Table C.86 Estimated economic effects of Wolf Creek Generating Station on Coffey County, 1989

Employment	
Direct basic	522
Indirect	397
Total plant-related	919
Percentage of Coffey County employment	17.5
Income (1989 $)	
Direct	27,601,000
Indirect	9,752,000
Total plant-related	37,352,000
Percentage of Coffey County income	22 5

Source: ORNL staff computations based on approach used in NUREG/CR-2750.

Table C.87 Projected employment effects of Wolf Creek Generating Station refurbishment on Coffey County, 2024

Refurbishment direct employment	455
Refurbishment indirect employment	108
Total plant-related employment	563
Percentage of Coffey County employment	6.8

Source ORNL staff computations based on approach used in NUREG/CR-2750

Table C.88 Projected employment effects of Wolf Creek Generating Station license renewal on Coffey County, 2025

Existing direct and indirect employment	522
Increase in direct employment	30
Increase in indirect employment	23
Total plant-related employment	575
Percentage of Coffey County employment	7.1

Source ORNL staff computations based on approach used in NUREG/CR-2750.

APPENDIX D

AQUATIC MICROORGANISMS AND HUMAN HEALTH

Aquatic Microorganisms and Human Health

Some aquatic microorganisms normally present in surface waters whose presence may be enhanced by thermal additions have been recognized as pathogenic for humans. Among these are *Salmonella* species (sp.), *Shigella* sp., *Pseudomonas* sp., thermophilic fungi, Legionnaires' disease (LD) bacteria [*Legionella* (*L.*) sp.], and the free-living amoebae of the genera *Naegleria* (*N.*) sp., the causative agents of various human infections.

Salmonella sp. is classified as a facultative intracellular parasite that has an incubation period of 10 to 14 days and can cause symptoms that include continued fevers, intestinal inflammation, formation of intestinal ulcers, splenic enlargement, toxemia, and the production of a characteristic "rose-spot" eruption on the abdomen. These bacteria are usually associated with areas of poor sanitation but can also be transmitted by the common house fly. The organisms do not multiply in water but can live for several weeks in water and can be transported over large distances.

Shigella sp. is similar to *Salmonella* sp. in its mode of transmission but has a much shorter incubation period (1 to 7 days). It produces severe dysentery with production of a potent exotoxin. The optimum growth temperature for the organism is 37°C (99°F), but it can grow at much higher temperatures.

Aeromonas sp. is also a facultative anaerobe and has been isolated from tap water, rivers, soil, and marine environments, as well as various foods. It has been isolated from healthy individuals, as well as those with diarrheal symptoms. It is primarily an opportunistic pathogen, although some strains produce a potent enterotoxin that increases its pathogenicity.

Pseudomonas aeruginosa can be found in soil, humidifiers, hospital respirators, water, and sewage and on the skin of healthy individuals. Certain strains can produce a potent endotoxin, and the organism can cause symptoms that include fever, bacteriuria, bacteremia, pneumonia, otitis, and opportunistic wound and ophthalmic infections. The organism can survive and grow in a wide range of environmental conditions.

Actinomycetes are ubiquitous and can be found in soil, water, and the oral flora of man (usually associated with caries). Infections are primarily opportunistic, but very aggressive strains can produce pulmonary disease; cervical or intestinal infections are not uncommon. This organism can also survive a wide range of environmental conditions, with thermophilic types being the most pathogenic.

Although the above-mentioned organisms are ubiquitous, the ingestion or inhalation of small quantities of these organisms would not adversely affect the health of individuals who are not immunosuppressed. However, inhalation of endotoxins and exotoxins produced by several of these organisms, which are readily aerosolized, may theoretically affect even healthy individuals who come in contact with mist, vapor, or minute droplets of water. No reports have been identified that suggest such occurrences in power plant workers. *Legionella* sp. infections, on the other hand,

can be infectious for uncompromised healthy workers.

The clinical significance of *Legionella* sp. was dramatized by the namesake outbreak in 1976 at an American Legion convention in Philadelphia (McDade et al. 1977). At this convention more than 100 people became ill and 34 died. After an intensive effort, laboratory isolations were made of the causative agent, *L. pneumophila*. Since 1977, various serogroups of *L. pneumophila* and more than 30 species of *Legionella* have been discovered (Thornsberry et al. 1984). *Legionella* sp. are gram-negative rods approximately 0.5 × 2.4 μm in size. Infection generally occurs by inhalation of the aerosolized bacteria. Two disease syndromes can be manifested by infection with *Legionella* sp. Legionnaires' Disease is a pneumonia with associated cough, fever, and malaise (Lattimer and Ormsbee 1981). The disease can be fatal, although Erythromycin is effective in treating it. Legionellosis may also be expressed as Pontiac fever, a nonpneumonic, flu-like illness that also responds to Erythromycin therapy (Fraser et al. 1979).

Estimates of the number of cases of Legionellosis range from 25,000 to 200,000 per year (W. H. Wilkinson, telephone interview with R. L. Tyndall, Oak Ridge National Laboratory, Oak Ridge, Tenn., 1982). Some of the known Legionellosis outbreaks were traceable to the aerosolization of water-borne *Legionella* sp. by cooling towers and evaporative condensers (NUREG/CR-1207; Berendt et al. 1980). The cooling devices are presumably seeded with *Legionella* sp. from their potable and natural water supplies. That *Legionella* sp. in fact are normal components of the aquatic flora was first demonstrated by Fliermans et al. (1981) and has been confirmed by subsequent studies (Fliermans 1985). In view of this ubiquity in natural surface waters, it is not surprising that water in cooling towers and evaporative condensers contains *Legionella* sp. These devices can then amplify *Legionella* sp. concentrations and disperse the pathogen through aerosolization.

In contrast to *Legionella* sp., the presence of *Naegleria* sp. in water and soil was known before their clinical significance was recognized. Butt (1966) and Carter (1970) described the first cases of *Naegleria* sp. infection in Floridian and Australian children who were infected by swimming or bathing in *Naegleria* sp.–infested waters. *Naegleria* sp. are small amoebae capable of using dissolved organic material or gram-negative bacteria as a food source. They are eukaryotic cells that generally have a single nucleus and a centrally located nucleolus. Locomotion is by means of eruptive pseudopodia. Four species of *Naegleria* have been isolated. *N. gruberi* and *N. jadini* have not shown any pathogenic potential in experimental animals or in man. *N. australiensis* is pathogenic for mice but as yet has not been implicated in human diseases. *N. fowleri* is pathogenic for humans and mice (Rondanelli 1987).

On entry into the nasal passage of a susceptible individual, *N. fowleri* will penetrate the nasal mucosa and migrate along the olfactory nerve through the cribriform plate to the cerebrum. The ensuing infection results in a rapidly fatal meningoencephalitis (Rondanelli 1987). Antibiotic therapy is generally ineffectual. Fortunately, primates in general are resistant to infection with *N. fowleri*. This has been demonstrated in laboratory studies with chimpanzees and in epidemiologic studies at sites where fatal cases of primary amoebic meningoencephalitis (PAME) occurred (Wong et al. 1975). In such cases, hundreds

of individuals were exposed, but only a single case of PAME occurred. Reasons for the susceptibility of the occasional individual are unknown. After reports of fatal cases of PAME in Australia and Florida, other cases of PAME were reported. Sources of infections included heated swimming pools (Cerva 1971), thermal springs (Hecht et al. 1972), and a variety of naturally or artificially heated surface waters (Fliermans et al. 1979; DeJonckheere 1978). One of the largest clusters of PAME occurred in Virginia, where 16 cases were reported over a 9-year period (Duma et al. 1971). Unlike the thousands of cases of Legionellosis per year in the United States alone, only 100 to 200 cases of PAME have been reported to date worldwide. Hallenbeck and Brenniman (1989) reviewed the world literature to derive a risk analysis model that would be helpful in the management of PAME. They concluded that the management of PAME risk was difficult; the prevention, almost impossible. However, they estimated the lifetime risk of PAME to be 4×10^{-5}, assuming 10 exposures per swimming season and 10 swimming seasons. As with *Legionella* sp., simple, rapid assays for detecting and quantifying *N. fowleri* in aquatic environments are not generally available.

In 1981, cooling waters of 11 nuclear power plants and associated control source waters were studied for the presence of thermophilic free-living amoebae, including *N. fowleri*. Presence of pathogenic *N. fowleri* was demonstrated by mouse inoculations. While all but one test site was positive for thermophilic free-living amoebae, only two test sites were positive for pathogenic *N. fowleri*. Pathogenic *N. fowleri* were not found in control source waters (NUREG/CR-2980). A recent analysis of heated water from a nuclear plant that began operations within the past 3 years also showed the presence of *N. fowleri*. Water from the plant impacts a public swimming area (Huizinga and McLaughlin 1990).

In addition to testing for pathogenic amoebae in cooling waters, the 11 nuclear power plants in the 1981 study were also studied for the presence of *Legionella* sp. (NUREG/CR-2980). Concentrations of *Legionella* sp. were determined microscopically by fluorescent antibody analysis, and infectious *Legionella* sp. were demonstrated by guinea pig inoculation. In general, the artificially heated waters showed only a slight increase (i.e., ≤ 10-fold) in concentrations of *Legionella* sp. relative to source water. In a few cases, source waters had higher levels than did heated waters. Infectious *Legionella* sp. were found in 7 of 11 test waters and 5 of 11 source waters.

Subsequently, a more detailed study of *Legionella* sp. presence in the environs of coal-fired electric power plants was undertaken to determine the distribution, abundance, and infectivity and aerosolization of *Legionella* sp. in power plant cooling systems (NUREG/CR-3364; EPRI/EA-4017; EPRI/EA-3153).

This study found that the infrequent occurrence of positive air samples at locations not adjacent to cleaning operations suggests that aerosolized *Legionella* sp. associated with downtime procedures have minimal impact beyond these locations. Even within plant boundaries, detectable airborne *Legionella* sp. appear to be confined to very limited areas. In these areas, however, the more contact individuals have with the most concentrated *Legionella* sp. populations—particularly if these become aerosolized as they do in some downtime operations—the more likely it becomes that workers may be exposed.

Exposure to *Legionella* sp. from power plant operations, while a potential problem for a subset of the work force, would not generally impact the public because concentrated aerosols of the bacteria would not traverse plant boundaries. Plant personnel most likely to come in contact with *Legionella* aerosols would be workers who dislodge biofilms, where *Legionella* are often concentrated, such as during cleaning of condenser tubes and cooling towers. Since Legionellosis is a respiratory disease, workers engaged in such activities should be protected by wearing appropriate respiratory protection.

Because the route of infection with *N. fowleri* is nasal, workers exposed to aerosols of this pathogen also should be protected with respiratory protection. If involved in underwater maintenance or other activities associated with thermally altered discharge waters known to harbor *N. fowleri*, workers should wear appropriate gear to prevent entry of the amoebae into the nasal cavity. The observed risk to swimmers from waters infected with *N. fowleri* is low but not zero (Hallenbeck and Brenniman 1989). Nevertheless, heavily used bodies of fresh water merit special attention and possibly routine monitoring for pathogenic *Naegleria*. Policies for public swimming and water skiing in plant discharges known or suspected to harbor *N. fowleri* should be reviewed by state health departments. Since *Naegleria* concentrations in fresh water can be enhanced by thermal additions, nuclear power plants that utilize cooling lakes, canals, ponds, or small rivers may enhance the naturally occurring thermophilic organisms.

REFERENCES

Berendt, R. F., et al., "Dose-Response of Guinea Pigs Experimentally Infected with Aerosols of *Legionella pneumophila*," *Journal Infectious Diseases*, 141(2), 186, 1980.

Butt, C., "Primary Amoebic Meningoencephalitis," *New England Journal of Medicine*, 274, 1473–76, 1966.

Carter, R. F., "Description of a *Naegleria* sp. Isolated from Two Cases of Primary Amoebic Meningoencephalitis," *Journal of Pathology*, 100, 217–44, 1970.

Cerva, L., "Studies of *Limax Amoebae* in a Swimming Pool," *Hydrobiologia*, 38, 141–61, 1971.

DeJonckheere, J. F., "Quantitative Study of *Naegleria fowleri* in Surface Waters," *Protistogica*, 14, 475–81, 1978.

Duma, R. J., et al., "Primary Amoebic Meningoencephalitis: A Survey in Virginia," *Archives of Environmental Health*, 23, 43–47, 1971.

EPRI/EA-3153, S. W. Christensen et al., *Legionnaire's Disease Bacterium in Power Plant Cooling Systems: Phase I Final Report*, Electric Power Research Institute, Palo Alto, California, 1983.

EPRI/EA-4017, R. L. Tyndall et al., *Legionnaires' Disease Bacteria in Power Plant Cooling Systems: Phase II Final Report*, Electric Power Research Institute, Palo Alto, California, 1985.

Fliermans, C. B., et al., "Isolation of *Naegleria fowleri* from Artificially Heated Waters," *Journal Thermal Biology*, 4, 303–6, 1979.

Fliermans, C. B., et al., "Ecological Distribution of *Legionella pneumophila*," *Applied Environmental Microbiology*, 41(1), 9–16, 1981.

Fliermans, C. B., "Ecological Niche of *Legionella pneumophila*," *Critical Reviews in Microbiology*, 1985.

Fraser, D. W., et al., "Nonpneumonic, Short-Incubation-Period Legionellosis (Pontiac Fever) in Men Who Cleaned a Steam Turbine Condenser," *Science*, **205**, 690–91, 1979.

Hallenbeck, W. H., and G. R. Brenniman, "Risk of Fatal Amoebic Meningoencephalitis from Waterborne *Naegleria fowleri*," *Environmental Management*, 13(2), 227–32, 1989.

Hecht, R. H., et al., "Primary Amebic Meningoencephalitis in California," *California Medicine*, **117**, 69–73, 1972.

Huizinga, H. W., and G. L. McLaughlin, "Thermal Ecology of *Naegleria Fowleri* from a Power Plant Cooling Reservoir," *Applied Environmental Microbiology*, 2200–05, July 1990.

Lattimer, G. L., and R. A. Ormsbee, *Legionnaires' Disease*, Mercel Dekker, New York, 1981.

McDade, J. E., et al., "Legionnaires' Disease: Isolation of a Bacterium and Demonstration of Its Role in Other Respiratory Disease," *New England Journal of Medicine*, **297**, 1197–203, 1977.

NUREG/CR-1207 (ANL/ES-83), A. P. Adams and B. A. G. Lewis, *Microbial Aerosols from Cooling Towers and Cooling Sprays: A Pilot Study*, Argonne National Laboratory, Argonne, Illinois, 1979.

NUREG/CR-2980, R. L. Tyndall, *Presence of Pathogenic Micro-Organisms in Power Plant Cooling Waters, Report for October 1, 1979 to September 30, 1981*, Oak Ridge National Laboratory, Oak Ridge, Tennessee, 1981.

NUREG/CR-3364 (ORNL/TM-8809), R. L. Tyndall, *Presence of Pathogenic Microorganisms in Power Plant Cooling Waters: Final Report for October 1, 1981, to June 30, 1983*, Oak Ridge National Laboratory, Oak Ridge, Tennessee, 1983.

Rondanelli, E. G., ed., "Infectious Diseases," Color Atlas Monographs 1, *Amphizoic Amoebae Human Pathology*, Piccin, Pavia, Italy, 1987.

Thornsberry, C., et al., eds., *Legionella, Proceedings of the 2nd International Symposium*, American Society for Microbiology, Washington, D.C., 1984.

Wong, M. M., et al., "Experimental Infections with Pathogenic Free-Living Amoebae in Laboratory Primate Hosts. (A) A Study of Susceptibility to *N. fowleri*," *Journal Parasitol*, **61**, 199–208, 1975.

APPENDIX E

RADIATION PROTECTION CONSIDERATIONS FOR NUCLEAR POWER PLANT LICENSE RENEWAL

RADIATION PROTECTION CONSIDERATIONS FOR NUCLEAR POWER PLANT LICENSE RENEWAL

Radiological issues are associated with the process of refurbishment and with normal operation in the period after license renewal. Both occupational personnel and members of the public will be affected by these processes as a result of radiation exposures in the plants and as a result of small losses of radioactive materials in the gaseous and liquid effluents.

This appendix is intended to provide pertinent background information for analyses and to supplement discussions in the Generic Environmental Impact Statement (GEIS).

E.1 THE REGULATORY STANDARDS PROCESS

Government agencies establish basic radiation protection standards that are consistent with guidance to federal agencies issued by the President. This guidance is prepared by interagency committees and reflects recommendations published by expert groups such as the International Commission on Radiological Protection (ICRP) and the National Council on Radiation Protection and Measurements (NCRP). In the preparation of their reports, the ICRP and NCRP scientific committees rely heavily on information published by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and other publicly available information. The UNSCEAR reports contain detailed radiobiological and epidemiological information that has been acquired on a worldwide basis. Through this system, the U.S. federal agencies maintain consistency in their basic standards, and scientific consensus on an international basis is ensured. The standards are published in the *Federal Register* for public comment before issuance in final form, and public hearings are often held.

E.2 RADIATION PROTECTION STANDARDS

E.2.1 Occupational

E.2.1.1 Basic Standards

The occupational radiation protection standards of primary interest are those for exposure of the whole body. These standards have changed at different times, as shown in Table E.1. The downward trend is evident, from 1.0 R/week (or 50 R/year) in 1947 to the current 5.0 rem/year total effective dose equivalent (TEDE). The table does not reveal the fact that, before introduction of the TEDE quantity, the permitted dose from radionuclides deposited in the body was in addition to the permitted dose from external sources. The dose data for nuclear power plant (NPP) workers are presented in Section E.3.1.

The U.S. Atomic Energy Commission (AEC) regulatory/Nuclear Regulatory Commission (NRC) standards in 10 CFR Part 20 have changed infrequently. Tables E.2 and E.3 present a summary of the occupational standards which were in effect from 1960 through 1990 (old Part 20) and standards in effect from 1991 (new Part 20). On an annual basis, the whole-body limit has decreased from 15 R (3 R/quarter) in 1957

Table E.1 Occupational radiation dose limits for the whole body[a]

Year	NCRP[b]	ICRP[b]	Federal guidance	AEC/DOE[b]	AEC-REG/NRC[b]
1947	0.1/day 0.5/week	0.2/day 1.0/week	—	0.1/day	—
1949	0.3/week	—	—	—	—
1950	—	3.0/week	—	0.3/week	—
1954	3.0/quarter 0.3/week	—	—	3.0/quarter 0.3/week	—
1957	—	—	—	—	0.3/week
1958	3.0/quarter 5.0/year average	—	—	3.0/quarter 0.3/week 5.0/year average	—
1960	—	—	3.0/quarter 5.0/year average	3.0/quarter 5.0/year average	—
1961	—	—	—	—	1.25/quarter or 3.0/quarter with 5.0/year average
1965	—	3.0/quarter 5.0/year maximum	—	—	—
1971	3.0/quarter 5.0/year maximum	—	—	—	—
1977	—	5.0/year EDE	—	—	—
1987	5.0/year EDE	—	5.0/year EDE	—	—
1988	—	—	—	5.0/year EDE	—
1991	—	—	—	—	5.0/year TEDE

[a]Units: 1947–57, the roentgen; 1958–76, the rem dose equivalent (DE); 1977 to present, the rem effective dose equivalent (EDE). The rem unit signifies the DE quantity except for the final entry in each column, where the quantity is the EDE. EDE is external, internal, or both The ICRP has announced its intention to reduce its limit to 2 rem/year total EDE, with a provision for operational flexibility. To convert rem to sievert, multiply by 0 01
[b]NCRP = National Council on Radiation Protection and Measurements; ICRP = International Council on Radiation Protection; AEC = Atomic Energy Commission; DOE = U.S Department of Energy; NRC = Nuclear Regulatory Commission.

(external radiation only) to 5 rem effective dose equivalent (EDE) (external plus internal). Regulatory control over the intake of radioactive materials in the workplace has always been a complex issue. Details are presented as a matter of interest in Attachment E.A. Before the new Part 20, limits on the intake of radioactive material into the body were based on the critical organ concept. The critical organ for a nuclide was the organ receiving the greatest radiation insult (considering its dose limit)

Table E.2 Occupational dose limits for adults under "Old Part 20" guidelines[a]

Tissue	External radiation	Internal radiation
Whole body	3 rem/quarter maximum, 5 rem/year average	
Lens	3 rem/quarter maximum, 5 rem/year average	
Extremities, including skin	18.75 rem/quarter	
All other skin	7.5 rem/quarter	
Thyroid		30 rem/year
Bone		30 rem/year
Marrow		5 rem/year
Gonads		5 rem/year
All other organs		15 rem/year

[a]Old Part 20 guidelines were in effect since 1960; the new Part 20 came into effect in 1991.
Note: To convert rem to sievert, multiply by 0.01.

from the intake of a specific radionuclide in a certain chemical form. AEC/NRC licensees were required to limit the quarterly intake of a given radionuclide to an amount that, under equilibrium conditions (rate of intake equal to the rate loss by decay or elimination), would deliver to the critical organ a dose equal to the limit for that organ. (The dose to the organ from radiation sources external to the body was not considered.) If a nuclide would not achieve equilibrium in the critical organ within 50 years, the quarterly intake limit would produce, at the end of 50 years, an annual dose equal to the limit for that organ.

This method of control did not take into consideration the risk to organs other than the critical organ. Beginning in 1991, NRC abandoned the critical organ approach in favor of the method published by the ICRP in its Publication 26 (described in Attachment E.A). Under the ICRP method, the dose to each significantly irradiated organ is weighted according to its sensitivity. The weighted doses are summed to produce an EDE that can be added to the dose from external sources.

The revised Part 20 provides additional flexibility for establishing more accurate dose controls. It allows the use of actual particle-

Table E.3 Occupational dose limits for adults under "New Part 20" guidelines[a]

Tissue	External radiation	Internal plus external radiation
Whole body	5 rem/year total dose equivalent,[b] not to exceed 50 rem/year total dose equivalent to any individual organ or tissue other than the lens of the eye	5 rem/year total effective dose equivalent,[c] not to exceed 50 rem/year total dose equivalent to any individual organ or tissue other than the lens of the eye
Lens	15 rem/year	
Extremities, including skin	50 rem/year	
All other skin	50 rem/year	
Thyroid		
Bone		
Marrow		
Gonads		
All other organs		

[a]New Part 20 guidelines became effective in 1991.
[b]The total dose equivalent is the sum of the external dose equivalent (at 1 cm depth) and the committed dose equivalent from nuclides deposited in the body.
[c]The total effective dose equivalent is the sum of the external dose equivalent (at 1 cm depth) and the committed effective dose equivalent from nuclides deposited in the body.
Note: To convert rem to sievert, multiply by 0.01.

size distribution and physiochemical characteristics of airborne particulates to define site-specific derived air concentration limits. With NRC approval, these modified concentration limits can be used in lieu of generic values provided in Part 20. Such adjustments result in the use of more precise estimates that use actual exposure conditions as compared with generic assumptions.

Although these adjustments might permit higher airborne radionuclide concentration limits to be used, the same degree of health protection would exist because the radiation dose (and risk) would remain the same as that intended in the generic values.

E.2.1.2 ALARA

Following the accident at Three Mile Island, the NRC required a number of improvements that caused the industry-wide annual collective dose (and the individual annual average) to increase temporarily. However, for two primary reasons, these dose values soon began to decrease and have continued to do so. First, the NRC and a new industry organization, the Institute of Nuclear Power Operations, began to demand better performance with respect to dose reduction. Second, additional risk information, primarily from the atomic bomb survivor study, became available. In 1977, the ICRP adopted risk estimates of 1.25 cancer fatalities and 0.4 serious genetic effects among 10,000 people (and their progeny for two generations) receiving 10,000 person-rem (ICRP Publication 26); in 1980, the National Academy of Sciences (NAS) published a revision of the 1972 Biological Effects of Ionizing Radiation (BEIR-I) report. The new report, BEIR-III, contained a range of radiation-risk estimates that, together with the ICRP estimate, caused the risk value previously mentioned to be doubled. It was recognized that the resulting 5 percent fatality estimate (to be associated with 5 rem/year for a working lifetime) was derived from instantaneous exposure, that actual lifetime occupational doses were far fewer than 250 rem as used in the estimate, and that the estimate was therefore of limited use in the standards development process. However, largely because of nonquantitative information indicating that instantaneous radiation was more carcinogenic than had been believed, efforts to ensure that radiation doses were as low as reasonably achievable (ALARA) were redoubled. Without specific regulations, the average annual occupational dose for the nuclear power plant (NPP) worker population fell below 0.5 rem, meeting or exceeding the ICRP overall occupational risk criterion of 1 fatality per 10,000 workers per year (ICRP Publication 26). In 1968, the percentage of NPP workers who received more than 5 rem was 0.5 percent, and three persons had doses in excess of 12 rem. By 1986, the percentage of workers receiving more than 5 rem was less than 0.01 percent, and no individual received more than 12 rem.

Two regulatory guides have been issued to provide guidance on ALARA programs for NPPs, one on ALARA philosophy (NRC Regulatory Guide 8.10, Rev. 1R) and one on implementation (NRC Regulatory Guide 8.8, Rev. 3). NPP licensees are required to maintain and implement adequate plant procedures that contain ALARA criteria. During plant licensing, applicants commit to implement ALARA programs consistent with Regulatory Guides 8.8 and 8.10. The 1991 revision to 10 CFR Part 20 codifies this requirement that licensees implement a program to maintain radiation doses ALARA. Compliance with the commitments is required through 10 CFR Part 50 and the technical specifications.

Recent developments among the Japanese atomic bomb survivors (as discussed in Section E.4) have revealed that gamma (and possibly neutron) radiation delivered uniformly at high doses and high dose rates is an even more efficient carcinogen than was believed (RERF TR 12-87). The new occupational risk estimates that result imply that an average annual dose of 0.5 rem may not meet the ICRP criteria of one fatality per year among 10,000 workers. ICRP has published revised recommendations concerning dose limits. Increased emphasis on the ALARA concept is therefore indicated and is adopted in the 1991 revision of Part 20.

E.2.2 Public

E.2.2.1 Basic Standards for Dose from Controlled Sources

The current federal guidance on radiation protection for the general public was issued in 1960 (FR 25, 97, May 18, 1960) and is now undergoing revision by an interagency committee chaired by the U.S. Environmental Protection Agency (EPA). The annual dose-equivalent limit for the whole body specified in the 1960 guidance is 0.5 rem.

For many years, the ICRP and NCRP recommended dose limits for the public that were 10 percent of those for workers. During the 1980s, both organizations adopted a more conservative value of 2 percent. In 1985, following a meeting of the ICRP in Paris, France, the ICRP released a statement that its principal limit for the whole body is 0.1 rem/year EDE (ICRP 1985). However, a subsidiary limit of 0.5 rem/year is authorized provided that the average dose does not exceed 0.1 rem/year. The ICRP limit for the skin and lens of the eye is 5 rem/year. In 1987, the NCRP recommended limits of 0.1 rem/year EDE for the whole body under conditions of continuous or frequent exposure and 0.5 rem/year for infrequent exposure (NCRP 1987). The NCRP limit for the lens of the eye, skin, and extremities is 5 rem/year.

Prior to the 1991 version of 10 CFR Part 20, the AEC and NRC required applicants for a license to operate a nuclear facility to demonstrate that an individual would be unlikely to receive in excess of 0.5 rem to the whole body in a year. In 1991, a limit of 0.1 rem/year EDE was imposed.

With regard to limits on radioactive material deposited in the body, until the advent of the EDE, annual average concentration values [or maximum permissible concentrations (MPCs)] were specified that would deliver (under equilibrium conditions) the following doses to critical organs: thyroid and bone, 1 rem/year; whole body and gonads, 0.05 rem/year; all other organs, 0.5 rem/year (ICRP 1960). The MPCs were recommended by the ICRP and NCRP and used in 10 CFR Part 20 (until 1991). The revised Part 20 employs the annual limits on intake (ALIs) and derived air concentrations (DACs) now recommended by these organizations. When these values are used, the EDE is limited to 0.1 rem/year. To provide additional protection for children and others who are smaller than the "reference man" used for the calculation of the ALIs, the new 10 CFR Part 20 specifies ALIs and DACs based on 0.05 rem/year.

E.2.2.2 ALARA Standards

In addition to the basic standards mentioned above, 10 CFR Part 50.36(a) contains license conditions that are imposed on licensees in the form of technical specifications applicable to effluents from nuclear power reactors. These specifications will ensure that releases of radioactive materials to unrestricted areas during normal operations, including expected operational occurrences, remain ALARA. Appendix I to 10 CFR Part 50 provides numerical guidance on dose-design objectives and limiting conditions for operation for light-water reactors (LWRs) to meet the ALARA requirements. As a part of the licensing process, all licensees have provided reasonable assurance that the design objectives will be met for all unrestricted areas. 10 CFR Part 20 requires compliance with EPA regulation 40 CFR Part 190, which also contains ALARA limits. The

dose constraints are summarized in Tables E.4 and E.5.

E.3 NUCLEAR POWER PLANT EXPOSURE DATA

E.3.1 Occupational

E.3.1.1 Past Data

Individual occupational doses are measured by NRC licensees as required by the basic NRC radiation protection standard, 10 CFR Part 20. The measurement results of primary interest are those recorded for exposure of the whole body to radiation from sources that are external to the body. The whole-body dose must be determined at a depth of 1 cm from the surface of the body. Measurements of the whole-body dose are normally derived from personal dosimeters worn by each worker. Since 1984, many of the NPPs have provided dosimetry programs accredited by the National Bureau of Standards [NBS, now National Institute of Standards and Technology (NIST)]; in general, ±50 percent accuracy is required. In 1988, NBS/NIST accreditation became an NRC requirement.

Whole-body dose data from NRC-licensed LWRs are shown in Tables E.6 and E.7 for the years 1973 through 1992. For each year, the number of reactors, the number of workers receiving measurable exposures, the workers' average annual dose, the collective (person-rem) dose for all reactors combined, and the number of individuals exceeding 12 rem are given. (The collective dose is the sum of all personal doses.) The collective and average annual doses appear to be leveling at about 30,000 person-rem and 0.3 rem respectively.

With regard to individual doses, Table E.8 reveals that fewer than 500 workers (0.5 percent) received whole-body doses exceeding 2 rem during 1992. No worker exposure exceeded 5 rem during that calendar year.

The NRC regulates the dose to the gonads and the lens of the eye by including those organs in the definition of whole body. Also included in this definition are the blood-forming organs, which are susceptible to radiation-induced leukemia. No other organs are specifically named in the definition. The dose to the extremities and the skin is regulated, although higher doses are allowed because of the lower risks. The data presented in Tables E.6–E.8 for the whole body apply to the gonads, eye lens, and bone marrow as well (neglecting attenuation). Data for the extremities and skin are recorded by licensees, but these data are listed in NRC reports only in connection with regulatory overexposures. NPP workers are exposed to airborne radioactive material—primarily fission and corrosion products—but such exposures have normally been small in comparison with external doses. Under old Part 20, licensees were not required to report inhalation exposures unless a quarterly intake limit was exceeded. Therefore, reports of internal dose issued by NRC included overexposures only. Some NPP licensees voluntarily include internal dose data in employee termination dose reports to NRC. A study of these data indicated that for ^{58}Co and ^{60}Co, the most prevalent nuclides, very few of the workers had organ burdens of more than 1 percent of the maximum permissible (see Tables E.9, E.10, and E.11).

These data indicate that occupational exposures within the nuclear power industry have been significantly reduced since 1973. Individual doses are characteristically far

Table E.4 Ten CFR Part 50, Appendix I, design objectives and annual limits on radiation doses to the general public from nuclear power plants[a]

Tissue	Gaseous	Liquid
Total body	5 mrem	3 mrem
Any organ (all pathways)	–	10 mrem
Ground-level air dose	10 mrad gamma and 30 mrad beta	–
		–
Any organ[b] (all pathways)	15 mrem	–
Skin	15 mrem	

[a]Calculated doses.
[b]Particulates, radioiodines.
Note: To convert millirem to millisievert, multiply by 0.01.

Table E.5 Forty CFR 190, Subpart B, annual limits on doses to the general public from nuclear power operations[a]

Tissue	Limit	Source
Total body	25 mrem	All effluents and direct radiation from nuclear power operations
Thyroid	75 mrem	"
Any other organ	25 mrem	"

[a]Calculated doses.
Note: To convert millirem to millisievert, multiply by 0.01.

below the regulatory limit currently in effect, and the annual average is less than 10 percent of the 5 rem/year limit that is now in effect. Effective implementation of the ALARA concept is largely responsible. The theoretical risks associated with the exposure data are discussed in Section E.4.

E.3.1.2 Considerations for the Future

The current 10 CFR Part 20 became effective in 1991. The new regulation adopted a 5-rem/year TEDE dose limit and applies this limit to external and internal doses combined. Although these constraints

Table E.6 Occupational whole-body dose data at light-water reactors

Year	Number of workers with measurable doses	Collective dose (person-rem)	Average annual dose (rem)	Number of reactors	Number of persons exceeding 12 rem in a year
1973	14,780	13,962	0.94	24	1
1974	18,139	13,650	0.75	33	1
1975	25,419	20,879	0.82	44	1
1976	34,192	26,107	0.76	52	3
1977	42,266	32,508	0.77	57	1
1978	45,978	31,801	0.69	64	3
1979	64,073	39,982	0.62	67	1
1980	80,331	53,795	0.67	68	0
1981	82,106	54,144	0.66	70	1
1982	84,381	52,190	0.62	74	0
1983	85,646	56,472	0.66	75	0
1984	90,099	55,235	0.56	78	0
1985	92,870	43,042	0.46	82	2
1986	100,923	42,381	0.42	90	0
1987	104,334	40,401	0.39	96	0
1988	103,226	40,769	0.39	102	0
1989	108,252	35,930	0.33	107	0
1990	108,658	36,592	0.34	110	0
1991	98,761	28,515	0.29	111	0
1992	103,143	29,309	0.28	110	0

Source: NUREG-0713.
Note: To convert rem to sievert, multiply by 0.01.

Table E.7 Light-water reactor (LWR) occupational whole-body dose data for boiling-water reactors (BWRs) and pressurized-water reactors (PWRs)

Year	Annual average whole-body dose (rem)		
	All LWRs	All BWRs	All PWRs
1973	0.94	0.85	1.00
1974	0.74	0.81	0.68
1975	0.82	0.86	0.76
1976	0.75	0.71	0.79
1977	0.84	0.89	0.65
1978	0.74	0.74	0.65
1979	0.66	0.73	0.56
1980	0.72	0.87	0.52
1981	0.71	0.73	0.61
1982	0.66	0.76	0.53
1983	0.70	0.82	0.56
1984	0.59	0.66	0.49
1985	0.46	0.54	0.41
1986	0.42	0.51	0.37
1987	0.39	0.40	0.38
1988	0.40	0.45	0.36
1989	0.34	0.36	0.33
1990	0.34	0.38	0.31
1991	0.29	0.31	0.27
1992	0.28	0.32	0.26

Source: NUREG-0713.
Note: To convert rem to sievert, multiply by 0.01

Table E.8 Number of workers at boiling-water reactor (BWR), pressurized-water reactor (PWR), and light-water reactor (LWR) installations who received whole-body doses within specified ranges during 1992

Dose range (rem)	BWRs	PWRs	LWRs
<0.1 (measurable)	17,740	28,220	45,960
0.1–0.25	8,094	12,503	20,597
0.25–0.5	6,883	10,259	17,142
0.5–0.75	3,995	4,926	8,881
0.75–1.00	2,339	2,287	4,626
1.00–2.00	2,366	2,602	5,468
2.00–3.00	204	245	449
3.00–4.00	11	6	17
4.00–5.00	3	0	3
5.00–6.00	0	0	0
6.00–7.00	0	0	0
7.00–12.00	0	0	0
>12.00	0	0	0
Totals	42,095	61,048	103,143

Source: NUREG-0713.
Note: To convert rem to sievert, multiply by 0.01.

are more stringent, they are not expected to have a significant impact on occupational exposures at NPPs for three reasons. First, the new regulation requires external/internal dose addition only if each type of exposure separately exceeds 0.5 rem in a year. Very few, if any, NPP workers are expected to exceed 0.5 rem from internal sources. Second, although the ICRP system being adopted by the NRC involves the determination of organ doses from external sources (as opposed to the whole-body dose at 1-cm depth), the new 10 CFR Part 20 continues to require measurement at 1 cm. Third, data in Tables E.6 and E.8 show that few, if any, workers will be affected by a reduction in the limit from essentially 12 to 5 rem/year.

The ICRP has announced its intention to reduce the 5-rem/year limit, which it currently recommends, to 2 rem/year, with a provision for maintaining operational flexibility (Radiological Protection Bulletin, No. 111). In ICRP-60, it is suggested that the 2 rem/year be applied over defined periods of 5 years. Further, provision is made that the effective dose should not exceed 5 rem in any single year.

Table E.9 Organ burden estimates submitted on employment termination reports from power reactors, 1975–1981

Year	Nuclide	Number of records	Organ burden estimates
1975	^{58}Co	22	all burdens <1% MPOB[a]
	^{60}Co	22	all burdens <1% MPOB
1980	^{58}Co	1410	98% of burdens <1% MPOB
	^{60}Co	5098	98% of burdens <2% MPOB
1981	^{58}Co	1246	98% of burdens <1% MPOB
	^{60}Co	4418	98% of burdens <2% MPOB

[a]MPOB = maximum permissible organ burden
Source· NUMARC (1989).

Table E.10 Estimated number of workers with organ burdens (in % MPOB[a]) from ^{58}Co and ^{137}Cs, 1983–1987[b]

Year	<1%	1-2%	2-3%	>3%
1983	8042	2	0	1
1984	5024	4	0	3
1985	2744	0	0	0
1986	2255	4	1	4
1987	1154	0	0	0

[a]MPOB = maximum permissible organ burden.
[b]Data taken from termination reports for employees of power reactors.
Source: NUMARC (1989).

