians	11
Security Personnel	13
Plant Operators and Assistants	56

There is a clear advantage to the NEC both in the numbers of trained emergency team members and in the quality of the manpower. Off-shift senior people from the unaffected reactors would be readily available to assist during the emergency. However, the most important segment of manpower from other reactors at the NEC would be a cadre of qualified health physicists and health physics technicians; they could be of significant immediate help in coping with an emergency. With a well rehearsed emergency plan, these trained people could be expected to make proper evaluations rapidly and expedite necessary emergency actions.

The manpower advantages and disadvantages of a NEC are:

- Advantages to NEC
  - Substantial numbers of additional trained emergency team members
  - Additional health physics personnel
- Disadvantages to NEC
  - None

RADIOLOGICAL FACTORS

Event Detection

The process and effluent radiation monitoring systems furnish information to operations personnel on radiation levels in the principal plant process stream (both liquid and gaseous systems). These monitoring systems initiate operation of emergency systems, provide inputs to the reactor protection system, and record the rate of release of radioactive material to the environs. The gaseous effluents exhausting through stacks or ducts are monitored continuously with alarm and level readout at the control center in accordance with ANSI N13.10-1974.[11] This standard applies specifically to routine operations; the ranges for routine releases may not be sufficient to measure rates of release of upper limit accidents should they occur via stack releases.

There would be no change in process and effluent monitoring equipment at the NEC, thus no apparent advantage in the NEC over the dispersed Quad in terms of in-plant radiation monitoring instrumentation for event detection. It is also apparent that this instrumentation at all reactors could be improved by extending the measurement range.

The in-plant area radiation monitoring system is designed to provide radiation measurements, indicate trends, record information, and sound alarms in areas where radioactive materials may be present, stored, handled, or inadvertently introduced. These monitors, which are in compliance with applicable NRC regulations, detect abnormal conditions within the plant and function as an alarm system in cases of spillage of radioactive liquids and materials, pipe or tank leaks, or a general spread of high-level radiation into lower level areas. This system gives control room personnel indications of gamma radiation levels at selected locations within the plant buildings. In addition, local alarms are provided to warn personnel of substantial immediate changes in radiation levels.

The in-plant area monitoring system at the NEC would serve the same functions and there is no advantage or disadvantage in terms of emergency response.

Environs

The status of fixed radiological sampling or monitoring instrumentation in current and proposed power reactor site environs is less clear than for in-plant areas. A review of six power reactor emergency plans (Appendix A) for single, dual, or uad reactors showed no uniformity in type or location of radiological instrumentation. Some power reactor plans rely completely on portable radiation-dose measurement instruments and portable air samplers to determine dose rate and concentrations after an emergency event occurs. In several other cases as many as ten fixed stations are located within 10 miles of the reactor site, where a beta-gamma detector monitors an air particulate sample. This information is telemetered to the central control room and a secondary emergency center. In addition, some power reactors maintain several air sampling stations in the environs out to 50 miles from the reactor close to major population centers. A number of reactors also have a large number (40 to 50) of TLD (thermoluminescent dosimeter) packets located mostly onsite to integrate the dose in the environs. Such sites maintain a readout device and spare TLD packets for emergency use.

A reasonable assumption was made that the Quad reactor base would have at least half of the fixed instrumentation in the environs found in the survey. This number of instruments was then scaled by a factor of 10 for the NEC with ten Quads. The resulting 60 air particulate monitoring stations telemetering data to an NEC control center is probably more than needed but would certainly provide useful data during an emergency. Some of the stations could use dose rate monitoring devices to measure the noble gas contribution instead of particulates. The 250 TLD packets at an NEC are useful at short distances from each Quad to measure the integrated dose after or during cloud passage. In general a more complete monitoring program would be probable at the NEC with a better chance of getting telemetered information that could be related to the source term during an emergency. All of the stations would not be required initially, but the telemetering network and station location would have to consider the overall NEC development.

Portable instrumentation is stored for emergency use in the control center and at any alternate emergency control centers. The portable instruments are used to determine dose rate levels in the building and environs after an emergency. The additional portable instrumentation from other reactors could provide backup supplies during an emergency at the NEC.

At a completed NEC there would be a sizable group of health physics personnel quickly available to perform environmental monitoring functions. Mobile monitoring devices such as a 4 x 4 inch NaI detector and readout device maintained for emergency purposes could be used by car or small plane to more rapidly track the release. Also, a plane or helicopter is available to many power companies.

The advantages and disadvantages for the environs of an NEC are:

- Advantages
  - Monitoring instrumentation both onsite and offsite could provide better information at the NEC.
  - Health physics personnel from other reactors at the NEC could be of substantial aid in coping with an emergency.

- The emergency supply storage area from other reactors at an NEC could provide readily available backup portable instrumentation and supplies.

- No significant advantage or disadvantage
  - Effluent monitoring and in-plant area monitoring instrumentation would be no different for the two cases.

METEOROLOGY

Each dispersed reactor site is assumed to consist of one Quad, and each site is served by one meteorological system, thus meeting the requirements of Regulatory Guide 1.23. The meteorological cost for a dispersed Quad site with an expected life of 20 years is about $34,000/year (see Appendix B). Assuming that expenditures at the NEC site would total the expenditure at all the dispersed Quad sites replaced, a more comprehensive meteorological network and program could be installed. Half of the Quads in the dispersed case were assumed to have a main tower and an auxiliary tower, while the other half will have only a main tower. Collectively, these facilities represent a total annualized investment of approximately $300,000 to $350,000/year; this resource is estimated to adequately establish, maintain and operate 20 to 24 telemetering wind stations on 100- and 200-ft towers and a 500-ft base station tower. In addition to these facilities, it is anticipated that remote sounding methods to describe wind directions at higher elevations could be supported.

These data could be fed to an onsite or offsite computer facility, which could make detailed calculations of plume diffusion and transport; these could be displayed at the emergency control center. The additional resources available to the NEC could also support full-time onsite meteorological specialists to provide local emergency forecasts. Dispersed facilities would have to depend on routine National Weather Services forecasts which will vary in their applicability to each site and its specific needs.

Generally, single onsite micrometeorological tower measurements are considered representative for the purposes of short-term plume description out to distances of 3 to 5 miles. This range, however, is qualitative and quite sensitive to specific site topography and meteorological conditions. Under certain conditions, measurements from a single tower might apply only over a few hundred yards, whereas under favorable conditions the diffusion and transport parameters may be the same over tens of miles. This indicates that the 20 to 24 outlying wind towers should all be located within a radius of 10 miles in a complex topographic situation or several tens of miles in a plain. On the average, it is expected that 20 to 24 stations would have to be distributed within about 25 to 30 miles of an NEC to adequately describe plume transport in the event of an accidental release to the air.

Although it is not possible to quantify the response improvement, the reallocation of resources with an NEC to provide 20 to 24 outlying wind stations could significantly reduce the consequences of an accidental release. This reduction would not improve in terms of speed, but through improved accuracy and detail of information in the outlying area (5 to 30 miles). In the close areas (3 to 5 miles), the meteorological factors will not significantly improve timeliness. Only minimal improved accuracy and detail over that possible for the dispersed Quads will occur. The improvements would be due primarily to the data handling and display conveniences and not significantly from the presence of the outlying station data.

Although a conclusive quantitative evaluation could not be presented, we expect that the additional resources available at an NEC over those available at a dispersed Quad, would likely yield the capacity to reduce consequences of an accident 30 miles downwind, if effective mitigating actions based on the improved plume descriptions are taken. Of course, if no actions are taken (such as evacuation, limited access, ventilation control, etc.), the only benefit will be a significant improvement in the identification of the population and property affected. Any reduction in consequences would be derived solely from measures to control contact with contaminated areas and medical treatment based upon the improved knowledge of the population sector and property affected.