Table E.11 Estimated number of workers with organ burdens (in % MPOB[a]) from ^{60}Co, 1983–1987[b]

Year	<1%	1-2%	2-3%	>3%
1983	3480	8	1	0
1984	2284	4	1	3
1985	764	2	0	0
1986	772	2	1	1
1987	596	0	0	0

[a]MPOB = maximum permissible organ burden.
[b]Data taken from termination reports for employees of power reactors.
Source· NUMARC (1989).

E.3.2 Public

The radiation dose to people who live in the vicinity of a U.S. NPP averages about 0.8 μrem/year. Pertinent data are provided in the following paragraphs.

Each year, the NRC issues a report titled *Population Dose Commitments Due to Radioactive Releases from Nuclear Power Plant Sites in XXXX*. The most recent volume covers the year 1989 (NUREG/CR-2850, vol. 11, February 1993) (see Table E.12). Radioactive material is released in gaseous and aqueous effluents under stringently controlled conditions in accordance with technical specifications and NRC regulations. The term "dose commitment" indicates that the reported doses come from the inhalation and ingestion of radionuclides, as well as from external radiation from noble gases; the population dose caused by direct radiation from plant buildings is negligible. The doses are calculated by the licensees in accordance with guidance provided by the NRC and based on measurements made at the point of release as well as in the environment. These measurements are performed and recorded by the licensees; however, the NRC conducts its own verification measurements. The prescribed calculation methods include several basic assumptions to ensure that the results are conservative. Table E.13 presents results obtained for a 15-year period ending in 1989. The numerical entries are person-rem received by those who live within an 80-km (50-mile) radius of a site; data for individual sites also appear in this report.

The total population dose within 80 km (50 miles) of each plant is calculated (Table 4 in NUREG/CR 2850, vol. 11) for each operating reactor in the United States. The number of person-rem is obtained by adding the individual doses received by this population. For 1989, the total number of person-rem varied from a low of 0.0017 at Grand Gulf to a high of 16 at McGuire. Seventy-five percent of the total came from 9 of the 67 sites, as shown in Table E.14. In the site summaries section of each report, dose data for each site are provided for airborne and waterborne pathways and are categorized by total body and individual organs. The doses received by workers at the plants and members of the public are shown in Table E.13 for comparison.

Projections into the future can be made on the basis of current trends. Therefore, an analysis of dose commitment information was performed. The first objective was to determine to what extent known information about the sites could be used to predict what the dose commitment values for the sites were for the years 1979–1989. The second objective, if prediction of current dose commitments could be done adequately, was to use the models to predict future dose commitment for U.S. sites by extrapolating into future years the characteristics used in the model and the population projections for the sites. Table E.15 portrays information that was available about U.S. nuclear power reactor sites.

Using these variables, other site characteristics were computed. These include the following:

- Interval from startup to observation (calendar year–year of startup).
- Status. This variable was based on the capacity factor. If the capacity factor was below 25 percent for the year, the site was designated as "down." If the capacity factor was above 25 percent, status was designated as "up" for that year. The cutoff point was chosen based on the observation that sites generally

Table E.12 Individual public dose data from power plant effluents, 1988

Individual dose range (mrem)	Percent of total	Cumulative percent
0 to 0.000001	6%	6%
0.000001 to 0.00001	4%	10%
0.00001 to 0.00003	18%	28%
0.00003 to 0.0001	30%	58%
0.0001 to 0.0003	21%	79%
0.0003 to 0.001	13%	92%
0.001 to 0.003	5%	97%
0.003 to 0.01	< 2%	99%
0.01 to 0.03	< 1%	100%

Source NUREG/CR-2850.
Note: To convert millirem to millisievert, multiply by 0 01.

were either substantially below that value or above it by a large margin. Status is a categorical variable representing the level of operation for a given year.

- Total output, which is the product of total megawatt size and capacity factor and is an estimate of output for a given year. A linear model was fitted to the dose data using combinations of the above variables as independent variables. Clearly, observed doses cannot be negative, and the model predictions also should not be negative. For this reason, the linear model was fit to *ln*(dose). The resulting model was then of the form

Dose = exp (linear function of independent variables) .

The resulting model also provided a considerably improved fit to the data over the linear model, based on the proportion of variability accounted for by the model.

Because population total dose commitment is the sum of the estimated population liquid dose commitment and the population air dose commitment, the liquid and air components were estimated separately, and the sum of the two estimates was used as the model estimate for the total population dose commitment. This proved to produce a better estimate than did a direct fit to the population total dose commitment.

To determine the best fit, various combinations of independent variables were tried based on percentage of total variability accounted for by the model. Not all variables can be included at one time because some are determined by combinations of others. Because all boiling water reactors (BWRs) in this analysis were manufactured by General Electric Co. (GE), it was not

Table E.13 Summary of population and occupational doses (person-rem) for all operating nuclear power plants combined

Year	Population			Occupational
	Liquid	Air	Total	
1975	76	1,300	1,300	20,879
1976	82	390	470	26,107
1977	160	540	700	32,508
1978	110	530	640	31,801
1979	220	1,600	1,800	39,982
1980	120	57	180	53,795
1981	87	63	150	54,144
1982	50	87	140	52,190
1983	95	76	170	56,472
1984	160	120	280	55,235
1985	91	110	200	43,042
1986	71	44	110	42,381
1987	56	22	78	40,401
1988	65	9.6	75	40,769
1989	68	16	84	35,980
1990	—[a]	—	—	35,592
1991	—	—	—	28,515
1992	—	—	—	29,309

[a]Data not available.
Source: NUREG/CR-2850; NUREG-0713.
Note: To convert person-rem to person-sievert, multiply by 0.01.

Table E.14 Highest public dose data from nuclear power plant effluents, 1988

Plant	Population dose (person-rem)	Population within 50 miles (80 km) (persons)	Average individual dose (mrem)
McGuire	16	1,800,000	0.0091
Summer	13	900,000	0.014
Zion	7.2	7,300,000	0.001
E. I. Hatch	6.4	350,000	0.018
Clinton	4	2,700	0.0015
Oconee	3.8	9,900	0.0039
Oyster Creek	2.2	3,600,000	0.0006
Harris	1.8	1,400,000	0.0013
Calvert Cliffs	1.7	2,800	0.00061
All sites	75	150,000,000[a]	0.0005

[a]This figure is inflated because not all sites are 100 miles apart, and some persons within each 50-mile radius were counted more than once.
Source Adapted from NUREG/CR-2850.
Note: To convert person-rem to person-sievert or millirem to millisievert, multiply by 0.01.

Table E.15 Information on U.S. nuclear power reactor sites that was used to model future trends

Age-time characteristics	Reactor operating characteristics
Year of first startup (first year of operation of any reactor at the site)	Total megawatt capacity by calendar year (sum of capacities of all reactors)
Calendar year (year of observation of dose value)	Capacity factor by calendar year (percentage of total megawatt capacity output in calendar year)
	Site reactor type (boiling water or pressurized water)
	Reactor manufacturer (if more than one, designated mixed). Manufacturers were General Electric Company, Westinghouse, Combustion Engineering, Babcock-Wilcox, and mixed

possible to include both site type [BWR/pressurized water reactor (PWR)] and vendor as independent variables. Including vendors proved to produce a better-fitting model. The independent variables that proved to be most predictive of the *ln*(dose) values included the following:

- calendar year,
- year of startup,
- size in megawatts,
- vendor or manufacturer, and
- status (up or down).

The first three variables are continuous and are included as covariates in the model. The last two are categorical variables and are treated as class variables in the model. Because the manufacturer proved to be an important factor in the relationship of dose to the independent variables, the vendor was taken into account for each reactor in the prediction equations. To do this, estimates of the coefficients (and significance) for the remaining independent variables were made separately for the vendor categories. Because the covariates were estimated *within* the different manufacturer (vendor) categories, differences in the values of the covariates among vendors are not taken into account when vendors are compared. Thus, for example, if sites with GE reactors have larger megawatt capacities than do other reactors, that difference influences the comparisons for the vendors.

Three sites proved to be highly variable in dose commitments and thus tended to unduly influence the linear model fit: Browns Ferry, Nine Mile Point, and Oyster Creek (all of which were GE BWRs). To exclude undue influence of these three sites on the results, the results reported are those for the model fitted to the subset, not including these sites. Three Mile Island (Babcock-Wilcox, PWR) was also excluded because it represented an accident scenario rather than routine releases, and the dose values were substantially larger for certain years than at any other reactor sites.

Tables E.16, E.17, and E.18 give the results of the linear model fitted to *ln*(dose) for liquid, air, and average individual doses, respectively. If a variable (startup year, for example) has a different pattern in the two site types, the *p* value for each site type is given because an overall value is no longer meaningful. The overall model accounts for approximately 42 percent of the variation in the *ln*(air dose) values.

Overall, liquid doses are much less predictable than air doses, as the resulting model fit for the liquid doses indicates. For liquid doses, the best-fitting model accounted for only about 20 percent of the overall variability in the model.

The linear model accounts for 27 percent of the variability in the log of the average individual dose commitment values.

Using the coefficients estimated within the analysis, it is evident that the population dose commitments by site and by calendar year are being systematically lowered. Results of the analysis were used to plot historical data against predicted doses. (See example figures in Attachment E.C.) These figures portray how each reactor has performed with respect to other reactors in its class (i.e., age, size, and vendor). The dominant theme is the decline in population dose commitment, observed nearly universally. However, if the decline in dose to the public suddenly ceased, levels are sufficiently low that they already represent an insignificant insult to humans.

Data on maximally exposed individuals from airborne emissions are also reported semi-annually to the NRC by each nuclear utility.

Table E.16 Linear model for estimation of liquid dose

Parameter	Significance (*Pr* > *T*)	Remarks
Vendor	0.0001	Babcock and Wilcox (B&W) manufactured reactors have significantly higher liquid doses than do reactors made by other manufacturers; General Electric (GE) reactors are next highest. Mixed sites have the lowest liquid doses
Status (by vendor)	0.01 (B&W) 0.10 (CE)[a] 0.05 (GE) 0.06 (mix) 0.21 (Westinghouse)	GE and mixed sites have higher doses from liquid sources when they are down (below 25 percent of theoretical maximum output). Many mixed sites are partly GE reactors. Reactors made by all other manufacturers, all of which are PWRs[b], have lower doses when they are operating below 25 percent capacity (classified as down)
Calendar year (by vendor)	0.39	Liquid emissions are not decreasing significantly with time for any of the five types, although the coefficients are negative except for the mixed sites. Thus the general trend with time is for air doses to be decreasing considerably, while doses from liquid sources are not decreasing significantly. The decreasing trend in total dose commitment is caused by the lower air dose estimates
Year of startup (by vendor)	0.29 (B&W) 0.80 (CE) 0.0001 (GE) 0.11 (mix) 0.63 (Westinghouse)	Liquid doses are higher in older reactors only for GE reactor sites. For others, there is not a significant trend with reactor age (start year)
Total size, MW (by vendor)	0.57 (B&W) 0.19 (CE) 0.0001 (GE) 0.78 (mix) 0.03 (Westinghouse)	For GE and Westinghouse reactors, the larger sites had higher liquid doses. The increase in liquid dose with megawatt capacity was much higher for GE reactors than for the other types

[a]CE = Combustion Engineering
[b]PWRs = pressurized-water reactors.

Table E.17 Linear model for estimation of air dose[a]

Parameter	Significance ($Pr > T$)	Remarks
Vendor	0.0003	Manufacturer with highest air doses is Babcock-Wilcox [but highly variable—next highest is General Electric (GE)]. Lowest is Combustion Engineering (CE)
Status (by vendor)	0.0001	For all reactor types (manufacturers), air doses decrease significantly when the reactor is operating at less than 25 percent capacity. This is not necessarily true for doses from liquid sources
Calendar year (by vendor)	0.005	Air doses are decreasing with calendar year (for 1979–87) for all reactor types. Rate of decrease is fastest for GE reactors. Rate of decrease is much smaller for CE reactors than for others, partly because these are lower to begin with
Year of startup (by vendor)	0.02 (B&W) 0.004 (CE) 0.0001 (GE) 0.13 (mixed) 0.0001 (Westinghouse)	With the exception of CE, all types have higher air doses in older reactors. For CE, newer reactors have higher doses
Total size, MW (by vendor)	0.0001	Larger reactors had higher air doses. This relationship was strong and was a major contributor to the prediction of dose for each reactor site. This held true for all manufacturers but was much less evident in B&W reactors. The increase in air dose with size was largest for GE and Westinghouse reactors

[a]The overall model accounts for approximately 42 percent of the variation in the *ln*(air dose) values.

These data for the period 1985–1987 were compiled in NUMARC (1989). These data are presented in Table E.19. Inspection of this table reveals that the highest organ and thyroid exposures to the maximally exposed individual are on the order of 5 mrem. The exposure level for the typical maximally exposed individual is orders of magnitude less.

The NRC design criteria for NPPs are 5 mrem/year from stack releases plus 3 mrem from aqueous effluents. The EPA annual dose limit (fuel cycle facilities) is 25 mrem. The anticipated new NRC limit from

Table E.18 Linear model for estimation of average individual dose commitment

Parameter	Significance (*Pr* > *T*)	Remarks
Vendor	0.0001	General Electric (GE)-manufactured reactors have significantly higher individual doses than do reactors by other manufacturers.
Status (by vendor)	0.08 (B&W) 0.11 (CE) 0.04 (GE) 0.96 (mix) 0.09 (Westinghouse)	Sites with GE reactors have higher individual doses when they are down. This is presumably because of the higher liquid doses. The doses from other manufacturers' reactors generally decrease, but not significantly.
Calendar year (by vendor)	0.63 (B&W) 0.98 (CE) 0.04 (GE) 0.18 (mix) 0.04 (Westinghouse)	Only significant for GE and Westinghouse reactors, for which individual doses have been decreasing continuously through successive calendar years.
Year of startup (by vendor)	0.94 (B&W) 0.47 (CE) 0.0001 (GE) 0.007 (mix) 0.02 (Westinghouse)	For GE sites, older reactor sites have significantly higher individual dose estimates. For Westinghouse and mixed sites, the newer sites have higher individual dose commitments
Total size, MW (by vendor)	0.0001	Same relationship as for the air doses. Larger sites have higher estimated individual dose commitments because of the air dose component

all sources (other than medical and natural background) is 100 mrem/year. It is evident that these plants are operating far below government requirements with respect to effluent control.

E.4 RISKS FROM RADIATION EXPOSURE

In January 1990, the National Research Council-NAS published a report on the health effects of exposure to low levels of ionizing radiation (BEIR-V). This report was prepared by a committee on BEIR organized by the council for this purpose and known as the BEIR-V Committee. The BEIR-V report concluded that the risk of radiation exposure was greater than previously estimated. The bases and limitations of these estimates are described in Section E.4.1 of this GEIS.

In light of these data, the ICRP requested comment from a number of organizations on a draft of its revised recommendations on radiation protection (ICRP/60/G-01); on June 22, 1990, the ICRP issued a press release recommending more stringent control over occupational exposures. These developments are very likely to affect the regulation of NPPs in the future but only

Table E.19 Doses (mrem) to the maximally exposed individual from routine airborne emissions[a]

			1985		1986		1987	
Plant	Unit	Docket	Total body	Thyroid	Total body	Thyroid	Total body	Thyroid
Arkansas One	1	50-313	NR[b]	NR	0.0017	0.036	0.0023	0.0070
	2	50-368			0.0060	0.83	0.0044	0.0054
Beaver Valley	1	50-334	NR	NR	0.023	0.092	0.0014	0.0017
	2							
Bellefonte Nuclear Plant	1	—	NR	NR	NR	NR	NR	NR
	2							
Big Rock Point Nuclear Plant	1	—	NR	NR	NR	NR	NR	NR
Braidwood Station	1	—	NR	NR	NR	NR	NR	NR
	2							
Browns Ferry Nuclear Power Station	1	50-296	0.060	NR	NR	NR	NR	NR
	2							
	3							
Brunswick Steam Electric Plant	1	50-324	NR	NR	NR	NR	0.028	0.093
	2							
Byron Station	1	—	NR	NR	NR	NR	NR	NR
	2							
Callaway Plant	1							
Calvert Cliffs Nuclear Power Plant	1	50-317	NR	NR	NR	NR	NR	0.44
	2							
Catawba Nuclear Station	1	50-413	0.88	NR	2.2	NR	0.89	0.67
	2							
Clinton Power Station	1	—	NR	NR	NR	NR	NR	NR
Comanche Peak Steam Electric Station	1	—	NR	NR	NR	NR	NR	NR
	2							
Donald C. Cook Nuclear Power Plant	1	50-315	0.057	1.9	0.020	0.27	0.024	1.3
	2							
Cooper Nuclear Station	1	50-298	0.57	0.60	0.40	0.56	0.018	0.097
Crystal River Nuclear Plant	3	50-302	0.022	0.31	0.21	0.0038	0.20	0.027
Davis-Besse Nuclear Power Station	1	50-346	0.0081	0.056	0.00064	0.00064	0.12	0.040
Diablo Canyon Nuclear Power Plant	1	50-275	NR	0.0014	NR	0.0043	NR	0.0047
	2	50-323	NR	0.0041	NR	0.0035	NR	0.0029

See footnotes at end of table.

Table E.19 (continued)

Plant	Unit	Docket	1985 Total body	1985 Thyroid	1986 Total body	1986 Thyroid	1987 Total body	1987 Thyroid
Dresden Nuclear Power Station	2, 3	50-249	NR	NR	NR	NR	NR	NR
Duane Arnold Energy Center	1	—	NR	NR	NR	NR	NR	NR
Joseph M. Farley Nuclear Plant	1, 2	50-348	0.13	0.18	0.12	0.090	0.081	0.054
Enrico Fermi Atomic Power Plant	2	—	NR	NR	NR	NR	NR	NR
James A. FitzPatrick Nuclear Power Plant	1	—	NR	NR	NR	NR	NR	NR
Fort Calhoun Station	1	—	NR	NR	NR	NR	NR	NR
Robert Emmett Ginna Nuclear Power Plant	1	—	NR	NR	NR	NR	NR	NR
Grand Gulf Nuclear Station	1	50-416	0.090	NR	0.068	NR	0.34	0.94
Haddam Neck Point (Connecticut Yankee)	1	50-213	1.0	0.14	0.39	0.087	0.66	0.073
Shearon Harris Nuclear Power Plant	1	50-400	NR	NR	NR	NR	0.022	0.022
Edwin I Hatch Nuclear Plant	1, 2	50-321	0.093	0.00065	0.0040	0.29	0.13	0.26
Hope Creek Generating Station	1	—	NR	NR	NR	NR	NR	NR
Indian Point Station	2, 3	50-286	0.00078	0.029	0.00049	0.062	NR	NR
Kewaunee Nuclear Power Plant	1	50-305	NR	NR	0.12	0.013	0.00001	0.022
LaSalle Country Station	1, 2	—	NR	NR	NR	NR	NR	NR
William B McGuire Nuclear Station	1	50-369	NR	NR	0.15	NR	0.081	NR
	2	50-370	1.8	2.6	NR	0.42	0.0036	NR
Millstone Nuclear Power Plant	1	50-245	0.007	0.0007	0.22	0.0007	0.083	0.0015
	2	50-336	0.015	0.038	0.01	0.043	0.013	0.04
	3	50-423	NR	NR	0.00052	0.1	0.017	0.014

See footnotes at end of table

Table E.19 (continued)

Plant	Unit	Docket	1985 Total body	1985 Thyroid	1986 Total body	1986 Thyroid	1987 Total body	1987 Thyroid
Monticello Nuclear Generating Plant	1	50-263	NR	1.3	NR	1.2	NR	2.6
Nine Mile Point Nuclear Station	1 2	—	NR	NR	NR	NR	NR	NR
North Anna Power Station	1 2	50-338	NR	1.3	NR	0.80	NR	0.44
Oconee Nuclear Station	1 2	50-287	0.15	NR	0.087	0.97	NR	NR
Oyster Creek Generating Station	1	50-219	1.4	8.8	4.3	0.81	0.17	17
Palisades Nuclear Plant	1	50-255	NR	0.10	NR	0.0073	NR	NR
Palo Verde Generating Station	1 2 3	—						
Peach Bottom Atomic Power Station	2 3	50-278	0 041	1.2	0.12	0.70	0.015	0.13
Perry Nuclear Power Station	1		NR	NR	NR	NR	NR	NR
Pilgrim Nuclear Power Station	1	50-293	0.49	0.18	0.027	0.064	NR	NR
Prairie Island Nuclear Generating Plant	1 2	50-232	NR	NR	NR	NR	NR	NR
Point Beach Nuclear Plant	1 2	—	NR	NR	NR	NR	NR	NR
Quad-Cities Station	1 2	50-254 50-265	0.0020 0 0020	0.16 0.16	NR NR	NR NR	0.0025 0.0021	0.12 0.10
H. B. Robinson Plant	2	50-261	NR	NR	0.016	0.35	0.068	0.11
Salem Nuclear Generating Station	1 2	50-311	0.016	NR	0.028	NR	0.047	NR
San Onofre Nuclear Generating Station	1 2 3	50-206 50-361	NR NR	0.16 0.41	NR NR	NR 0.14	NR NR	0.014 0.049
Seabrook Station	1	—	NR	NR	NR	NR	NR	NR
Sequoyah Nuclear Plant	1 2	50-327	0.19	0.054	0.0020	NR	NR	NR

See footnotes at end of table

Table E.19 (continued)

			1985		1986		1987	
Plant	Unit	Docket	Total body	Thyroid	Total body	Thyroid	Total body	Thyroid
Shoreham Nuclear Power Station	1	—	NR	NR	NR	NR	NR	NR
South Texas Project	1 2	—	NR	NR	NR	NR	NR	NR
St. Lucie Plant	1 2	50-335 50-389	0.013 0.0062	4.2 2 4	0.011 0.0021	5.8 0.89	0.0023 0.0028	0.76 1.1
Virgil C. Summer Nuclear Station	1	50-395	NR	NR	0.00051	NR	0.00000 1	NR
Surry Power Station	1 2	50-281	NR	NR	NR	0.035	NR	0.36
Susquehanna Steam Electric Station	1 2	50-238	0.10	0.14	0.0069	NR	0.011	NR
Three Mile Island Nuclear Station	1	50-289	NR	NR	0 019	NR	0.0028	NR
Trojan Nuclear Plant	1	50-344	0.069	NR	NR	NR	NR	NR
Turkey Point Plant	3 4	50-250 50-251	NR NR	NR NR	0 0038 0.0042	0.032 0.025	0.0087 0.0088	0.20 0.22
Vermont Yankee Nuclear Power Station	1	50-271	NR	NR	NR	NR	NR	0.42
Watts Bar Nuclear Plant	1 2	—	NR	NR	NR	NR	NR	NR
Washington Nuclear Project	2	50-220	NR	NR	0.013	0 48	0 024	0.73
Wolf Creek Generation Station	1	—	NR	NR	NR	NR	NR	NR
Yankee Nuclear Power Station	1	50-29	NR	NR	NR	NR	NR	NR
Zion Nuclear Plant	1 2	50-295	0.044	0.0078	0.092	0.029	0 00047	NR

[a]Data compiled from semi-annual reports submitted to the Nuclear Regulatory Commission by each nuclear utility. Adapted from NUMARC 1989.
[b]Not recorded in source document.
Note: To convert millirem to millisievert, multiply by 0.01.

after the current Presidential Guidance to Federal Agencies is modified to take them into account. With regard to this GEIS, the primary importance of these developments lies in the selection of the most appropriate radiation risk coefficients to use for evaluating health effects; it is therefore necessary to recount earlier developments.

E.4.1 Background

E.4.1.1 Stochastic Effects

In 1972, NAS had sufficient epidemiological information, primarily from the study of Japanese atomic bomb survivors, to publish (in BEIR-I) a radiation risk estimate that was widely interpreted as 1 cancer fatality among 10,000 people receiving 10,000 person-rem. This estimate was applicable to large populations receiving acute doses instantaneously, such as persons exposed to nuclear-weapon explosions. The validity of such estimates for large or small doses received over a lifetime was (and remains) unknown. With additional information from the atomic bomb survivor study, the NAS in 1980 published (in BEIR-III) a range of radiation-risk estimates that, in general, doubled federal agencies' estimates. It was recognized that the new estimates were derived from instantaneous exposure data and were therefore of limited use in the standards development process. The BEIR-III committee's linear quadric dose-response model for solid cancers did, however, contain an implicit dose rate factor of nearly 2.5.

Subsequently, two developments in the atomic bomb survivor study caused another doubling of the overall risk estimate. First, a reassessment of the radiation doses received by the survivors was completed (National Research Council 1987). This study indicated that any gamma-radiation-induced malignancies at Nagasaki had been caused by less radiation than previously believed. However, the opposite effect was observed among the Hiroshima survivors. The new dose estimates include more structural shielding and also include shielding by tissues overlying the affected organs.

The second development concerned the number of survivors who later died from solid tumors, which was greater than had been anticipated. In the 1980 BEIR-III report, the committee expressed its preference for a risk model that essentially assumed that subsequent excess death rates would be similar to those already observed. However, within a few years, publications issued by the Radiation Effects Research Foundation (RERF) reported a departure from this model, attributable to deaths from solid tumors (RERF TR 12-87). The newer data tend to fit a model that predicts that the excess cancer deaths from atomic-bomb radiation will be a constant percentage increase over the cancer deaths from all other causes. In consideration of these findings, federal agencies began to use a risk estimate of 4 or 5 excess cancer deaths among 10,000 people receiving 10,000 person-rem. For example, the EPA used 4 per 10,000 to arrive at the 10 mrem/year limit promulgated in 40 CFR Part 61 (FR 54, 9612, March 7, 1989). NRC used 5 per 10,000 in the development of its *Below Regulatory Concern: Policy Statement* (1990). The following statement appears in the executive summary of the BEIR-V report:

> On the basis of the available evidence, the population-weighted average lifetime excess risk of death from cancer following an acute dose equivalent to all body organs of 0.1 Sv [0.1 Gy of low—linear energy transfer (LET) radiation] is estimated to be 0.8 percent, although the lifetime risk varies considerably with age at the time of exposure. For

low-LET radiation, accumulation of the same dose over weeks or months, however, is expected to reduce the lifetime risk appreciably, possibly by a factor of 2 or more.

The 0.8 percent estimate is equivalent to 800 excess cancer fatalities among 100,000 people, each exposed to 10 rem. It is important to note that the risk values tabulated in the report are for a population size of 100,000 and that the 0.8 percent estimate is applicable to instantaneous, uniform irradiation of all organs. With regard to the lower extreme of the dose range over which the estimate is applicable, the committee observes elsewhere in the BEIR-V report that "In general, the estimates of risk derived in this way for doses of less than 0.1 Gy are too small to be detectable by direct observation in epidemiological studies."

An absorbed dose of 0.1 Gy corresponds to a gamma radiation dose equivalent of 10 rem. It is also important to note that the report does not provide a risk estimate for instantaneous doses of fewer than 10 rem. The committee's estimate is considered useful for estimating fatalities among large populations, including all ages, that are irradiated instantaneously and uniformly to individual external radiation doses of 10 rem or more. Risk assessments based on the Japanese experience are only theoretical under the following conditions:

- exposures are protracted,
- the people are irradiated nonuniformly,
- the exposed population is small,
- individual doses are fewer than 10 rem,
- the irradiation is caused by internally deposited radionuclides,
- the exposed population differs significantly from the atomic bomb survivor study group,
- some combination of these conditions exists, or
- any of an almost infinite list of unknowns applies.

The risk estimate published in the 1990 BEIR-V report is consistent with estimates published earlier by RERF scientists (RERF TR 12-87) and by UNSCEAR (1988). Their estimates, shown in Table E.20, reveal the greater susceptibility of populations that include children, as well as the reduced effects if the radiation doses are low and delivered at low dose rates (i.e., protracted). In the pertinent literature, this phenomenon of reduced effects is usually referred to as the dose rate effectiveness factor (DREF). Risk estimates for instantaneous exposure are divided by the DREF to obtain estimates that can be applied to protracted exposure conditions. Lack of data on humans dictates primary reliance on animal studies for DREF estimates. For the values reported in Table E.20, a DREF of 2.5 was used by the RERF authors. A DREF range of 2 to 10 was used in the UNSCEAR report.

For its new reactor safety study, the NRC has published a DREF of 3 (NUREG/CR-4214). In the 1990 BEIR-V report, a DREF of 2 or more is mentioned for low-LET radiation (gamma) as previously quoted; and a DREF of 4 is given as the "single best estimate" for tumorigenesis identified in laboratory animal studies. The ICRP is considering the use of a DREF of 2 in the forthcoming major revision of its recommendations. The DREF question is critical to risk assessments and to decisions regarding dose limits and ALARA requirements.

Table E.21 shows the progression in the risk estimate values used by federal government agencies following the publication of authoritative reports on the subject, as discussed in the preceding narrative.

Table E.20 RERF[a] and UNSCEAR[b] risk coefficients; excess cancer fatalities

	All ages		Adults	
	RERF	UNSCEAR	RERF	UNSCEAR
High doses and dose rates	12	3–11	8	4–8
Low doses and dose rates	5	0.3–5.5	3	0.4–4

[a]Radiation Effects Research Foundation (RERF) authors used a dose rate effectiveness factor (DREF) of 2.5.
[b]United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) authors used a DREF range of 2 to 10.

Table E.21 Radiation risk estimates used by federal agencies following publication of the documents shown

Publication	Excess cancer fatalities among 100,000 people receiving instantaneous external radiation doses of 10 rem
1972 BEIR-I report	100
ICRP Publication 26	200
1980 BEIR-III report	200
RERF Publications	400–500
1990 BEIR-V report	800

Note: To convert millirem to millisievert, multiply by 0.01.

Note that the 1980 BEIR-III report used a DREF in the preparation of tabulated risk estimates and that the 1990 BEIR-V report did not. The occupational risk estimates of current interest from both reports are given in Table E.22.

Because 88 percent of the deaths included in the later data from the atomic bomb survivor study are from solid tumors, leukemia is now considered a small contribution to the total risk. It is important to recognize that if a DREF of 2 is used for solid tumors as well as leukemia, the BEIR-V fatality estimate is reduced from 2975 to 1666 excess cancer fatalities among 100,000 adults each receiving 1 rem/year for a working lifetime.

Table E.22 Radiation risk estimates to 100,000 adult workers (50 percent male and 50 percent female) for continuous exposure to 1 rem/year during a working lifetime using the relative risk projection model

	BEIR-III	BEIR-III	BEIR-V
Model	L-Q[a]	L[b]	L-Q; L[c]
Excess fatal cancers	551	2336	2975

[a]Linear-quadratic dose response model.
[b]Linear dose response model (combines leukemia and solid tumor deaths).
[c]Linear-quadratic dose response model for leukemia; linear dose response model for solid tumors.
Note: To convert rem to sievert, multiply by 0.01.

E.4.1.2 Nonstochastic Effects

Nonstochastic effects do not occur unless the radiation dose exceeds a threshold, permitting the use of limiting values that prevent rather than control the probabilities of occurrence of the effects. For parts of the body (organs and tissues) such as the lens of the eye, the skin, and the extremities, radiation protection standards are intended primarily to control the dose from external sources. For the internal organs, it is necessary to control the dose from internally deposited radioactivity as well. Because radiation can damage or kill any living cell if the dose is sufficiently high, a nonstochastic dose limit must also be established for all tissues, including tissues other than those mentioned above. A significant point to consider in connection with an effect that has an accurately known threshold is that the implementation of the ALARA concept to reduce doses to levels below the threshold will not offer additional protection against that effect. However, if the organ or tissue under consideration is also susceptible to radiation-induced cancer, such implementation will reduce that probability. For this reason, the ALARA concept is applicable to the nonstochastic inhalation standards.

ICRP Publication 41 (1983) provides the database supporting the position that, with the exception of the lens of the eye, nonstochastic effects will not be observed among adults if every organ and tissue receives fewer than 50 rem/year. The NRC is not aware of later radiobiological information indicating that this dose limit should be changed and notes that the ICRP has proposed the retention of this value in the forthcoming revision of its recommendations (ICRP/90/G-01).

E.4.2 Risk Coefficient Selection for this Generic Environmental Impact Statement

E.4.2.1 The 1990 BEIR-V and the 1988 UNSCEAR Reports

The BEIR-V risk estimate can be arithmetically converted to the more familiar terminology of 8 cancer fatalities among 10,000 people exposed to 10,000 person-rem, leading to a convenient expression, or risk coefficient, of 8×10^{-4} fatalities per person-rem. This coefficient is considered useful for estimating fatalities among large populations irradiated instantaneously and uniformly to individual external radiation doses of 10 rem or more. However, since no DREF is included in this risk factor, as the individual

doses and the size of the exposed population become progressively smaller, the fatality estimates become speculative. As noted in the previous section, a DREF of 2 is considered appropriate for use in the GEIS analysis for license renewal.

An additional source of uncertainty is that many of the exposed people who were included in the atomic bomb survivor study are still alive. The risk estimate is therefore based in part on a projection of future excess cancer deaths that may or may not occur. For making this projection, the BEIR-V committee chose a method (the relative risk projection model) that involves multiplying solid tumor cancer fatality rates within an unexposed U.S. population by a constant percentage increase factor determined for a Japanese population. The number of excess fatalities on which the risk estimates are based is epidemiologically small. Of the 93,669 "in-city" members of the study group, 37,874 (or 40 percent) had died by the end of 1989; 8,422 (or 9 percent) of the deaths were caused by cancer. RERF epidemiologists estimate that 505 (or 0.5 percent) of the cancer deaths are attributable to radiation from the bombs.

The collective dose to a population must become a great deal larger than current doses from NPPs if health effects are to be a concern. In its 1988 report (paragraph 251), UNSCEAR stated:

> The product of risk coefficients appropriate for individual risk and the relevant collective dose will give the expected number of cancer deaths in the exposed population, provided that the collective dose is at least of the order of 100 man Sv. If the collective dose is only a few man Sv, the most likely outcome is zero deaths.

A collective dose of 100 man-sievert is equivalent to 10,000 person-rem. In the 1990 BEIR-V report (p. 181), the NAS Committee on BEIR stated:

> Moreover, epidemiologic data cannot rigorously exclude the existence of the threshold in the millisievert dose range. Thus the possibility that there may be no risks from exposures comparable to external natural background radiation cannot be ruled out. At such low doses and dose rates, it must be acknowledged that the lower limit on the range of uncertainty in the risk estimates extends to zero.

One millisievert is equivalent to 100 mrem. An important perspective to recognize is that the approximately 140 million people who live within 50 miles of a U.S. NPP receive about 43 million person-rem every year from natural background radiation.

E.4.2.2 Risk Coefficients Selected

The risk coefficients used in this GEIS are listed in Table E.23. These coefficients are consistent with the risk factors repeated in BEIR-V if a DREF of 2 is applied to 88 percent of the cancer fatality risk (i.e., to solid tumors) and are the same as those recently published by the ICRP in connection with a revision of its recommendations (ICRP/60/G-01).

The somewhat higher public risk coefficients reflect the fact that individuals under age 18 at the time of exposure are more susceptible to radiation-induced cancer. To receive occupational radiation exposure, a person must be 18 years or older. Excess hereditary effects are listed separately because radiation-induced effects of this type have not been observed in any human population, as opposed to excess malignancies that have

been identified among people receiving instantaneous and near-uniform exposures of 10 rem or more. Considering the range of uncertainty, the lower limit of the range is assumed to be zero because there may be biological mechanisms that can repair damage caused by radiation at low doses and/or dose rates.

E.5 OVERVIEW AND PERSPECTIVE

E.5.1 Program Costs

The data presented in Section E.2 of this document provide convincing evidence that the U.S. nuclear power industry is conducting a highly successful radiation protection program. The recent annual average doses are about 0.3 rem for workers (5-rem/year regulatory limit) and about 1 μrem for members of the general public (25-mrem/year regulatory limit) who live within 50 miles of a NPP. This performance leaves reason to believe that the planned refurbishment operations and operation under license renewal can and will be conducted in a radiologically safe manner.

Actual industrial costs for achieving this record have not been made available and may not be known. A comprehensive analysis of programmatic effectiveness would have to include the costs, in particular the cost in dollars per person-rem averted. These values could then be compared with the criterion of $1000 per person-rem used in Appendix I, 10 CFR Part 50, and with the considerably lower criteria used in Europe. Considering the distribution of radiation protection resources between workers and the public, this type of analysis would provide a basis for prioritization.

Table E.23 Nominal probability coefficients used in this generic environmental impact statement[a]

Health effect	Occupational	Public
Fatal cancer	4	5
Hereditary	0.6	1

[a]Estimated number of excess effects among 10,000 people receiving 10,000 person-rem. Coefficients are based on "central" or "best" estimates. To convert person-rem to person-sievert, multiply by 0.01.
Source: ICRP-60.

E.5.2 Risks

The costs of radiation protection are recovered by the nuclear utilities through charges for electric power. Ideally, radiation-protection costs would be commensurate with the risk averted. However, even if the costs were accurately known, it would not be possible to determine whether actual risks were being averted. The radiation risk data base does not provide the answers, creating a dependence on hypotheses and assumptions. This problem is becoming more serious as the costs become larger and resources are demanded for other public health concerns. Because of the higher

individual doses, the technical justification that can be offered for worker-protection costs is stronger than that for public protection. However, studies of exposed workers within recommended limits have not actually verified the existence of a low-level radiation risk.