At shorter distances and on the NEC site, purely meteorological considerations cannot be expected to provide any significant improvement in capability that can be clearly translated into a probable and significant reduction in consequences.

The meteorological advantages of an NEC are:

- Advantages
  - Onsite meteorological specialists
  - Minicomputer data analysis
  - Improved description of plume location at distances beyond 5 miles
- Disadvantages
  - None

RELATED SERVICES

Fire Protection

The dispersed Quad site has a fire brigade of plant employees to initially combat fires; backup firefighting is obtained by contract with local fire districts. The contract service may be paid in the form of local taxes (in one instance a power reactor has a contract that specifies $100,000/yr or 90% of the tax district base, whichever is less). Thus, an NEC could have as much as $1 million a year available for fire services. To provide a minimum response time one or more fire stations may be required at a large acreage NEC. It has been estimated by an ERDA facility fire chief that capital costs for a two-company station are about $300,000 with another $130,000 for two fire trucks. The operating cost per 12-man fire company was estimated to be about $300,000/year.

The NEC that is about one-third to one-half complete would be able to support its own fire company. The first response in individual facilities may still involve fire brigades made up of employees at that facility. A fire department solely responsible for service to a large facility will improve emergency response capability for those accidents involving fire and explosion. Their main contribution will be in firefighting and life-saving; with their specialized training this will be of prime importance. In addition the location of the station or stations will permit quick response and may prevent release of radioactive materials to the public.

The advantages and disadvantages of related services for an NEC are:

- Advantages
  - Onsite professional industrial fire protection services
  - Probable more rapid response
- Disadvantages
  - None

Radiation Dosimetry Services

The dosimetry services required in the routine operation of any facility include: external dosimetry (TLD badge, finger ring, neutron badges), internal dosimetry (bioassay and in vivo analysis), and environmental monitoring. These services will most likely be contracted for at dispersed sites.

Discussion with a commercial service indicated that a capital investment of more than $1 million is required to establish complete routine radiation dosimetry. This business must generate sales of about $750,000/yr to provide a viable minimum business with about $1.2 million/yr in sales required to ensure backup capability in terms of technical personnel. Such a business could be located near a dispersed facility but would with some assurance be found as part of or near an NEC. The total radiation dosimetry service sales volume may range from $500,000 to $750,000 when the NEC is fully established.

A local dosimetry services capability would enhance evaluation, response, and recovery actions in an emergency. Personnel in the services group may also be responsible in emergency situations for field survey, mobile and aerial monitoring. Their environmental laboratory would be a natural point to place responsibility for such services, permitting the facility staff to concentrate on the emergency conditions within the facility. The dosimetry services group may also run a central service for calibration, repair and storage of portable instruments. This would be of extreme value during a major emergency; these instruments, in addition to those stored at each facility, would provide a backup supply.

The advantages and disadvantages of the radiation dosimetry services of an NEC are:

- Advantages
  - Additional professional personnel specializing in environmental analysis
  - Additional instrumentation for backup of emergency events
  - Rapid internal and external occupational dose assessment
- Disadvantages
  - None

Medical Services

The typical power reactor site contracts with a physician for routine medical service as needed. In addition, contracts are in place for emergency services with medical groups and hospitals. The NEC when complete would have sufficient routine medical requirements to use the full-time services of one or more industrial physicians. Thus, the NEC may have some advantage over the Quad dispersed facility. However, when considering effects of the plant medical force to actions protecting the public under accident conditions, it seems likely that the medical staff at nearby hospitals will be of primary importance. The most benefit derived in the NEC case is that relationships and contracts for accident medical services will only be established in one area for one large site rather than at 10 dispersed sites. The industrial physicians will be of service in coordinating the plans and relationships with the nearby hospitals.

The advantages and disadvantages of the medical services of an NEC are:

- Advantages
  - Assigned full-time industrial physicians
  - Fewer total offsite hospital and medical personnel involved
- Disadvantages
  - None

Ambulance Service

Typically, power reactor sites have emergency vehicles that serve as ambulances when needed. In addition, employees trained in first aid are part of each work shift. Assuming that fire protection forces provided the ambulance service, the NEC may be better equipped since firemen may be well-trained in rescue and first aid. The ambulance if required by the population in an emergency will come from offsite sources at both the NEC or dispersed siting cases.

There is no discernible advantage to the NEC case with respect to ambulance service and public emergency response.

EVALUATION OF CHANGE IN RISK FOR NEC

The Base Case for the Quad dispersed site and the changes caused by formation of an NEC discussed in the previous section are qualitatively examined and ranked on relative merit as to advantage or disadvantage. The Quad Base Case is ranked as zero and + (plus) or - (minus) assigned to response criteria for the NEC. The results of the rating are shown in Table 3.

TABLE 3. Emergency Response Capability - Power Reactor

Response Criteria	Relative Capability of an NEC Compared to Base Case	Sum
Site Related		
Site Area	+	
Population	+	
Individual or Critical Population	-	+++
Emergency Plans	+	
Communications	0	
Manpower	+	
Radiological Factors		
Event Detection	0	+
Environs	+	
Meteorological		
Plume Measurement	+	+++
Plume Evaluation	+	
Meteorologist	+	
Related Services		
Fire Protection	+	
Dosimetry Services	+	+++
Medical	+	
Ambulance	0	

+,- = Δs from reference level of zero

The four general categories examined for emergency response affecting the general public all favor the NEC when compared to the equivalent number of dispersed Quad sites.

In all, 15 criteria in four major categories were rated with three showing no significant advantage or disadvantage for the NEC. One of 15 showed a significant disadvantage and the other 11 items showed significant advantage for the NEC. Four subcategories of considerable emergency response significance were favorable: emergency plans, radiological instrumentation in the environs, meteorological plume description, and manpower for coping with an emergency.

No method of numerical evaluation to quantify the degree of advantage of the NEC was found that could be considered valid. It appears that the promptness and effectiveness of the emergency response could be significantly greater in the NEC case than in the dispersed Quad site case, with no additional cost and possibly even if fewer dollars were expended per reactor.

APPENDIX A

SURVEY OF RADIOLOGICAL EMERGENCY RESPONSE INSTRUMENTATION

APPENDIX A

SURVEY OF RADIOLOGICAL EMERGENCY RESPONSE INSTRUMENTATION

An evaluation of instrumentation capabilities from the emergency plans of six different reactor facilities(3-8) was performed in this program. Instrumentation is typically available at different locations which will be designated as Onsite (local or in-plant), Near Site (up to the perimeter), and Distant to Site (at remote locations); the types and numbers of instruments being used is given in ranges.

FIXED

Fixed instruments are instruments that are permanently installed in a given location or that cannot be easily moved or set up in the field. They may be remote reading, continuous recording, instantaneously reading in nature, or counting room type equipment. Table A.1 contains a compilation of the fixed instrument survey for the six reactors.

PORTABLE

Portable instruments are instruments which may be transported and used at any location where they might be needed. In addition to direct reading meters this category includes such things as air samplers and personnel dosimeters. Table A.2 contains a compilation of the portable instrument survey for the six reactors.

TABLE A.1. Survey of Radiological Instrumentation at Power Reactors (Fixed Instruments)

Fixed Instruments	Number of Instruments Onsite	Near Site	Distant to Site
Area Monitors (routine) (in building)	20-30	-[a]	-
Air Monitors (particulate)	0-3[b]	0-8[b]	0-5
Air Sampler (I_2) Charcoal Filter	0-3	0-8	0-5
TLDs (in grids or remote stations)	0-50		0-5
TLD Reader	0-1	-	0-1
MC Analyzer	0-1	-	0-2
4 x 4 MaI	-	-	0-2
Well NaI	-	-	0-1
Ge(Li)	•	-	0-1
Liquid Scintillation	0-1	-	0-1
Proportional Counter	0-1	-	0-1
Low Background Counter	0-1	-	0-2
Counter/Scalers	Several	-	0-2
Electrometers	Several	-	-
Whole Body Counter (Body Burden Analyzer)	0-1	-	0-1

(a) Dashes (-) represent no known capability; the ranges are averages of several facilities with the provision that some plants may have no capability in one or more of these categories.

(b) Telemetered to central readout

TABLE A.2. Survey of Radiological Instrumentation at Power Reactors (Portable Instruments)

Portable Instruments	Number of Instruments Onsite	Near Site	Distant to Site
GM Survey Meter	3-12	2-3	3-9
Ion Chamber: Range → 5-10 R/hr	2-16	2-3	2-9
Ion Chamber: Range → 50-100 R/hr	2-3	2-3	0 - 10
Ion Chamber: Range → 1000 R/hr	1-2	-[a]	0-2
Low E Survey Meter	0-1	-	-
Teletector (1000 R/hr-13 ft probe)	0-2	-	-
Neutron Dose Rate Survey Meter (Thermal and Fast)	0-4	x	x
Alpha Survey Meter	4	x	x
Pocket Chambers and Chargers (Emergency, Self-reading, etc.)	10-15	10-12	10-15
Personnel Dosimeters (Film or TLD)	6	x	20
TLDs	-	-	0 - 150
Gummed Acetate Fallout Paper	-	-	0 - 50
Air Sampler - Battery or Gas	1 - x	3	x
Air Samplers - AC - Hi Vol.	x	1-3	3-10
Air Sampler - AC - Lo Vol.	-	-	3
Charcoal Filters for I	-	-	0 - 30
Portable Scaler + NaI or GM	-	-	1-2
Road Survey - GM	-	-	1
Airplane Survey - Scaler + NaI	-	-	0 - 1
Whole Body Counter	-	-	0 - 1

(a) Dashes (-) represent no known capability; x's indicate capability but with no knowledge of the quantity of instruments available; the ranges are averages of several facilities with the provision that some plants may have no capability in one or more of these categories.

APPENDIX B

A COMPARISON OF METEOROLOGICAL EMERGENCY PREPAREDNESS PROGRAM (EPP) CONSIDERATIONS FOR DISPERSED REACTOR SITES, NUCLEAR ENERGY CENTERS AND MIXED SITES

APPENDIX B

A COMPARISON OF METEOROLOGICAL EMERGENCY PREPAREDNESS PROGRAM (EPP) CONSIDERATIONS FOR DISPERSED REACTOR SITES, NUCLEAR ENERGY CENTERS AND MIXED SITES

OBJECTIVE

The objective of this investigation is to compare meteorological EPP resources and procedures at dispersed four-unit reactor sites, NECs made up of 10 four-unit reactor sites, and a mixed center which integrates the NEC and integrated fuel cycle facility.

SCOPE

Due principally to time limitations, the FY-75 investigation has been limited to a qualitative consideration of readily available information and experience. It is proposed that the FY-76 effort determine the feasibility of an objective methodology to quantitatively determine the change in dose, and thus risk, possible by the implementation of alternate short-term strategies for mitigating consequences for a given site situation, and develop and implement the methodology if such is determined feasible and necessary. At this time such methodology is considered necessary to meet the above stated objective and is technically feasible.

APPROACH

The question of the change of risk was investigated from the standpoint of determining if the consequences of an accident at grouped facilities could be reduced sufficiently to offset the increased accident probability. The reduced consequences was hypothesized to be the result of improved emergency response capability from the increased equipment and personnel resources that could be supported at the grouped facility by combining the resources previously in place at the equivalent dispersed facilities. This was accomplished by estimating the capital, installation, and operating costs for the dispersed facilities and totaling these to determine the resources available to dedicate to the meteorological EPP in terms of a meteorological measurement system and dedicated labor. A meteorological EPP for the grouped facility was then described in terms of the measurement system and labor that could be dedicated within the total resources available. It is important to recognize that costs were approximations used solely for the purpose of facilitating a qualitative comparative evaluation on a reasonable comparison basis.

In the above process certain assumptions are necessary based more on judgment and expectations than data. These assumptions include:

1. Each dispersed fuel reprocessing plant (FRP) and mixed oxide fuel fabrication plant (MOX) that would hypothetically be replaced by collocated or integrated fuel cycle facilities would have sufficient capacity that would comply with the equipment and program requirements of NRC Regulatory Guide 1.23, Onsite Meteorological Programs. This assumption is fundamental since it dictates the costs associated with the dispersed facilities meteorological emergency preparedness programs.

2. Each dispersed reactor site consists of one Quad (four-reactor unit), and that each Quad is served by one meteorological system meeting the requirements of Regulatory Guide 1.23.

3. Because of complexities in the terrain, it is often difficult (if not impossible) to locate one meteorological tower so that it can adequately represent the conditions that will effect plume transport from the source to a potential receptor. It is common to correct this deficiency by the location of a second auxillary tower, although in some situations even more would be required. To reflect this situation in this analysis it was judged reasonable to assume that one-half of the dispersed sites would require such an auxillary tower.

4. It has been assumed that dispersed FRP and MOX plants would have the appropriate onsite waste and fuel storage facilities as well as

decontamination and repair facilities. Therefore, such facilities would not represent independent dispersed sites for which onsite meteorological programs would be required. If this were not the case, this analysis would be conservative to the extent that the resources that could be dedicated to the meteorological EPP at the grouped facilities would be underestimated.

5. The dispersed facility meteorological EPP costs for purchase, installation and operation were based on the following estimates:

	Capital and Installation, $K	Operating, $K/yr
Main Tower	100	20
Auxillary	50	12

6. It was assumed that the total replacement time for the towers and measuring system is 20 years.

THE NUCLEAR ENERGY CENTER (NEC)

The NEC is assumed to be made up of ten sites each containing a four-reactor or Quad unit. In keeping with previous assumptions, half of the Quads in the dispersed case would have had a main and an auxillary tower and the other half only a main tower. Thus, these facilities and their respective meteorological EPPs collectively represent a total annualized investment of approximately $300 to $350 K/yr. It is estimated that this resource would be adequate to establish, maintain and operate 20 to 24 telemetering wind stations on 100- and 200-ft towers and a 500-ft base station tower to satisfy regulatory requirements. In addition to these facilities, it is anticipated that remote sounding methods to describe wind directions at higher elevations could be supported.

These data could be fed to an onsite or offsite computer facility where detailed calculations of the plume diffusion and transport could be made and displayed at the ECC. The additional resources available to the NPP could also support full-time onsite meteorological specialists to provide local emergency forecast services. Dispersed facilities forecasting support would have to come from routine National Weather Services forecasts which will vary in their applicability to these sites and their specific needs. The justification for full-time forecasting at an NEC will likely be on the basis of both emergency and routine operating needs. Note that a benefit of the NEC is that resources required for both the emergency and routine meteorological requirements can be derived from the benefits of the integration of emergency facilities alone.

Generally, single onsite micrometeorological tower measurements are considered representative for the purposes of short-term plume description out to distances of 3 to 5 miles. However, this range is qualitative and represents an average of a range that is quite sensitive to specific site topography and meteorological conditions. At some sites under certain conditions, the measurements from a single tower might be representative only over a few hundred yards, whereas, at others under favorable conditions the diffusion and transport parameters may be the same over distances on the order of tens of miles. In the situation being considered here, this indicates that the 20 to 24 outlying wind towers might all be located within a radius on the order of 10 miles in a complex topographic situation or several tens of miles in a plain. On the average, it is expected that 20 to 24 stations would have to be distributed within about 25 to 30 miles of an NEC to adequately describe plume transport in the event of an accidental release to the air.

The reallocation of resources with an NEC so as to provide 20 to 24 outlying wind stations would permit the area requiring evacuation to be more closely defined in a more timely manner. In the close areas, out to 3 to 5 miles, the meteorological factors will not provide significantly improved timeliness and only minimally improved accuracy and detail over that possible for the dispersed Quads. These improvements would be due primarily to the data handling and display conveniences and not significantly from the presence of the outlying station data.