The most definitive study to date of the possibility of occupational radiation-induced health effects among workers conducting Department of Energy operations has recently been published (Gilbert et al. 1989). This study included almost 36,000 workers at the Hanford site, at Oak Ridge National Laboratory, and at the Rocky Flats Weapons Plant. About 8 percent of the workers had lifetime doses exceeding 10 rem. There was no evidence of a correlation between radiation exposure and mortality when examining all cancers combined or when examining leukemia. When examining other specific cancers, the only one found to exhibit a statistically significant correlation with radiation exposure was multiple myeloma. Twelve deaths occurred from this disease at the Hanford site; none at the other two locations. The researchers report that it is not clear whether the Hanford correlation results from a cause and effect relationship. Only three of the deaths occurred among workers receiving more than 5 rem. There is a 50/50 chance of observing all three deaths in the same population. Overall, Gilbert et al. found that cancer fatalities occurred less often among the more significantly exposed workers: "The relationship of cancer mortality and radiation exposure was in the negative direction in all three populations." When a suspected carcinogen is examined in an epidemiological study, a correlation in the positive direction (progressively higher disease incidence among the more highly exposed groups) is usually followed by the study of individual cases. A statistically significant correlation in the negative direction is often interpreted to mean that such case studies are unnecessary. It may be important to note that the negative direction finding has been replicated in studies that have been reported of people (including children) who live in areas of abnormally high natural background radiation. Despite these findings, the NRC is operating under a policy of caution. It is recognized that not all of the workers in the Gilbert study have died yet, and people in the high-background studies tend to live in areas where the average life span is relatively short. It is possible that many of them do not live long enough to develop cancer that could otherwise be induced by natural background radiation. For this and other reasons, the NRC has strengthened its occupational radiation protection program by clearly stating, in the new 10 CFR Part 20, the role of the ALARA process within the radiation protection program of each NPP.

Several workers in the nuclear power industry have lifetime doses exceeding 10 rem; however, in a very large majority of these cases, the dose was accumulated over a period of many years. In the Japanese atomic bomb survivor studies, statistically significant increases in cancers have been detected only for the situation in which large populations were irradiated instantaneously and uniformly to external radiation doses of 10 rem or more. The dose rate effect for humans is not well understood, creating a dependence on animal data and molecular and cellular studies. Repair mechanisms have been demonstrated and are being studied. It may eventually be possible to identify a dose rate below which human health effects either do not occur or have a probability of occurrence that is sufficiently small to be of no concern. Until that happens, it would be wise to maintain the present interest in occupational ALARA programs.

E.5.3 Standards

E.5.3.1 Occupational

The new 10 CFR Part 20 contains a codified requirement on the ALARA process, which is in keeping with current trends in radiation risk information. Greater emphasis would not necessarily mean greater costs, particularly if cost-beneficial source-term reduction methods are adopted.

If, in the future, the NRC decides to lower the dose limit from 5 to 2 rem/year, this limit will ensure a lower lifetime risk for a few of the most highly exposed individuals. If some provision for operational flexibility were made, a 2 rem/year limit should not be disruptive or needlessly costly, particularly if dose reduction were achieved through cost-effective and cost-beneficial measures.

The impact on plant refurbishment plans should be preparatory in nature (i.e., planning should take full advantage of reasonable dose-reduction opportunities).

E.5.3.2 Public

The current and limiting standards of 40 CFR Part 190 are not expected to be changed for some time, but it does appear likely that 40 CFR Part 61 will be finalized and will lower the annual total body dose limit for members of the public from 25 to 10 mrem/year for airborne radionuclides. Doses from NPPs are so low that this change in the limit is not expected to have an effect.

E.5.4 Conclusions

With respect to the radiological health aspects of extending NPP licenses, under normal operating conditions, it is evident that the radiation protection programs currently in place are adequate in the case of worker protection and more than adequate for protection of the general public. Experience following the Three Mile Island accident indicates that refurbishment operations can temporarily increase occupational doses. Experience has also shown that the judicious implementation of the ALARA concept can minimize such increases at low cost.

Although radiation doses are a tangible measure for evaluating the license-extension question, the major issue comprises two intangibles: the existence of risk from these doses and the probability that health effects will actually occur. The existence of risk has not been verified for protracted low-level radiation. Under the assumption that the risks are without threshold and real, the probability of risk expression becomes the key issue. But until more is known about dose rate effectiveness, continued caution is indicated for lifetime occupational doses.

E.6 REFERENCES

BEIR-I, *The Effects on Populations of Exposure to Low Levels of Ionizing Radiations*, National Research Council, Advisory Committee on the Biological Effects of Ionizing Radiation, National Academy of Sciences, Washington, D.C., 1972.

BEIR-III, *The Effects on Populations of Exposure to Low Levels of Ionizing Radiation: 1980*, National Research Council, Advisory Committee on the Biological Effects of Ionizing Radiation, National Academy of Sciences, Washington, D.C., 1980.

BEIR-V, *Health Effects of Exposure to Low Levels of Ionizing Radiation*, National Research Council, Advisory Committee on the Biological Effects of Ionizing Radiation, National Academy of Sciences, Washington, D.C., 1990.

Gilbert, E. S., et al., "Analyses of Combined Mortality Data on Workers at the Hanford Site, Oak Ridge National Laboratory, and Rocky Flats Nuclear Weapons Plant," *Radiation Research*, **120**, 19–35, 1989.

ICRP Publication 26, "Recommendations of the International Commission on Radiological Protection," *Annals of the ICRP* 1(3), International Commission on Radiological Protection, Pergamon Press, New York, 1977.

ICRP Publication 27, "Problems Involved in Developing an Index of Harm," *Annals of the ICRP*, **1**(4), International Commission on Radiological Protection, Pergamon Press, New York, 1977.

ICRP Publication 37, *Cost-Benefit Analysis in the Optimization of Radiation Protection*, International Commission on Radiological Protection, Pergamon Press, New York, 1983.

ICRP Publication 41, *Nonstochastic Effects of Ionizing Radiation*, **14**(3), International Commission on Radiological Protection, Pergamon Press, New York, 1983.

ICRP (International Commission on Radiological Protection), "Report of ICRP Committee II on Permissible Dose for Internal Radiation (1959)," *Health Physics*, **3**, 1960.

ICRP (International Commission on Radiological Protection), "Statement from the 1985 Paris Meeting of the ICRP," *Health Physics*, **48**, 828, 1985.

ICRP (International Commission on Radiological Protection), *Recommendations of the Commission*, ICRP Publication 60, Pergamon Press, New York, 1991.

NBS (National Bureau of Standards), *Permissible Dose from External Radiation: Recommendations of the National Committee on Radiation Protection*, National Bureau of Standards Handbook 59, 1954.

National Research Council, *An Assessment of the New Dosimetry for A-Bomb Survivors*, Advisory Committee on the Radiation Effects Research Foundation, National Academy of Sciences, Washington, D.C., 1987.

NCRP (National Council on Radiation Protection and Measurements), *Influence of Dose and Its Distribution in Time on Dose-Response Relationships for Low-LET Radiations*, Report No. 64, Bethesda, Maryland, 1980.

NCRP (National Council on Radiation Protection and Measurements), *Recommendations on Limits for Exposure to Ionizing Radiation*, Report No. 91, Bethesda, Maryland, 1987.

NRC (U.S. Nuclear Regulatory Commission), *Below Regulatory Concern: Policy Statement*, available in the NRC Public Document Room, Washington, D.C., July 3, 1990.

NRC Regulatory Guide 8.8, Rev. 3, *Information Relevant to Ensuring That Occupational Radiation Exposures at Nuclear Power Stations Will Be As Low As Reasonably Achievable*, U.S. Nuclear Regulatory Commission, 1978.

NRC Regulatory Guide 8.10, Rev. 1R, *Operating Philosophy for Maintaining Occupational Radiation Exposures As Low As Reasonably Achievable*, U.S. Nuclear Regulatory Commission, 1977.

NUMARC (Nuclear Management and Resources Council), *Study of Generic Environmental Issues Related to License Renewal*, Washington, D.C., 1989.

NUREG-0713, *Occupational Radiation Exposure at Commercial Nuclear Power Reactors and Other Facilities, 1992*, Vol. 11, U.S. Nuclear Regulatory Commission, 1993.

NUREG/CP-0101, *Workshop on Rules for Exemption from Regulatory Control*, U.S. Nuclear Regulatory Commission, 1989.

NUREG/CR-2850, D. A. Baker, *Population Dose Commitments Due to Radioactive*

Releases from Nuclear Power Plant Sites in 1989, U.S. Nuclear Regulatory Commission, 1993.

NUREG/CR-4214, S. Abrahamson et al., *Health Effects Models for Nuclear Power Plant Accident Consequence Analysis; Low LET Radiation; Scientific Bases for Health Effects Models*, U.S. Nuclear Regulatory Commission, 1989.

Radiological Protection Bulletin, No. 111, *A Summary of the Draft Recommendations of the ICRP, 1990*, National Radiological Protection Board, 1990.

RERF TR 12-87, *Comparison of Risk Coefficients for Site-Specific Cancer Mortality Based on the DS86 and T65R Shielded Kerma and Organ Doses*, Radiation Effects Research Foundation, Life Span Study Report 1 Pt. 1, 1987.

SECY-89-184, *Proposed Commission Policy Statement on Exemptions from Regulatory Control*, U.S. Nuclear Regulatory Commission, available in the NRC Public Document Room, 1989.

UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation), *Sources, Effects and Risk of Ionizing Radiation: 1988 Report to the General Assembly, Forty-third Session*, Supplement No. 45 (A/43/45), United Nations, New York, 1988.

ATTACHMENT E.A

CONCEPTS, TERMINOLOGY, QUANTITIES, AND UNITS USED IN THE OLD AND NEW VERSIONS OF 10 CFR PART 20

10 CFR Part 20 was first promulgated in 1957. In 1961, the regulation was amended to add an appendix containing maximum permissible concentrations (MPCs) and a new dose limit structure for whole-body exposure to external radiation (1.25 rem/quarter, or 3 rem/quarter with 5 rem/year average as a limit on the cumulative dose). The most recent revision went into effect in 1991. The 1961–1991 version is often called "the old Part 20"; the 1991 version, "the new Part 20." The new version differs considerably from the old, particularly with respect to basic concepts, terminology, radiation dose quantities, and the associated dose units. This attachment is included for those who need to become familiar with important details that underlie the coming changes in federal regulations.

E.A.1 CONVENTIONAL QUANTITIES AND UNITS

E.A.1.1 Old Part 20 Quantities and Units

In the old Part 20, the unit "rad" is usually used for the quantity "radiation absorbed dose" whenever early biological effects are the concern. When latent effects (e.g., cancer and genetic effects) are being considered, the unit "rem" is used for the dose equivalent (DE) quantity. The absorbed dose in rads is multiplied by an overall efficiency factor Q to obtain the DE in rem. Each type of radiation has its own value of Q, which in a very rough way makes absorbed doses from different radiations additive for latent effects. Values of Q in the old Part 20 are indicated in Table E.A.1.

These values of Q reflect the overall efficiency of a given type of radiation in causing latent effects and are not used for early effects such as acute radiation syndrome. In the old Part 20, these Q values are also applied to protection of the eye lens from cataracts and protection of the skin from cosmetic effects. The values were derived in consideration of the ability of the various radiations to ionize atoms in water as well as the relative biological effectiveness factors (RBEs) observed for specific effects. Most of the dose limits given in the old Part 20 are DE, and the rem unit is used.

The DE was used to calculate the MPCs in the old rule. The MPC is defined as the concentration of a radionuclide in air that, if the hypothetical standard man were exposed to it for a working lifetime of 50 years, would cause an annual DE to the critical (most highly exposed) organ after 50 years of exposure. Values are shown in Table E.A.2. The quantity of a radionuclide maintained continuously in an organ that will cause the DE is referred to as the maximum permissible organ burden (MPOB).

The old Part 20 allows the worker to receive external radiation at the rate of 5 rem/year average plus a DE to each organ, as shown in Table E.A.2. This regulation also ignores the internal radiation risk from the DE to noncritical organs and ignores the DE received by an organ from nuclides located in other organs.

Table E.A.1 Efficiency for different radiation types

Radiation	Absorbed dose (rads)	Q	Dose equivalent (rem)
250-kVp X-rays	1	1	1
Gamma	1	1	1
Beta	1	1	1
Beta (< 0.03 MeV max)	1	1.7	1.7
Alpha	1	10	10
Neutron (spectrum unknown)	1	10	10

Note: To convert rem to sievert, multiply by 0.01.

Table E.A.2 Annual dose equivalent limits used for calculating the maximum permissible concentrations

Organ	*r* (rem)
Thyroid	30
Bone	30
Gonads	5
Marrow	5
All others	15

Note: To convert rem to sievert, multiply by 0 01.

E.A.1.2 Collective Dose

The old Part 20 makes no use of the collective dose equivalent (person-rem). However, this quantity is used extensively by the Nuclear Regulatory Commission (NRC) in risk analyses and in its decision-making processes. The collective DE may be obtained as the sum of all individual doses or as the product of the average individual dose and the number of people exposed. The linear-nonthreshold hypothesis is accepted by the NRC for purposes of standards setting. Such acceptance means that standards based on the hypothesis, coupled with the as-low-as-reasonably-

achievable concept, are believed to provide an adequate degree of protection.

E.A.2 NEW PART 20 QUANTITIES AND UNITS

All of the quantities and units discussed above remain in use in the new Part 20; the only change is that the "penetrating dose equivalent" is now called the "deep dose equivalent." However, NRC licensees must become familiar with several additional International Commission on Radiological Protection (ICRP) concepts and quantities.

The ICRP system is based on the recognition of two basic types of radiation-induced health effects: stochastic and nonstochastic. The stochastic (cancer and hereditary) effects are considered to be probabilistic in nature, and the objective is to control the probability to acceptable levels. For stochastic effects, the severity is not dose dependent (i.e., once caused, a malignancy from 100 rem is no worse than one from 50 rem). In contrast, nonstochastic effects are not caused at all unless a threshold dose is exceeded. The objective is to prevent nonstochastic effects, for which severity is dose dependent; for example, a radiation-induced cataract caused by 400 rem will impair vision more than one caused by 300 rem.

E.A.2.1 Nonstochastic Effects

In ICRP Publication 41, technical justification is presented for the ICRP position that, with the exception of cataracts in the lens of the eye, nonstochastic effects will not occur among humans if the DE from external and internal radiation combined, to every organ and tissue, is limited to 50 rem or fewer in a year. To achieve compliance, it is necessary during a given year to ensure that the organ or tissue receiving the highest DE does not exceed this limit.

E.A.2.2 Stochastic Effects

For these effects, the ICRP in 1977 adopted the risk then associated with 5 rem in a year, delivered to every organ, as the basis for its dose-limitation system. Therefore, the stochastic annual limit on intake (ALI) for each radionuclide is the quantity that, if inhaled, would cause the same stochastic risk as a uniform, whole-body dose of 5 rem delivered by external sources in 1 year. To establish these ALIs, the ICRP considered the possibility that a given nuclide taken into the body eventually reaches the bloodstream and is then distributed selectively to the various organs and tissues, where DEs are delivered over a time course determined by the retention capabilities of the organ or tissue and the physical characteristics of the nuclide. Using a radiation risk coefficient specific for each organ or tissue and the 50-year integrated DE for each of these, the risk associated with each is estimated. The total fatality risk to the worker per microcurie of this nuclide inhaled is the sum of the individual organ or tissue risks. The intake that will produce the same overall stochastic risk as 5 rem of uniform external radiation can then be readily calculated as the ALI. Of course, the worker may be exposed to several airborne nuclides and to external radiation as well. When this happens, the total risk is still limited to that associated with 5 rem in a year from uniform external radiation. Compliance is achieved if the fraction of the external dose limit that is received, added to the fraction(s) of the ALI(s) inhaled, does not exceed unity.

The risk of hereditary effects is included in a special way that, in the view of the ICRP, renders it additive to the cancer fatality risk. The ICRP considered only detrimental effects that the worker is likely to

experience personally, so that effects manifested after the second generation are not included in the genetic risk coefficient used. The coefficient is also limited to very serious genetic effects (i.e., those comparable in severity to premature death).

E.A.2.3 Weighting Factors

Although all organs and tissues receive the same DE under uniform exposure conditions, the cancer risks often are not the same. Each organ or tissue contributes its own fraction of the risk. This fraction is called the weighting factor; the sum of all of the weighting factors is unity. The product of the weighting factor and the DE is the effective dose equivalent (EDE). This quantity is used for both external and internal irradiation and may be used for individual organs and tissues or for the sum of all organs and tissues. The unit used for either quantity is the same as for the DE, namely, the rem (or sievert). In the unique case of uniform irradiation of all organs and tissues, the sum of their EDEs is by definition equal to the whole-body DE. The EDE may be determined irrespective of the degree of uniformity among the organ or tissue doses. The sum of the EDEs is not allowed to exceed 5 rem in a year. The committed dose equivalent (CDE) is a familiar quantity defined as the 50-year integrated DE to a specific organ or tissue following the inhalation of a radionuclide. This quantity is still used, but only in connection with nonstochastic effects. The committed effective dose equivalent (CEDE) is the same quantity as the CDE, with the exception that, in the case of the CEDE, each DE is multiplied by a weighting factor. The rem (or sievert) is also the unit for both of these quantities.

The mathematical weighting method used by the ICRP is shown in Table E.A.3. The first column lists the organs, and the second column lists the risk coefficients from ICRP-26 and their sum; namely, 1.65×10^{-4}. This sum is the total annual risk to the exposed person, assuming exposure to these organs at 1 rad/year. [Multiplication by 5 gives the annual risk at 5 rads/year (i.e., 8.25×10^{-4} per year). This risk value means that if groups of 10,000 workers were to receive the dose limit every year for their entire careers, data as of the mid-1970s indicate that an average of 8.25 fatal occupational radiation-induced cancers per year would occur within each group. Assuming the approximate worst case of 45 years of exposure, the toll theoretically would be about 370 deaths per group, or almost 4 percent.] The fraction of this risk per rad for each organ can be obtained by dividing its risk coefficient by 1.65×10^{-4}. These fractions represent the relative sensitivity of the organs; they are the weighting factors and are designated by the symbol w_T, where T represents the organ or tissue. The weighting factors appear in column three of the table. If T is the DE to tissue T, then $w_T H_T$ is the weighted dose equivalent. For example, w_T for the lung is 0.12. If a weighted lung dose of H rem is set equal to a highly penetrating, uniform whole-body dose of 5 rem,

$$\begin{aligned} 0.12\ H &= 5 \text{ rem and} \\ H &= 41.7 \text{ rem ;} \end{aligned}$$

by hypothesis and analogy, an annual DE of 41.7 rem to only the lung would have the same effect as 5 rem to all of the organs combined. For this reason, $w_T H_T$ is called the EDE.

Nonstochastic effects have thresholds, and they become more severe as the dose gets larger. ICRP believes that none of the thresholds will be exceeded if the annual dose does not exceed 50 rad. This nonstochastic limit is reflected in column five of the table, where it is evident that

Table E.A.3 International Commission on Radiological Protection-26 risk weighting system

Organs	Risk coefficients (effects per organ-rem)	Weighting factors	Organ dose equivalent (DE) causing same risk as 5 rem to whole body (rem)	Annual DE permitted, exposure of one organ (rem/year)
Gonads	4×10^{-5}	0.25	20	20
Breasts	2.5×10^{-5}	0.15	33-1/3	33-1/3
Lung	2×10^{-5}	0.12	41-2/3	41-2/3
Red marrow	2×10^{-5}	0.12	41-2/3	41-2/3
Bone	5×10^{-6}	0.03	166-2/3	50
Thyroid	5×10^{-6}	0.03	166-2/3	50
1st RO[a]	1×10^{-5}	0.06	83-1/3	50
2nd RO	1×10^{-5}	0.06	83-1/3	50
3rd RO	1×10^{-5}	0.06	83-1/3	50
4th RO	1×10^{-5}	0.06	83-1/3	50
5th RO	1×10^{-5}	0.06	83-1/3	50
Totals	1.65×10^{-4}	1.0		

[a]The remainder organs (ROs) are the five organs that receive, from a given radionuclide, the highest effective dose equivalent, integrated over 50 years.
Note: To convert rem to sievert, multiply by 0.01.

nonstochastic effects are controlling for all but four organs that have the largest weighting factors—the most sensitive organs with respect to highly serious effects.

E.A.3 INTERNATIONAL SYSTEM OF UNITS

The International System (SI) units of particular interest to health physicists are the gray, sievert, and becquerel, shown in Table E.A.4. The SI units are part of the metric system; however, they are not yet

widely used in the United States. The new Part 20 prohibits their use in records required by the NRC. The major concern of the NRC staff is that use of both the conventional and SI units would introduce confusion under emergency conditions.

Table E.A.4 Conventional and International System (SI) units

Quantity	Conventional unit	SI unit	SI unit equivalent
Absorbed dose	Rad (100 ergs/gram)	Gray (10,000 ergs/gram)	100 rad
Dose equivalent	Rem ($Q \times$ rad)	Sievert ($Q \times$ gray)	100 rem
Activity	Curie (3.7×10^{10} d/s)[a]	Becquerel (1 d/s)[a]	3×10^{-11} Ci

[a]Disintegration per second.

ATTACHMENT E.B

THE ICRP DOSE LIMITATION SYSTEM

In International Commission on Radiological Protection (ICRP) Publication 26, a three-tiered system of dose limitation, was introduced—justification, optimization, and limitation. This system was adopted for occupational radiation protection in the 1987 Presidential guidance to federal agencies. Revised Presidential guidance for protection of the public is in preparation.

E.B.1 JUSTIFICATION

The first tier, justification, is an admonition that governments should take radiation risks into full consideration before adopting programs that would involve the exposure of personnel to radiation or radioactive material. An example of such a programmatic consideration would be a decision to construct and operate nuclear electric power plants. Another example, on a much smaller scale, would be a decision to permit the use of jewelry containing small amounts of radioactivity induced by neutron irradiation.

E.B.2 OPTIMIZATION

In ICRP Publications 26 and 37, the phrase as low as reasonably achievable (ALARA) was discontinued (for ICRP purposes) in favor of the term "optimization." The ICRP considers the terms to be synonymous but apparently feels that "optimization" is more descriptive of the intent of its recommendation. In the United States, ALARA has traditionally been a concept used to justify radiation protection measures that further reduce doses already within regulatory limits. The probabilistic nature of stochastic radiation effects supports continuation of the application of the concept to the point at which the probabilities become too small to be of concern.

In the case of public protection, the Environmental Protection Agency (EPA) (40 CFR Part 190) and the Nuclear Regulatory Commission (NRC) (10 CFR Part 50) have established ALARA limits that are enforced rather than the considerably larger limits recommended by the ICRP and the National Council on Radiation Protection and Measurements (NCRP). The ALARA limits were derived using analytic techniques to identify approximately the point at which the cost of providing additional protection would exceed the risk averted. A more qualitative approach has been taken in the implementation of the occupational ALARA concept—no ALARA limits have been set. The basic dose limits have been coupled with the avoidance of unnecessary exposure. Soon after the ICRP introduced optimization in 1977, a more aggressive approach was initiated. Operators began to identify dose-reduction measures that were cost effective or even cost beneficial. Annual average doses among occupational groups are now characteristically below 10 percent of the limits. It is evident that actual doses to workers or the public are controlled by the ALARA concept rather than by dose limits, and that is why the ICRP lists optimization as the second tier of its system.

ICRP optimization is an analytical method through which the financial costs of dose reduction are compared with those of radiation-induced health effects to find the

point at which the total costs of both are minimized (i.e., optimized). ICRP optimization takes only radiation risks into account.

E.B.3 LIMITATION

The third tier is limitation (i.e., the establishment and enforcement of dose limits for workers and the public). Compliance with a dose limit normally involves the measurement or calculation and recording of radiation doses to individuals to demonstrate that the doses did not exceed any limit established by cognizant government authorities. Because the primary risks of radiation are proportional to the lifetime accumulated dose, it is considered to be safe in the case of workers to allow a relatively large dose infrequently as long as the dose is compensated for in previous or subsequent years by commensurately smaller doses. This situation permits operational flexibility without sacrificing control of the lifetime risk. The ICRP and NCRP have therefore recommended dose limits for workers that are not to be approached routinely, but infrequently, if at all, as special operational needs arise.

ATTACHMENT E.C

PLOTS OF POPULATION DOSE COMMITMENTS BY REACTOR

LEGEND:

Δ Predicted total dose commitment (model)

* Air Dose Commitment (Data)

□ Liquid Dose Commitment (Data)

◇ Total Dose Commitment (Data)

ORNL-DWG 95-1763

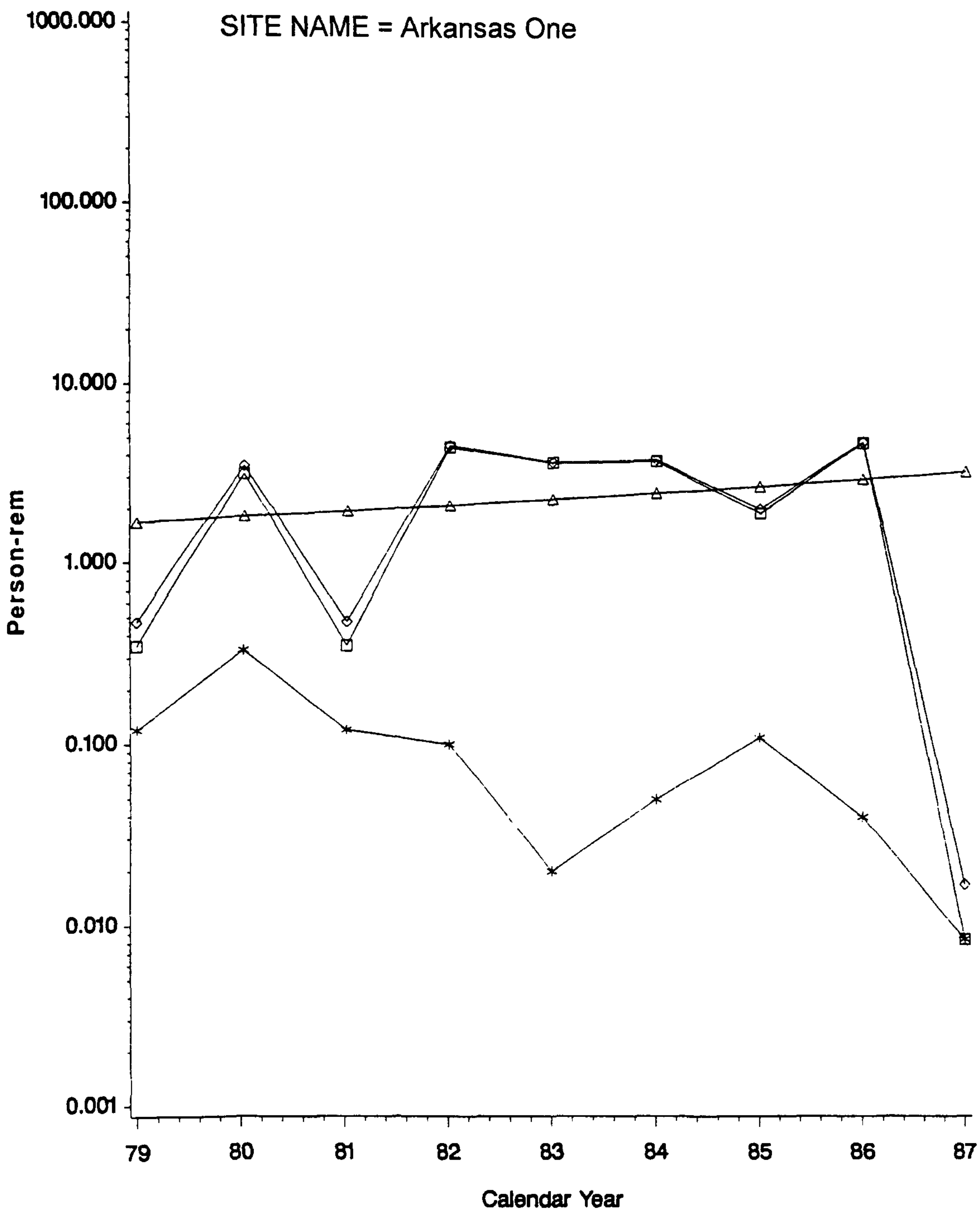

Figure E.C.1 Person-rem per year for Arkansas One.

ORNL-DWG 95-1764

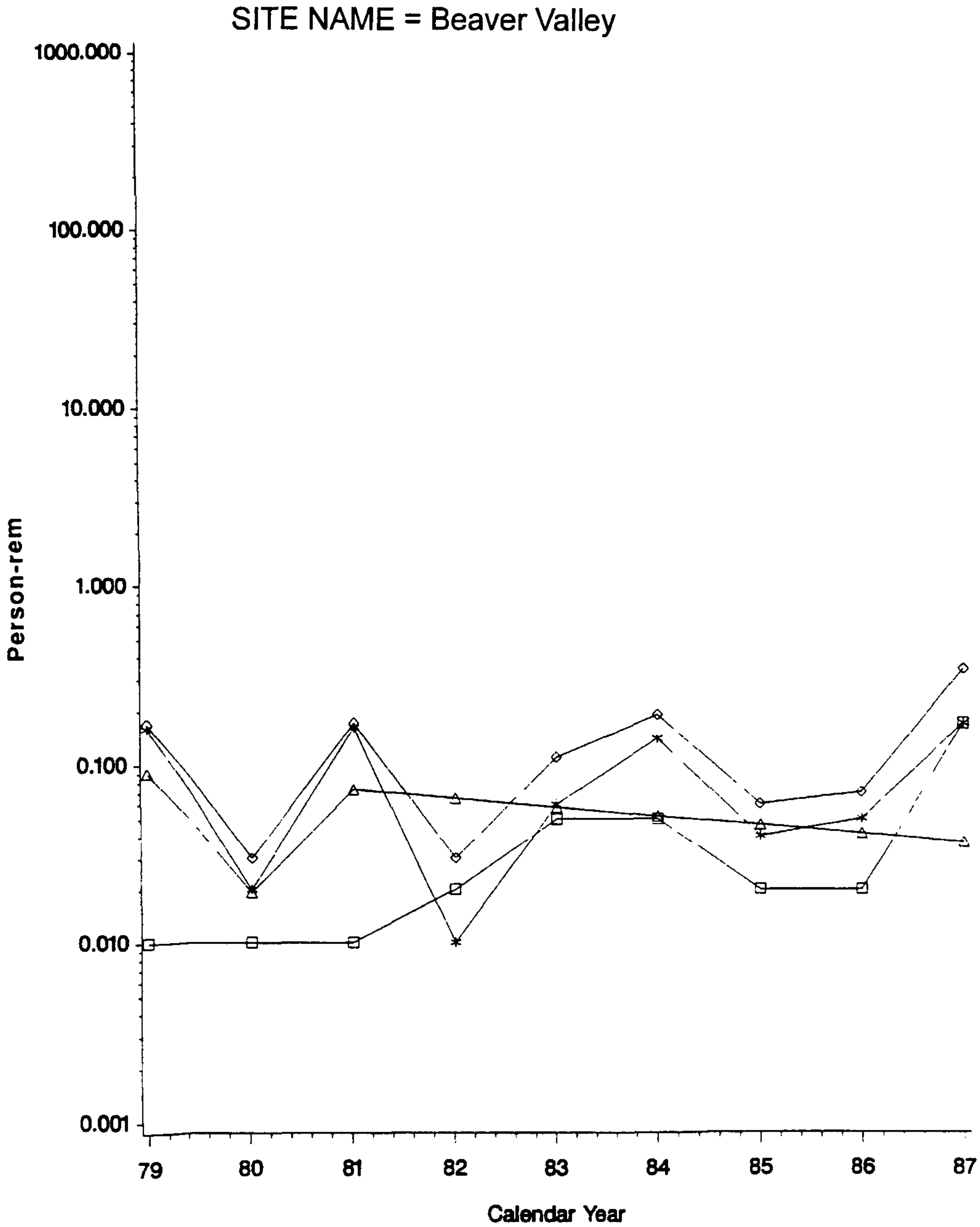

Figure E.C.2 Person-rem per year for Beaver Valley.

ORNL-DWG 95-1770

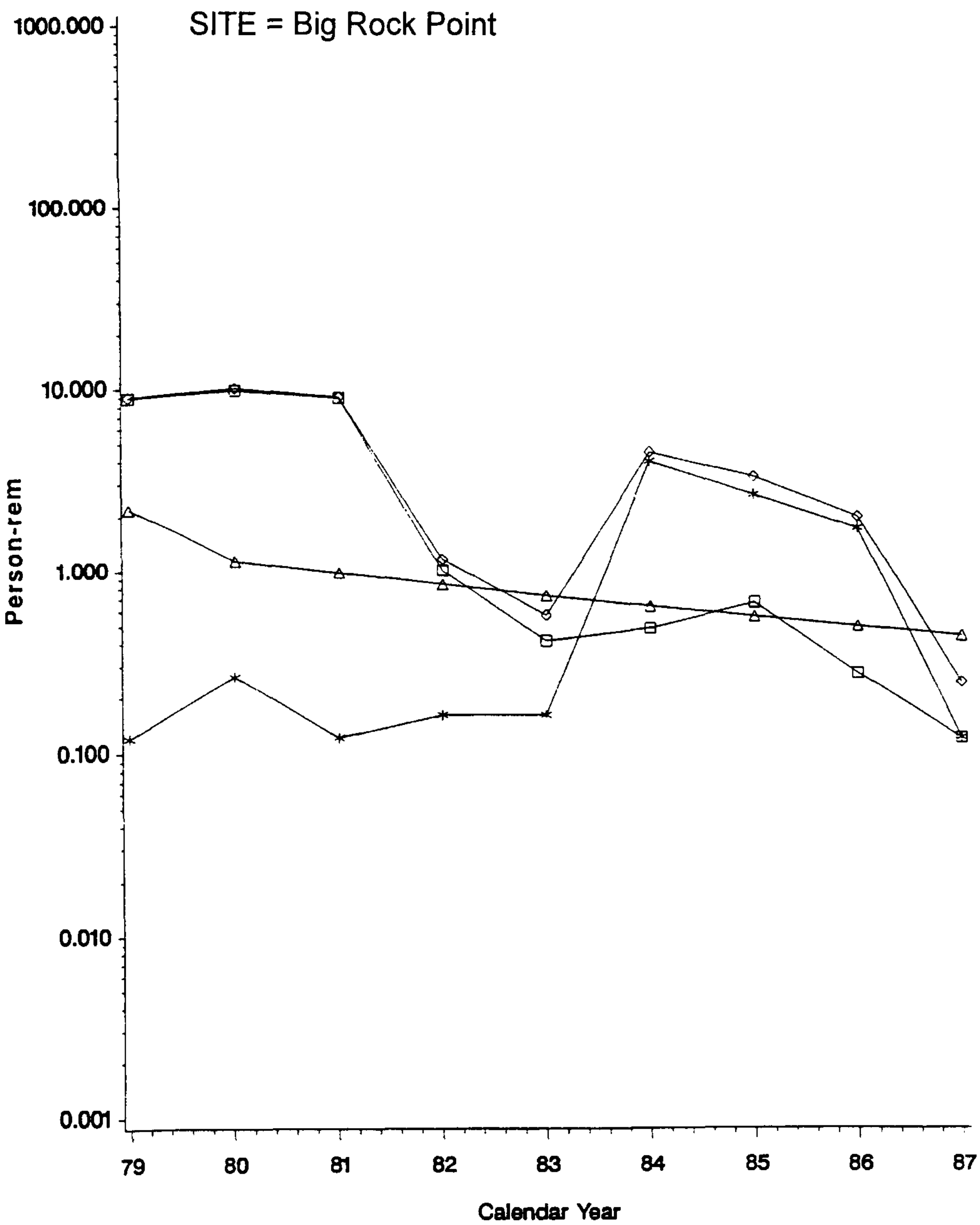

Figure E.C.3 Person-rem per year for Big Rock Point.