Some insight into the magnitude of improvement in the detail and accuracy of the plume estimates in the 5 to 30 mile distance range can be obtained from a summary of statistics where estimates of air parcel trajectories as determined from a number of outlying stations are compared to those inferred from measurements at one point. The statistics for the 12 km and shorter distances represent inferences from the 16 km to 48 km data presented in Table B.1. The data were only obtained over a few weeks around Oklahoma City. Because of the relatively simple topography, these values are probably indicative of the smallest improvement in the capability to describe plume position that would be realized by the establishment of outlying stations about an NEC facility. Unfortunately, similar summaries for more complex topographic situations are not available although some basic data exists. Even with data summarized in this form it is not possible to quantitatively and directly address the question of the extent to which the consequences of an accident could be mitigated because of the improved accuracy and detail in plume position. However, it is apparent, that even with a simple terrain case and at distances of the order of 30 miles, average errors of the order 14 km and maximum errors of the order of 90 to 100 km could likely be avoided using the outlying towers at an NEC. Improvements of these magnitudes could be a major factor in effectively identifying the population and property affected.

TABLE B.1. Comparison of Wind Field and Single Station Trajectory Points[12]

Distance Downwind km (mi)	Mean Separation, km		Maximum Separation, km	
	0800-1900	2000-0700 CDT	0800-1900	2000-0700 CDT
4	<1[a]	<1[a]	0-4[a]	0-2[a]
8 (5)	<1[a]	<1[a]	3-7[a]	0-4[a]
12	~1[a]	~1[a]	9-13[a]	2-6[a]
16 (10)	1.6	1.4	21.6	5.7
32	7.4	8.0	66.4	61.2
48 (30)	14.8	14.0	98.0	91.9

(a) Interpolated

An additional factor in favor of the NEC is the aspect of reliability through redundancy. In the event that the main onsite tower were to fail, the outlying station data could be used to describe the plume transport although with some loss of information. At a dispersed Quad, a similar failure would reduce the effectiveness of the emergency operation substantially more.

Although a conclusive quantitative evaluation could not be presented, it is considered reasonable to expect that the additional resources available at an NEC, over those available at a dispersed Quad, would likely result in the capability to significantly reduce the area to be evacuated. If no action is taken (such as evacuation, limitation of access, ventilation control, etc.,) the benefit will be a significant improvement in the identification of the population and property that would be most affected, resulting in improved measures to control contact with contaminated areas and medical treatment based upon an improved knowledge of the population sector and property affected.

THE COMBINED POWER AND FUEL CYCLE ENERGY CENTER

The combined center is assumed to be made up of the NEC discussed above and the Integrated Fuel Cycle Facility (IFCF) discussed in Tasks 1.3.7 and 2.2.4.(13) Based on the stated assumptions, the integration of the NEC and the IFCF to form the combined center doubles the resources available to the meteorological EPP to a total of $600 to $700 K/yr. However, practically speaking, it is judged that only a portion of the additional $300 to $350 K/yr provided by integration could be justified for further improvements to the meteorological EPP. Qualitatively, it is expected that the reduction in dose per additional dollar expenditure for the meteorological EPP will decrease rapidly above about $400 K/yr. This then translates into either a savings of $250 to $300 K/yr for 20 years ($5 to $6 million total) for the combined center versus the separate NEC and IFCF, or the availability of these funds for transfer to other components of the EPP.

APPENDIX C

MULTIPLE SITING AND RELATIVE RISK

APPENDIX C

MULTIPLE SITING AND RELATIVE RISK

In considering multiple siting and its effect on the relative risk to a critical population the four-reactor (Quad) site is taken as the base case. The postulated NEC, containing up to 10 Quads, may consequently be compared to the single Quad Base Case. The NEC layout selected for comparison is the United Engineers' Case III, Random Arrangement. The assumptions used in this analysis were:

1. The probability of an accident at an NEC is the sum of the probabilities for each of the 10 Quad units.
2. There are no synergistic effects from adjacent reactors.
3. The critical population is located at the middle of the northern fence boundary.
4. Meteorology consists of: wind from the south at 1 meter per second; Type D stability; and gaussian plume.

At first it might seem that the risk to a critical population should be 10 times larger for an NEC containing 10 Quads than for a single Quad. However, this is not the case since the relative risk is the product of the probability of an accident and the consequences associated with that accident. When considering an atmospheric release, the distance from the source to the receptor radically affects the concentration of material at the receptor's location and, correspondingly, the consequences of the release.

To calculate the relative risk the following steps were taken. The downwind and crosswind distances were measured from the site layout drawing. From these measurements, which were proportional to the actual proposed distances, a X/Q or concentration per unit release was calculated at the receptor's location using the following formula:

$$\frac{\overline{X}}{Q} = \frac{1}{\pi\sigma_y \sigma_z \overline{u}} \exp - \left[\left(\frac{y^2}{2\sigma_y} 2 + \frac{h^2}{2\sigma_z 2}\right)\right].$$

where

σ_y = horizontal dispersion coefficient,

σ_z = vertical dispersion coefficient,

$\overline{u}$ = average wind speed,

y = crosswind distance, and

h = height of release (assumed ground level = 0).

The values for σ_y and σ_z were extracted from "Meteorology and Atomic Energy - 1968", U.S. AEC, and depend only on the downwind distance (X) and the stability class. The X/Qs were calculated for two cases: 1) where the wind was always assumed to be blowing from the source directly toward the receptor (X - R, Y = 0), and 2) for a constant sound wind (X = X, Y = Y). The relative risk was then estimated by normalizing the X/Q values to the closest facility and summing all the 10 facilities' contributions. If these values are then related to the Base Case or single Quad, with a 1/2 mile exclusion boundary, the relative risks for the two NEC cases are 0.43 and 0.26. If both the NEC and the single Quad have 1.25 mile exclusions distances the risks for the NEC relative to the single Quad are 2.23 and 1.31 for the two cases. Details of the calculations are presented in Table C.1.

In looking at other stability classes it was found that the maximum relative risks for equal 1.25 mile exclusion distances varied from 1.1 for "A" stability to 2.5 for "F" stability. Consequently, the value of 2.23 for "D" stability seems a good compromise. It may also be observed that changes in wind speed, $\overline{u}$, will change the individual X/Q values; however, they will have no effect on the relative risks.

Considering the relative risks for the NEC and single Quad facilities, it becomes clear that the risk is highly dependent on the exclusion distance. In the situation where an NEC has a significantly larger exclusion distance than the single Quad (1.25 miles versus 0.5 miles) the risk from

TASK 2.1.12 AGEING OF NUCLEAR ENERGY CENTERS the NEC to the maximum individual is between one-fourth and one-half the risk from the single Quad unit. However, with the same exclusion distance the risk from an NEC is only 1.3 to 2.2 times the risk from the single Quad.

TABLE C.1. Relative Risk - NEC Versus Dispersed

Facility	X, miles	Y, miles	R, miles	X/Q X = R Y = 0	Relative Risk X = R Y = 0	X/Q X = X Y = Y	Relative Risk X = X Y = Y
1	1.25	0	1.25	3.9E-5	1	3.9E-5	1
2	3.5	0	3.5	9.1E-6	0.23	9.1E-5	0.23
3	7.25	0	7.25	3.3E-6	0.08	3.3E-5	0.08
4	5.5	1.5	5.7	4.4E-6	0.11	1.4E-10	4E-6
5	2.5	2.5	3.54	9.1E-6	0.23	0	0
6	8.5	2.5	8.86	2.3E-6	0.06	4.0E-12	1E-7
7	7.0	1.5	7.16	3.2E-6	0.08	3.3E-9	8E-5
8	2.0	2.25	3.0	1.1E-6	0.28	0	0
9	5.5	2.25	5.94	4.2E-6	0.11	3.4E-16	IE-11
10	9.0	2.25	9.28	2.1E-6	0.05	7.9E-11	2E-6
NEC Sum					2.23		1.31
Base Case(a)	0.5	0	0.5	2.0E-4	5.13	2.0E-4	5.13
Base Case	1.25	0	1.25	3.9E-5	1.0	3.9E-5	1.0
Relative Risk of NEC Relative to Base Case					0.43 → 2.23		0.26 → 1.31

X = downwind distance

Y = crosswind distance

$R = (X^2 + Y^2)^{1/2}$

(a) The difference between the base cases is in the distance to the site boundary - 0.5 miles and 1.25 miles.