ORNL-DWG 95-1771

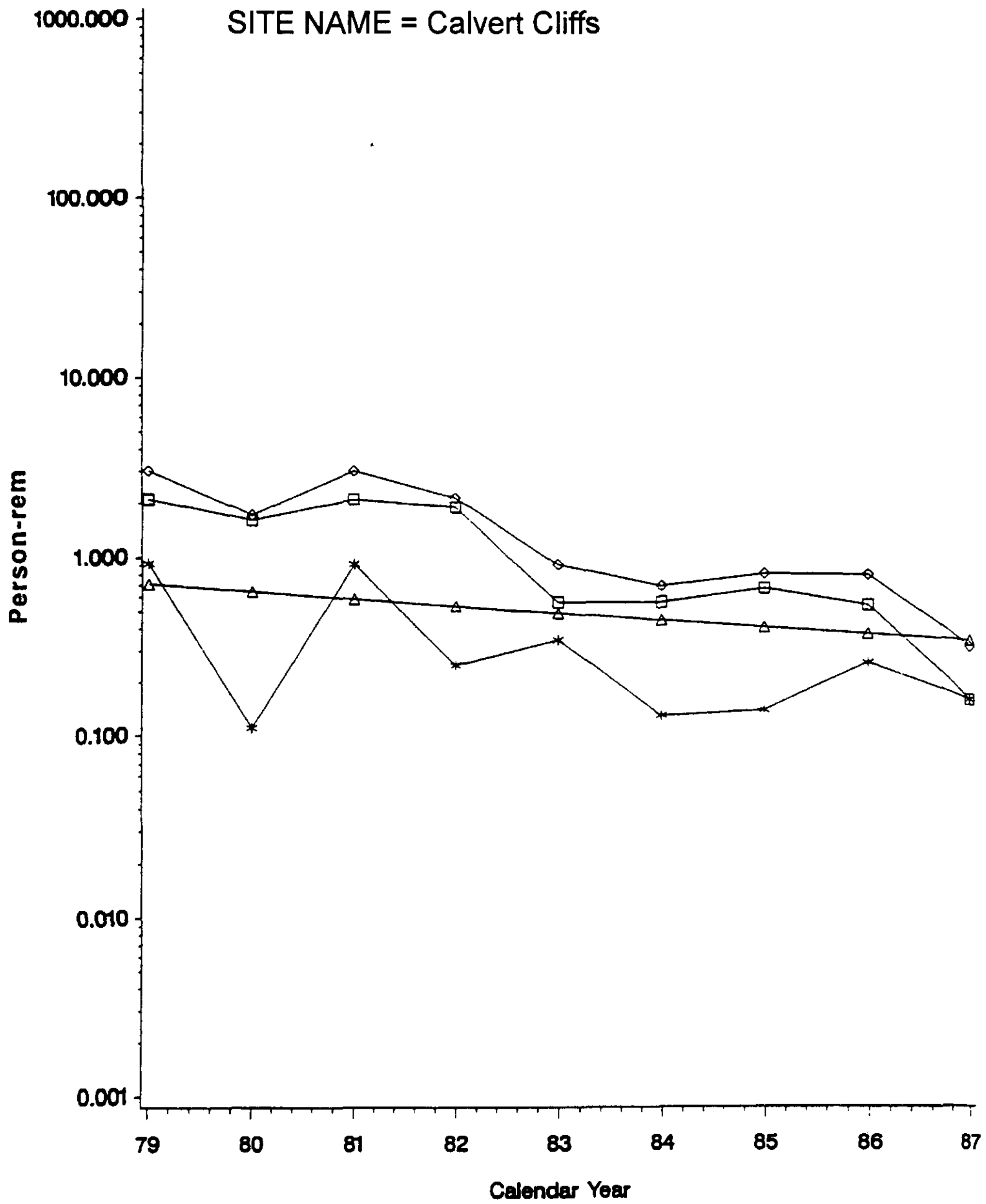

Figure E.C.4 Person-rem per year for Calvert Cliffs.

Appendix F

Methodology for Assessing Impacts to Aquatic Ecology and Water Resources

METHODOLOGY FOR ASSESSING IMPACTS TO AQUATIC ECOLOGY AND WATER RESOURCES

F.1 LIST OF ISSUES

The nonradiological aquatic effects of continuing operations during a license renewal period are not unique to nuclear power plants but instead are typical of potential impacts from any large steam-electric power plant (whatever the fuel type) and operation of the associated condenser cooling systems. The aquatic resources issues listed in Table F.1 have been identified from literature reviews, reviews of environmental impact statements (EISs), and professional contacts.

All of the issues listed in Table F.1 are addressed in Chapters 3 and 4, but primary emphasis is on the areas of water use, intake effects (entrainment and impingement), and thermal and chemical discharges. These areas consistently have been the most common issues raised in power plant impact assessments and permitting actions, and they have been the subject of considerable study and postoperational monitoring.

F.2 SOURCES OF INFORMATION

Information about historical and ongoing aquatic impacts associated with nuclear power plants was obtained from three general sources: (1) contacts with state and federal resource and regulatory agencies, (2) a survey of utilities that operate nuclear power plants, and (3) published literature.

Agencies with responsibility either for regulating the construction and operation of protection and maintenance of aquatic resources in the vicinity of the power plants were contacted for this document. For example, the U.S. Environmental Protection Agency (EPA) is responsible for protecting the quality of waters receiving discharges from the power plants and regulating the operation of the condenser cooling water intake and discharges. Regulation of intake and discharge effects to prevent significant impacts to aquatic communities is carried out by issuance and periodic renewal of National Pollutant Discharge Elimination System (NPDES) permits and, if necessary, by Clean Water Act Section 316(a) and (b) determinations (see Section 4.2 for a discussion of these regulatory requirements). Most often these permitting responsibilities have been delegated to the water quality regulatory agencies of the individual states. Although the state fish and wildlife agencies, the U.S. Fish and Wildlife Service (FWS), and the National Marine Fisheries Service (NMFS) do not issue permits to the nuclear power plants, they are concerned about the protection and enhancement of aquatic resources and thus have an essential consulting role with the U.S. Nuclear Regulatory Commission (NRC). Resource agency concerns may range from maintenance or enhancement of sport and commercial fisheries to protection of threatened and endangered species to restoration of anadromous fish or aquatic habitats.

Information request letters were sent to 151 individuals representing 74 state regulatory and resource agencies and to representatives in all of the regions of EPA, FWS, and NMFS. The letters solicited agency input

Table F.1 **Aquatic resources issues associated with the refurbishment and op. ation of nuclear power plants**

Refurbishment

- Soil erosion and sedimentation
- Water quality degradation from spilled chemicals

Operation

Water quality, hydrology, and use issues

- Water use conflicts
- Effects of consumptive water use on riparian communities
- Altered current patterns at intake and discharge structures
- Altered salinity gradients
- Temperature effects on sediment transport capacity
- Altered thermal stratification of lakes
- Scouring caused by discharged cooling water
- Eutrophication
- Discharge of chlorine or other biocides
- Discharge of other chemical contaminants (e.g., metals)
- Discharge of sanitary wastes

Aquatic ecology issues

- Threatened or endangered species
- Impingement of large organisms on the intake screens
- Entrainment of organisms into the condenser cooling water system
- Heat shock
- Cold shock
- Effects on movements and distribution of aquatic organisms
- Premature emergence of aquatic insects
- Stimulation of nuisance organisms (e.g., shipworms)
- Increased losses caused by predation, parasitism, and disease among organisms exposed to sublethal stresses
- Gas supersaturation (gas bubble disease)
- Low dissolved oxygen in the discharge
- Accumulation of contaminants (e.g., chlorinated organic materials or metals) in sediments or biota

about any existing or potential problems associated with operation of nuclear power plants in their state or region and any issues to be treated in thelicense renewal effort. An example information request letter is shown in Figure F.1. Responses were received from 17 federal agency regions and 55 state agencies, some of which provided references to specific studies that had been conducted to assess power plant impacts. These responses were used to augment information available from other sources on power plant effects.

A survey of all electric utilities that operate nuclear power plants was developed by Oak Ridge National Laboratory (ORNL) staff and administered by the Nuclear Management and Resources Council (NUMARC). The survey was intended to obtain the utilities' overview of the impacts of their power plants on aquatic resources. The survey contained nine questions related to aquatic resources; these are listed in Table F.2. As with the agency information requests, the utility responses to the survey were used as another source of information for assessment of power plant effects on aquatic resources.

For further information on aquatic impacts of power plant operations, published literature was reviewed, including peer-reviewed scientific journal articles that resulted from impacts studies, as well as periodic and topical reports submitted to or prepared by agencies [e.g., NRC EISs for the construction permit and operating license, environmental monitoring reports to the NRC, periodic reports to agencies associated with NPDES permits, and Section 316(a) and (b) demonstrations].

F.3 ANALYTICAL APPROACH

Analysis of impacts to aquatic resources focused on effects of power plant operation on water quality, water use, and aquatic biota. The potential impacts to these resources stem mainly from operation of the cooling water systems, although possible effects of refurbishment during the license renewal period were also examined.

Potential impacts to aquatic resources during the license renewal period result primarily from operation of the condenser cooling system. Water quality and availability can be altered by (1) use of biocides to prevent condenser tube fouling; (2) loss of water through evaporation, especially from cooling towers; (3) discharge of salts, metals, and other chemical contaminants; and (4) discharge of heated effluents. Aquatic biota can be affected by entrainment, impingement, and water quality changes from discharge of heated effluents and chemical contaminants. All of these effects were considered by the NRC in the EISs associated with the construction permit and operating license; they continue to be evaluated by the EPA or the state water quality permitting agency as part of the issuance and periodic renewal of the NPDES permit.

The approach used to assess effects of license renewal of existing nuclear power plants was to obtain information relating to these aquatic resources issues from monitoring data, other published information, and utility and regulatory agency contacts. If no impacts have been demonstrated for a given issue during the initial operating period of any plant, then continued operation under similar circumstances during the relicense period would not be expected to result in significant impacts. If impacts have been demonstrated

ORNL-DWG-90-16007

Date

Dear ________:

Oak Ridge National Laboratory is developing a report for the U.S. Nuclear Regulatory Commission that will evaluate environmental impacts of relicensing of nuclear power plants. Information on 118 reactors at 74 sites in the U.S. is being gathered to evaluate potential impacts from relicensing and an additional 20 or more year relicense period (beginning 40 years after the original license).

The results of this study will be used to modify 10 CFR 51 "Environmental Protection Regulations for Domestic Licensing and Related Regulatory Functions." These modifications may result in some issues no longer being considered for nuclear plants in National Environmental Protection Agency evaluations at their time of relicensing. Therefore, it is important that we obtain information from your office to help in evaluating any impacts of nuclear plants in your state with regard to fish and wildlife resources.

We would appreciate any information you may have on existing impacts and on the presence of important fish and wildlife resources that may be affected by continued operation of the ________ Nuclear Plant(s) and their power lines. For your convenience, a list of such resources and potential impacts is attached.

We would like to have your response by June 30, so that we can use the information in preparing the draft report. Thank you for your assistance.

Sincerely,

Glenn F. Cada
Aquatic Ecologist
Bldg. 1505, MS-6036
Phone: 615/574-7320

Roger L. Kroodsma
Terrestrial Ecologist
Bldg. 1505, MS-6038
Phone: 615/574-7310

Figure F.1 **Example information request letter sent to state fish and wildlife resource agencies, state water pollution control agencies, and regions of the U.S. Fish and Wildlife Service, National Marine Fisheries Service, and U.S. Environmental Protection Agency.**

List of Important Fish and Wildlife Resources and Potential or Known Impacts

- Important sport and commercial fisheries and level of harvest
- Important spawning, nursery, or other habitats for aquatic fauna
- Impacts of entrainment, impingement, or thermal and chemical releases on aquatic biota
- Adverse effects of water withdrawals or discharges on water quality and water use
- Other sources of impacts (e.g., other power plants, industrial discharges, agricultural runoff) that could contribute to cumulative impacts to aquatic resources
- Construction impacts (construction for relicensing is expected to be relatively minor and entirely contained within existing site boundaries)
- Aquatic or terrestrial flora and fauna that are listed as threatened or endangered
- Salt drift and icing impacts on vegetation as a result of cooling towers or cooling ponds
- Bird mortality due to collision with power lines and natural draft cooling towers
- Impacts on fauna as a result of vegetation cutting and herbicides in power line corridors
- Rare plant communities
- Bird colonies
- Bird roosts (e.g., raptors)
- Waterfowl staging areas
- Wetlands
- Breeding/strutting/wintering grounds for big game or certain gallinaceous birds

Figure F.1 **Example information request letter sent to state fish and wildlife resource agencies, state water pollution control agencies, and regions of the U.S. Fish and Wildlife Service, National Marine Fisheries Service, and U.S. Environmental Protection Agency.** (continued)

Table F.2 Questions relating to nuclear power plant impacts on aquatic resources that were part of the electric utility survey

1. Post-licensing modifications or changes in operations of intake or discharge systems may have altered the effects of the power plant on aquatic resources or may have been made specifically to mitigate impacts not anticipated in the design of the plant. Describe any such modifications or operational changes to the condenser cooling water intake and discharge systems since the issuance of the operating license

2. Summarize and describe (or provide documentation of) any known impacts to aquatic resources (e.g., fish kills, violations of discharge permit conditions) or National Pollutant Discharge Elimination System (NPDES) enforcement actions that have occurred since issuance of the operating license. How have these been resolved or changed over time? The response to this item should indicate whether impacts are ongoing or were the result of start-up problems that were subsequently resolved

3. Changes to the NPDES permit during operation of the plant could indicate whether water quality parameters were determined to have no significant impacts (and were dropped from monitoring requirements) or were subsequently raised as a water quality issue. Provide a brief summary of changes (and when they occurred) to the NPDES permit for the plant since issuance of the operating license

4. An examination of time trends in the results of aquatic resources monitoring can indicate whether impacts have increased, decreased, or remained relatively stable during operation. Describe and summarize (or provide documentation of) results of monitoring of water quality and aquatic biota (e.g., related to NPDES permits, environmental technical specifications, site-specific monitoring required by federal or state agencies). What trends are apparent over time?

5. Summarize types and numbers (or provide documentation) of organisms entrained and impinged by the condenser cooling water system since issuance of the operating license. Describe any seasonal patterns associated with entrainment and impingement. How have entrainment and impingement changed over time?

6. Aquatic habitat enhancement or restoration efforts (e.g., anadromous fish runs) during operation may have enhanced the biological communities in the vicinity of the plant and increased its impacts beyond that originally anticipated. Alternatively, degradation of habitat or water quality may have resulted in loss of biological resources near the site. Describe any changes to aquatic habitats (both enhancement and degradation) in the vicinity of the power plant since the issuance of the operating license that may have resulted in different plant impacts from those initially predicted

Table F.2 (continued)

7. Plant operations may have had positive, negative, or no impacts on the use of aquatic resources by others. Harvest by commercial or recreational fishermen may be constrained by plant operation or may be relatively large compared with fish losses caused by the plant. Describe (or provide documentation for) other nearby uses of waters affected by cooling water systems (e.g., swimming, boating, annual harvest by commercial and recreational fisheries) and how these have changed since issuance of the operating license

8. Describe other sources of impacts to aquatic resources (e.g., industrial discharges, other power plants, agricultural runoff) that could contribute to cumulative impacts. What are the relative contributions by percentage of these sources, including the contributions due to the power plant, to overall water quality degradation and losses of aquatic biota?

9. Provide a copy of your Section 316(a) and (b) Demonstration Report required by the Clean Water Act. What 316(a) and (b) determinations have been made by the regulatory authorities?

at some plants, then the analysis attempted to define the source and extent of the problem, to examine efforts to mitigate the problem, and to determine whether these site-specific impacts represent potential issues for the entire industry. The conclusions of this analysis were used to make judgments about limiting or eliminating the treatment of particular issuesin the license renewal applications of particular types of plants.

Because this Generic Environmental Impact Statement (GEIS) is intended to consider potential impacts across the industry and is not a site-specific license renewal action, the corresponding information required for the analysis is different. The objective is not to evaluate in detail the effects of each nuclear power plant on aquatic ecosystems but rather to examine information available from a variety of sources from a large sampling of plants with a view toward defining common, industry-wide issues that may need to be addressed in (or can be eliminated from) future license renewal actions. The assessments of aquatic resources issues in this GEIS are necessarily less detailed than the full analyses typically performed at the initial licensing stage. In such full analyses, the applicant supplied an environmental report containing detailed results of sampling programs, with appropriate analyses. The NRC staff reviewed this material, usually obtaining clarification and further information, and visited the site and discussed the information in detail as part of their independent analyses of the costs and benefits of the proposed action.

The possible endpoints of the evaluation of aquatic ecological effects in this GEIS are also constrained, regardless of the amount of information available from operation during the initial license period. Power plant impacts cannot be measured simply by comparing preoperational data with postoperational data. To accurately evaluate the impact of a power plant, one needs to know what the environment would have been like if the power plant had not been built (NUREG-CONF-002). This is not generally possible for aquatic systems. Reservoirs change as they age (in

productivity and potentially in species composition). Even in rivers or estuaries, standing crops of fish change from year to year, or even from decade to decade. These systems' responses to changes in environmental, biological, and anthropogenic factors are poorly understood. Power plants superimpose their effects on a mosaic of background influences from water flow rates, temporal pattern of runoff, temperature, productivity of other trophic levels, competition and predation, chemical pollution, habitat modification, fishing pressure, and other factors. However, the acceptability of power plant effects must be periodically reconsidered in the renewal of NPDES permits. The judgment that a facility employs "best available technology" or ensures a "balanced, indigenous population of shellfish, fish and wildlife" connotes that such effects, although real, are acceptable.

Because the nuclear power plants considered in this GEIS are now operating, some kinds of local (near-field, short-term) impacts (e.g., on benthic organisms) can be measured from localized studies at the intake and discharge. Mainly of interest, however, are the system-level (ultimate, long-term, population-level) effects, particularly on fish and shellfish. Models and professional judgment have been used to extrapolate the local power plant impacts to the resulting long-term, far-field effects on the whole system (Section F.4). Comparisons can also be made with sites not directly affected. Because of the interfering effect of other factors, however, such comparisons do not represent the actual system-level effects attributable solely to a power plant.

It is possible to measure the behavior of aquatic systems affected by operating nuclear power plants through time. Usually, a limited amount of data is collected before power plant operation. If the effects of the plant were drastic enough, an obvious change coinciding with operation could be detected when preoperational data were compared with postoperational data. Combined with information about near-field plant impacts, the change could be attributed to the plant. With less drastic plant impact, monitoring might show maintenance of a balanced and indigenous aquatic community. This does not always mean that the plant is without impact but could indicate that we are unable to detect a change from preoperational conditions (whether in spite of, because of, or regardless of the effects of the plant). However, it is reasonable to conclude that system-level effects are not evident, and whatever effects the plant is having are acceptable.

When the amount of preoperational data available is small, our confidence that the plant's impact is not serious is greatly reduced (Van Winkle et al. 1981). Uncertainties also arise when changes in the system occur that may be caused primarily by natural or anthropogenic factors (e.g., fish restoration projects or changes in fishing regulations).

The main purpose of our assessments is to identify aquatic ecology issues that generally do not need to be considered in the license renewal process as opposed to those that may or do need to be considered. By examining evidence for system-level effects (e.g., from entrainment and impingement) based largely on operational information, we can determine whether there is clear evidence for effects or whether the importance of these effects is still uncertain and may need to be resolved before license renewal. In this latter case, we cannot dismiss the issue for all plants, but its potential importance for many plants would be greatly lessened.

F.4 PLANT-SPECIFIC ANALYSIS

In addition to the review of all aquatic resources issues, selected issues were examined in greater detail for a subset of power plants. These issues, entrainment and impingement of fish and the effects of thermal discharges on aquatic biota, were the most common concerns expressed by the agencies. Because of factors such as large cooling water withdrawal and discharge rates, high Δ-Ts (large increases in temperature between intake and discharge) (Table 2.3), unique characteristics of the water body, or concerns expressed by the resources agencies, the power plants selected for detailed evaluation are believed to represent the types of power plants with the greatest potential for intake and discharge effects. These examples also represent a variety of aquatic systems affected by nuclear power plant operations, including reservoirs [Arkansas Nuclear One (ANO) and William B. McGuire Nuclear Station], the Great Lakes (D. C. Cook Nuclear Power Plant and the cumulative effects of Lake Michigan nuclear power plants), large rivers (cumulative effects of Hudson River power plants), and marine systems [San Onofre Nuclear Generating Station (SONGS) and the Crystal River Nuclear Plant]. Although some power plants with once-through cooling systems operate in relative isolation from other obvious sources of man-induced stress to aquatic biota, most of the examples considered here may affect aquatic resources in conjunction with other nuclear and coal-fired power plants, and therefore may represent the most severe cases. Where appropriate, the cumulative effects of these combined sources of stress have also been discussed.

F.4.1 Arkansas Nuclear One

The ANO station is a 2-unit, 1762-MW(e) plant located in Pope County, Arkansas, on Lake Dardanelle, an impoundment of the Arkansas River completed in the 1960s. Unit 1 uses a once-through cooling system, whereas Unit 2 has a natural-draft cooling tower system. Intake water is withdrawn from the Illinois Bayou arm of Lake Dardanelle through a 981-m (3220-ft) canal. The discharge is through a 158-m (520-ft) canal to an embayment of Lake Dardanelle. The Δ-T at full load is 8.3°C (15°F) for Unit 1. Because of the small volumes of blowdown associated with the closed-cycle cooling system of Unit 2, its contribution to discharge temperature increases is negligible. Arkansas Power and Light (AP&L) has conducted an extensive environmental monitoring program relating to the effects of ANO on Lake Dardanelle, including the effects of heated water discharges, impingement, and entrainment.

ANO has operated under a series of NPDES permits issued by EPA; no Section 316(a) demonstration has been required. Utility consultations with EPA Region 6 in the early 1980s confirmed that there was no 316(b) requirement; reevaluation would be needed only if there were a dramatic change in impact [AP&L, response to NUMARC survey (NUMARC)]. The following sections discuss the impacts of ANO operation.

F.4.1.1 Thermal Discharges

A portion of AP&L's monitoring program is designed to assess the impacts of the thermal discharge on fish and aquatic life (AP&L 1984). Discharge temperature is limited to 35°C (95°F), with a maximum increase over ambient of 2.8°C (5°F) based on a monthly average of daily depth-averaged values measured at

unspecified locations in Lake Dardanelle (Geo-Marine, Inc. 1976; AP&L 1984). Most of the heat added to the water is dissipated within 2.5 km (1.6 miles) of the point of discharge (Rickett 1983).

The plant discharge has been studied with respect to effects on physicochemical parameters, phytoplankton, zooplankton, and fish. Statistically significant differences in turbidity, suspended solids, chloride, and hardness, but not conductivity, were found between the intake area and an upstream area in Lake Dardanelle, but not between the intake and the discharge (Rickett and Watson 1985). The differences appear to be small and may be the result of characteristically different water quality in the Illinois Bayou and the Arkansas River mainstream (e.g., Geo-Marine, Inc. 1976). A comparison of the phytoplankton communities at close versus distant sampling stations after power plant operation began showed (1) no noticeable effects on phytoplankton abundance and the number of taxa and (2) no significant effects on diversity (Rickett and Watson 1983b), although an indication is given that phytoplankton were stimulated at close stations (Rickett and Watson 1983a). The heated effluent was considered to have slightly suppressed overall abundance and variety, but not diversity, of the zooplankton community, and to have generally increased the ratio of phytoplankton to zooplankton abundance at close stations (Rickett and Watson 1983a). Also attributed to the power plant was a dominance exchange between the rotifer genera *Brachionus* and *Polyarthra*, with the latter genus moving from third to first rank in terms of the number of times it was dominant at individual sampling stations (both close and distant). Such a shift is consistent with experimental results showing an increase in abundance of *Polyarthra major* in a heated enclosure relative to an unheated control (CONF-740820).

Evaluating effects of the discharge on fish communities is one of the main objectives of multiyear fish surveys conducted by AP&L. Fish are attracted to the discharge area in the winter and to the intake area in the summer; sport fish tend to avoid the discharge area in the summer because of the elevated temperatures [AP&L, response to NUMARC survey (NUMARC)]. Concern was expressed in the Final Environmental Statement (FES) for Unit 1 (AEC Docket 50-313) about potential cold shock in the event of rapid plant shutdown during the winter. Recent information [AP&L, response to NUMARC survey (NUMARC 1990)] does not discuss whether such shutdowns have occurred, but only one significant fish kill incident (excluding entrainment and impingement mortality) is reported from 1974 through 1989. The deaths, in the discharge area, were related to lordosis (humpback or crooked spine). This abnormality may have been caused primarily by toxaphene, an agricultural pesticide that washed into the reservoir from the surrounding watershed and was enhanced by the thermal discharge. Toxaphene was banned, and lordosis has rarely been observed after 1978 [AP&L, response to NUMARC survey (NUMARC 1990)].

Time trends in mean weights of adult fish have been examined over several years (Tilley 1983). Mean weights for five species of fish tended to be somewhat higher in the discharge embayment than in stations elsewhere, as did the ratio of predators to prey based on weights. It was concluded that species composition in the reservoir had not reached equilibrium in the 15 years after impoundment, and it was considered unlikely to do so in the future. The species composition in the vicinity of the discharge

is, however, not significantly different from that in other sample areas (Tilley 1983).

F.4.1.2 Entrainment and Impingement

The potential for entrainment at ANO is not negligible. At full power operation, the plant withdraws 48 m^3/s (765,000 gal/min) of water. If the reservoir is viewed as a closed system, this is 0.5 percent of the reservoir volume per day. Viewing the reservoir as an open system, the intake is 5 percent of the mean flow through the reservoir; much larger percentages can be calculated during periods of low flow. Although these percentages do not represent estimates of entrainment or impingement, they may be large enough to result in significant impacts.

An assessment of entrainment at ANO has been conducted by AP&L (1990). Summary data are presented for 1977–1982 for fish larvae from meter net samples in the Illinois Bayou in the vicinity of the entrance to the intake canal and in the intake canal itself. Clupeid larvae represented 79–97 percent of all larvae captured in the entrainment samples, depending on the year. Although clupeids were the most frequently entrained larvae, these species have been able to reestablish themselves in the intake area and the reservoir each year. AP&L does not regard entrainment at ANO as having a significant impact on these or other species of fish in the lake (AP&L 1990).

Impingement samples have been taken from at least 1974 through 1982. Impingement has been substantial. In the FES for Unit 2, NRC staff reported that from June 10, 1974, through July 19, 1975, 34 species had been impinged at Unit 1; estimated impingement was 27.5 million fish weighing 213,000 kg (470,000 lb), of which 99.6 percent by number and 99.3 percent by weight were threadfin or gizzard shad (NUREG-0254). These fish were predominantly young-of-year and presumably stressed by low water temperatures (Zweiacker et al. 1977). Ten million fish weighing 97,900 kg (215,900 lb) were impinged during the first year of operation, compared with an average impingement of 2 million fish weighing 13,000 to 30,000 kg (29,000 to 66,000 lb) in ensuing years [AP&L, response to NUMARC survey (NUMARC 1990)]. Also during 1974–1975, an air bubble curtain was evaluated as a possible means of reducing impingement. It was considered ineffective. Impingement levels were found to be inversely correlated with temperature (Zweiacker et al. 1977).

An indication of the magnitude of ongoing impingement can be obtained by comparing estimated impingement of fish with estimated reservoir standing crops. These estimates were provided for 1981 for some of the more important commercial and sport fish and forage fish in the reservoir. Impingement in 1981 represented less than 3 percent of the estimated gizzard shad population and less than 13 percent of the estimated threadfin shad population, either by numbers or by weight. For the 11 other species, the fraction was 1 percent or less and usually less than 0.1 percent. Impingement rates of the magnitude estimated for threadfin shad could have a significant effect on the population, although demonstrating (i.e., measuring) the effect would probably be impossible given the limited preoperational data and the natural variability inherent in fish populations (Van Winkle et al. 1981). Loar et al. (1978) studied impingement of threadfin shad at 32 southeastern power plants, including ANO. The impingement rate of shad [number impinged per million cubic meters (2.6×10^8 gal) of water withdrawn] at ANO was more than 4 times that of the second highest plant in their study and more than 10 times

higher than rates at the other nuclear power plants. Loar et al. concluded that the characteristic of peak winter impingement of threadfin shad was widespread for southeastern U.S. power plants between 33° and 37° N latitude (ANO is near 35° N latitude) and that impingement rates were higher in reservoirs than on rivers. They could not firmly relate the rates to type of intake structure or to plant operational parameters (e.g., flow rates; velocity near the intake screens).

F.4.1.3 Summary of Impacts

Information about preoperational (1969–72) and postoperational (1975–84, except for 1979) standing crops of fish from Lake Dardanelle are available in one of the National Reservoir Research Data Bases. Four multivariate analyses of variance, or MANOVAs, of the Lake Dardanelle data were conducted. These compared preoperational status of fish communities in the reservoir with postoperational status based on standing crops for selected important commercial, sport, or forage species within four groups of fish: clupeids (threadfin shad, gizzard shad, and skipjack herring); catfishes (channel catfish, flathead catfish, and blue catfish); basses (largemouth bass, striped bass, and white bass); and crappies and sunfishes (black crappie, white crappie, bluegill, and longear sunfish). A significant ($p < 0.05$) difference was found only with the basses. The individual univariate analyses of variance, or ANOVAs, for individual bass species showed a significant decrease in largemouth bass. However, a nonparametric test using the Mann-Whitney U statistic showed, in addition, a significant increase in striped bass (which had not been caught at all in the preoperational period). Whether these changes are related primarily to operation of ANO, to natural changes in Dardanelle Reservoir as it ages, or to other anthropogenic factors is not clear. Because entrainment and impingement of largemouth bass are low, substantial effects of ANO on this species would only be expected as an indirect consequence of effects on one of their food sources, clupeids; such effects on clupeids were not detected.

The combined effects of thermal discharges and entrainment and impingement stresses are likely greatest on the threadfin and gizzard shad populations. Quantifying the level of stress would require extensive additional analyses, far beyond the scope of this GEIS. Evaluating the consequences of these effects and stresses at the fish population level presents additional difficulties, due in large part to uncertainty about biological compensatory mechanisms (EPRI EA-5200s). However, as AP&L points out, threadfin and gizzard shad are able to reestablish themselves in the intake area and the reservoir each year [AP&L, response to NUMARC survey (NUMARC 1990)]. Effects of changes in zooplankton dominance and high annual levels of shad impingement are not apparent. In addition, state and federal regulatory agencies have not expressed concern about operation of ANO.

F.4.2 William B. McGuire Nuclear Station

The William B. McGuire Nuclear Station is a 2-unit, 2360-MW(e) plant located on Lake Norman, the largest impoundment in North Carolina. Both units use a once-through cooling system, drawing a combination of surface water from a manmade embayment and deep water from an intake located near the base of Cowan's Ford Dam. The near-shore discharge is channeled through a canal 1 km (0.6 mile) long. The Δ-T (change in temperature) at full load ranges from 8.6° C

(15.5°F) in the summer to 13.7°C (24.7°F) in the winter (Duke Power Company 1985).

Concerns about McGuire's impacts to aquatic resources have focused mainly on effects of heated water discharges on recreational fisheries (DUKE PWR/82-02), although entrainment and impingement are also of potential concern for aquatic life. Water use has also been identified as an issue.

Lake Norman was impounded in 1963 primarily for power generation. The Marshall Steam Station (coal-fired) also uses the lake for cooling water; with both facilities operating, the lake has the highest thermal loading from the discharge of once-through condenser cooling water of any lake of comparable size in the United States (DUKE PWR/82-02). Several sport fish species have been successfully introduced to the reservoir. Largemouth bass, crappie, striped bass, and white bass dominated the fishery in the early 1980s (DUKE PWR/82-02).

The following sections discuss the major potential sources of impacts from the McGuire plant.

F.4.2.1 Thermal Discharges

Extensive attention has been devoted to evaluating the thermal effects on Lake Norman of discharges from both Marshall and McGuire. Postoperational versus preoperational comparisons of fish standing crops based on cove rotenone sampling show fluctuations, but the only documented trend is a decline in gizzard shad standing stocks near the discharge since operation [Duke Power Company, response to NUMARC survey (NUMARC 1990)]. Minor sporadic die-offs of striped bass and yellow perch have been observed before and after operation of McGuire. These have been attributed to a loss of oxygenated cool-water habitat. The original NPDES permit for McGuire specified a maximum discharge temperature of 35°C (95°F). A new permit, issued in 1990, increases this limit to 37°C (99°F) during July to September. The new higher limit can be attained with a lower proportion of cool, deep (hypolimnetic) water from the lower-level intake structure. This in turn is expected to reduce the depletion of habitat for cool-water fish species (primarily adult striped bass and yellow perch).

Avoidance of the discharge area by fish during summer, which varies depending on the level of operation, has been documented and will probably increase with the new thermal limit. Because areas of Lake Norman water affected by thermal discharges will be increased only by approximately 1 percent as a result of the changed limits (Duke Power Company 1988), the loss of summer aquatic habitat should have negligible effects on fish populations. Attraction of fish to the discharge area during cooler months has occurred in the past and will probably continue. The likelihood of mortalities due to cold shock is substantially reduced with two units operating. No incidences have been reported of fish mortalities resulting from thermal shock in the first few years of operation (Carter 1990).

Gas bubble disease (GBD), which sometimes leads to mortality, has regularly been observed in the discharge of the Marshall plant (McInerny 1990). Duke Power (1985) projected only low incidences of GBD for the McGuire station, based on operating data from Marshall and the Δ-Ts expected for McGuire. In the limited postoperational data provided, the incidence of GBD was low. Incidence of disease and parasitism was

also low, both in preoperational and operational years (Duke Power Company 1985).

F.4.2.2 Entrainment and Impingement

The only report currently available about entrainment and impingement is from a preoperational, predictive study (Duke Power Company 1978). Threadfin shad were expected to be the fish species most subject to both entrainment and impingement. A formal 316(b) demonstration has not been required at McGuire, and no extensive studies of fish entrainment and impingement have been conducted (Carter 1990).

F.4.2.3 Cumulative Impacts

Combined effects of the Marshall and McGuire plants on fisheries are difficult to document. This difficulty is typical of situations where not only power plants but also other external factors are operating on the system. Despite the potential for entrainment, impingement, and thermal effects, the overall fish populations of Lake Norman appear to be healthy and to support an increasing amount of recreational activity. In responses from federal and state agencies, the North Carolina Wildlife Resources Commission expressed a concern about mortalities of large striped bass in Lake Norman but also indicated that it was uncertain whether these are related to operation of McGuire (Hamilton 1990).

Consideration of impacts to aquatic resources in Lake Norman is an ongoing cooperative effort between Duke Power Company and the resource and regulatory agencies (Lewis 1990). This is evidenced by the recent modification of maximum discharge temperatures of the McGuire station to protect cool-water fish habitat.

F.4.3 D. C. Cook Nuclear Power Plant

The D. C. Cook Nuclear Power Plant is a 2-unit, 2130-MW(e) plant located on the southeastern shore of Lake Michigan. The plant uses a once-through cooling system for both units, drawing water from three intake cribs located 680 m (2231 ft) offshore in 7.3 m (24 ft) of water (Thurber and Jude 1984). Cooling water is also discharged offshore through two slot-jet discharge structures located 366 m (1200 ft) offshore in 5.5 m (18 ft) of water. The maximum temperature to which discharged water is heated above ambient temperatures (i.e., the Δ-T) is variously reported as 10°C (18°F) (Evans et al. 1977; Evans 1984; Chang and Rossman 1985) or 21°C (38°F) (Thurber and Jude 1984). A riprap bed of crushed limestone was deposited around the intake and discharge structures during construction to prevent erosion and scour.

Concerns about D. C. Cook impacts to aquatic resources have focused on effects of entrainment, impingement, and heated water discharges on recreational and commercial fisheries. The most frequently impinged and entrained fish species in Lake Michigan are alewife, yellow perch, and rainbow smelt (Jensen et al. 1982). All three species support small commercial fisheries, and yellow perch and rainbow smelt are also important to sport fishermen. In addition, there are important cold-water sport fishes (e.g., lake trout and various other stocked salmonids) that could be affected by thermal discharges.

Chang and Rossman (1985) report that the plant no longer requires biofouling control and that chlorination did not occur during their study period. The spread of the fouling organisms *Corbicula* and the zebra mussel in the Great Lakes in recent years may once again require the use of some type of

biocide. In any case, D. C. Cook would be unlikely to cause biocide impacts because it discharges treated water through a diffuser (to ensure rapid mixing and dilution) into a large body of water. Chemical effluents would be rapidly diluted and are unlikely to accumulate in the system.

F.4.3.1 Thermal Discharges

The rapid mixing of heated water and discharge into a large body of cold water is unlikely to result in significant adverse impacts. Evans studied benthic communities in the vicinity of the discharge structure and found few or no differences between the thermal plume and control areas in abundances of bottom-dwelling organisms; the few differences that were detected were limited to small areas within a few hundred meters of the intake and discharge structures.

Spigarelli et al. (1983) studied movements of a cold-water sport fish, the brown trout, near the thermal plume of a Lake Michigan power plant similar to D. C. Cook [essentially the same discharge rate and Δ-T (change in temperature)]. The trout took up residence in the thermal plume instead of avoiding it, especially during the winter months when ambient temperatures are lower than those preferred by the fish. In Lake Michigan, fish can easily avoid thermal plumes, but some species (brown trout, rainbow trout, alewife, carp, and salmon) frequently occupy these gradients (Spigarelli et al. 1983).

F.4.3.2 Entrainment and Impingement

Because of the large volumes of water withdrawn for condenser cooling of the two units and the large numbers of important fishes in the vicinity, D. C. Cook has been studied for entrainment and impingement impacts. Studies before and during operation of the plant sought changes that could be attributed to operation. Few significant effects were detected from the entrainment of phytoplankton (Chang and Rossman 1985) or zooplankton (Evans et al. 1977), and even these effects were considered inconsequential or highly localized.

Madenjian et al. (1986) used two statistical procedures to assess D. C. Cook impacts. They compared catches of alewives and yellow perch before operation (1973–74) and during operation (1975–82). Both analyses disclosed no significant power plant impacts. State and federal resource agencies contacted for this document did not express concerns about the continuing operation of D. C. Cook (Madenjian et al. 1986).

F.4.4 Lake Michigan Nuclear Power Plants

Six nuclear generating stations are located on Lake Michigan. Except for the Palisades Nuclear Plant, they all use once-through cooling. Listed with the number of units, they are Big Rock Point Nuclear Plant (1), D. C. Cook Nuclear Power Plant (2), Kewaunee Nuclear Power Plant (1), Palisades Nuclear Plant (1), Point Beach Nuclear Plant (2), and Zion Nuclear Plant (2). The near-field aquatic effects of one of these, the D. C. Cook plant, have been considered separately in this section. In addition, EPA, the Illinois Environmental Protection Agency, and the Illinois Department of Conservation all specifically identified entrainment and impingement of fish at the Zion Nuclear Plant as issues of concern; and studies of potential mitigative measures have been requested. In terms of the far-field, long-term effects, it is appropriate to consider these plants as a group and to examine their cumulative impacts, considering also other sources of impact (including fossil-fuel power plants)

on Lake Michigan as a whole. This approach has been taken in several publications that consider the cumulative effects of entrainment and impingement of fish.