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TASK 2.1.12

AGEING OF NUCLEAR ENERGY CENTERS

D. W. Fraley

CONTENTS

TASK 2.1.12
AGEING OF NUCLEAR ENERGY CENTERS

INTRODUCTION

An evaluation of Nuclear Energy Centers (NECs) with dispersed siting of reactor plants requires that the entire life cycle of both facilities be compared and, in addition, the effect of each on the "system" into which they will grow should be examined.[a] An example of a difference in life cycle can be seen in the planning horizons for each. The planning horizon (which would include construction, operation, and decommissioning) for an NEC could be 80 to 100 years, almost double that for a typical dispersed site. Also, the degree of preplanning is clearly greater for an NEC site which may contain up to 10 times or more the number of facilities contained in a dispersed site. An example of a "system" interaction that might be different for NECs and dispersed siting relates to provision (amount, type, and location) for peaking capacity.

The purposes of this report are: 1) to identify areas in which the aging aspects of the two types of facilities may differ, and 2) to consider in a preliminary way what these differences may entail. Other parts of the NECSS-75 study will provide information on some aging differences. More detailed analyses will be required in other areas before definitive statements on aging can be made.

Differences in aging can be readily apparent in several areas. The effects of an NEC on its environs -- be they ecological, sociological, technical, or economic -- will be dynamic in nature, similar to dispersed siting. However, the evolution of an NEC will be more affected by its environment since: 1) it develops over a longer period of time, 2) there

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(a) For purposes of this report, differences in the life cycles of NECs and dispersed plants are called "aging" differences.

is more opportunity for environmental feedback, and 3) the local environmental effect will be greater. Planning an NEC will involve a greater effort initially as well as a continuing effort as it evolves.

The necessity of flexibility in planning competes with other factors, i.e., economics. Nuclear power generation is capital intensive. To achieve savings there will be efforts toward mass production of plants, as well as standardization. The need for flexibility and the inevitable evolution of technology over the life of an NEC, if used to advantage, tends to negate cost saving possibilities.

A number of areas have been identified which may produce aging differences. These areas are listed below and are discussed in the following subsections.

- Facility Lifetime
- Forecasted Capacity Factors
- Load Following
- Energy Storage
- Concentration of Generation
- Transmission
- Generation Technology and the Nuclear Fuel Cycle
- Regulatory Considerations
- Environmental Factors
- Heat Dissipation
- Decommissioning

FACILITY LIFETIME

The construction time horizon for an NEC commences in approximately 1985 to 1990 and extends as many as 40 years. The projected lifetime for a reactor plant is typically 30 to 40 years. Thus, the overall life cycle for an NEC may be 80 to 100 years compared to about half that time for dispersed units.

Clearly, there is a difference in planning horizons and preplanning needs. Typically, a dispersed plant is constructed and operates fairly autonomously through most of its life. An NEC can expect to be continually analyzed, monitored, reviewed, etc., as feedback from ecological, sociological, technical, and economic considerations are received.

FORECASTED CAPACITY FACTORS

In terms of either national or regional load growth rates, an increasing portion will be met by nuclear generation either as NECs or dispersed. Figure 1 shows an example forecast, for several NERC regions, of the expected mix of plants (nuclear and other) to meet the predicted buildup of demand.(1) As shown, nuclear generation becomes an increasingly larger share of total generation. In the year 2000 from about 35 to 70% of the generation capacity for several regions will be nuclear. It is this large growth that makes inquiry of the concept of NECs feasible.

As the share of nuclear generation increases, there will be a need for nuclear plants to change from one of base-loaded operation to one of base-load plus cycling. The degree to which this change will take place is a function of many factors, but for this analysis it is necessary to compare the cycling aspects for NEC versus dispersed plants.

Several factors are important in this comparison. Traditionally, the average costs versus utilization are considered for the various generation candidates. Due to large capital costs and relatively low operating costs, nuclear generation has been frequently selected for filling base load requirements. Planning of future additions to generating capacity will require increasing consideration of cycling capability, capacity factors, fuel availability and lead times for various types of units as well as the availability of capital. This will require design studies of fuel and control technology, and economic analysis of non-base load operation. This potential change in operating modes may affect the comparison of NECs and dispersed generation, but it is not presently clear in what ways. Therefore, further study is needed.

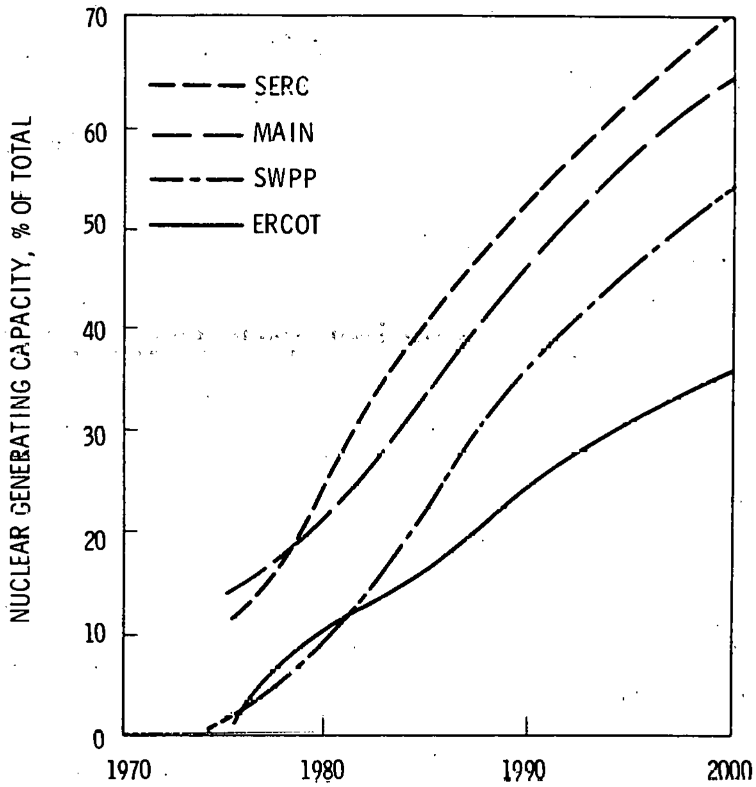

FIGURE 1. Predicted Percent Nuclear Generation Capacity for Several NERC Regions[1]

LOAD FOLLOWING

Load following is the system's response to short-term variations in demand. Typically, load following needs have been met by a variety of approaches, including hydro systems, standby units, gas turbines, etc. The mix of nuclear and non-nuclear generating capacity may affect the approach used. It is not clear whether the approach will differ between NECs and dispersed generation; however, it must be considered.

The problems of load following in the future may be lessened by several factors, including load management, rate structure modification (to persuade consumers to reduce peak demands and transfer loads to off-peak hours), and improved energy storage methods. In either case the effects will be to permit a larger percentage of the system's generation capacity to be base loaded. These factors should be evaluated in comparing NECs to dispersed generation.