Kelso and Milburn (1979) evaluated cumulative entrainment and impingement during 1975 or 1976 at 89 power plants using once-through cooling systems located on all five of the Great Lakes. The combined capacity of these plants was 54,118 MW(e). Consideration was also given to an additional 17 plants with once-through cooling systems not yet operational at that time but expected to be operational by 1982, with 30,705 MW(e) additional capacity. Of these, 25 existing and 3 planned plants, with 14,932 and 4,969 MW(e) capacities, respectively, were located on Lake Michigan.

Impingement information was available from 43 percent of the existing power plants. Impingement in Lake Michigan was second highest (after Lake Ontario), with a broad peak from May to July. Entrainment information was more limited, available from only 24 percent of the plants. Regression equations were developed for annual impingement and annual entrainment as functions of power plant size (apparently, with all units combined within plants); these were used to extrapolate to plants lacking adequate data. Based on these equations, annual impingement at existing Lake Michigan plants was estimated to be about 15.4 million fish; the proposed plants were projected to increase this by 755,000 fish. The corresponding estimates for entrainment of larvae were about 196 million and 10 million, respectively.

Kelso and Milburn (1979) estimated annual impingement in the Great Lakes by these power plants of approximately 100 million fish. Calculating an average weight of an impinged fish at about 75 g (2.6 oz), they estimated that the "harvest" by power plants through impingement was at least 7500 metric tons (8300 tons), or 15 percent of the total commercial landings (about 50,000 metric tons (55,000 tons), obtained from references dated 1970 and before). Because they considered their impingement figures to be low, they estimated that impingement losses were in excess of 25 percent of the total annual commercial fish harvest. Kelso and Milburn (1979) estimated an annual entrainment in the Great Lakes of about 1.2 billion larval fish, but because of inadequate information they did not try to relate these losses to the size of the commercial catch.

Scott-Wasilk et al. (1981) believed that Kelso and Milburn's (1979) comparison of the loss estimates with commercial catch data overstated the impact. They noted that 85 percent of the impingement and entrainment was of "ecologically less desirable, but very abundant species" that are increasingly dominant in the commercial catch. Alewife and smelt stocks fluctuate substantially but have shown no consistent trends in abundance in Lake Michigan, despite the entrainment and impingement and a steadily increasing commercial catch of alewives. They considered standing crops to be a more appropriate basis for comparison. Viewed this way for Lakes Michigan and Ontario and the western basin of Lake Erie, annual impingement losses (expressed variously as numbers or as weights) typically constituted less than 1 percent of total stocks. Scott-Wasilk et al. (1981) also felt that the probable effect of power plants on sport and commercial landings was negligible and that (biological) compensatory reserves for impacted stocks, although unquantified, were probably sufficient to minimize the impact of these losses.

Kelso and Milburn (1981), in their response, noted that although losses of alewife and smelt may be small in Lake Michigan, such losses might constitute a significant reduction in the forage base for trout and salmon. The concern was also expressed that discrete stocks and local populations might be depleted by clustering power plants with once-through cooling systems in areas including the southern basin of Lake Michigan.

A different approach, involving the adaptation and use of conventional fishery stock assessment models, was taken by Jensen et al. (1982) to estimate the effects of 15 power plants on Lake Michigan. All of the nuclear plants except Big Rock Point were included. Both the surplus-production and the dynamic- pool models were applied to estimate the proportions of the Lake Michigan standing stocks of alewife, yellow perch, and rainbow smelt impinged and the proportions of eggs and larvae entrained.

The impingement proportions should be reasonably comparable to those calculated by Scott-Wasilk et al. (1981) for 17 Lake Michigan power plants. Although all of the impingement estimates calculated in either paper for Lake Michigan were less than 1 percent, the estimates of Jensen et al. (1982) for alewife (0.25 percent and 0.21 percent, depending on the model used) were substantially smaller than the 0.77 percent estimated by Scott-Wasilk et al. (1981). Conversely, the Jensen et al. (1982) estimates for rainbow smelt of 0.15 percent (both models) were more than double the Scott-Wasilk et al. estimates.

Referring to the type of analysis conducted by Kelso and Milburn (1979), Jensen et al. (1982) also presented estimates of biomass impinged as a percentage of 1975 commercial catch statistics. They estimated that impingement amounted to 10 percent of the commercial catch of alewife, 3.6 percent that of yellow perch, and 3.1 percent that of rainbow smelt which, given the recent predominance of alewife in the commercial catches, compare reasonably well with Kelso and Milburn's (1979) calculation of 15 percent of total commercial landings (all species), based on older catch data.

The main advantage of the approach taken by Jensen et al. (1982) is that, rather than just ratios, the *effects* of entrainment and impingement can be estimated on standing stocks and on maximum sustainable yields. Using the full-flow scenario, but including entrainment and impingement, they estimated reductions of standing crops (biomass) of 2.86 percent for alewife, 0.28 percent for yellow perch, and 0.76 percent for rainbow smelt. Corresponding reductions in the maximum sustainable fishery yield are larger: 4 percent for alewife, 0.5 percent for yellow perch, and 1.2 percent for rainbow smelt. Using "maximum" entrainment and impingement coefficients, there is about a 10 percent decrease in biomass (species not specified). They concluded, "Although large numbers of alewife, rainbow smelt, and yellow perch are killed by entrainment and impingement, the proportions of the populations affected are relatively small. Still, the loss of fish biomass is not negligible, and entrainment and impingement impacts need to be considered in the design of new intake facilities" (Jensen et al. 1982).

The main lesson to be learned from these analyses of entrainment and impingement impacts on fisheries in Lake Michigan is that it may not be sufficient to evaluate the significance of these types of impacts one power plant at a time. The main effects of concern are not local but relate to the entire lake (or at least to entire basins). The issue

is one of resource management, and the logical level for management is at the level of the resource: cumulative impacts of all plants (and other water uses) in an area or on a lake.

F.4.5 Hudson River Power Plants

Seven power stations (including two nuclear stations, Indian Point 2 and 3), with a total net rated capacity of 5798 MW(e), are located along the Hudson River estuary between river kilometers 8 and 228 (Hutchison 1988). The most extensive consideration of entrainment and impingement impacts on the aquatic environment ever undertaken centered on these facilities. During the late 1970s, the studies, analyses, and hearings involved four federal agencies, five utilities, and numerous other parties and drew on the cumulative efforts of nearly 2000 technical personnel. The results of these studies have recently been integrated and summarized as a case study (Barnthouse et al. 1988b) that is the best available evaluation of what can and what cannot be determined about these kinds of impacts.

The greatest attention focused on the population-level effects of entrainment and impingement of fish at the three largest plants: the Indian Point Nuclear Generating Station (Units 2 and 3) and the Bowline Point and Roseton fossil-fuel plants. In particular, the final EPA hearing that ended with the 1980 settlement agreement (Barnthouse et al. 1988a) focused on whether reducing entrainment and impingement effects by retrofitting closed-cycle cooling systems to the six active units at these three facilities was necessary. However, most of the later analyses included the effects of five power plants by adding Lovett and Danskammer, two smaller fossil-fuel stations. The other two plants were near each end of the estuary beyond the region for which data were available but also outside of the main spawning and nursery areas of key fish species. Therefore, analyses assessed the cumulative impact of steam-electric power generation on the Hudson River estuary. Impacts on striped bass received greatest attention, but white perch, Atlantic tomcod, American shad, alewife, blueback herring, and bay anchovy were also considered.

Numerous mathematical models have been developed to evaluate the extent and effects of entrainment and impingement (Christensen and Englert 1988; Barnthouse and Van Winkle 1988). The Hudson River approaches differ from those used for Lake Michigan, in which the numbers entrained or impinged were related to numbers or weights of fish in the lake or caught in the fishery. Interpreting such comparisons is very difficult because (1) the entrained (and probably also impinged) fish are younger and less valuable than those in the fishable stock and (2) impingement needs to be considered in relation to the life-cycle of the fish, not just on an annual basis. In the Hudson River, these issues were moot because estimates of the absolute size of stock standing crops or fishery yields were not available, in part because of the open nature of the estuary. Rather, emphasis was placed on the conditional entrainment and impingement mortality rates (Ricker 1975) (the fraction of an initial population that would be killed during the year if no other sources of mortality operated) imposed on each year class and on the resulting projected percentage reduction of the standing stock.

A reasonable consensus was eventually achieved about the magnitude of entrainment impact (Englert and Boreman 1988; Barnthouse et al. 1988a). Estimates of

conditional entrainment mortality based on historical and projected once-through cooling operations at the five power plants ranged from 5 to 7 percent for Atlantic tomcod to 35 to 79 percent for bay anchovy (Englert and Boreman 1988). For most species, the impact of entrainment was considered more important than that for impingement. For white perch, however, the estimates of conditional impingement mortality were relatively large, ranging from 10 to 59 percent (Barnthouse and Van Winkle 1988).

The Hudson River studies were relatively unsuccessful in meeting the broader objective of extending these direct impact estimates to determine the percentage reduction of the corresponding fish populations in the estuary (Klauda et al. 1988; Barnthouse et al. 1988c). Out-of-court negotiations among many of the parties involved began in August of 1979 (Barnthouse et al. 1988a) in an effort to end the stalemate that was increasingly apparent, especially concerning the long-term effects of the conditional mortality rates attributable to the power plants. These conditional entrainment and impingement mortality rates became the measures used to assess the impacts of existing operation. The successful result of these negotiations is summarized in Barnthouse et al. (1988a p. 269): "On December 19, 1980, the historic settlement agreement was signed by all parties. For the 10-year duration of the settlement, no cooling towers would be required. As an alternative, the utilities agreed to a variety of technical and operational changes intended to reduce entrainment and impingement. In addition, they agreed to supplement the production of striped bass in the Hudson River by means of a hatchery, to conduct a biological monitoring program, and to fund an independent research foundation for study of Hudson River environmental problems." The remainder of Barnthouse et al. (1988a) provides details of these elements of the settlement agreement.

The settlement agreement is expiring, and it is not certain what administrative procedures will occur in its aftermath. In responses to requests to federal and state agencies, NMFS mentioned that the Indian Point plant is "famous for entraining striped bass eggs and larvae" (Gorski 1990). The NMFS indicated that the attempt at mitigation by means of a striped bass hatchery has never been acceptable to the resource agencies, who have asked for closed-cycle cooling. The New York State Department of Environmental Conservation (NYSDEC) is the agency responsible for NPDES permits. It has expressed concerns about entrainment, impingement, and thermal discharge effects at Indian Point (Wich 1990). At present, entrainment and impingement effects at Indian Point are active issues; whether they will still be issues at the time of license renewal will be determined by the course of events that cannot now be predicted.

F.4.6 San Onofre Nuclear Generating Station

SONGS is a three-unit nuclear facility located on the coast of Southern California, roughly midway between Los Angeles and San Diego. All three units use once-through cooling systems, withdrawing water from the Pacific Ocean through submerged velocity-capped intake structures located at distances between approximately 900 and 980 m (3000 and 3200 ft) from shore in about 9 m (30 ft) of water. During normal operation, Unit 1 [436 MW(e)] withdraws water at a rate of 22 m^3/s (350,000 gal/min) and increases its temperature about 10°C (18°F) during passage through the plant. Units 2 and 3 are each rated at 1070

MW(e), and each withdraws approximately 50 m^3/s (800,000 gal/min), with a temperature increase of about 11°C (20°F). The Unit 1 discharge is through a single vertical pipe in 7.6 m (25 ft) of water about 762 m (2500 ft) from shore. Discharge of the larger units (2 and 3) is through 760-m (2500-ft) diffusers offset from one another and positioned more or less in sequence; for Units 2 and 3, they terminate 2500 m (8200 ft) and 1800 m (5900 ft) offshore, respectively.

Extensive studies of the effects of SONGS on aquatic biota have been conducted by the Marine Review Committee (MRC), appointed by the California Coastal Commission, over the period 1975–1989. These studies have recently been summarized and interpreted in a report of the MRC (MRC Document 89-02) supported by many other technical reports, databases, and other reports. Most of the conclusions are based on both near-field and far-field sampling before and after startup of Units 2 and 3. In the summary report, the extent of biological effects is estimated quantitatively. Adverse impacts are estimated to the kelp community (kelp, some fish, and kelp-bed invertebrates), to local populations of midwater fish species, and to far-field populations of fish in the Southern California Bight (the area between Point Conception and Cabo Colnett in northern Baja California). Besides quantifying these adverse impacts and identifying other biological effects, the report considers several distinct mitigative techniques, a combination of which is considered capable of providing complete mitigation (MRC Document 89-02). Note that the three-member MRC was not always unanimous in its judgments. In particular, one member felt that some of the conclusions understated the severity or extent of plant impact and that cooling towers should be installed as a mitigative measure.

Local adverse effects were measured on the kelp community in the San Onofre kelp bed (SOK), including giant kelp, kelp-bed fish, and large benthic kelp-bed invertebrates. The best estimate of reduction in the area covered by moderate- to high-density kelp in the SOK is 80 ha (200 acres). Fish living near the bottom in the SOK (e.g., sheephead, barred sandbass, and black surfperch) were estimated to be reduced by 70 percent [roughly 200,000 fish weighing about 25.4 metric tons (28 tons)] below the abundance expected in the absence of SONGS. The abundance of 13 species of snails and of the white sea urchin was estimated to have been reduced substantially (30–90 percent) below the levels expected without SONGS; other kelp-bed invertebrate species too rare to permit accurate sampling were also thought to have declined. According to the report, "these effects, although local, are deemed substantial because kelp is a valuable and limited habitat." These kelp-bed effects were attributed mainly to changes in the physical environment in the SOK as a result of the sometimes turbid discharge plume. These key environmental changes were (1) reduction in light levels reaching the bottom, (2) increases in the flow and the rates of particles near the bottom, and (3) modification of currents near the plant.

Two kinds of additional adverse impacts were attributed mainly to losses because of entrainment or impingement (see also Helvey 1985). First, reductions in the local abundance of some midwater fish populations were measured. The local abundance of queenfish (a forage fish) was reduced by an estimated 30 to 70 percent, depending on the location, out to a distance of 1.9 to 3.1 km (1.2 to 1.9 miles) from

SONGS. The estimated reduction for white croaker (a sport fish) was similar in magnitude, but over a smaller area. Several other species were believed to have experienced smaller reductions. Loss in the intake, predominantly due to impingement, was considered capable of explaining the loss of croaker and some of the loss of queenfish, but the operation of some other factor (such as plume turbidity) would also be required to explain some of the effects.

The second adverse entrainment/impingement impact concerns far-field effects. Consistent with the evaluation of such far-field effects in other plant-specific analyses (see, for example, the Hudson River power plants), the MRC report also recognizes that "even a major effect will be so diluted that the change will be indistinguishable from natural variation." For these effects, the MRC relied on inferred reductions rather than on attempts to measure effects. An "equivalent adult losses" method was used to estimate losses in recruitment due to measured (interpolated for young juveniles too small to be impinged) entrainment and impingement, and assumptions were made about the effect of biological compensation. Reductions "probably between one and ten percent" in the standing stocks of several midwater fish populations in the Southern California Bight were inferred. Because these latter entrainment/impingement effects could occur over large populations, they were considered by MRC to be substantial.

In contrast to these particular groups of organisms for which adverse plant impacts were measured or inferred, other groups of organisms showed no change or increased locally in abundance. With the exception of meroplankton (benthic larvae), which increased, other plankton was largely unaffected by operation of SONGS. Also, although entrainment of fish larvae, which are concentrated inshore at about the depths of the intakes, is considered an important contributor to reductions in adult stocks, there is no clear pattern of decreases in the abundance of fish larvae near SONGS. Differences between local and more distant sand crab populations are also felt to be unrelated to plant operation. General patterns of increases were seen among local benthic fish populations, soft-bodied benthic invertebrates, and mysids (semi- planktonic shrimp-like crustaceans).

Besides quantifying the biological effects of the operation of SONGS, the MRC report made recommendations concerning two sets of potential mitigative options. The first set concerned structural changes to the power plant. A majority of the MRC was opposed to backfitting cooling towers, and the MRC also discouraged moving the discharge diffusers. The second set of options would involve implementation of three to five mitigative techniques, selected from more than 30 that were considered. Finally, the MRC recommended increased monitoring as part of the changes to the NPDES program to determine the value of mitigative measures.

F.4.6.1 Cumulative Impacts

The MRC report (MRC Document 89-02) does not explicitly consider SONGS in the context of other power plants, of which there are at least six in the Southern California Bight (Helvey 1985). However, the fact that entrainment and impingement at these plants also contributes to impacts is recognized, and reduction of these impacts at other nearby plants is an optional part of one mitigative measure recommended by the MRC. In fact, noting studies at SONGS indicating that the thermal effluent from the plant is of little environmental concern, the

MRC states that "the greatest environmental protection might result from a waiver of thermal standards at Southern California Electric's coastal power plants, because this would minimize the volume of water pumped through the plants" (MRC Document 89-02, pp. 297–298).

As of late 1990, the California Coastal Commission had not acted on the MRC's recommendations (personal communication, R. F. Ambrose, Marine Science Institute, University of California, Santa Barbara, to S. W. Christensen, ORNL, Oak Ridge, Tennessee, October 5, 1990). The final MRC report initially gives the impression of considerable confidence in the conclusions of impact and in the ability of the recommended mitigative measures to achieve complete mitigation. Further reading reveals the importance of many estimates and assumptions made in reaching the conclusions and an explicit discussion of uncertainties. Whether the report's conclusions are contested or not remains to be seen. Nonetheless, the report demonstrates the ability of a focused, long-term project, applying consistent sampling and study techniques, to reach meaningful conclusions about the impacts of a power plant on aquatic organisms and about ways to mitigate these impacts.

F.4.7 Crystal River Nuclear Plant

The Crystal River Power Station consists of five units that withdraw cooling water from the Gulf of Mexico. Only one of the units, Unit 3, is nuclear powered; the other units are coal-fired. Two of the coal-fired units use closed-cycle cooling; the remaining units are once-through. All units use a common 5.5-km- (3.4-mile-) long intake canal and a 2.6-km- (1.6-mile-) long discharge canal (FPC 1985). Unit 3 discharges heated water into Crystal Bay at a rate of 43 m^3/s (680,000 gal/min) (Table 2.1); the total discharge of the three once-through units is approximately 83 m^3/s (1,318,000 gal/min) (FPC 1985). The change in temperature of the Unit 3 condensers is 9.5°C (17.1°F) (Table 2.3).

Important aquatic resources of Crystal Bay include a diverse benthic macroinvertebrate community, submerged macrophytes (seagrasses), coastal salt marshes, oyster reef communities, and a variety of finfish (e.g., bay anchovy, batfish, seatrout, red drum, spot, striped mullet) and shellfish (e.g., squid, shrimp, stone crab, blue crab) (FPC 1985).

Concerns about the impacts of the Crystal River Power Station on aquatic resources focus on thermal discharges and entrainment (Gardner 1990; Smallwood 1990). Based on data collected for the plant's 316(a) demonstration (FPC 1985), thermal effluents from the multiunit power station were considered by the Florida Department of Environmental Regulation (DER) to have substantially damaged the benthic macroinvertebrate and seagrass communities in a 1100-ha (2700-acre) mixing zone around the discharge canal (Olsen 1986). The DER also expressed concern about the entrainment by Crystal River Units 1, 2, and 3 of bay anchovies, crab larvae, and penaeid shrimp larvae. Conversely, DER agreed with the Florida Power Commission (FPC) conclusions that thermal discharges from Crystal River Units 1, 2, and 3 had enhanced productivity in the nearby salt marshes and increased the growth rates of oysters in areas moderately affected by heat.

Impacts to aquatic resources continue to be examined at this site as part of NPDES permit renewals. The Crystal River Station has recently been required by EPA to reduce total condenser cooling water

withdrawals during a portion of the year [FPC, response to NUMARC survey (NUMARC)]. This flow reduction scheme would reduce the number of entrained organisms but would not reduce thermal effects. Installation of helper cooling towers would reduce thermal discharges from the Crystal River site (Charles Kaplan, Region 4 EPA, personal communication to G. F. Cada, ORNL, Oak Ridge, Tennessee, November 12, 1990).

F.5 SUMMARY

A detailed consideration of these once-through nuclear power plants indicates that many of the aquatic resources issues evaluated in the licensing stage have not materialized as significant problems. Even at facilities where impact potential is considered to be greatest, these impacts have been difficult to quantify. For example, while localized effects of phytoplankton entrainment or scouring of bottom sediments near the discharge structure have been demonstrated in some instances, such impacts have not precluded the maintenance of balanced, indigenous populations of shellfish, fish, and wildlife; and the regulatory agencies regard these effects as acceptable.

Conversely, these examples illustrate that the entrainment and impingement of fish and the discharge of heated effluents from once-through power plants continue to concern some regulatory and resource agencies. In some instances, the NPDES permit and 316(a) and (b) review processes have not been completed, and the acceptability of impacts or the need for mitigation are still under consideration. As noted in Section 4.2, those aquatic resources issues that have not been resolved to the satisfaction of EPA or the state water quality permitting agency as part of the discharge permitting process will need to be considered in the license renewal application.

F.6 ENDNOTES

1. The discrepancy between the estimates in the FES and the estimates provided by AP&L are probably explained in large part by one or both of two possibilities. First, comparison of information in Zweiacker et al. (1977) with AP&L's estimate suggests that AP&L's estimate may consist of actual collections of impinged fish during sampling that covered 6 days per week during 6 weeks per quarter, without scaling up to estimate impingement during periods not sampled. Second, the first year of operation represented by AP&L's estimates may not correspond exactly to the period for which estimates were made in the FES.

2. The National Reservoir Research Data Bases are available from Southeastern Wildlife and Fisheries Statistics Project, Institute of Statistics, North Carolina State University, Box 8203, Raleigh, NC 27605-8203. Documentation describing the data is not currently available. In addition, other caveats apply: serial correlation is possible and may interfere with the analysis, and other assumptions (e.g., equality of the within-group covariance matrices) sometimes were not satisfied or could not be tested.

3. The (calculated) estimates for both entrainment and impingement at the proposed plants appear to be too low by at least a factor of 8 in relation to the regression equations and the stated number and capacity of the new plants.

The reason for this apparent discrepancy cannot be determined from the information available (John Kelso, Great Lakes Biolimnology Laboratory, personal communication to S. W. Christensen, ORNL, Oak Ridge, Tennessee, January 28, 1991).

4. The staff presents these results from Jensen et al. but notes that it is not able to reproduce approximately the estimates of percentages impinged, even though seemingly sufficient information is provided in the paper. Insufficient information is provided to try to reproduce the estimates of percentages entrained.

5. The staff noted that the commercial catch estimates presented and used by Jensen et al. for alewife in Lake Michigan, but not for smelt, differ typically by a factor of 2 to 4—depending on the year—from those given by Scott-Wasilk et al. These differences result from the exclusion from the Scott-Wasilk et al. table of commercial catch data for alewife in Green Bay.

6. The source of the variation in the entrainment and impingement coefficients is not clear, but it may be derived from year-to-year variation in biomass in the models.

F.7 REFERENCES

AEC Docket 50-313, *Final Environmental Impact Statement Related to the Arkansas Nuclear One, Unit 1*, U.S. Atomic Energy Commission, February 1973.

AP&L (Arkansas Power and Light Company), *Arkansas Nuclear One Generating Station, Dardanelle Reservoir Environmental Monitoring Program, Summary Report of Environmental Impact of Thermal Discharge*, October 30, 1984.

AP&L. *Summary of Entrainment at Arkansas Nuclear One from 1977 through 1982*, undated report with responses to the NUMARC survey, 1990.

Barnthouse, L. W., and W. Van Winkle, "Analysis of Impingement Impacts on Hudson River Fish Populations," *American Fisheries Society Monograph*, **4**, 182–90, 1988.

Barnthouse, L. W., et al., "Hudson River Settlement Agreement: Technical Rationale and Cost Considerations," *American Fisheries Society Monograph*, **4**, 267–73, 1988a.

Barnthouse, L. W., et al., "Science, Law, and Hudson River Power Plants: A Case Study in Environmental Impact Assessment," *American Fisheries Society Monograph*, **4**, 1988b.

Barnthouse, L. W., et al., "What We Didn't Learn About the Hudson River, Why, and What It Means for Environmental Assessment," *American Fisheries Society Monograph*, **4**, 329–35, 1988c.

Carter, J. S., Duke Power Company, letter to S. W. Christensen, ORNL, Oak Ridge, Tennessee, September 4, 1990.

Chang, W. Y. B., and R. Rossman, "Effects of Power Plant Entrainment on Phytoplankton Response," *Verhandlungen Internationale Vereinigung Limnologie*, **22**, 2493–97, 1985.

Christensen, S. W., and T. L. Englert, "Historical Development of Entrainment Models for Hudson River Striped Bass," *American Fisheries Society Monograph*, **4**, 133–42, 1988.

CONF-740820 (STI/PUB/378, IAEA-SM-187/48), J. W. McMahon and A. E. Docherty, "Effects of Heat Enrichment on Species Succession and Primary Production in Fresh-Water Plankton," pp. 529–46 in *Proceedings of*

a Symposium on the Environmental Effects of Cooling Systems at Nuclear Power Plants, 1975.

Duke Power Company, *McGuire Nuclear Station, 316(b) Predictive Study of Impingement and Entrainment*, Charlotte, North Carolina, 1978.

Duke Power Company, *McGuire Nuclear Station, 316(a) Demonstration*, Charlotte, North Carolina, 1985.

Duke Power Company, *McGuire Nuclear Station, Summary of Ecological Impacts, and Plan of Continuing Study: Supporting Documentation for Modification of NPDES Permit No. NC0024392*, Charlotte, North Carolina, 1988.

DUKE PWR/82-02, J. E. Hogan and W. D. Adair, eds., *Lake Norman Summary*, Vols. 1 and 2, Duke Power Company, Production Environmental Services, Huntersville, North Carolina, 1982.

Englert, T. L., and J. Boreman, "Historical Review of Entrainment Impact Estimates and the Factors Influencing Them," *American Fisheries Society Monograph*, **4**, 143–51, 1988.

EPRI EA-5200s, *Compensatory Mechanisms in Fish Populations: Literature Reviews*, Vols. 1–3, Electric Power Research Institute, Palo Alto, California, 1987.

Evans, M. S., "Benthic and Epibenthic (*Microcrustaceans, Macrobenthos*) Community Structure in the Vicinity of a Power Plant, Southeastern Lake Michigan," *Verhandlungen Internationale Vereinigung Limnologie*, **22**, 488–94, 1984.

Evans, M. S., et al., "Effects of the Donald C. Cook Nuclear Power Plant on Zooplankton of Southeastern Lake Michigan," pp. 125–39 in L. D. Jensen, ed., *Fourth National Workshop on Entrainment and Impingement*, EA Communications, Melville, New York, 1977.

FPC (Florida Power Corporation), *Final Report—Crystal River*, 316 Studies, Florida Power Corp., January 15, 1985.

Gardner, T., Florida Department of Natural Resources, letter to G. F. Cada, ORNL, Oak Ridge, Tennessee, May 30, 1990.

Geo-Marine, Inc., *The Distribution of Temperature and Dissolved Oxygen in the Vicinity of Arkansas Nuclear One, Final Report*, Vol. 1, conducted for Arkansas Power and Light Company, 1976.

Gorski, S. W., NMFS, letter to G. F. Cada, ORNL, Oak Ridge, Tennessee, July 18, 1990.

Hamilton, R. B., North Carolina Wildlife Resources Commission, conversation with S. W. Christensen, ORNL, Oak Ridge, Tennessee, August 31, 1990, clarifying a letter from R. B. Hamilton to G. F. Cada, ORNL, Oak Ridge, Tennessee, dated June 20, 1990.

Helvey, M., "Behavioral Factors Influencing Fish Entrapment at Offshore Cooling-Water Intake Structures in Southern California," *Marine Fisheries Review*, **47**(1), 18–26, 1985.

Hutchison, J. B., Jr., "Technical Descriptions of Hudson River Electricity Generating Stations," *American Fisheries Society Monograph*, **4**, 113–20, 1988.

Jensen, A. L., et al., "Use of Conventional Fishery Models to Assess Entrainment and Impingement of Three Lake Michigan Fish Species," *Transactions of the American Fisheries Society*, **111**, 21–34, 1982.

Kelso, J. R. M., and G. S. Milburn, "Entrainment and Impingement of Fish by Power Plants in the Great Lakes Which Use the Once-Through Cooling Process," *Journal of Great Lakes Research*, **5**, 182–94, 1979.

Kelso, J. R. M., and G. S. Milburn, "Response to Comment by J. Scott-Wasilk et al.," *Journal of Great Lakes Research*, **7**, 495–97, 1981.

Klauda, R. J., et al., "What We Learned About the Hudson River: Journey Toward an Elusive Destination," *American Fisheries Society Monograph*, 4, 316–28, 1988.

Lewis, R. E., "Opportunity for Management of Natural Resources Through Utility and Regulatory Cooperation," *Presentations at the 120th Annual Meeting of the American Fisheries Society*, Pittsburgh, Pennsylvania, 1990.

Loar, J. M., et al. "An Analysis of Factors Influencing the Impingement of Threadfin Shad at Power Plants in the Southeastern U.S.," pp. 245–55 in L. D. Jensen, ed., *Fourth National Workshop on Entrainment and Impingement*, Chicago, Illinois, December 5, 1977, EA Communications, Inc., Melville, New York, 1978.

Madenjian, C. P., et al., "Intervention Analysis of Power Plant Impact on Fish Populations," *Canadian Journal of Fisheries and Aquatic Sciences*, 43, 819–29, 1986.

McInerny, M. C., "Gas-Bubble Disease in Three Fish Species Inhabiting the Heated Discharge of a Steam-Electric Station Using Hypolimnetic Cooling Water," *Water, Air, and Soil Pollution*, 49, 7–15, 1990.

MRC Document 89–02, W. W. Murdoch, et al., *Final Report of the Marine Review Committee to the California Coastal Commission*, California Coastal Commission, Marine Review Committee, San Francisco, 1989.

NUMARC (Nuclear Management and Resources Council), *Survey of U.S. Utility-Owned Nuclear Power Plants*, Oak Ridge National Laboratory, Oak Ridge, Tennessee, and NUMARC, Washington, D.C., June 1990.

NUREG-0254, *Final Environmental Statement Related to Operation of Arkansas Nuclear One, Unit 2*, U.S. Nuclear Regulatory Commission, Office of Nuclear Reactor Regulation, 1977.

NUREG-CONF-002, S. W. Christensen, et al., "Defining and Determining the Significance of Impacts: Concepts and Methods," pp. 191–219 in R. K. Sharma et al., eds., *The Biological Significance of Environmental Impacts*, U.S. Nuclear Regulatory Commission, 1976.

Olsen, L. A., Florida Department of Environmental Regulation, interoffice memorandum to J. P. Subramani, Florida Department of Environmental Regulation, February 4, 1986.

Ricker, W. E., "Computation and Interpretation of Biological Statistics of Fish Populations," *Fisheries Research Board of Canada,* Bulletin 191, 1975.

Rickett, J. D., *Dardanelle Reservoir–Illinois Bayou Embayment Survey,* Progress Report Number 26, February 7, 1983.

Rickett, J. D., and Watson, R. L., "Phytoplankton Community Structure in Dardanelle Reservoir, Arkansas, 1975–1982," *Arkansas Academy of Science Proceedings*, 37, 70–73, 1983a.

Rickett, J. D., and Watson, R. L., "Zooplankton Community Structure in Dardanelle Reservoir, Arkansas, 1975–1982," *Arkansas Academy of Science Proceedings*, 37, 65–69, 1983b.

Rickett, J. D., and Watson, R. L., "Fluctuations and Relationships of Selected Physicochemical Parameters in Dardanelle Reservoir, Arkansas, 1975–1982," *Arkansas Academy of Science Proceedings*, 34, 98–102, 1985.

Scott-Wasilk, J., et al., "A Comment on the Paper by John R. M. Kelso and Gary S. Milburn, 'Entrainment and Impingement of Fish by Power Plants in the Great Lakes Which Use the Once-Through Cooling Process,'" [*J. Great Lakes Res.*, 5, 182–94 (1979)], *Journal of Great Lakes Research*, 7, 491–95, 1981.

Smallwood, S., Florida Department of Environmental Regulation, letter to G. F. Cada, ORNL, Oak Ridge, Tennessee, May 31, 1990.

Spigarelli, S. A., et al., "Selected Temperatures and Thermal Experience of Brown Trout, *Salmo Trutta*, in a Steep Thermal Gradient in Nature," *Env. Biol. Fish.*, 8(2), 137–49, 1983.

Thurber, N., and D. Jude, *Impingement Losses at the D. C. Cook Nuclear Plant During 1975–1979 with a Discussion of Factors Responsible and Relationships to Field Catches,* Special Report No. 104, Great Lakes Research Division, University of Michigan, Ann Arbor, Michigan, 1984.

Tilley, S., *A Summary of the Dardanelle Reservoir Fishery Survey Annual Reports*, Arkansas Power and Light, Environmental and Technical Services, 1983.

Van Winkle, W., et al., "An Analysis of the Ability to Detect Reductions in Year-Class Strength of the Hudson River White Perch (*Morone Americana*) Population," *Canadian Journal of Fisheries and Aquatic Sciences*, 38(6), 627–32, 1981.

Wich, K. F., NYSDEC, letter to G. F. Cada, ORNL, Oak Ridge, Tennessee, July 6, 1990.

Zweiacker, P. J., et al., "Evaluation of an Air-Bubble Curtain to Reduce Impingement at an Electric Generating Station," pp. 343–56 in *Proceedings of the 31st Annual Conference of the Southeastern Association of Fish and Wildlife Agencies*, Vol. 31, 1977.

APPENDIX G

POSTULATED ACCIDENTS

POSTULATED ACCIDENTS

G.1 STATISTICAL ANALYSIS

G.1.1 Introduction

For 28 nuclear plants, final environmental statement (FES) estimates of risk quantities exist: early fatality, normalized latent fatality, normalized total dose, and normalized expected cost. The last three estimates are normalized to a per 1000-MW(t) (thermal megawatts) basis. The estimates are made using the Calculation of Reactor Accident Consequences (CRAC) computer code for the middle year of the current licensing (MYL) period. The CRAC runs are costly and difficult, requiring expensive input data.

There are also 16-, 80-, and 240-km (10-, 50-, and 150-mile) exposure index projections for the MYL and for the middle year of the license renewal (MYR) period, usually either 2030 or 2050, for the 28 (FES) nuclear plants and 46 other (non-FES) plant sites. Exposure indices are population averages weighted by wind-direction frequency, as discussed in Chapter 5. The exposure index projections are relatively easy and inexpensive to compute. Thus, the FES data will be used to investigate the relationship between the calculated FES estimates of the four risk quantities and the exposure index and to derive a prediction equation with which we could (1) predict the MYR estimates as a function of exposure index and (2) place upper confidence bounds on the predictions.

Because of the basic design differences, a nuclear power plant's reactor type (pressurized water or boiling water) may be an important factor in the relationship between the risk quantity estimates and exposure index. Of the FES plants, 18 are pressurized-water reactors (PWRs) and 10 are boiling-water reactors (BWRs). BWRs can be further subgrouped based on the containment type (Mark I, Mark II, or Mark III), but among the FES plants there are only a few of each type. (For example, only two are Mark I containment plants.) Using a regression analysis that parallels the one to be described, tests were conducted for differences in regression parameters among the three boiling-water containment types, but none of significance for any risk estimate (i.e., $p > 0.05$ for all estimates) was found. Therefore, at the outset, all BWRs were identified simply as "B" and PWRs as "P."

Prediction equations are based on regression relations between risk estimates and exposure indices. Perhaps the most natural starting point is the straight-line model: estimate = $a + b$ (exposure index) + random error. Because there are two reactor types, two lines are considered simultaneously; that is,

$$\text{estimate} = a_{type} + b_{type}(\text{exposure index}) + e, \qquad (G.1)$$

where e denotes a random error, and *type*, B or P, distinguishes BWRs from PWRs. The error term represents the lack of information that would be provided by other independent variables, if available, as well as the randomness of the 28 FES plants considered as a random sample of all plants. The CRAC estimate is deterministic in the sense that it is the output of a computer program but could also exhibit randomness associated with random input arguments. Eq. (G.1) has four parameters: two intercepts and two slopes.

Fitting the model gives least squares estimates of the a_{type} and b_{type}. Call them $\hat{a}_{type}$ and $\hat{b}_{type}$. For each plant in the observed data set, there are also predicted values, $\hat{a}_{type}$ + $\hat{b}_{type}$ (exposure index) and residuals, which are the estimates minus their predicted values. The residual for an observation may be thought of as an approximation to the error for that observation, because under fairly general conditions the difference approaches zero as the sample size increases.

The error component in a model like Eq. (G.1) is often assumed without justification to be normal. Perhaps this is because the parameter estimates do behave normally as the sample size increases (Huber 1981, Section 7-2). However, in applications involving prediction, it is known that the assumption of normality can lead to serious errors. This is because laws of large numbers, which apply to parameter estimates, do not apply to predictions of single new observations.

The objective is to obtain a strong regression relationship that will provide prediction confidence bounds and will allow inferences to be made regarding the regression parameters. To do this, a good regression must exhibit the following properties.

1. The distribution of residuals should be roughly normal—symmetric and without extreme outliers. This property ensures that the asymptotic (large-sample) normality of parameter estimates can be used as an adequate approximation in finite samples, which in turn is needed to make inferences about the parameters.

2. The residuals should show no trend in the predictor variable(s). The presence of a trend in the residuals suggests that additional (e.g., higher order) terms in the predictors might improve the fit significantly.