ENERGY STORAGE

As mentioned in the previous discussion on load following, an alternative to shaping the load to reduce peaks, allowing more efficient use of generating equipment, would be the development of a broader range of economic energy storage systems. Storage systems may provide advantages in addition to the ability to supply peak loads (for example, rapid response to spinning reserves requirements, overload capability and low losses in normal load situation, improvement of transmission load problems by siting close to load centers and, possibly, better system stability).

At present, the only operating systems are pumped storage; batteries are receiving considerable attention as storage devices. Other energy storage concepts under consideration include hydrogen storage, compressed air storage, flywheel, magnetohydrodynamic and heat storage systems. These are in various stages of development. The impact of energy storage technology should be studied in terms of how it might impact NECs and dispersed siting.

TRANSMISSION

The electrical transmission system is one of the key elements in the evaluation of NECs and dispersed siting. In terms of power delivered and the technology of delivery, there appears to be no great differences between NEC and dispersed cases. Careful consideration must be given to transmission reliability for the two concepts.[2] Also, there are several advanced transmission technologies which will probably become realities during the development of an NEC case, and these need to be evaluated. Transmission expansion for integrating NEC output into the existing system must be evaluated. These factors are all relevant to the aging of an NEC.

Transmission Reliability

In terms of transmission reliability the Hanford Nuclear Energy Center concept meets all Western System Coordinating Council and Bonneville Power Administration criteria for reliability of transmission systems.[3] On the other hand, discussions with the Energy Park Development group at Pennsylvania Power and Light indicate that new concepts might not be as transmission reliable in the traditional sense. For example, present design usually dedicates at least two lines to a single unit and three to a pair of units. It is difficult to conceive of single units or several units in a center, as electrically isolated from the remainder. It is expected that it will be technically feasible to develop a transmission system capable of delivering an energy center's capacity to load centers. The following are several factors which need to be examined in the context of aging of NECs:

a) For centers beyond approximately 100 miles from the load, ac transmission will require series capacitor compensation. Significant technical problems could occur with long, radial, highly compensated transmission lines.[4] Such problems indicate solutions other than series compensation either by traditional means or by use of advanced technology.

b) Typically the minimum fault clearing time used in transient stability analysis is 3.25 cycles for primary clearing. Recent developments[5] indicate the possibility of reducing the total fault duration by about 1 cycle.

c) It is assumed that an NEC will be located somewhat remotely from the load. As a result, losses become sizable and should be evaluated in comparison with dispersed siting. The costs of lost energy may require construction of additional units to make up the losses.

d) For ac transmission, several voltages may be utilized in combinations to carry the generation from the center. It may be possible that the best transmission scheme will be to include networked and mixed voltages.

Advanced Transmission Technologies

With respect to advanced transmission technologies, faster breakers are indicated within the immediate future; higher capacity busses and high voltage dc transmission are within the NEC planning horizon.

High voltage dc has a definite possible role in NECs. It appears less likely to require as large right-of-ways as for a high voltage ac system. A dc system also has the advantage of automatic power flow control. Furthermore, the problem of short circuit duties which may result from concentration of more than 10,000 MW at a single site would not exist with a dc system.

The reliability criteria associated with a dc transmission system need evaluation as well as the associated reliability problems. There will be losses associated with dc transmission, in this case associated with the terminal equipment. Future high voltage dc technology depends on the availability of dc breakers and on new methods for performing dc stability analysis.(6) From a cost effective viewpoint a rule-of-thumb often used is that dc is feasible for overhead transmission in ranges of several hundred miles or more.

Another possible use of dc might be to improve transmission line reliability by utilization of underground dc for several miles out from the center. Such a concept implies the interaction of both an ac and a dc system in hybrid manner. For this situation, underground cable technology must be assessed as well.

A second possibility is the extension of present ac transmission technology from 500 and 765 kV to 1100 kV or higher. The principal advantage for the increase is in the reduction of line losses. On the other hand, significant technical problems may also be encountered as is usually the case when a new voltage level is introduced. The width of right-of-way as well as the expected tower height may rule out the higher voltages on the basis of environmental or political considerations. Areas that need study are the electric field effects and the availability of transformers for this voltage class. Finally, there may also be greater problems in integrating the transmission into the existing system, as addressed below.

The possibility of cryogenic transmission over short distances should also be considered. Methods of development and costing cryogenic cables need evaluation, in terms of tradeoffs with respect to right-of-way, and stability advantages. Since such a concept may be viable for short distances, it is a possibility for both dispersing the power from the center and for routing into densely populated load centers.

Transmission Expansion Planning

The evolution of an NEC may entail a new perspective in transmission expansion planning. The horizon year approach to transmission planning may not be valid in considering the very long time period associated with the development of an NEC.

If generation requirements presently predicted are accepted, the overall transmission system in the year 2020, for example, will probably bear little resemblance to that seen today. Simply stated, the transmission system developed from hereon, particularly if NECs are adopted, will be the major system and the present system will be auxiliary to it. This view somewhat modifies what is meant by integrating new generation into the present system.

Generating plant development usually involves installation of several units at reasonable intervals so that minimal economic penalty is involved in the initial construction of the total transmission. In a nuclear energy center, however, a major problem is in developing the transmission such that it is optimal or at least adequate at each point in time. Still, the total transmission would not be required for the first few units.

At present, transmission system expansion is quite site specific. The specifics for NECs would be similar in that the nature of the expansion would depend on the distances to load centers, the underlying system capability in the area, and the relative economics of alternatives. However, with the extended horizon the problem is compounded by possible technological developments and by the fact that the optimal system may have little resemblance to the underlying system.

One possible advantage lies in the ability to plan transmission expansion over a much greater time period, avoiding patchwork networks that can occur. At this time, each addition of generation has implied that the transmission would be integrated into the extant network. If used to advantage, the long-term planning could have the altered goal of integrating the extant network into the scheme for the ultimate system.

Implicit in these discussions are the difficulties with acquisition of massive right-of-ways at the onset, the institutional arrangements between participating companies which are part of the energy center, and difficulties with technology forecasts. By comparison with dispersed siting, acquisition of right-of-ways may be more difficult in the future if traditional expansion is continued. These "softer" issues may ultimately be the hard constraints relative to bringing an NEC into operation.

The greatest possible flexibility must be allowed for transmission expansion planning, particularly if a major portion of the transmission must be developed with the first few units in a center. If such is the case, high voltage dc may be more economic to operate below intended levels. Alternatively, parts of the underlying system may be used initially to allow more time for right-of-way acquisition, engineering, and construction of the ultimate transmission system designed for an NEC.

GENERATION TECHNOLOGY AND THE NUCLEAR FUEL CYCLE

The guidelines for the study of the NEC concept visualize a light water reactor (LWR) dominated generation technology. The indications for this outlook are founded in financial as well as demonstrated reliability considerations.[7] For these reasons the adoption of other reactor types, i.e., HTGRs, LMFBRs, light water breeders, molten salt breeders, heavy water breeders, etc., may be limited for NECs in their early stages of development. The reactor concepts presently expected to be commercially available near the beginning for NECs besides LWRs are HTGRs and LMFBRs. No changes in the basic design of LWRs are required for NEC application.

At present technology levels some unique advantages may be accrued from use of a NEC to its potential. These advantages may include the following: a) onsite factory modular construction, b) central spent-fuel storage for later reprocessing, c) open cycle or recycle LWR or self-generation, d) shared operations, etc. At present, guidelines indicate LWRs of 1300 MWe, but plants of larger size may be feasible.

The major factor affecting generation technology subsequent to the inception of NECs could be the integration of the fuel cycle with the reactors. Within this area, the synergy of several factors must be considered in long range planning. The character of the potential mix of reactor concepts may be a significant factor to consider in long range planning.

Motivation for integrating the nuclear fuel cycle is projected on factors such as lessening transportation costs and transportation risks and improving safeguards. Several possible scenarios may be candidates for generation planning at a nuclear energy center. As a baseline assumption given initial planning time constraints and present technology, a sufficient number of LWRs will form the initial units at a center. This number could be a function of the economics of scale and improved construction techniques, one study indicates from 6 to 10 units.(8) This perspective allows an increased planning horizon relative to possible reactor mixes and fuel cycle scenarios.

Next upon the horizon is the advent of plutonium recycle in LWRs. This is the self-generation mode. In this situation all the discharged plutonium would be returned for recycle in the reload fuel assemblies. If desired, all extant LWRs at a center could be operated in this mode. Although the recycle could begin by gradual substitution of the available mixed oxide fuel for the ^{235}U enriched fuel, onsite reprocessing and mixed-oxides fabrication admits to planning opportunities.(9) For instance, the tradeoffs between spent fuel storage and refabrication need to be studied in terms of the expansion of an NEC. Although the breeder reactor is somewhat distant future, it is within the time frame for NECs, and should be considered in conjunction with the LWRs presently envisioned.

Prior to breeder development, improved converters (the HTGR) may have come into being. The HTGR is in an advanced developmental state and has a role in the NEC concept as well as in the future of nuclear power in general. For example, the possibility of mixing HTGRs with other reactor types within a fuel cycle is not clear; however, evaluation of this possibility remains. At present, most considerations have separated HTGRs from the assumed possible synergy between LWRs and LMFBRs.

It is likely that the role of NEC generation and associated fuel cycle facilities will be constrained by the environmental and regulatory climate surrounding it. Undoubtedly, future technology developments will start to play a role in the lifetime of an NEC if the planning allows such flexibility. Within the time frame of 10 years of planning, 20 to 40 years of construction, and an indeterminate lifetime, the entire energy environment will take on new perspectives.

In planning the evolution of a hypothetical energy center, the first step will be developing an exhaustive scenario which indicates the sensitivity of the factors involved in generation and fuel cycle technology.

The evolution of alternatives available in dispersed siting must also be considered. If dispersed nuclear generation will continue to any degree, then planning must include the role of centers and dispersed generation in terms of their interaction within the fuel cycle. From this viewpoint, the concept of both NEC and dispersed sites shipping spent fuel to a single Pu burning energy center, at which reprocessing and fabricating plants are located, may also be a viable alternative.

In summary, the planning process for alternate generation technology and fuel cycle candidates, and their possible combinations and interactions, may be constrained by many factors, including future regulatory requirements. Additionally, regulatory policies and constraints have substantial impact on facilities designs and costs.

REGULATORY CONSIDERATIONS

The planning and evolution of an NEC will certainly be affected by the future regulatory climate. While the general safety criteria for dispersed nuclear installations may be expected to stabilize for LWR technology, the regulations that will govern NECs remain to be defined.

ENVIRONMENTAL FACTORS

The primary environmental aspects of NEC evolution, aside from the problem of heat dissipation, which is discussed later, are discussed herein. Offsite radiation exposure will not be permitted to exceed regulatory limits at any time whether from an NEC or dispersed unit. The limits, however, remain to be established for the NEC concept. This applies to onsite as well as offsite exposures. The former is important since a number of units will be under construction while other units are operational. A dispersed site shares some of these considerations but not to the same extent.

Recovery capabilities at an energy center are expected to differ from dispersed sites. Construction equipment, fire, security, and medical services and experienced personnel may be more available to respond to an accident at an NEC. In terms of the evolution of a center, the buildup of these services must be included in the planning process.

The radioactive effluents from reactors, reprocessing, fabrication, and waste treatment are probably the same whether at NECs or dispersed; that is, the frequency on a per unit basis should not be different. An NEC may benefit from increased boundary distance for offsite exposures.

When viewed in the overall sense, it is possible that more people may be potentially affected by a similar number of dispersed units, and the satellite function of reprocessing, fabrication, transportation, etc., for equivalent power generation in a non-NEC scenario. The evolution of these possible factors adds another dimension to the consideration of the potential problems.

HEAT DISSIPATION

Within the area of waste heat dissipation there are two prime considerations for the long range planning of an NEC. The first is the possible alternative technologies available for the heat dissipation. To some degree interactive with the first is the possible effect of the significant thermal energy rejection expected for NECs.

A number of waste heat dissipation methods are available to the designer of NECs (and dispersed sites). The present methods include once through cooling, cooling ponds, spray canals, mechanical and natural draft coolers, wet/dry towers and possibly dry cooling towers. Large scale use of once through cooling is unlikely due to the threat to the environment. The immensity of the envisioned centers lends less credence to either cooling ponds or spray canals as alternatives. Typically, past engineering practice has employed only a single cooling method at any particular generator site. The options above for combining extant methods for heat dissipation need to be given further consideration.

The possible economic and environmental benefits which may be gained by employing mixed-mode heat dissipation systems and methods need consideration and development. Optimal utilization of available heat rejection resources may indicate a mixed mode system based on current technology. Such considerations are not presently available and should be considered for NECs. Possible combinations may include: natural draft wet towers, with spray systems or cooling ponds; or mechanical draft wet towers, with natural draft wet towers, dry towers, or cooling ponds. As such studies indicate, the evolution of an NEC may possibly include one of the above combinations.

There are several site specific characteristics which also must be addressed in considering candidate cooling technologies. The nuclear center concepts being considered include as much as 48,000 MWe at single sites. This would require as much as 75,000 to 100,000 MW of waste thermal energy rejection. In cooler climates, wet cooling technology may cause fog, icing, and similar climatological interference. The problem of noise pollution may also be significant for various forms of mechanical cooling.

A major uncertainty presently exists regarding potential climatological effects of heat dissipated for a hypothetical NEC. There may be general surface temperature increases, cloudiness and precipitation initiation as well as catalysis of meteorological events. There is a clear need for research on the above considerations.

Cooling towers are expected to be employed in the heat dissipation system for NECs in some form or other. There is not agreement among meteorologists whether it is desirable to have interaction among thermal plumes from several such towers. Some have expressed concern about storm initiation possibilities if such interaction occurs to any great extent. The ability to predict such effects is not well developed. Thus, there is a potential problem in terms of evolution. Judicious siting to minimize the possible thermal climatic hazards should be part of any specific planning for an NEC.

On the positive side, waste heat utilization in other forms may become feasible due to the ultimately large thermal output. Up to now the traditional difficulty has been the reliability of such heat as a potential energy source. Here we have the compounded technical problem of heat transmission beyond the perimeter of a center and the related problems of associated industries possibly situated near a center. The synergisms here compound the safety and regulatory problems as well.

DECOMMISSIONING

To date only small demonstration-type LWRs have been decommissioned, but no large plants have been decommissioned. Thus there may be some uncertainty about the lifespan of LWRs, though it is typically considered to be 30 to 40 years. A nuclear energy center is best viewed as a dynamic entity, growing and evolving in response to a changing energy environment. If an NEC is envisioned in more than a "power only" sense with possible fuel processing, fabrication, and waste storage incorporated within its boundaries, then it may be considered as dedicated for an indefinite future. It then becomes reasonable, as units reach the limits of their useful lifetime, to replace them with new generation. Such a view may be envisioned for an NEC at maturity.

The methods and procedures for decommissioning large plants may need further study.[10] The Office of Standards Development of NRC is presently developing criteria and standards on the extent of decontamination in connection with plant design objectives, plant decommissioning, and license terminations. Information is needed on safety aspects and costs related to the decontamination and decommissioning of such facilities. The technical areas which need consideration may be broken down into: a) generation of reference information and guidelines, b) methods of decommissioning, c) safety analysis, d) assessments of benefits and costs, and e) the associated research and development requirements.

The actual determination of the expected lifetime for various nuclear units may be considered within area a) above. Present rule-of-thumb estimates vary from 20 to 40 years. This may well be a function of reactor types, size, components, and structural details. Possible synergy in the design and the ultimate lifetime of a nuclear unit must be identified. Possible site specific characteristics must also be identified which may exist prior to decommissioning activities. The residual radionuclide and chemical concentrations at the facility and site must be defined and characterized. Other possible inputs for guideline and criteria development will be projections of regulatory, legal, and environmental standards at the time decommissioning is initiated.