3. The residuals should be statistically stable in the predictor(s) (e.g., they should not fan out). If the residuals are not statistically stable, the error distribution probably changes with the predictors, so neither residuals nor errors can be lumped together for study, at least without other strong assumptions.

Properties 1, 2, and 3 can be assessed using residual plots.

The following discussion makes use of the R^2 statistic, known as "the squared multiple correlation coefficient" and "the proportion of explained variance." R^2 indicates how well data and model agree; it is 1 when the data fit perfectly. However, a higher R^2 does not automatically imply a better model. Additional predictor variables always increase R^2, regardless of whether there is any significant improvement, and the inclusion of insignificant terms in a model can inflate the standard errors of predictions based on it. Also, sometimes R^2 is quite high for models with severe outliers among the residuals. These factors were considered in the development of these models.

Now consider a new exposure index, say exposure index ′, not necessarily in the original 28. A prediction of a new risk estimate (estimate′) at exposure index′ is obtained by simply plugging the new exposure index into the fitted regression model for the appropriate reactor type. According to the most common definition, an upper confidence bound U for estimate′ is a function of the observed data that satisfies the probability statement

$$P(estimate' \leq U) = 1 - \alpha \quad \text{(G.2)}$$

for some specified level of confidence $1 - \alpha$. Often α is taken to be 0.05. The probability in Eq. (G.2) is with respect to an assumed statistical model, in our case Eq. (G.1), before (and not conditional upon) any of the observations. We have

$$estimate' = a_{type} + b_{type}\ (exposure\ index') + e' \,. \quad \text{(G.3)}$$

The random error components, e in Eq. (G.1) and e' in Eq. (G.3), affect the prediction problem in two ways. First, estimates $\hat{a}_{type}$ and $\hat{b}_{type}$ are uncertain. Second, even if a_{type} and b_{type} were known exactly, estimate$'$ would still not be known because of e'. As indicated above, assessing the errors $\hat{a}_{type}$ and $\hat{b}_{type}$ is fairly straightforward, although an asymptotic approximation is usually incurred. The difficulty is in estimating the distribution of e. Because our interest is in upper confidence bounds for predictions, there is special interest in the upper tail of the error distribution. Usually, many more observations are needed to estimate upper tails than for central quantities such as a mean.

Compounding the problem is that errors are not observed—they are only residuals. Although the residuals and errors converge as the sample size increases, the sample size is only 28. The residuals depend on $\hat{a}_{type}$ and $\hat{b}_{type}$. They do differ from the errors, and they are not statistically independent.

The "standard" approach to prediction confidence bounds is based on the assumption of normality of errors. When this assumption holds, the standard approach is optimal and valid in the sense of Eq. (G.2). When the assumption fails, Eq. (G.2) may be off considerably. This is discussed in further detail in Schmoyer (1990).

Coming up with small-sample regression prediction confidence bounds without making strong assumptions (e.g., normality of errors) is a difficult problem for which no good solution is currently known. Such confidence bounds would be considered "distribution free" or "nonparametric," because they require no parametric assumptions about the error distribution.

Schmoyer (1990) discusses asymptotically valid nonparametric prediction confidence bounds. For these bounds, under a few weak conditions, Eq. (G.2) holds in the limit as the sample size increases. Schmoyer discusses "bootstrap" (Stine 1985) and "cross-validation" (Butler and Rothman 1980) prediction bounds. The bootstrap bounds are computationally intensive and not exactly reproducible (i.e., they involve a Monte Carlo procedure). The cross-validation bounds were designed for symmetrically distributed data. However, Schmoyer considers an asymmetric analog. He also proposes new bounds and shows that they tend to be better than the cross-validation bounds in terms of approximating [Eq. (G.2)].

The asymptotically valid approach seems better than the standard approach, if normality is unsubstantiated. However, the former is still premised on a large-sample approximation. For this project, the prediction bounds proposed by Schmoyer were computed for comparison with the normal-theory approach. Disparity between the two suggests that the normal-theory bounds may be off. These bounds will here be referred to as the "distribution-free" bounds.

In Schmoyer, it is argued that distribution-free upper prediction bounds should not be calculated for levels of confidence higher than $1-1/(n+1)$, where n is the sample size. This is related to the idea that the largest distribution-free upper prediction bound from a simple random sample of size n is the n^{th} (the largest) order statistic, and the probability that a new observation exceeds the n^{th} order statistic is $1/(n+1)$.

If the assumption of normality is suspect, the same caveats would seem to apply even more strongly to the normal-theory bounds. One can formally use higher levels of confidence to obtain higher bounds. However, attaching an interpretation such as Eq. (G.2) to such bounds seems very tenuous.

As R^2 decreases from 1, the issue of statistical noise becomes more important and must be addressed. In particular, as R^2 decreases, the best predictions will tend to become considerably lower than their corresponding upper confidence bounds, whether normal or distribution free. For additional discussion of regression, residuals, prediction, and R^2, see Draper and Smith (1981).

G.1.2 Regressions

Individual regressions are discussed in the following paragraphs. For each regression, models such as Eq. (G.1) were fitted both without and with log-transforming the data. In the log case, logs of both estimates and exposure indices were used. In all cases, for the regressions without log transformations, the residuals have outliers and tend to fan out as the exposure index increases, whereas the residual plots look much better in the log case. This is illustrated in residual plots, which follow. Therefore, the no-log approach has not been pursued.

G.1.2.1 Early Fatality Caused by a Severe Accident

Because of a threshold dose phenomenon, it does not make sense to normalize early fatalities. Therefore, only the 22 plants with capacities greater than 3025 MW(t) (and consequently the largest source terms) were considered for this regression.

Of these, the Wolf Creek plant has an estimated early fatality that is (identically) zero and therefore had to be dropped when logs were taken. This leaves 21 plants for the early fatality regression. (Note that the zero expected early fatality estimate may be illogical in the sense that the expectation of a nonnegative quantity can only be zero if the quantity is itself zero with certainty.)

The FES consequence analyses found that most early fatalities occurred within 8 to 80 km (5 to 50 miles) of the plant. Therefore, early fatality was considered to be most highly related to the 16- or 80-km (10- or 50-mile) exposure indices. Consequently, the regression of early fatality on the 16- and 80-km (10- and 50-mile) indices was considered, first individually, then together in a multiple regression. R^2 values are 0.55 for the 16-km (10-mile) index, 0.32 for the 80-km (50-mile) index, and 0.68 for the multiple regression. Each of these regressions has a high overall significance ($p < 0.0001$). However, in the multiple case, the 16-km (10-mile) term is significant ($p = 0.0027$), whereas the 80-km (50-mile) term is not ($p = 0.93$). Therefore, only the 16-km (10-mile) exposure index and reactor type were selected for predicting early fatality.

Figure G.1 is a residual plot for the regression of early fatality on the 16-km (10-mile) exposure index and reactor type. This and all subsequent plots in this

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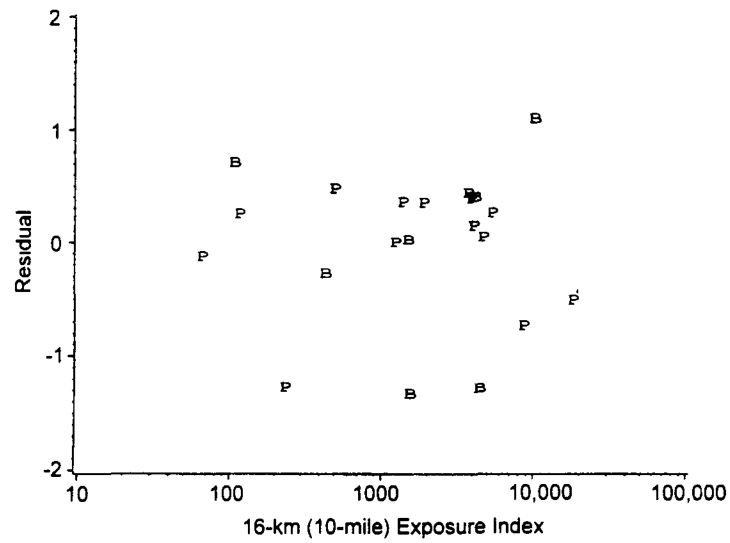

Figure G.1 Residuals from regression of the log of early fatality (average deaths per reactor year) on the log of 16-km (10-mile) exposure index of persons at risk. (Reactor type: B = boiling water, P = pressurized water.)

appendix are on base-10 log scales. Thus a difference of one unit in the residuals corresponds to a factor of 10 difference between the fitted and actual values on the original scale. It seems to satisfy properties 1 through 3, except perhaps for a tendency for the B residuals to be slightly more scattered. This could be because the B-types are not resolved into their three subclasses. The intercept and slope estimates (± standard error) for this regression are −7.81 ± 0.91 and 1.22 ± 0.28 for PWRs and −5.09 ± 1.40 and 0.42 ± 0.42 for BWRs.

Figure G.2 shows the log of acute fatalities within 16 km (10 miles) of 21 FES plants.

G.1.2.2 Normalized Latent Fatalities and Normalized Total Dose Resulting from a Postulated Severe Accident

Normalized latent fatalities and total dose are thought to be related to the 240-km (150-mile) exposure index. R^2 for the regression of either the normalized total dose or latent fatality on the 240-km (150-mile) index is 0.68. Both of these regressions are highly significant ($p < 0.0001$). Figures G.3 and G.4 are residual plots. In both cases, assumptions 1 through 3 seem to be met, except for (1) a tendency for the B residuals to be more dispersed, (2) a single P outlier, and (3) a slight suggestion that a quadratic term in the 240-km (150-mile) index might improve the fit. The significance levels for quadratic

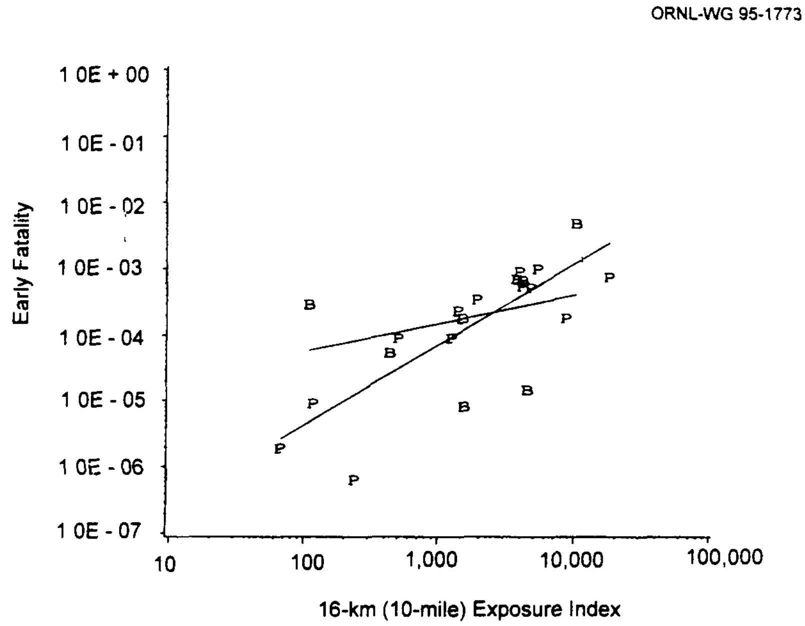

Figure G.2 **Log plot of early fatalities per reactor year within 16 km (10 miles) of 21 nuclear power plants [3300 MW(t) or greater], resulting from postulated accidents, regressed on log of exposure index (EI) for 16 km (10 miles).** (EI is the sum of the products of wind frequency in 22.5° quadrants and population in those sectors. P = pressurized-water reactors, B = boiling-water reactors.)

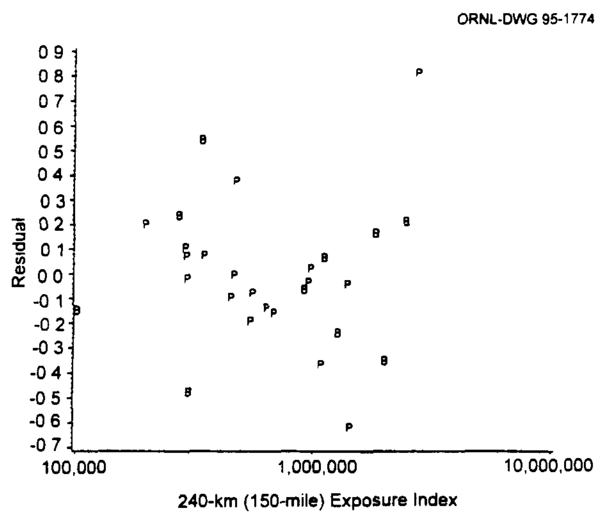

Figure G.3 **Residuals from regression of log of normalized latent fatality (average deaths per 1000-MW reactor-year) on the log of 240-km (150-mile) exposure index of persons at risk.** (Reactor type: B = boiling water, P = pressurized water.)

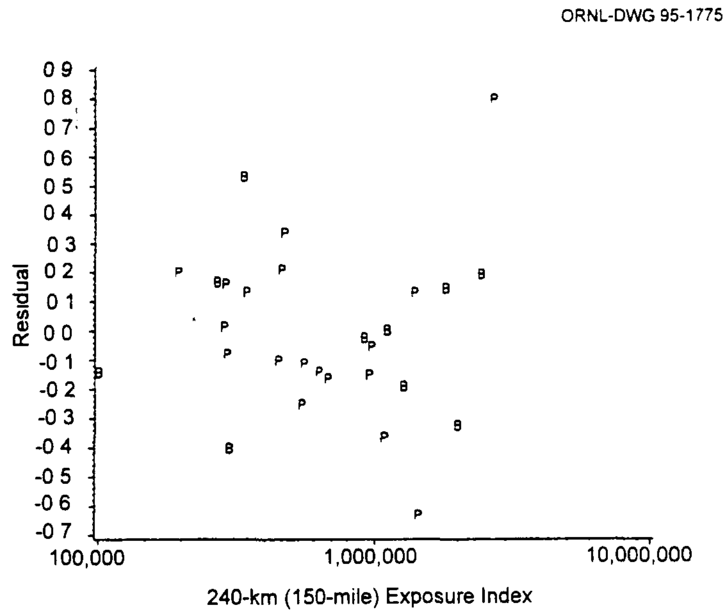

Figure G.4 Residuals from regression of the log of normalized total dose (rem per 1000-MW reactor-year) on the log of 240-km (150-mile) exposure index of persons at risk. (Reactor type: B = boiling water, P = pressurized water.)

terms, when included in the models, are 0.05 for normalized latent fatalities and 0.04 for normalized total dose. Fitting the quadratic terms does not improve the problem of the greater dispersion among B residuals. The outlier, which is Indian Point, is discussed further in Section G.1.3. Intercept and slope estimates are shown in Table G.1.

Figures G.5 and G.6 show the normalized latent fatalities and total dose, respectively, at 28 FES plants.

G.1.2.3 Normalized Expected Cost Resulting from a Postulated Severe Accident

Loss of property and other economic impacts caused by a postulated accident generally would be larger as population increased. Consequently, as with latent fatalities and fatal dose, it is reasonable to project the expected costs for an accident during the license renewal period using population or using the exposure index. Because the relationship of cost to the various candidate explanatory variables was less clear than in the fatality or dose cases, it was necessary to experiment with a greater variety of regression models. First considered were the regressions of normalized expected cost on 80-km (50-mile) radius population values; the 16-, 80-, and 240-km (10-, 50-, and 150-mile) exposure indices, and on each index in conjunction with population. Because only about half of the cost of an accident is expected to be incurred within 80 km (50 miles), the 240-km (150-mile) radius seems more appropriate.

Economic consequences were also benchmarked to the MELCOR Accident

Table G.1 Regression estimates (± standard error) for reactor plants

Dependent variable	Intercept	Slope
Pressurized-water reactors		
Normalized latent fatalities	−11.35 ± 1.47	1.55 ± 0.25
Normalized total dose	−6.94 ± 1.45	1.51 ± 0.25
Boiling-water reactors		
Normalized latent fatalities	−6.05 ± 1.32	0.67 ± 0.23
Normalized total dose	−1.78 ± 1.30	0.66 ± 0.25

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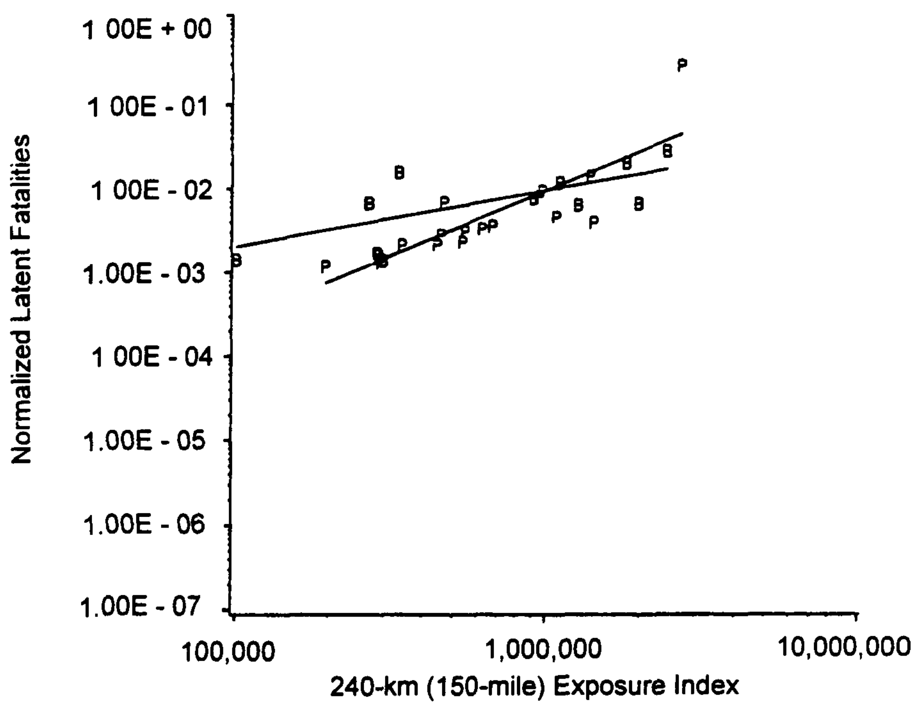

Figure G.5 **Log plot of normalized latent fatalities per 1000 MW(t) per reactor-year of 28 nuclear power plants resulting from postulated accidents, regressed on log of exposure index (EI) at 240 km (150 miles).** (EI is the sum of the products of wind frequency in 22.5° sectors and population in those sectors. P = pressurized-water reactors, B = boiling-water reactors.)

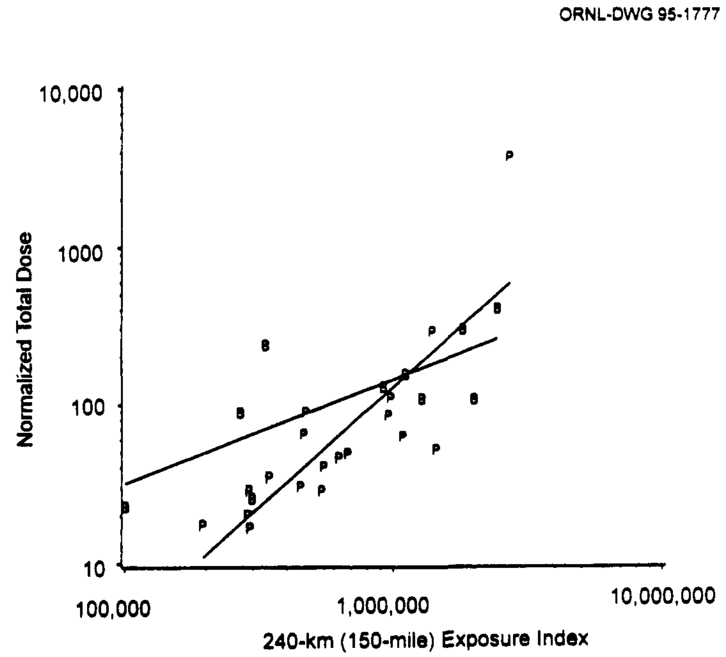

Figure G.6 **Log plot of normalized total dose in person-rem per 1000 MW(t) per reactor-year within 240 km (150 miles) of 28 nuclear power plants [3300 MW(t) or greater] resulting from postulated accidents, regressed on log of exposure index (EI).** (EI is the sum of the products of wind frequency in 22.5° sectors and population in those sectors. P = pressurized-water reactors, B = boiling-water reactors.)

Consequence Code System (MACCS) computer code to ensure the calculated values were based on the most current models and data. The benchmark computations indicated that the CRAC calculations used to estimate the economic impacts for the FES plants did not have a continuous linear relationship with population. Rather, the MACCS code predicted higher costs than did the CRAC code; low population sites were underpredicted by substantial margins. The differences were primarily due to the difference in the handling of decontamination costs in the two codes. Results from Tingle (1993) indicate that for the results to be comparable to results calculated from MACCS, the regression values should be adjusted through the use of population-dependent correction factors. Table 5.31 reflects average expected cost values that were derived from the regression and then corrected with the following factors:

- Sites with MYR 10 mile populations ≤ 10,000 multiply cost data by 40.
- Sites with MYR 10 mile populations > 10,000 and ≤ 50,000 multiply cost data by 25.
- Sites with MYR 10 mile populations > 50,000 multiply cost data by 15.

Also, the FES values were in 1980 dollars. To correct for this, the average expected cost values were inflated to 1994 dollars.

Because no expected cost data are available for Indian Point, these regressions are based on 27 observations. R^2 values for the regressions are listed in Table G.2.

All of these regressions are highly significant ($p < 0.0001$). However, in each of the multiple regressions, the regression terms associated with population, after adjusting for the exposure index, were insignificant ($p > 0.05$). Thus, the model based on reactor type and only the 240-km (150-mile) exposure index were selected for predicting normalized expected cost.

Figure G.7 is a residual plot for the regression of normalized expected cost on the 240-km (150-mile) exposure index. Assumptions 1 through 3 are supported, except that the residual dispersion is greater among the Bs than the Ps. The intercept and slope estimates for this regression are -4.12 ± 1.92 and 1.30 ± 0.33 for PWRs and -0.06 ± 1.45 and 0.62 ± 0.25 for BWRs. Figure G.8 shows the regression for normalized expected cost on the 150-mile exposure index.

G.1.2.4 Comments on the Regressions

The previous regression analyses have led to fairly simple straight-line models. There are problems with the models, however, particularly the greater dispersion among the B residuals. If separate B types (1, 2, 3) are considered, the B dispersion is much smaller—so small, in fact, that the B residuals should not be used for making predictions. This is because of the large number of parameters (i.e., slopes and intercepts) being used to accommodate the B data. In this case, the P residuals alone should be used to compute prediction intervals, even for the B data, and there are only 18 P residuals. According to our "1/(n+1)" rule, even 95 percent confidence levels would then be suspect. We could use 90 percent confidence intervals instead, but then the intervals would be shaky simply because 90 percent does not represent a very high level of confidence.

Table G.2 R^2 values for normalized expected cost regressions

Predictors	R^2 value
Reactor type and population	0.39
Reactor type and 16-km (10-mile) index	0.40
Reactor type and 80-km (50-mile) index	0.49
Reactor type and 240-km (150-mile) index	0.51
Reactor type, 16-km (10-mile) index, and population	0.45
Reactor type, 80-km (50-mile) index, and population	0.48
Reactor type, 240-km (150-mile) index, and population	0.56

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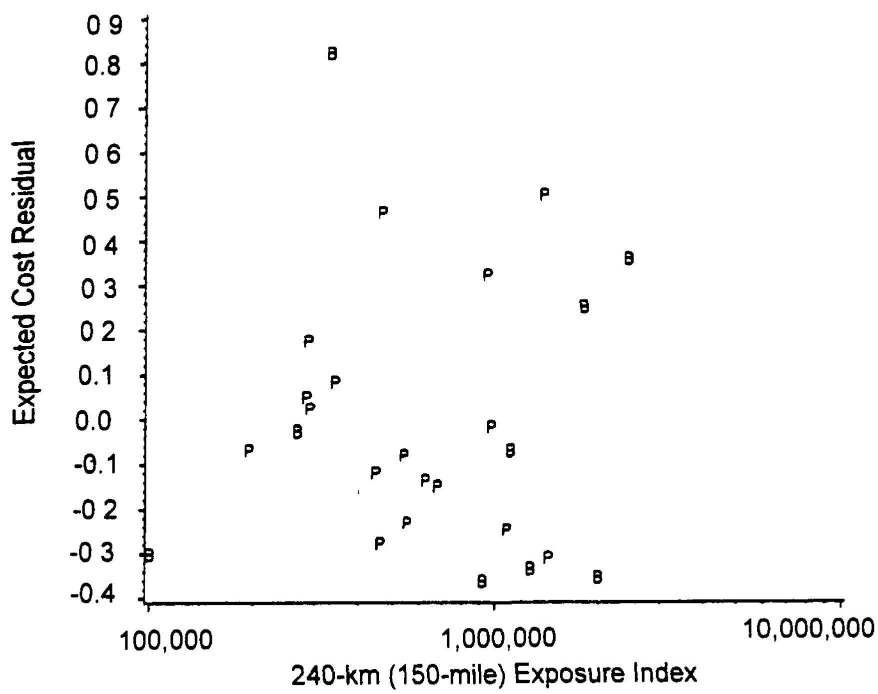

Figure G.7 Residuals from regression of the log of normalized expected cost (dollars per 1000-MW reactor-year) on the log of 240-km (150-mile) exposure index of persons at risk. (Reactor type: B = boiling water, P = pressurized water.)

Alternatively, separate regressions could be performed for the B and P data. However, because there are only ten B data points, the P predictions would still suffer from the small size and the B predictions even more so.

The best remedy for the problem of the greater B dispersion is to get more B data.

When the B residuals are numerous enough relative to the number of parameters being fitted to them, they can be used together with the P residuals to make predictions.

G.1.3 Predictions

Predictions are computed simply by plugging predictors into fitted regression equations. Collectively, they form the fitted regression line or curve. This is illustrated in Figures G.8 through G.16.

That the MYL exposure indices are representative of the MYR exposure indices is evident from the cumulative distribution functions in Figures G.17 and G.18. A cumulative distribution function of a set of data (here exposure indices) specifies for every number x the proportion of the set

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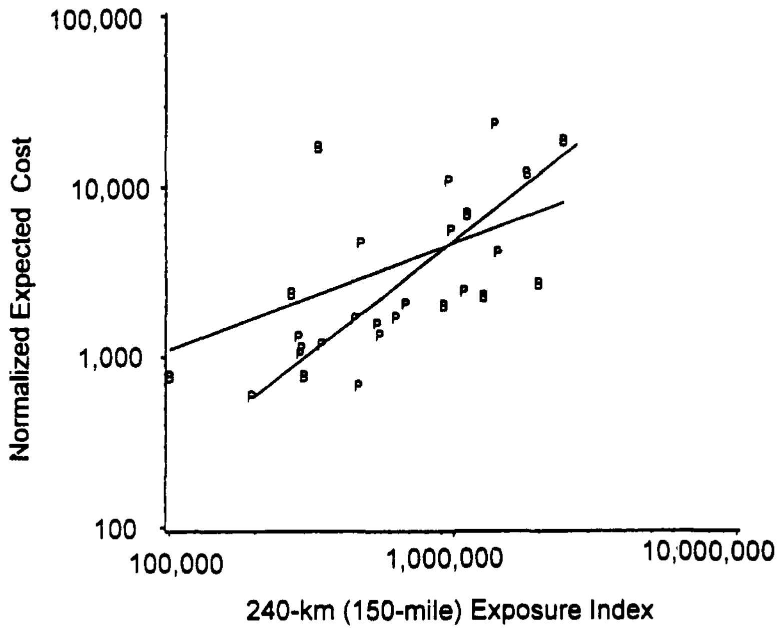

Figure G.8 **Log plot of normalized expected cost per 1000 MW(t) per reactor-year of 27 nuclear power plants [3300 MW(t) or greater] resulting from postulated accidents, regressed on the log of exposure index (EI).** (EI is the sum of the products of wind frequency in 22.5° sectors and population in those sectors. P = pressurized-water reactors, B = boiling-water reactors.)

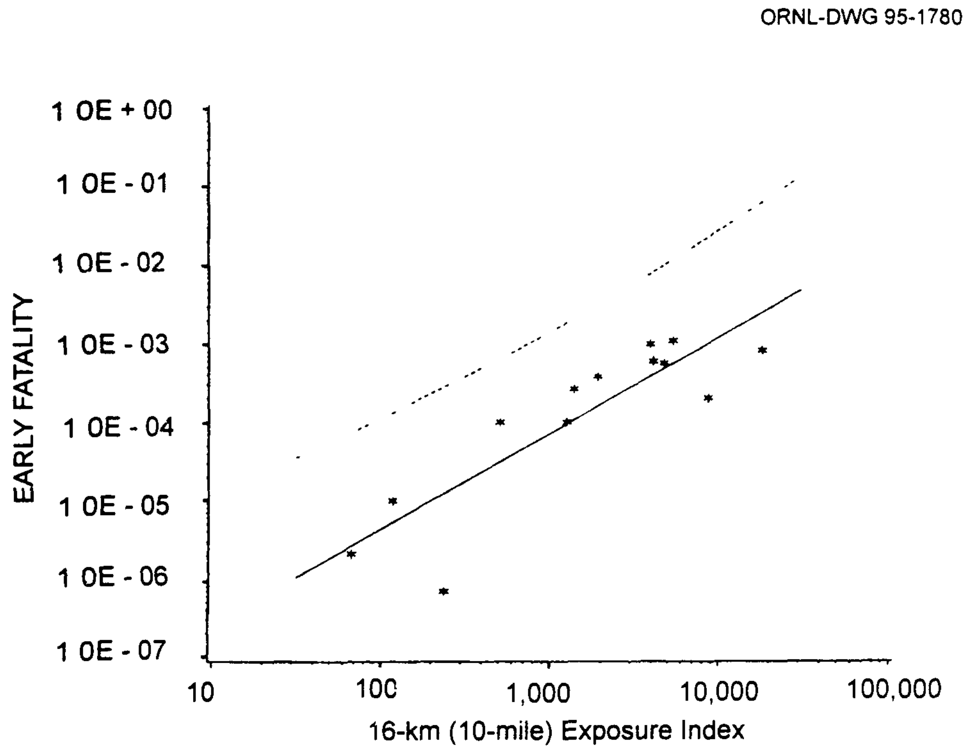

Figure G.9 **Log plot of early fatalities (average deaths per reactor-year) for final environmental statement pressurized-water reactor plants, fitted regression line, and 95 percent normal-theory upper prediction confidence bounds (dotted curve).**

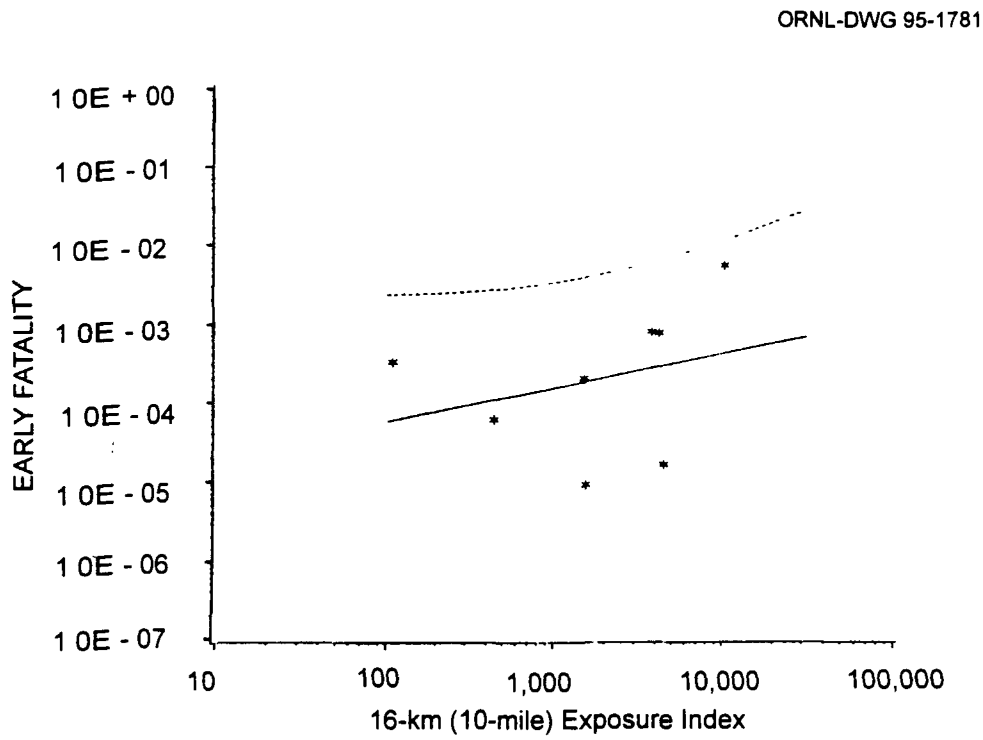

Figure G.10 **Log plot of early fatalities (average deaths per reactor-year) for final environmental statement boiling-water reactor plants, fitted regression line, and 95 percent normal-theory upper prediction confidence bounds (dotted curve.)**

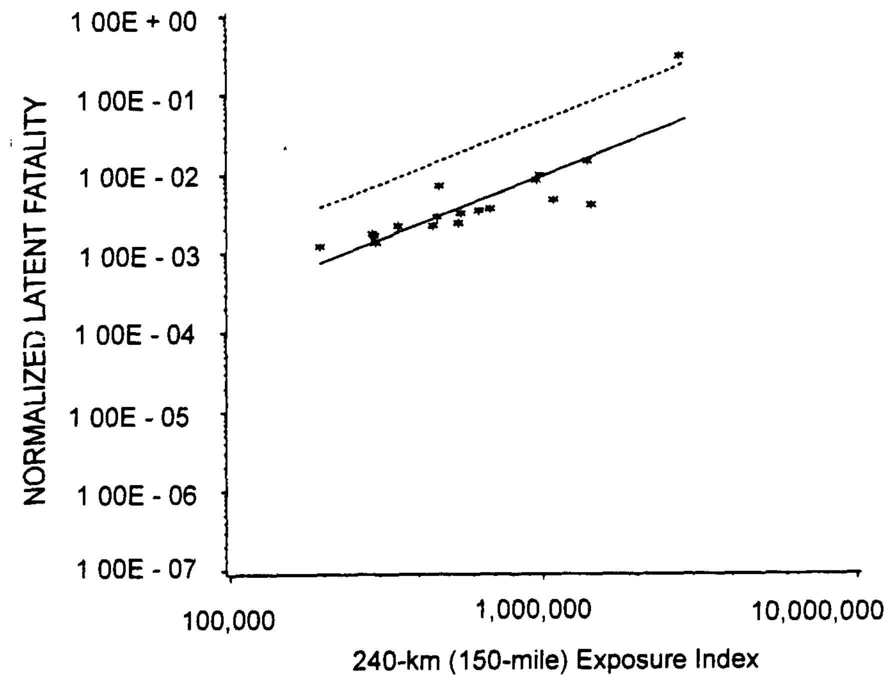

Figure G.11 **Log plot of normalized latent fatalities (average deaths per 1000-MW reactor-year) for final environmental statement pressurized-water reactor plants, fitted regression line, and 95 percent distribution-free upper prediction confidence bounds (dotted curve).**

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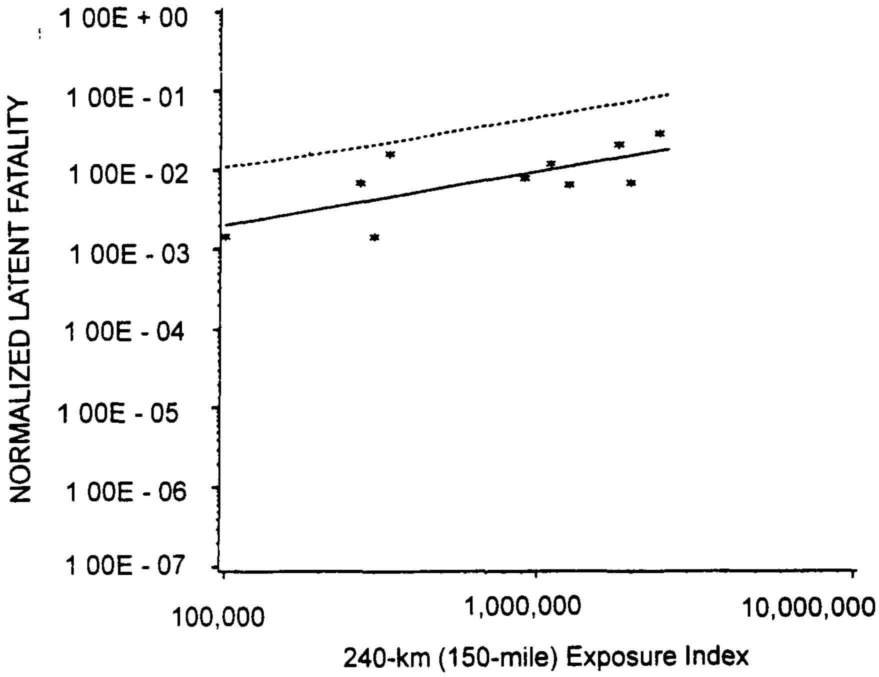

Figure G.12 **Log plot of normalized latent fatalities (average deaths per 1000-MW reactor-year) for final environmental statement boiling-water reactor plants, fitted regression line, and 95 percent distribution-free upper prediction confidence bounds (dotted curve).**

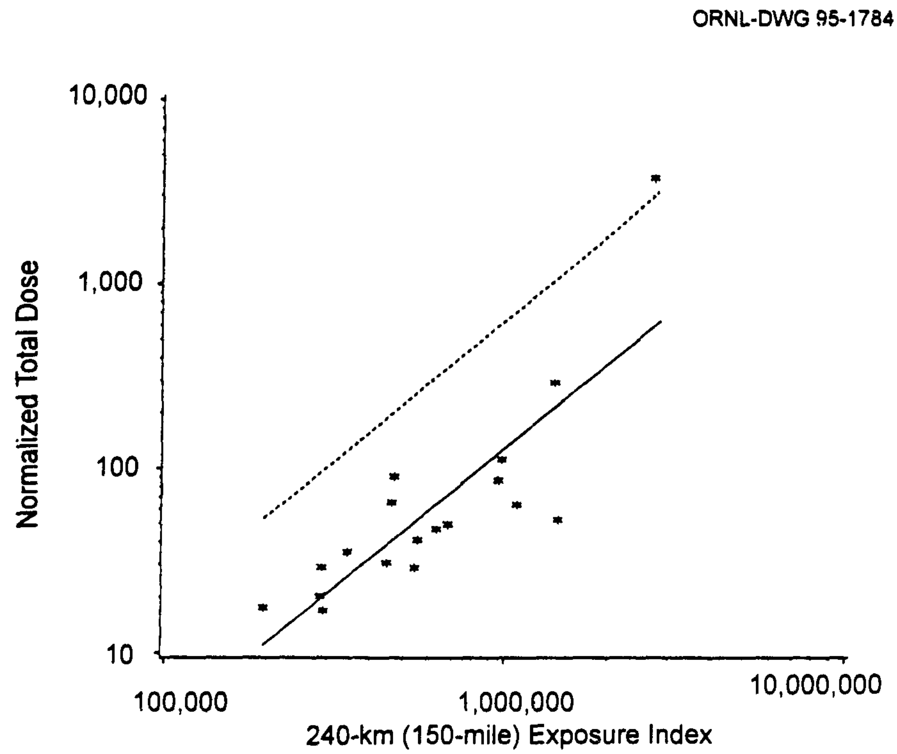

Figure G.13 **Log plot of normalized total dose (person-rem per 1000-MW reactor-year) for final environmental statement pressurized-water reactor plants, fitted regression line, and 95 percent distribution-free upper prediction confidence bounds (dotted curve).**

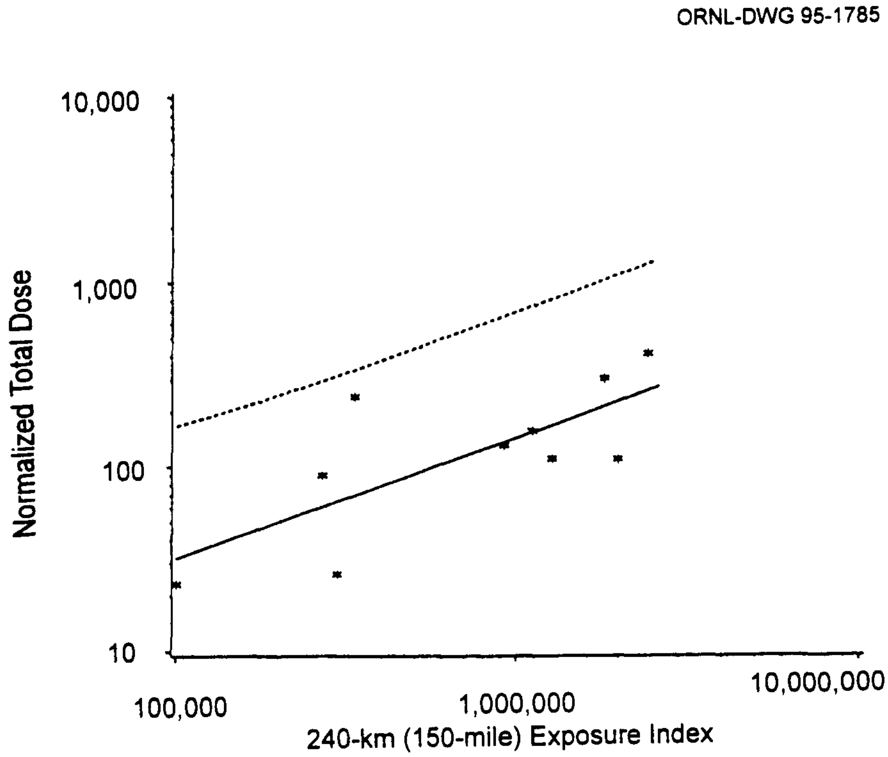

Figure G.14 **Log plot of normalized total dose (person-rem per 1000-MW reactor-year) for final environmental statement boiling-water reactor plants, fitted regression line, and 95 percent distribution-free upper prediction confidence bounds (dotted curve).**

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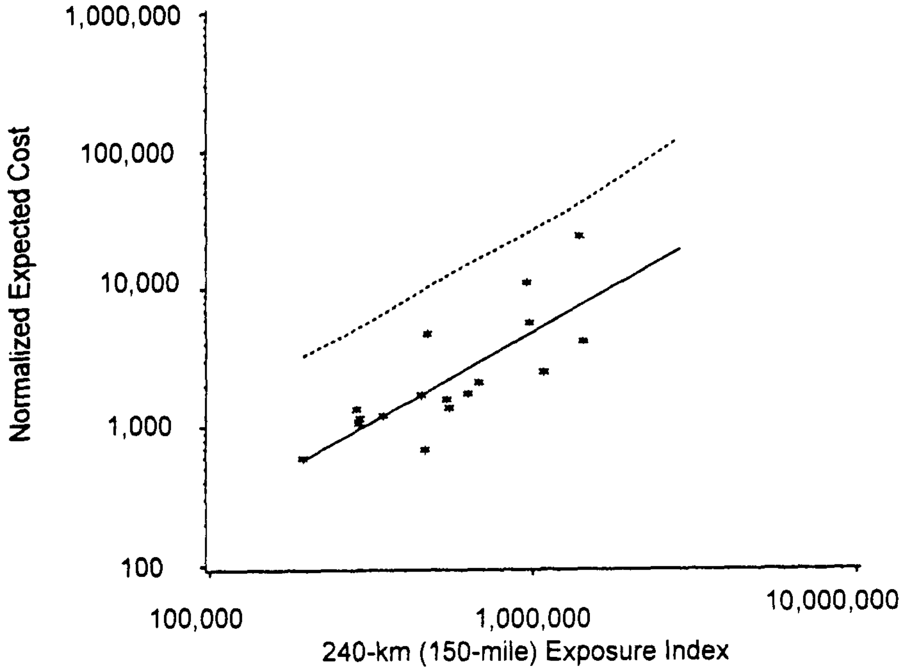

Figure G.15 **Log plot of normalized expected cost (dollars per 1000-MW reactor-year) for final environmental statement pressurized-water reactor plants, fitted regression line, and 95 percent distribution-free upper prediction confidence bounds (dotted curve).**

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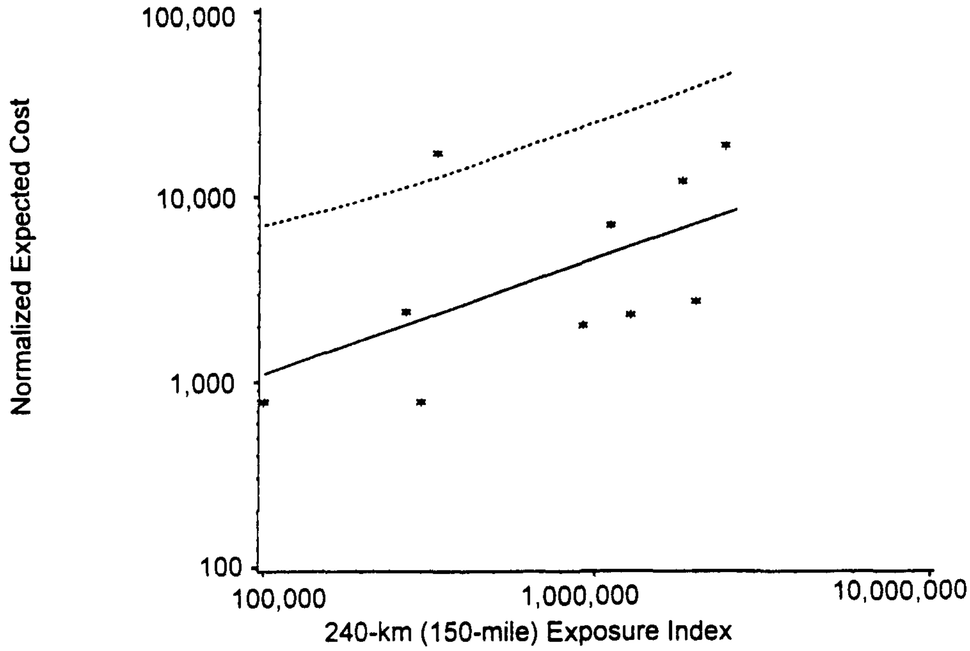

Figure G.16 **Log plot of normalized expected cost (dollars per 1000-MW reactor-year) for final environmental statement boiling-water reactor plants, fitted regression line, and 95 percent distribution-free upper prediction confidence bounds (dotted curve).**

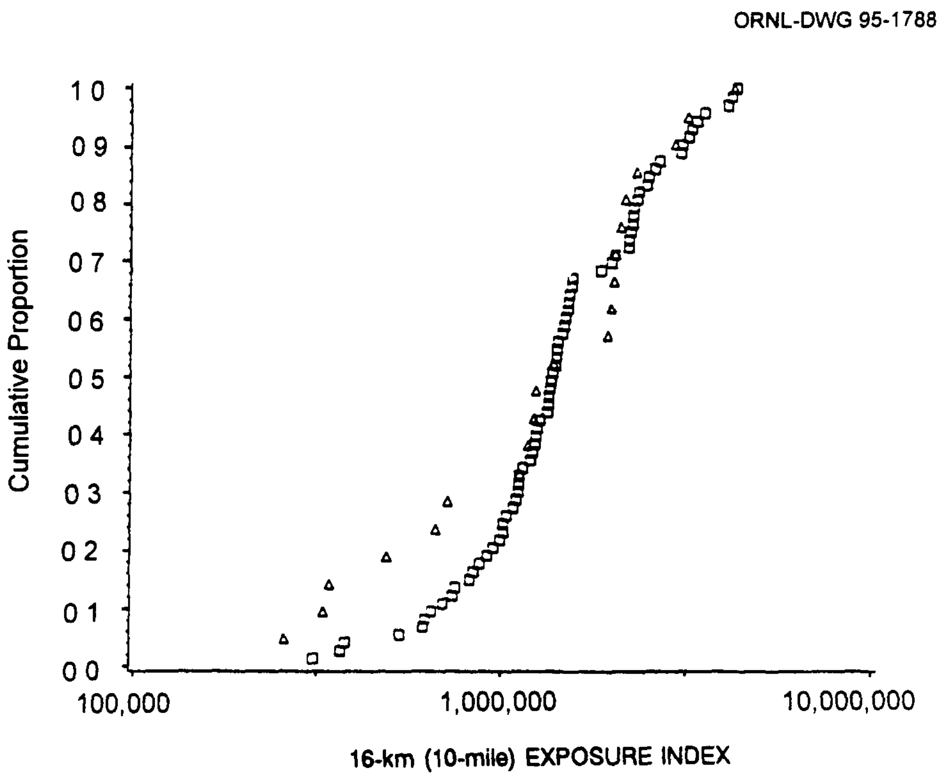

Figure G.17 **Cumulative proportions of the midyear license date for 16-km (10-mile) exposure index of persons at risk for final environmental statement plants and all other plants.** [Year: △ = middle year of license (MYL), □ = middle year of license renewal (MYR).]

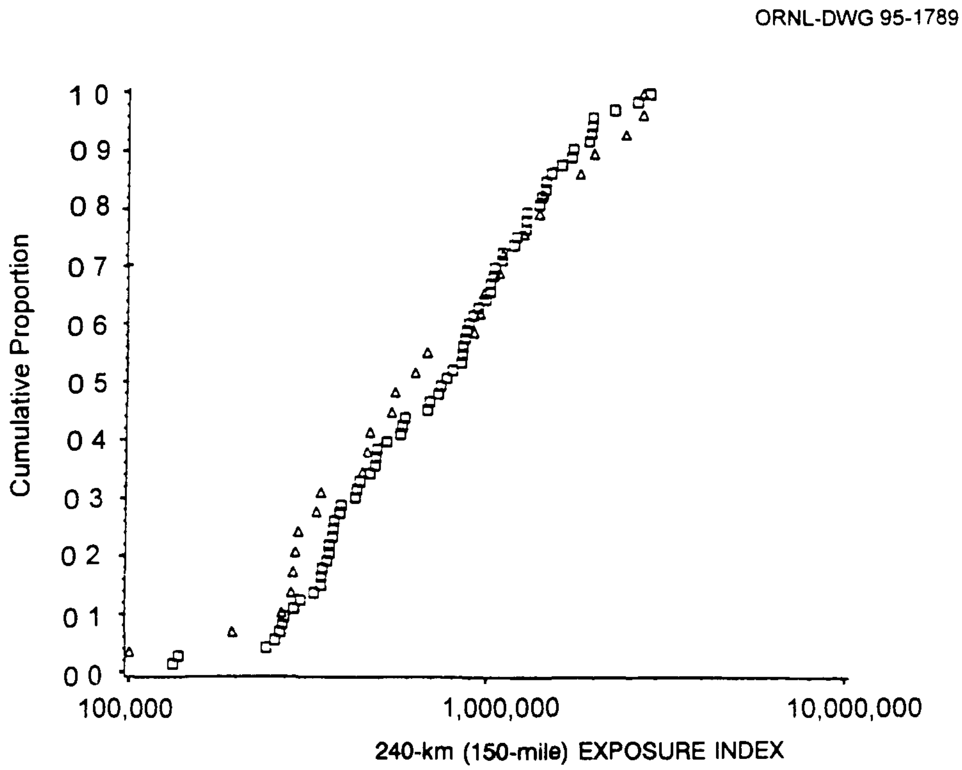

Figure G.18 Cumulative proportions of the midyear license date for 240-km (150-mile) exposure index of persons at risk for final environmental statement plants and all other plants. [Year: △ = middle year of license (MYL), □ = middle year of license renewal (MYR).]

having value no greater than *x*. In the figures, the MYL and MYR cumulative distribution functions are similar, indicating that the two populations are similar. Plots for individual reactor types are similar.

Representativeness is an advantage in several ways, one of which is that it implies that the predictions are not extrapolations. Extrapolation itself does not violate the assumptions of prediction interval theory, but it is known to exacerbate the effect of violating them.

When the assumption of normality of errors fails, normal-theory prediction confidence bounds can be far from valid. Testing the normal assumption in regression is a difficult problem. If regression errors were observable (rather than just residuals), a goodness-of-fit test for normality would be straightforward. Unfortunately, goodness-of-

fit tests must be based on residuals, which depend on parameter estimates and are statistically dependent.

Even if errors were observable, it is essentially impractical to determine the practical importance of accepting or rejecting with a goodness-of-fit test. The test may be so lacking in power that an important deviation from normality would most likely go undetected. In that case, goodness-of-fit tests would likely also accept many non-normal distributions, some of which would imply considerably different prediction confidence limits. It can also happen that a goodness-of-fit test is so powerful that even unimportant deviations from normality would most likely be detected with high statistical significance.

In spite of the above caveats, a Shapiro-Wilks goodness-of-fit test for normality was performed on the regression residuals for the four models selected. Significance levels are $p = 0.04$ for acute fatalities, 0.55 for normalized total dose, 0.53 for normalized latent fatalities, and 0.21 for normalized expected cost. Thus, at least in the case of acute fatality, the normal assumption is immediately suspect. The outlying P residual in the normalized latent fatality and normalized total dose residual plots (Figures G.3 and G.4) casts doubt on the normal assumption for these variables as well, in spite of the acceptance of the goodness-of-fit test ($p > 0.05$).

Figures G.9 through G.16 contain the observed MYL data; the fitted regression lines; and normal-theory 95 percent (in the sense of Equation G.2) upper prediction confidence bounds for the fatality, dose, and cost variables. In our application, the sample size n is either 21, 27, or 28. [FES early fatalities could not be normalized, so only plants with MWT(t) > 3000 (21 out of 28 FES plants) were used to develop the correlation for early fatalities.]

The $n/(n+1)$ upper limit for a suitable level of confidence for prediction bounds is thus either 0.95, 0.96, or 0.97. Because 0.95 is a standard level, it is used for all prediction bounds.

The acute fatality regression is based only on plants of more than 3025 MW(t). These plants should tend to have greater expected acute fatality estimates than plants of less than 3025 MW(t). Therefore, acute fatality predictions based on the fitted regression for plants with less than 3025 MW(t) should tend to be high and thus conservative.Also computed for comparison were 95 percent distribution-free upper bounds, discussed in the introduction of this appendix and in Schmoyer. Tables G.3 through G.6 contain predictions and normal and distribution-free upper 95 percent prediction confidence bounds for the variables. Although the best fitted lines for both B and P reactors are determined solely by their own respective data, it is important to note that all (i.e., both B and P) residuals affect the upper prediction bounds, whether normal or distribution free. The MYR predictions are based on a projection of the exposure index for those time points (usually 2030 or 2050). The MYL actual estimates, when available, are included for reference.

In comparing the normal theory and distribution-free predictions bounds, the normal bounds can be either higher or lower. In the case of acute fatalities, they are higher, in the other cases, they are lower. In all cases they are clearly different. What the difference means in terms of practical importance is critical here, but it is not a statistical issue.

Table G.3 Middle year of the license renewal (MYR) early fatality predictions

Power plant	Reactor type[a]	16-km (10-mile) exposure index	MYL[b] early fatality estimate × 1000	MYR early fatality prediction × 1000	Normal theory 95 percent UCB[c] × 1000	Distribution free 95 percent UCB × 1000
Arkansas	P	1993		0.17	3.3	2.1
Beaver Valley	P	9535	2.0	1.1	25	17
Bellefonte	P	2317		0.20	4.0	2.5
Big Rock Point	B	476		0.11	2.7	1.9
Braidwood	P	2126	0.38	0.18	3.6	2.3
Browns Ferry	B	2019		0.20	4.3	2.8
Brunswick	B	1195		0.16	3.5	2.2
Byron	P	1468	0.26	0.11	2.3	1.4
Callaway	P	541	0.10	0.034	0.69	0.44
Calvert Cliffs	P	1232		0.093	1.8	1.2
Catawba	P	7219	1.1	0 80	17	11
Clinton	B	760	0 0090	0.13	3.0	2.0
Commanche Peak	P	1518	0.10	0.12	2.3	1.5
Cooper	B	411		0.10	2.6	1.8
Crystal River	P	1064		0 077	1.5	0.98
DC Cook	P	4163		0.41	8.4	5.4
Davis Besse	P	979		0.070	1.4	0.89
Diablo Canyon	P	1020		0 073	1.5	0.93
Dresden	B	2345		0.22	4.6	3.0
Duane Arnold	B	6283		0.33	8.0	5.6
Farley	P	1021		0 074	1.5	0.93
Fermi 2	B	4919	0 74	0.30	6.8	4.6
Fitzpatrick	B	1532		0 18	3.8	2.5
Fort Calhoun	P	1155		0.086	1.7	1.1
Ginna	P	2291		0.20	3.9	2.5
Grand Gulf	B	562	0 060	0 12	2.8	1.9
Haddam Neck	P	5476		0.57	12	7.7

See footnotes at end of table

Table G.3 (continued)

Power plant	Reactor type[a]	16-km (10-mile) exposure index	MYL[b] early fatality estimate × 1000	MYR early fatality prediction × 1000	Normal theory 95 percent UCB[c] × 1000	Distribution free 95 percent UCB × 1000
Hatch	B	372		0.099	2.6	1.8
Hope Creek	B	1807	0.0090	0.19	4.1	2.6
Indian Point 2						
Indian Point 3			0.83			
Kewanee	P	671		0.044	0.89	0.57
La Salle	B	1307		0.17	3.6	2.3
Limerick	B	10709	5.4	0.41	11	8.7
Maine Yankee	P	1246		0.094	1.8	1.2
McGuire	P	4919		0.50	10	6.7
Millstone 3	P	9420	0.20	1.1	25	16
Monticello	B	1832		0.19	4.1	2.6
Nine Mile Point	B	1568	0.20	0.18	3.8	2.5
North Anna	P	704		0.047	0.94	0.60
Oconee	P	5184		0.53	11	7.2
Oyster Creek	B	5584		0.31	7.4	5.1
Palisades	P	2421		0.21	4.2	2.7
Palo Verde	P	96	0.0021	0.0041	0.11	0.078
Peach Bottom	B	1972		0.20	4.2	2 7
Perry	B	5020	0 016	0.30	6.9	4.7
Pilgrim	B	1435		0.18	3.7	2.4
Point Beach	P	1612		0.13	2.5	1.6
Prarie Island	P	2188		0.19	3 7	2.4
Quad Cities	B	2228		0.21	4.5	2.9
Rancho Seco	P	835		0.058	1.1	0.73
River Bend	B	1857	0.40	0 20	4.1	2.7
Robinson	P	1889		0.16	3.1	2 0
Salem	P	1808		0.15	2.9	1 9

See footnotes at end of table

Table G.3 (continued)

Power plant	Reactor type[a]	16-km (10-mile) exposure index	MYL[b] early fatality estimate × 1000	MYR early fatality prediction × 1000	Normal theory 95 percent UCB[c] × 1000	Distribution free 95 percent UCB × 1000
San Onofre	P	5179	1.0	0.53	11	7.2
Seabrook	P	5234	0.60	0.54	11	7.3
Sequoyah	P	3471		0.33	6.6	4.2
Sheron Harris	P	1773	0.18	0.14	2.8	1.8
Shoreham	B	5915		0.32	7.7	5.3
South Texas	P	278	0 00070	0.15	0.33	0.22
St. Lucie	P	11447	0.070	1.4	32	22
Summer	P	902	0.17	0.063	1.3	0.80
Surry	P	6796		0.74	16	10
Susquehanna	B	3976	0.77	0.27	6.0	4.0
TMI	P	10327		1.2	28	19
Trojan	P	12556		1.6	37	25
Turkey Point	P	17852		2.4	60	42
Vermont Yankee	B	2408		0.22	4.6	3.0
Vogtle	P	141	0.010	0.0066	0.16	0.11
WNP-2	B	134	0.32	0.064	2.3	2.0
Waterford	P	6163	0.57	0.66	14	9.1
Watts Bar	P	1241		0.093	1.8	1.2
Wolf Creek	P	381		0.022	0.47	0.30
Yankee Rowe	P	1998		0.17	3.3	2.1
Zion	P	16913		2.3	56	39

[a]P = pressurized-water reactor; B = boiling-water reactor.
[b]MYL = middle year of license.
[c]UCB = upper confidence bound.

Table G.4 Middle year of the license renewal (MYR) normalized latent fatality (NLF) predictions

Power plant	Reactor type[a]	240-km (150-mile) exposure index	MYL[b] NLF estimate × 1000	MYR NLF prediction × 1000	Normal theory 95 percent UCB[c] × 1000	Distribution free 95 percent UCB × 1000
Arkansas	P	265479		1.2	4.5	6.0
Beaver Valley	P	1021547	8.3	9.8	35	49
Bellefonte	P	678549		5.2	18	26
Big Rock Point	B	136942		2.5	11	13
Braidwood	P	1615088	4.0	20	76	100
Browns Ferry	B	491751		6.0	22	30
Brunswick	B	256923		3.8	15	19
Byron	P	1214624	4.7	13	47	64
Callaway	P	373564	2.2	2.1	7.4	10
Calvert Cliffs	P	1459323		17	64	86
Catawba	P	914688	3.6	8.2	30	42
Clinton	B	1418383	6.6	12	45	61
Commanche Peak	P	353530	1.3	2.0	7.1	9.9
Cooper	B	428471		5.4	20	27
Crystal River	P	573211		4.0	14	20
DC Cook	P	1051654		10	37	51
Davis Besse	P	1104797		11	40	55
Diablo Canyon	P	302887		1.5	5.4	7.4
Dresden	B	1193394		11	40	54
Duane Arnold	B	329426		4.5	17	23
Farley	P	344405		1.8	6.6	9.1
Fermi 2	B	1287935	12	11	42	57
Fitzpatrick	B	270532		4.0	15	20
Fort Calhoun	P	242370		1.0	3.9	5.3
Ginna	P	357773		1.9	6.9	9.6
Grand Gulf	B	388245	1.4	5.1	19	25

See footnotes at end of table.

Table G.4 (continued)

Power plant	Reactor type[a]	240-km (150-mile) exposure index	MYL[b] NLF estimate × 1000	MYR NLF prediction × 1000	Normal theory 95 percent UCB[c] × 1000	Distribution free 95 percent UCB × 1000
Haddam Neck	P	1722399		22	85	110
Hatch	B	347873		4.7	18	24
Hope Creek	B	1955878	21	15	58	76
Indian Point	P	2863844		49	200	260
Indian Point 2			300			
Indian Point 3						
Kewanee	P	440217		2.6	9.4	13
La Salle	B	1396350		12	45	60
Limerick	B	2647224	29	18	74	95
Maine Yankee	P	391929		2.2	7.9	11
McGuire	P	890305		7.9	28	40
Millstone 3	P	1510698	15	18	68	90
Monticello	B	487606		5.9	22	30
Nine Mile Point	B	273322	6.9	4 0	15	20
North Anna	P	876587		7.7	28	39
Oconee	P	867675		7.6	27	38
Oyster Creek	B	1970098		15	58	77
Palisades	P	1041961		10	37	51
Palo Verde	P	290395	1.2	1.4	5.1	6.9
Peach Bottom	B	1453860		12	46	62
Perry	B	1021049	8.0	9.7	36	49
Pilgrim	B	486154		5.9	22	30
Point Beach	P	469985		2.9	10	15
Prarie Island	P	375227		2.1	7.4	10
Quad Cities	B	854803		8 6	31	43
Rancho Seco	P	992605		9 4	34	47
River Bend	B	432680	16	5.5	20	27

See footnotes at end of table.

Table G.4 (continued)

Power plant	Reactor type[a]	240-km (150-mile) exposure index	MYL[b] NLF estimate × 1000	MYR NLF prediction × 1000	Normal theory 95 percent UCB[c] × 1000	Distribution free 95 percent UCB × 1000
Robinson	P	738770		5.9	21	30
Salem	P	1979840		27	110	140
San Onofre	P	1284282	9.7	14	52	70
Seabrook	P	523715	2.2	3.5	12	18
Sequoyah	P	769140		6.3	22	32
Sheron Harris	P	688554	3.2	5.3	19	27
Shoreham	B					
South Texas	P	579617	2.8	4.1	14	21
St. Lucie	P	727763	2.4	5.8	21	29
Summer	P	852405	3 4	7.4	26	37
Surry	P	846246		7.3	26	37
Susquehanna	B	2279528	6.9	17	66	85
TMI	P	1928285		26	100	130
Trojan	P	944628		8.7	31	44
Turkey Point	P	345115		1.8	6.6	9.1
Vermont Yankee	B	1286085		11	42	57
Vogtle	P	590283	7 0	4.2	15	21
WNP-2	B	132195	1 5	2.5	10	13
Waterford	P	370569	1.7	2.0	7.3	10
Watts Bar	P	798733		6.7	24	34
Wolf Creek	P	363380	1.6	2.0	7.1	9.9
Yankee Rowe	P	1739663		22	86	110
Zion	P	1107448		11	40	56

[a]P = pressurized-water reactor; B = boiling-water reactor
[b]MYL = middle year of license.
[c]UCB = upper confidence bound.

Table G.5 Middle year of the license renewal (MYR) normalized total dose (NTD) predictions

Power plant	Reactor type[a]	240-km (150-mile) exposure index	MYL[b] NTD estimate	MYR NTD prediction	Normal theory 95 percent UCB[c]	Distribution free 95 percent UCB
Arkansas	P	265479		18	64	85
Beaver Valley	P	1021547	87	130	480	650
Bellefonte	P	678549		72	250	360
Big Rock Point	B	136942		39	160	200
Braidwood	P	1615088	53	270	1000	1300
Browns Ferry	B	491751		91	330	440
Brunswick	B	256923		59	220	290
Byron	P	1214624	64	170	630	840
Callaway	P	373564	35	29	100	140
Calvert Cliffs	P	1459323		230	840	1100
Catawba	P	914688	50	110	400	550
Clinton	B	1418383	110	180	670	880
Commanche Peak	P	363530	17	28	100	140
Cooper	B	428471		83	300	400
Crystal River	P	573211		56	200	280
DC Cook	P	1051654		140	500	680
Davis Besse	P	1104797		150	540	730
Diablo Canyon	P	302887		21	77	100
Dresden	B	1193394		160	590	790
Duane Arnold	B	329426		70	260	340
Farley	P	344405		26	93	130
Fermi 2	B	1287935	160	170	620	830
Fitzpatrick	B	270532		61	230	300
Fort Calhoun	P	242370		15	57	74
Ginna	P	357773		27	98	130
Grand Gulf	B	388245	26	78	280	380
Haddam Neck	P	1722399		290	1100	1400

See footnotes at end of table.

Table G.5 (continued)

Power plant	Reactor type[a]	240-km (150-mile) exposure index	MYL[b] NTD estimate	MYR NTD prediction	Normal theory 95 percent UCB[c]	Distribution free 95 percent UCB
Hatch	B	347873		72	270	350
Hope Creek	B	1955878	300	220	850	1100
Indian Point	P	2863844		630	2600	3200
Indian Point 2			3800			
Indian Point 3						
Kewanee	P	440217		38	130	180
La Salle	B	1396350		180	660	870
Limerick	B	2647224	410	270	1100	1400
Maine Yankee	P	391929		32	110	150
McGuire	P	890305		110	380	530
Millstone 3	P	1510698	290	240	890	1200
Monticello	B	487606		90	330	440
Nine Mile Point	B	273322	90	62	230	300
North Anna	P	876587		110	370	520
Oconee	P	867675		100	370	510
Oyster Creek	B	1970098		230	860	1100
Palisades	P	1041961		140	490	670
Palo Verde	P	290395	18	20	73	97
Peach Bottom	B	1453860		190	680	900
Perry	B	1021049	130	150	530	710
Pilgrim	B	486154		90	330	440
Point Beach	P	469985		41	150	200
Prarie Island	P	375227		30	100	140
Quad Cities	B	854803		130	470	630
Rancho Seco	P	992605		130	450	620
River Bend	B	432680	240	84	300	400
Robinson	P	738770		82	290	400
Salem	P	1979840		360	1400	1800

See footnotes at end of table

Table G.5 (continued)

Power plant	Reactor type[a]	240-km (150-mile) exposure index	MYL[b] NTD estimate	MYR NTD prediction	Normal theory 95 percent UCB[c]	Distribution free 95 percent UCB
San Onofre	P	1284282	110	190	690	910
Seabrook	P	523715	31	49	170	240
Sequoyah	P	769140		87	310	430
Sheron Harris	P	688554	41	74	260	360
Shoreham	B					
South Texas	P	579617	66	57	200	280
St. Lucie	P	727763	29	80	280	390
Summer	P	852405	47	100	360	500
Surry	P	846246		100	350	490
Susquehanna	B	2279528	110	250	960	1200
TMI	P	1928285		350	1300	1700
Trojan	P	944628		120	420	580
Turkey Point	P	345115		26	93	130
Vermont Yankee	B	1286085		170	620	830
Vogtle	P	590283	91	59	200	290
WNP-2	B	132195	23	38	160	200
Waterford	P	370569	20	29	100	140
Watts Bar	P	798733		92	320	450
Wolf Creek	P	363380	29	28	100	140
Yankee Rowe	P	1739663		300	1100	1500
Zion	P	1107448		150	540	730

[a]P = pressurized-water reactor; B = boiling-water reactor.
[b]MYL = middle year of license
[c]UCB = upper confidence bound.

Table G.6 Middle year of the license renewal (MYR) normalized expected cost (NEC) predictions

Power plant	Reactor type[a]	240-km (150-mile) exposure index	MYL[b] NEC NLF[c] estimate	MYR NEC prediction	Normal theory 95 percent UCB[d]	Distribution free 95 percent UCB
Arkansas	P	265479		850	3600	4700
Beaver Valley	P	1021547	11000	4900	21000	27000
Bellefonte	P	678549		2900	12000	16000
Big Rock Point	B	136942		1300	6500	8100
Braidwood	P	1615088	4100	8900	41000	51000
Browns Ferry	B	491751		3000	12000	16000
Brunswick	B	256923		2000	8800	11000
Byron	P	1214624	2500	6200	27000	34000
Callaway	P	373564	1200	1300	5400	7400
Calvert Cliffs	P	1459323		7800	35000	44000
Catawba	P	914688	2100	4300	18000	23000
Clinton	B	1418383	2300	5800	24000	31000
Commanche Peak	P	363530	1100	1300	5300	7100
Cooper	B	428471		2700	11000	15000
Crystal River	P	573211		2300	9300	13000
DC Cook	P	1051654		5100	22000	28000
Davis Besse	P	1104797		5400	23000	30000
Diablo Canyon	P	302887		1000	4200	5500
Dresden	B	1193394		5200	22000	28000
Duane Arnold	B	329426		2300	9900	13000
Farley	P	344405		1200	4900	6600
Fermi 2	B	1287935	7000	5400	23000	30000
Fitzpatrick	B	270532		2100	9000	11000
Fort Calhoun	P	242370		760	3300	4200
Ginna	P	357773		1300	5200	6900
Grand Gulf	B	388245	780	2600	11000	14000
Haddam Neck	P	1722399		9700	45000	56000

See footnotes at end of table.

Table G.6 (continued)

Power plant	Reactor type[a]	240-km (150-mile) exposure index	MYL[b] NEC NLF[c] estimate	MYR NEC prediction	Normal theory 95 percent UCB[d]	Distribution free 95 percent UCB
Hatch	B	347873		2400	10000	13000
Hope Creek	B	1955878	12000	7000	31000	39000
Indian Point	P	2863844		19000	100000	120000
Indian Point 2						
Indian Point 3						
Kewanee	P	440217		1600	6600	9300
La Salle	B	1396350		5700	24000	31000
Limerick	B	2647224	19000	8500	39000	48000
Maine Yankee	P	391929		1400	5800	7900
McGuire	P	890305		4100	17000	23000
Millstone 3	P	1510698	23000	8200	37000	46000
Monticello	B	487606		3000	12000	16000
Nine Mile Point	B	273322	2400	2100	9000	11000
North Anna	P	876587		4000	17000	22000
Oconee	P	867675		4000	16000	22000
Oyster Creek	B	1970098		7100	31000	39000
Palisades	P	1041961		5000	21000	28000
Palo Verde	P	290395	590	960	4000	5200
Peach Bottom	B	1453860		5800	25000	32000
Perry	B	1021049	2000	4700	20000	26000
Pilgrim	B	486154		3000	12000	16000
Point Beach	P	469985		1800	7200	10000
Prarie Island	P	375227		1300	5500	7400
Quad Cities	B	854803		4200	17000	23000
Rancho Seco	P	992605		4700	20000	26000
River Bend	B	432680	17000	2800	12000	15000
Robinson	P	738770		3200	13000	18000
Salem	P	1979840		12000	56000	69000

See footnotes at end of table

Table G.6 (continued)

Power plant	Reactor type[a]	240-km (150-mile) exposure index	MYL[b] NEC NLF[c] estimate	MYR NEC prediction	Normal theory 95 percent UCB[d]	Distribution free 95 percent UCB
San Onofre	P	1284282	5600	6600	29000	37000
Seabrook	P	523715	1700	2100	8300	12000
Sequoyah	P	769140		3400	14000	19000
Sheron Harris	P	688554	1400	2900	12000	17000
Shoreham	B					
South Texas	P	579617	680	2400	9500	14000
St. Lucie	P	727763	1600	3200	13000	18000
Summer	P	852405	1700	3900	16000	21000
Surry	P	846246		3800	16000	21000
Susquehanna	B	2279528	2700	7700	35000	43000
TMI	P	1928285		11000	54000	66000
Trojan	P	944628		4400	18000	24000
Turkey Point	P	345115		1200	4900	6600
Vermont Yankee	B	1286085		5400	23000	30000
Vogtle	P	590283	4700	2400	9700	14000
WNP-2	B	132195	780	1300	6400	7900
Waterford	P	370569	1300	1300	5400	7300
Watts Bar	P	798733		3600	15000	20000
Wolf Creek	P	363380	1100	1300	5300	7100
Yankee Rowe	P	1739663		9800	46000	57000
Zion	P	1107448		5500	23000	30000

[a]P = pressurized-water reactor; B = boiling-water reactor
[b]MYL = middle year of license.
[c]NLF = normalized latent fatality
[d]UCB = upper confidence bound

G.2 ENDNOTES

1. Current evidence indicates that, for BWRs, the type of containment may significantly influence the public risk compared with PWR containments, and the degree of influence may vary between the different BWR containment types. This variation of risk influence among containment types does not seem to be as prevalent for PWR containments.

G.3 REFERENCES

Butler, R., and E. D. Rothman, "Predictive Intervals Based on Reuse of the Sample," *Journal of the American Statistical Association*, **75**, 881–89, 1980.

Draper, N., and H. Smith, *Applied Regression Analysis, Second Addition*, Wiley, New York, 1981.

Huber, P. J., *Robust Statistics*, Wiley, New York, 1981.

Schmoyer, R. L., "Asymptotically Valid Prediction Intervals for Linear Models," *Technometrics* (submitted), 1990.

Stine, R. A., "Bootstrap Prediction Intervals for Regression," *Journal of the American Statistical Association* **80**, 1026–31, 1985.

Tingle, A., *CRAC2S-MACCS Comparison of Exposure Index Calculations*, Brookhaven National Laboratory, Upton, N.Y., February 1993.