Possible decommissioning methods are currently being addressed in terms of safety-based disposition criteria, decontamination processes and plans for alternative modes. Disposition alternatives may be categorized on the basis of ultimate use of the facility in the future. Dismantling is the only feasible method if the specific site will be further utilized. Conditional utilization of the site, as in the NEC case, has several alternatives: 1) entombment, 2) dismantle internals, entomb or mothball structure, 3) mothball facility, or 4) layaway the facility. These various modes may or may not preclude indefinite surveillance of decommissioned units. Finally, restricted use of the site may require only isolation.

Of the numerous ways to decommission nuclear reactors, the viable alternatives may be greatly limited for dispersed sites. Presently only dismantling and mothballing disposition modes have been chosen for the dispersed case. For an NEC at maturity, the method of decommissioning will be affected by the ultimate role of the center. If the site is assumed to be perpetually dedicated, then flexibility in disposition alternatives for cost and safety effectiveness may be greater.

The radiological and chemical consequences associated with decommissioning and decommissioned nuclear facilities and sites requires further investigation. Similarly, the safety factors, relevant to the working force, the general population, and the environment, of actions taken to decontaminate and decommission nuclear facilities and sites must be evaluated for both the short and long term.

In terms of planning for NECs, preliminary investigation should be made of which disposition mode has the best combination of safety and economic advantage. This may affect both design and siting considerations. If an NEC scenario is envisioned containing fuel cycle facilities, then similar investigations for those facilities must be made. The role of new processes, technology, procedures, and designs within the time frame to maturity for an NEC needs definition. If preliminary investigations indicate that decommissioning is reasonably independent of the planning process for the buildup of NECs, then decommissioning planning may be deferred while accruing actual experience as extant plants reach their maturity.

CONCENTRATION OF GENERATION

A rule-of-thumb sometimes used by public utilities is not to have more than approximately 10 to 15% of their system's generation capacity at a single location. If future generation requirements are to be met by nuclear energy centers to any degree, then this rule-of-thumb needs to be examined. The concentration of load problem may not be unacceptable in National Electric Reliability Council (NERC) regions which could warrant several energy centers, none concentrating the bulk of that region's capacity at one geographic location. However, the evolution of NECs within the U.S. power system indicates that greater interconnection between NERC regions will also be required. A second major area requiring interaction among utilities may be financial in nature. Although the financial aspects of NECs are being addressed in the NECSS-75 report, some of the aging aspects will be reviewed here.

A major problem facing public utilities today is in financing the growth of generation capacity. Due to the sheer magnitude of the capital investment required for NECs, some form of joint participation among utilities may be indicated. A factor to be resolved, beyond agreement to participate, will be on legal contracts defining the responsibilities and obligations of the participants, as well as the functional organization required to manage an energy center project.

Some small utilities may not want to be heavily involved in power generation. On the other hand, even with utility cooperation, some utilities will be hesitant to make the long-term capital commitment required to develop an NEC. This hesitancy is not unjustified in light of uncertainties in the present economic, environmental, and regulatory climates. The future role of many regulatory agencies is not well defined at this time. At the very least, cooperation and feedback in licensing, regulations, and guidelines over the long time periods envisioned for NECs are required between industry and government. State and local agencies must also be involved during the planning stages of the NECs.

Specifically, recommendations concerning ownership, participation, financing arrangements and requirements, responsibility and accountability for construction, operation and maintenance of NECs must be addressed in a generic sense in the immediate future. The implications in these terms are important to both governmental agencies and the utilities. Among possibilities for specific nuclear energy centers is the formation of separate generation and/or transmission corporations to develop the energy centers and to sell energy to participating companies. Other possibilities of ownership and participation should be explored.

Some form of governmental participation may be indicated because of the large amounts of capital required for the initial development of an energy center. These costs are, for an energy center, more of a one-time basis and may include such things as land, plant fabrication facilities, transportation links, and possibly initial transmission costs.

Relative to the long-term planning for an NEC, the implications of the concept are significant. Liability among joint participants must be addressed for possible accidents and inability to raise future capital. Also, as before, the evolution of an energy center, including fuel cycle facilities and the interaction between centers in all aspects of power and fuel, serves to compound the problem of financial planning.

CONCLUSIONS

No insurmountable technical problems are apparent on the long-term horizon for the NEC concept. However, the evolution of a center raises some fundamental questions with regard to its planning. As indicated, the planning process must be flexible and adaptable as the NEC evolves.

It is easy to underestimate the long-term planning problems for such a concept due to both the long time frame involved and the monumental size of a center. The effect of an NEC on its environs will be dynamic in nature, and in turn its evolution will be affected by its environment. Sufficient foresight in those factors which will influence its evolution can be viewed as an advantage in the planning process.

Several factors not discussed herein should be considered in the evolution of an NEC. These are best characterized as sociological in nature. For example, an NEC will involve a large construction and operation labor force, whose maintenance and management will vary over the lifetime of the center. In addition, the support of the workforce and their families will have significant impact on the local economic environment. The buildup and support of communities, and the goods and services infrastructure to support the necessary labor force must also be considered over the horizon of an NEC. These are ancillary problems to the actual evolution of an NEC.

The following comments can be made about aging of NECs:

- No specific "aging" factors preclude giving the concept of nuclear energy centers further consideration.
- Consideration of the "aging" problem for NECs indicates that the planning process must extend beyond their inception and continue throughout their foreseeable lifetime.
- There may be a combined environmental effect of all the plants. Examples are: 1) climatic changes in the area due to concentrated use of evaporative cooling, 2) gaseous and vapor emissions, accidental or otherwise, and 3) waste products, etc.
- The centers may be susceptible to previously unidentified synergistic effects or common mode failures.
- Future regulatory climates for licensing future installations are difficult to predict.
- Future transmission and generation technologies which may be incorporated in the center at some later date are difficult to predict.

To help clarify some of the general issues above, the following areas are suggested for further investigation.

- Determine the feasibility of nuclear units operating in a non-base loaded mode. Evaluate trade-offs in energy storage, off-peak uses of surplus capacity, and load flattening as alternatives.
- Determine the transmission reliability requirements for an NEC in terms of potential advanced technology and optimal transmission expansion.
- Consider future alternatives for generation expansion in NECs and their effect on the potential benefits expected of standardization of engineering and construction.
- Consider the character of the mix of generation concepts if NECs will ultimately include integrated fuel cycle facilities.
- Evaluate necessary changes in the regulatory process to facilitate long-term planning for nuclear energy centers.

- Investigate the combination effects of multiple siting in exposure and accident potential to both the environment and the workers.
- Identify the potential climatic effects from heat dissipation and the possibility of mixed mode cooling.
- Determine guidelines and procedures for decommissioning and prediction of lifetimes for candidate generation technologies and fuel cycle facilities.

The need is evident for integrated planning of a nuclear energy center in terms of the long-term horizons envisioned. New approaches are required to consider the interaction of the various aspects of such a concept. Similarly, the development of optimum strategies for the expansion of nuclear power generation will take on different perspectives with such considerations. The evolution may be a graceful process if planning has its basis in the identification of those factors which will make it so.

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TASK 2.1.13 DRY-COOLED NUCLEAR ENERGY CENTERS

TASK 2.1.13

DRY-COOLED NECs

W. W. Laity and A. Brandstetter

TASK 2.1.13

DRY-COOLED NECs

The work performed under Task 2.1.13 has been reported in a separate document, BNWL-1985, "Technical, Environmental, and Socioeconomic Factors Associated with Dry-Cooled Nuclear Energy Centers," Battelle, Pacific Northwest Laboratories, April 1976.

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