APPENDIX H

ENVIRONMENTAL STATUTES AND REGULATIONS AFFECTING LICENSE RENEWAL ACTIVITIES

ENVIRONMENTAL STATUTES AND REGULATIONS AFFECTING LICENSE RENEWAL ACTIVITIES

H.1 INTRODUCTION

This appendix summarizes the statutes and executive orders that may affect license renewal applications for nuclear power plants. The summary builds on the information in Section 2.3, "Plant Interaction With the Environment," and addresses the following topics: land use, water use, water quality, air quality, aquatic resources, terrestrial resources, radiological impacts, solid waste, chemical impacts, and socioeconomic factors.

The federal and state statutes and the executive orders presented in this part include

(1) statutes and executive orders that could require the Nuclear Regulatory Commission (NRC) or the applicant to undergo a *new* authorization or consultation process with federal or state agencies outside the NRC; or

(2) statutes and executive orders that could require the NRC or the applicant to *renew* authorizations currently granted or hold additional consultations with federal or state agencies outside the NRC.

This summary is provided as a general overview to assist the applicant in identifying environmental and natural resources laws that may affect the license renewal process. The summary is not intended as a complete and final list, and the applicant is reminded that a variety of additional local and regional requirements may exist for the specific plant site.

H.2 FEDERAL STATUTES AND EXECUTIVE ORDERS

H.2.1 Land Use

Coastal Zone Management Act of 1972, as amended, Title 16 U.S.C. 1451, et seq.

Congress enacted the *Coastal Zone Management Act* (CZMA) in 1972 to address the increasing pressures of over-development upon the nation's coastal resources. The National Oceanic and Atmospheric Administration administers the Act. The CZMA encourages states to preserve, protect, develop, and, where possible, restore or enhance valuable natural coastal resources such as wetlands, floodplains, estuaries, beaches, dunes, barrier islands, and coral reefs, as well as the fish and wildlife using those habitats. Participation by states is voluntary. To encourage states to participate, the CZMA makes federal financial assistance available to any coastal state or territory, including those on the Great Lakes, that is willing to develop and implement a comprehensive coastal management program.

H.2.2 Water Use

Water use law is dominated by state regulation rather than federal regulation.

H.2.3 Water Quality

(a) Clean Water Act, as amended, Title 33 U.S.C. 1251, et seq.

The *Clean Water Act* (CWA), formerly known as the Federal Water Pollution Control Act, is intended to "... restore

and maintain the chemical, physical, and biological integrity of the Nation's water" (Section 101). The CWA has five elements: (1) a system of minimum national effluent standards for each industry, (2) water quality standards, (3) a discharge permit program that translates these standards into enforceable limits, (4) provisions for special problems such as toxic chemicals and oil spills, and (5) a revolving construction loan program (formerly a grant program) for publicly-owned treatment works.

The CWA requires the Environmental Protection Agency (EPA) to establish effluent limitations for the amounts of specific pollutants that may be discharged by municipal sewage plants and industrial facilities. The two-step approach to setting the standards includes (1) establishing a nationwide base-level treatment through an assessment of what is technologically and economically achievable for a particular industry and (2) requiring more stringent levels of treatment for specific plants if necessary to achieve water quality objectives for the particular body of water into which that plant discharges. For example, EPA sets limits based on water quality to control pollution in waters designated by the states for drinking, swimming, or fishing.

The primary method by which the CWA imposes limitations on pollutant discharges is the nationwide permit program established under Section 402 and referred to as the National Pollutant Discharge Elimination System (NPDES). Under the NPDES program, any person responsible for the discharge of a pollutant or pollutants into any waters of the United States from any point source must apply for and obtain a permit.

Section 502(6) of the CWA defines the term *pollutant* to include radioactive materials. In its implementing regulations (40 CFR 122 in particular), however, EPA refined the definition *of pollutant* to exclude radioactive materials regulated under the Atomic Energy Act of 1954 (AEA), as amended. Thus, although the CWA and its implementing regulations clearly apply to naturally occurring (e.g., radium) and accelerator-produced radioisotopes, they do not apply to source, byproduct, or special nuclear materials as defined by the AEA.

Note that, quite apart from the CWA, states may under certain circumstances exercise a limited role in the regulation of these materials. Until Section 274 was added to the AEA in 1959, states had no role in the licensing and regulation of source, byproduct, or special nuclear materials. Section 274, however, provided a statutory basis by which states could assume from NRC a measure of authority over the regulation of byproduct and source materials and special nuclear materials in quantities not sufficient to form a critical mass. To effect this transfer of authority, (1) NRC must find that the state's radiation control program is compatible with NRC's and that it is adequate to protect public health and safety, (2) the state must establish its authority to enter into an agreement with NRC, and (3) NRC must enter into an agreement with the governor of the state desiring such authority. Thus far, 29 states have entered into such agreements with NRC. Even in agreement states, however, NRC retains regulatory authority over

several important areas, including construction and operation of production and utilization facilities and disposal of certain source, byproduct, and special nuclear materials [AEA, Section 274(c)].

Section 404 enables the Corps of Engineers in the Department of the Army to issue permits for the discharge of dredged or fill materials into waters of the United States at specific sites. The Corps specifies a site by applying guidelines promulgated by EPA (40 CFR 230). Further, any proposal to dump dredged or fill material into the ocean must comply with the dumping criteria set forth in Section 227.13 of the Marine Protection, Research, and Sanctuaries Act (MPRSA) regulations. Under Subsection 404(c) of the CWA, EPA can prohibit (or limit the use of) a proposed disposal site or withdraw an already designated site, under regulations codified at 40 CFR 231. This determination may occur if EPA foresees unacceptable impacts on municipal water supplies, shellfish beds, fishery areas, or wildlife and recreational areas. However, such a determination must be made after consultation with the Corps and the permit applicant.

A significant feature of Section 404 is that the Corps may issue general permits on a state, regional, or nationwide basis for dredging or fill activities that are similar in nature and cause only minimal individual and cumulative adverse impacts. General permits are granted for a period not to exceed 5 years. The Corps issues individual permits for actions that have a potential for significant environmental impacts.

(b) Marine Protection, Research, and Sanctuaries Act of 1972, Title 16 U.S.C. 1431, et seq.

The MPRSA (Pub.L. 92-532) regulates ocean dumping of waste, provides for a research program on ocean dumping, and provides for the designation and regulation of marine sanctuaries. Also known as the Ocean Dumping Act, the Act regulates the ocean dumping of all material beyond the territorial limit or 3 miles from shore and prevents or strictly limits dumping material that "would adversely affect human health, welfare, or amenities, or the marine environment, ecological systems, or economic potentialities." "Material" includes (but is not limited to) dredged material, solid waste, incinerator residue, garbage, sewage, sewage sludge, munitions, chemical and biological warfare agents, radioactive materials, chemicals, biological and laboratory waste, wrecked or discarded equipment, rock, sand, excavation debris, and industrial, municipal, agricultural, and other waste. The term does not include sewage from vessels or oil, unless the oil is transported via a vessel or aircraft for the purpose of dumping. Disposal by means of a pipe, regardless of how far at sea the discharge occurs, is regulated by the CWA, through the NPDES permit process.

Some of the waste material as defined above may be transported to and dumped into the ocean under conditions stipulated in a permit issued by EPA or the Corps of Engineers, depending upon the type of waste involved. Ocean dumping, however, is only possible if no other reasonable alternatives, such as landfilling, are available.

(c) Safe Drinking Water Act, as amended, Title 42 U.S.C. 300 F., et seq.

In 1974 Congress enacted the *Safe Drinking Water Act* (SDWA) to manage potential contamination threats to groundwater. The act instructed EPA to establish a national program to prevent underground injections that would endanger drinking water sources. Primary drinking water standards promulgated under the SDWA apply to drinking water "at the tap" as delivered by public water supply systems.

Section 1447 of the SDWA states that each federal agency having jurisdiction over a federally owned or maintained public water system must comply with all federal, state, and local requirements, administrative authorities, and processes and sanctions regarding the provision of safe drinking water. Sections 1412, 1414, and 1445(a) of the SDWA provide drinking water regulations and specific operating procedures for public water systems.

Public water systems, as defined in 40 CFR 141.2, provide piped water for human consumption and have at least 15 connections or regularly serve at least 25 people. Public water systems are either

(1) community water systems, that is, public water systems that serve at least 15 connections used by year-round residents or regularly serve at least 25 year-round residents; or

(2) non-community water systems, all other water systems (e.g., campgrounds and gas stations).

On July 8, 1987 (FR 52, 25690), EPA amended 40 CFR 141.2 to add a definition of a "non-transient non-community water system" as a public water system that is *not* a community water system but that regularly serves at least the same 25 people for 6 months per year (e.g., work places and hospitals).

The SDWA requires EPA to establish primary water regulations for contaminants that may cause adverse public health effects. The regulations include both mandatory levels (maximum contaminant levels) and nonenforceable health goals [maximum contaminant level goals (MCLGs)] for each included contaminant.

MCLGs have extra significance because they can be used under the *Comprehensive Environmental Response, Compensation, and Liability Act* (CERCLA) as amended by the *Superfund Amendments and Reauthorization Act* (SARA) as applicable or relevant and appropriate requirements in national priorities list cleanups.

H.2.4 Air Quality

Clean Air Act, as amended, Title 42 U.S.C. 7401, et seq.

On November 15, 1990, President Bush signed into law sweeping revisions of the *Clean Air Act* (CAA). The new law contains titles that

- strengthen measures for attaining air quality standards (Title 1),
- set forth provisions relating to mobile sources (Title II),
- expand the regulation of hazardous air pollutants (Title III),

- require substantial reductions in power plant emissions for control of acid rain (Title IV),
- establish operating permits for all major sources of air pollution (Title V),
- establish provisions for stratospheric ozone protection (Title VI), and
- expand enforcement powers and penalties (Title VII).

The CAA Amendments will have far-reaching effects not only on environmental activities at federal facilities, but also on procurement, maintenance, and motor vehicle operation activities.

The original 1970 CAA authorized EPA to establish National Ambient Air Quality Standards (NAAQS) to limit levels of pollutants in the air. EPA has promulgated NAAQS for six criteria pollutants: sulfur dioxide, nitrogen dioxide, carbon monoxide (CO), ozone, lead, and particulate matter. All areas of the United States must maintain ambient levels of these pollutants below the ceilings established by the NAAQS; any area that does not meet these standards is a "nonattainment" area (NAA).

The 1990 Amendments require that the boundaries of serious, severe, or extreme ozone or CO NAAs located within metropolitan statistical areas (MSAs) or consolidated metropolitan statistical areas (CMSAs) be expanded to include the entire MSA or CMSA unless the governor makes certain findings and the administrator of EPA concurs. Consequently, all urban counties included in an affected MSA or CMSA, regardless of their attainment status, will become part of the NAA.

Under previous law "major sources" were those with the potential to emit more than 100 tons per year (tpy). The CAA Amendments reduced the size of plants subject to permitting and stringent retrofitting or offsetting requirements. In *serious* ozone NAAs, "major sources" include those with the potential to emit more than 50 tpy of volatile organic compounds. In *severe* ozone NAAs, "major sources" include those that emit 25 tpy or, in extreme areas, 10 tpy. For serious CO NAAs, a "major source" is now one that emits 50 tpy. For serious particulate matter NAAs, a "major source" is now one that emits 70 tpy.

The new source performance standards (NSPS) set minimum nationwide emission limitations for classes of facilities. The NSPS are set at levels that reflect the degree of control achievable through the application of the best system of continuous emission reduction that has been adequately demonstrated for that category of sources. The NSPS must take into consideration the cost of achieving such emissions reductions and any non-air-quality health and environmental impacts and energy requirements.

The National Emissions Standards for Hazardous Air Pollutants aim to control pollutants that may reasonably be anticipated to result in either an increase in mortality or an increase in serious irreversible or incapacitating, but reversible, illness. Since 1970 EPA has listed only eight hazardous air pollutants and has established standards for only seven. The 1990 Amendments directed EPA to establish technology-based standards for 189 hazardous substances based on the use of "maximum achievable control technology."

Title V of the CAA Amendments established a federal permitting program, similar to the CWA permitting program, which is to be administered by the states. Title V declared that after the effective date of any approved or promulgated permit program, it will be

unlawful to operate a major source, affected source, or any other source (including an area source) subject to regulation under the CAA unless the source complies with all air quality requirements and has an operating permit. Under previous federal law, construction permits were required only for new sources; existing sources were left largely unpermitted, unless the state elected to require an operating permit. The CAA Amendments eliminated the distinction between new and existing sources; all major sources are now required to have an operating permit.

The new permit program will be fee-based, and federal facilities are explicitly required to pay a fee or charge imposed by a state or local agency to defray the costs of its air pollution regulatory program. The statute sets minimum rates for such fees at $25 per ton of each regulated pollutant, up to 4000 tpy. The EPA administrator may set other amounts to adequately reflect reasonable costs of the permit program. The following sources must have a permit to operate:

- major hazardous air pollutant sources,
- major sources under NAAQS,
- all affected sources under Title IV, and
- all sources subject to NSPS.

H.2.5 Aquatic Resources

(a) Fish and Wildlife Coordination Act, as amended, Title 16 U.S.C. 661–664, et seq.

The *Fish and Wildlife Coordination Act* (FWCA), as amended, proposes to ensure that fish and wildlife resources receive equal consideration with other values during the planning of water resources development projects. The act was passed because the goals of water-related projects (e.g., flood control, irrigation, navigation, and hydroelectric power) may conflict with the goal of conserving fish and wildlife resources. Conversely, developers can design water development projects to enhance the quality and enjoyment of fish and wildlife resources if such goals are incorporated into project plans.

The act authorizes the Secretary of the Department of the Interior (DOI) to provide assistance to and cooperate with federal, state, and public or private agencies and organizations in the development and protection of wildlife resources and habitat; make surveys and investigations of the wildlife in the public domain; and accept donations of land and funds that will further the purposes of the act.

The act requires consultation with the head of the state agency that administers wildlife resources in the affected state. The purpose of this process is to promote conservation of wildlife resources by preventing loss of and damage to such resources and to provide for the development and improvement of wildlife resources in connection with the agency action.

Although the recommendations of the Secretary of the Interior and state officials are not binding, the federal agency must give them full consideration. Furthermore, any reports and recommendations made by those officials become an integral part of any report prepared by the responsible federal agency when seeking authorization for the water-resource development project. Such a report must also include an estimate of the wildlife benefits or losses to be derived from the proposed project and a description of the conservation

measures the agency finds should be adopted to obtain maximum overall project benefits.

The FWCA authorizes federal agencies to acquire lands in connection with water development projects for use in activities designed to conserve and enhance wildlife resources. These activities should be conducted in accordance with plans approved by the federal agency, the Secretary of the Interior, and the head of the applicable state agency. The report that accompanies the authorization request should describe the probable extent of land acquisition.

In other conservation provisions the FWCA authorizes the Secretary of DOI [through the Fish and Wildlife Service (FWS) and the Bureau of Mines] to investigate and report to Congress on the effects of domestic sewage; mine, petroleum, and industrial wastes; erosion silt; and other pollutants on wildlife and to make recommendations for alleviating their effects. It also directs the Corps of Engineers to consider fish and wildlife resource and habitat in its management of water levels in the upper Mississippi River.

Two general types of activities exempt from the act are (1) water impoundments with a surface area of less than 4 ha (10 acres) and (2) programs for land management and use carried out by federal agencies on land under their jurisdiction.

(b) Fish and Wildlife Conservation Act of 1980, Title 16 U.S.C. 2901, et seq.

The *Fish and Wildlife Conservation Act* provides federal technical and financial assistance to states for the development of conservation plans and programs for nongame fish and wildlife. The act also encourages federal agencies to conserve and promote the conservation of nongame fish and wildlife and their habitats. Conservation plans are required to identify appropriate nongame fish and wildlife species and significant problems that may adversely affect these species and their habitats. The conservation plan must also determine the actions that should be taken to conserve the nongame fish and wildlife species. The designated state agencies are expected to consult with the appropriate federal agencies during the development, revision, and implementation of the plan.

H.2.6 Terrestrial Resources

Endangered Species Act of 1973, as amended, Title 16 U.S.C. 1531, et seq.

The *Endangered Species Act* (ESA) originally passed in 1973. It provides for the designation and protection of invertebrates, wildlife, fish, and plant species that are in danger of becoming extinct and conserves the ecosystems on which such species depend.

The act defines an endangered species as any species that is in danger of becoming extinct throughout all or a significant portion of its range (the act excludes recognized insect pests from this definition). A threatened species is one that is likely to become endangered in the foreseeable future. The act makes it illegal for any individual to kill, collect, remove, harass, import, or export an endangered or threatened species without a permit from the Secretary of DOI. DOI's FWS performs most administrative and regulatory actions under the act. The National Marine Fisheries Service in the

U.S. Department of Commerce deals with actions affecting marine species.

To be protected, a species must be listed by the Secretary of the Interior as endangered or threatened. The listing process generally begins with a petition to the Secretary. Consultation with affected states is required prior to listing, but the Secretary makes the final decision. Whenever possible, a designation of critical habitat accompanies the listing of an endangered or threatened species. The Secretary must publish and periodically update the lists and develop and implement "recovery plans" for the conservation and survival of endangered and threatened species. Recently, the American bald eagle has been removed from the list because of FWS recovery plans.

The act directs the Secretaries of Interior and Commerce to establish programs to conserve fish, wildlife, and plants, including endangered and threatened species. Also, the Department of Agriculture oversees the import and export of endangered and threatened species. Implementation of such programs usually includes acquisition of lands under the act itself and under the FWCA of 1958, as amended; the *Fish and Wildlife Act* of 1956, as amended; and the *Migratory Bird Conservation Act* of 1929, as amended.

The act mandates cooperation between the U.S. federal, state, and foreign governments. The Secretary of the Interior must cooperate with the states to acquire and manage land and has authority to enter into cooperative agreements to provide assistance to those states that establish programs for the conservation of endangered and threatened species. The President and the Secretary of the Interior may provide financial and technical assistance to foreign countries to encourage conservation of fish, wildlife, and plants. The Secretaries of the Interior and Commerce must also carry out obligations under two international agreements: the *Convention on International Trade in Endangered Species of Wild Fauna and Flora* and the *Convention on Nature Protection and Wildlife Preservation in the Western Hemisphere.*

All federal agencies must utilize their authorities to carry out programs for the conservation of endangered and threatened species. Regulations promulgated under Section 7 of the act define the process whereby proposed federal actions that may affect threatened or endangered species are approved, disapproved, and appealed. In particular, "Each Federal agency shall, in consultation with and with the assistance of the Secretary [of DOI], ensure that any action authorized, funded, or carried out by such agency ... is not likely to jeopardize the continued existence of any endangered species or threatened species or result in the destruction or adverse modification of habitat of such species which is determined by the Secretary ... to be critical ... [Endangered Species Act Section 7(a)(2)]."

H.2.7 Radiological Impacts

Occupational Safety and Health Act

The Occupational Safety and Health Administration (OSHA) of the Department of Labor is responsible for the implementation of the *Occupational and Safety Health Act*. The act establishes safe and healthful workplace standards. Employers who fail to comply with OSHA standards can be penalized by the federal government. The act allows states to develop and enforce OSHA standards if such programs have been approved by the Secretary of Labor.

H.2.8 Solid Waste

Resource Conservation and Recovery Act of 1976, as amended, Title 42 U.S.C. 6901, et seq.

In 1976 Congress remodeled the *Solid Waste Disposal Act,* which dealt with the disposal of nonhazardous waste, into a major new program on hazardous waste. The *Resource Conservation and Recovery Act* (RCRA) outlines the framework for national programs to achieve environmentally sound management of both hazardous and nonhazardous wastes. RCRA also promotes resource recovery techniques and methods to reduce the generation of waste. The *Hazardous and Solid Waste Amendments* of 1984 (HSWA) both expanded the scope of RCRA and increased the level of detail in many of its provisions.

RCRA, as amended, contains ten subtitles. Subtitle C, "Hazardous Waste Management"; Subtitle D, "State and Regional Solid Waste Plans"; Subtitle I, "Regulation of Underground Storage Tanks"; and Subtitle J, "Demonstration Medical Waste Tracking Program," constitute the regulatory portion of the law. The other subtitles provide the legal and administrative structure for achieving the objectives of the law.

EPA, the Department of Commerce, the Department of Energy, and DOI all have specific responsibilities under RCRA. EPA issues guidelines and regulations for proper management of solid wastes, oversees and approves the development of state waste management plans, and provides financial aid to agencies and firms performing research on solid waste. The Department of Commerce encourages greater commercialization of proven resource recovery technologies. The Department of Energy oversees activities involving research and development of new techniques for producing energy from wastes. DOI oversees mineral waste problems, including recovery of metals and minerals and methods for stabilizing mining wastes.

Generators of hazardous waste must notify EPA that the wastes exist and require management in compliance with RCRA. Proper identification and initial management of hazardous wastes promote the success of the "cradle-to-grave" program. Generators must determine if the wastes are hazardous. If so, they notify EPA that they are managing a hazardous waste; obtain an EPA identification number for the generating facility; and verify that the transportation, treatment, storage, and disposal of the waste is conducted only by others with EPA numbers.

Generators must also prepare a Uniform Hazardous Waste Manifest to accompany shipments of hazardous waste. The manifest includes the name and EPA identification number of persons authorized to manage the waste and serves as a document of accountability to prevent improper disposal. The manifest system promotes self-enforcement of RCRA's requirements.

Under RCRA, no material can be a hazardous waste without first being a solid waste. RCRA defines a *solid waste as* "... any garbage, refuse, sludge from a waste treatment plant, water supply treatment plant, or air pollution control facility and other discarded material, including solid, liquid, semisolid, or contained gaseous material resulting from industrial, commercial or mining and agricultural operations, and from community activities ... [excluding] ... solid or dissolved materials in domestic sewage, or solid or dissolved materials in irrigation return flows, or industrial discharges which are point sources subject to

permits under Section 402 of the Federal Water Pollution Control Act .... or source, special nuclear, or byproduct material as defined by the Atomic Energy Act [AEA] of 1954 ... [Section 1004(27)]."

RCRA then defines a *hazardous waste* as "a solid waste, or combination of solid wastes, which because of its quantity, concentration, or physical, chemical, or infectious characteristics may ... cause, or significantly contribute to an increase in mortality or an increase in serious irreversible, or incapacitating reversible, illness; or ... pose a substantial present or potential hazard to human health or the environment when improperly treated, stored, transported, or disposed of, or otherwise managed [Section 1004(5)]."

The 1984 HSWA addressed Congressional concern that inadequate or improper controls for management of hazardous waste would increase risks to human health and the environment. HSWA introduced three major changes in RCRA.

First, Congress restricted land disposal of untreated hazardous waste unless it could be demonstrated that there will be no migration of hazardous constituents from the disposal unit for as long as the wastes remain hazardous [Section 3004(d)(1)]. Second, facilities were required to adopt "minimum technical requirements" for landfills and surface impoundments to keep hazardous constituents from migrating into groundwater and to permit detection if migration occurs. Third, EPA was granted the authority to require corrective action for releases of hazardous constituents from any solid waste disposal unit at a facility seeking a RCRA

Subtitle I (implemented at 40 CFR Part 280), added by HSWA, established a program to regulate the three to five million underground storage tanks in the United States and to prevent their leaking. Under this subtitle RCRA regulates the storage of a product (e.g., petroleum products), rather than hazardous waste. In addition the substances regulated under Subtitle I include all the hazardous substances (except those regulated as a hazardous waste under Subtitle C of RCRA) defined under CERCLA. *Hazardous substances* under CERCLA encompass a wide variety of items regulated under other federal statutes including the CWA, CAA, and *Toxic Substances Control Act* (TSCA). (Radionuclides, which are specifically excluded under RCRA's definition of *solid waste,* are regulated under CERCLA because they are defined as *hazardous air pollutants* under the CAA.) Subtitle I of RCRA regulates underground storage tanks containing radioactive materials unless they are "mixed" with hazardous waste, in which case they are regulated under Subtitle C.

Federal agencies and departments that own or operate underground storage tanks are subject to and must comply with all applicable federal, state, interstate, and local requirements, except when the President determines that exemption of specific tanks from these requirements is in the "paramount" interest of the United States.

Section 3006 of RCRA authorizes states to develop and enforce their own hazardous waste programs in place of the federal program administered by EPA. Before administering any of the provisions of HSWA, authorized states must again go through the state program approval process.

H.2.9 Chemical Impurities

Federal Insecticide, Fungicide, and Rodenticide Act, as amended, Title 7 U.S.C. 135, et seq.

The *Federal Insecticide, Fungicide, and Rodenticide Act* as amended by the Federal Environmental Pesticide Control Act and subsequent amendments, requires the registration of all new pesticides with EPA before they are used in the United States. Manufacturers are required to develop toxicity data for their pesticide products. Toxicity data may be used to determine permissible discharge concentrations for an NPDES permit.

H.2.10 Socioeconomic Factors

Historic Preservation Requirements

Five laws, one executive order, and a Presidential memorandum have been passed during the last 75 years to help protect and preserve the nation's archaeological and historic resources.

The Antiquities Act of 1906 provided for the protection of historic and prehistoric remains and monuments on federal lands. It established a permit system for conducting scientific archaeological investigations, which could only be conducted by recognized institutions that would report results and maintain all collections for the public.

In 1935 Congress passed the *Historic Sites Act* that declared it was a national policy "to preserve for public use historic sites, buildings, and objects of national significance." This act extended protection to sites on both federal and non-federal lands by giving the Secretary of the Interior the authority to survey, document, evaluate, acquire, and preserve archaeological and historical sites throughout the country. It led to the creation of the Historic Sites Surveys, the Historic American Buildings Survey, and the Historic American Engineering Record (now the National Architectural and Engineering Record).

The Archaeological Recovery Act of 1960 gave DOI the major responsibility for preserving archaeological data that might be lost through federal dam construction. The *Archaeological and Historic Preservation Act* of 1974 amended and significantly expanded the scope of the 1960 Act by requiring preservation of archaeological data affected as a result of any federal or federally related land modification activities.

The act made the Secretary of the Interior responsible for coordinating and administering a nationwide program for the recovery, protection, and preservation of scientific, prehistoric, historic, and archaeological data that would otherwise be damaged or destroyed through federal action. This act, also referred to as the *Archaeological Salvage Act* or the *Moss-Bennett Act,* for the first time authorized up to 1 percent of the cost of a project to be transferred to the Secretary of the Interior for preserving archaeological data on federal construction projects, other than dam construction. The 1 percent limitation can be waived by federal agencies after obtaining concurrence from DOI and then notifying Congress.

The most comprehensive national policy on historic preservation was established by Congress with the passage of the *National Historic Preservation Act* of 1966 (NHPA). In this act historic preservation was defined to include "the protection, rehabilitation, restoration and reconstruction of districts, sites, buildings, structures, and objects significant in American history, architecture, archaeology, or culture." The act led to the creation of the National Register of Historic Places, a file of cultural resources of national, regional, state, and local significance. The act also established the Advisory Council on Historic Preservation (the Council), an independent federal agency

responsible for administering the protective provisions of the act.

Two of the major provisions of the NHPA for federal agencies are Sections 106 and I 10. Both sections aim to ensure that historic properties are appropriately considered in planning federal initiatives and actions. Section 106 is a specific, issue-related mandate to which federal agencies must adhere. It is a reactive mechanism that is driven by a federal action. Section I 10, in contrast, sets out broad federal agency responsibilities with respect to historic properties. It is a proactive mechanism with emphasis on ongoing management of historic preservation sites and activities at federal facilities.

Section 106 requires that the head of any federal agency having direct or indirect jurisdiction over a proposed federal or federally assisted undertaking in any state, and the head of any federal department or independent agency having authority to license any such undertaking, must ensure that the provisions of the NHPA are administered. Section 106 also mandates consultation during such federal actions. It compels federal agencies to "take into account" the effect of their projects on historical and archaeological resources and to give the Council the opportunity to comment on such effects.

Section 110(a) of the NHPA and Executive Order (E.O.) 11593 (which was substantially incorporated into the NHPA amendments of 1980) require agencies to provide leadership in preserving, restoring, and maintaining the historic and cultural environment of the nation. The 1980 NHPA amendments expanded the NHPA of 1966 by making federal agencies responsible for identifying, preserving, and nominating to DOI all sites, buildings, districts, and objects under their jurisdiction or control that appear to qualify for listing on the National Register of Historic Places. It also required DOI to develop criteria and procedures for federal agencies to use in these reviews and nominations. As a result, both Section 110(a) and E.O. 11593 require each federal agency, in cooperation with the state historic preservation officer in the state involved, to "establish a program to locate, inventory, and nominate to the Secretary (DOI) all properties under the agency's ownership or control by the agency, that appear to qualify for inclusion on the National Register in accordance with the regulations promulgated under Section 101(a)(2)(A)."

Amendments to NHPA in 1980 also provided additional guidance and clarification to the historic preservation program. Congress gave DOI the authority to waive the 1-percent limitation on the use of project funds to defray the costs of data recovery, increased the role of the state historic preservation officer in the administration of the National Historic Preservation Program, and clarified federal agency responsibilities under E.O. 11593.

The *Archaeological Resources Protection Act of 1979* was enacted to provide a comprehensive framework for protecting and regulating the use of archaeological resources on public and Indian lands protected by the *Antiquities Act* of 1906. The act requires that a permit be received from the federal land manager for the excavation and removal of archaeological resources on public land.

The President's 1978 *Memorandum on Environmental Quality and Water Resources Management* directed the Council to issue final regulations under the NHPA and directed federal agencies with water resource responsibilities and programs to publish

procedures implementing the NHPA within 3 months after promulgation of the final Council regulations.

Federal agencies should coordinate National Environmental Policy Act (NEPA) compliance with the responsibilities of the NHPA to ensure that historic and cultural properties are given proper consideration in the preparation of environmental assessments (EAs) and environmental impact statements (EISs). However, agency obligations under NHPA are independent from NEPA and must be complied with even when an EA or EIS is not required. That is, for proposed projects that are not classified as major federal actions with significant environmental impacts, federal agencies must still consider impacts to historic properties and sites. Where both NEPA and the NHPA are applicable, draft EISs must integrate NHPA considerations along with other environmental impact analyses and studies. (See 40 CFR Part 1502.25.)

To coordinate the independent responsibilities of the two acts (NEPA and NHPA), federal agencies should undertake compliance with NHPA regulations as soon as it is determined that a National Register listed or eligible property may be affected by a proposed project or program.

H.2.11 Other

(a) Emergency Planning and Community Right-to-Know Act of 1986, Title 42 U.S.C. I 1001, et seq.

The *Emergency Planning and Community Right-to-Know Act* (EPCRA), enacted on October 17, 1986, represents a significant first step toward a major federal role in areas previously regulated by state and local government. EPCRA was enacted by Congress as a stand-alone provision, Title III, of SARA.

Title III was passed in response to concerns regarding the environmental and safety hazards posed by the storage and handling of toxic chemicals. The disaster in Bhopal, India, in which more than 2000 people suffered death or serious injury from the accidental release of methyl isocyanate, triggered this concern. To reduce the likelihood of such a disaster in the United States, Congress imposed requirements on both states and regulated facilities. Facilities must notify the local emergency planning districts regarding materials and releases at sites.

The emergency planning aspect requires local communities to prepare plans to deal with emergencies relating to hazardous substances. The community right-to-know aspect creates new rights for members of the public and local governments to obtain information concerning potential threats in their neighborhoods involving hazardous substances. EPCRA provides the tools for local governments and members of the community to make their own decisions regarding hazardous materials in their communities.

EPCRA contains three subtitles. Subtitle A, "Emergency Planning and Notification," establishes mechanisms to enable states and communities to prepare to respond to unplanned releases of hazardous substances.

Subtitle B, "Reporting Requirements," contains three distinct reporting provisions concerning two different groups of chemical substances. The first two sets of reports require submission of

inventory-related data on *hazardous chemicals* (i.e., those substances for which a material safety data sheet is mandated under the hazard communication regulations of OSHA). The third reporting provision requires annual reports to the EPA and to the state in which the reporting facility is located of environmental releases of listed *toxic chemicals* manufactured, processed, or otherwise used at the facility in excess of specified threshold quantities.

Subtitle C, "General Provision," contains a variety of general provisions, including, but not limited to, civil, criminal, and administrative penalties for violations of the statute's reporting requirements; enforcement actions that can be brought by citizens, states, and emergency planning and response entities; and restrictions on an owner's or operator's rights to make trade secrecy claims in the reports required by EPCRA.

(b) National Electric Safety Code

The *National Electric Safety Code* provides a comprehensive listing of criteria regarding electrical safety.

(c) Executive Order 11990, Protection of Wetlands

Executive Order 11990 was issued to avoid direct or indirect support of new construction on wetlands wherever there is a practicable alternative. Federal agencies are required to evaluate the potential effects of any actions they may take on wetlands when carrying out their responsibilities (e.g., planning, regulating, and licensing activities). However, this executive order does not apply to the issuance by federal agencies of permits, licenses, or allocations to private parties for activities involving wetlands on nonfederal property.

(d) Pollution Prevention Act of 1990

This legislation focuses on treating and disposing of waste rather than on meeting source reduction limits. The millions of tons of pollution generated each year could be reduced in a cost-effective manner through changes in production, operation, and types of raw materials used in industry. The technique of source reduction is considered fundamentally different from and more desirable than waste management and pollution control. EPA is to carry out the responsibilities set forth in this act.

(e) The Bald and Golden Eagle Protection Act

The *Bald and Golden Eagle Protection Act* prohibits knowingly (or with disregard for the consequences of one's actions) taking, possessing, selling, transporting, importing, or exporting the American or golden eagle, dead or alive, without a permit.

(f) The American Indian Religious Freedom Act

The *American Indian Religious Freedom Act* (AIRFA) clarifies U.S. policy pertaining to the protection of Native Americans' religious freedom. The special nature of Native American religions has frequently resulted in conflicts between federal laws and policies and religious freedom. Some federal laws, such as those protecting wilderness areas or endangered species, have inadvertently given rise to problems such as denial of access to sacred sites or

prohibitions on possession of animal-derived sacred objects by Native Americans.

AIRFA, passed in 1978, acknowledged prior infringement on the right of freedom of religion for Native Americans. Furthermore, it stated in a clear, comprehensive, and consistent fashion the federal policy that laws passed for other purposes were not meant to restrict the rights of Native Americans. The act established a policy of protecting and preserving the inherent right of individual Native Americans (including American Indians, Eskimos, Aleuts, and Native Hawaiians) to believe, express, and exercise their traditional religions.

AIRFA is primarily a policy statement. Approximately half of the brief statute is devoted to Congressional findings. Following the Congressional findings, the act makes a general policy statement regarding American Indian religious freedom: "... henceforth it shall be the policy of the United States to protect and preserve for American Indians their inherent right to freedom to believe, express, and exercise the traditional religions of the American Indian, Eskimo, Aleut, and Native Hawaiians, including but not limited to access to sites, use and possession of sacred objects, and the freedom to worship through ceremonial and traditional rites (42 U.S.C. 1996)."

The final section of the act requires the President to order agencies to review their policies and procedures in consultation with traditional native religious leaders.

(g) Native American Graves Protection and Repatriation Act

The *Native American Graves Protection and Repatriation Act*, enacted on November 16, 1990, established a means for American Indians, including members of Indian tribes, Native Hawaiian organizations, and Native Alaskan villages and corporations, to request the return or "repatriation" of human remains and other cultural items presently held by federal agencies or federally assisted museums or institutions.

The act also contains provisions regarding the intentional excavation and removal of, inadvertent discovery of, and illegal trafficking in Native American human remains and cultural items.

All federal agencies that manage land and/or are responsible for archaeological collections from their lands or generated by their activities must comply with the Native American Graves Protection and Repatriation Act.

(h) Marine Mammal Protection Act

The *Marine Mammal Protection Act* (MMPA) was enacted in 1972 to protect and manage marine mammals and their products (e.g., the use of hides and meat). The primary authority for implementing the act belongs to the FWS and National Marine Fisheries Service. The FWS manages walruses, polar bears, sea otters, dugongs, marine otters, and West Indian, Amazonian, and West African manatees. The National Marine Fisheries Service manages whales, porpoises, seals, and sea lions. The two agencies may issue permits under MMPA Section 104 (16 U.S.C.

1374) to persons, including federal agencies, that authorize the taking or importing of specific species of marine mammals.

After the Secretary of the Interior or the Secretary of Commerce approves a state's program, the state can take over responsibility for managing one or more marine mammals. Regulations governing the transfer of responsibility were published in May 1983. Although certain states actively participate in the management of marine mammals, as of August 9, 1994, no state has fully taken on this duty.

The MMPA established a Marine Mammal Commission whose duties include reviewing laws and international conventions relating to marine mammals, studying the condition of these mammals, and recommending steps to federal officials (e.g., listing a species as endangered) that should be taken to protect marine mammals. Federal agencies are directed by MMPA Section 205 (16 U.S.C. 1405) to cooperate with the commission by permitting it to use their facilities or services.

(i) Executive Order 11988,. Floodplain Management

Executive Order 11988 was issued to avoid direct or indirect support of floodplain development whenever there is a practicable alternative. A federal agency is required to evaluate the potential effects of any actions it may take in a floodplain. Federal agencies are also required to encourage and provide appropriate guidance to applicants to evaluate the effects of their proposals on floodplains prior to submitting applications for federal licenses, permits, loans, or grants.

(j) Low-Level Radioactive Waste Policy Act, Title 42 U.S.C. 2021b, et seq..

The *Low-Level Radioactive Waste Policy Act* is designed to improve the procedures for the implementation of compacts providing for the establishment and operation of regional low-level radioactive waste disposal facilities. It also allows for Congress to grant consent for certain interstate compacts. The amended act sets forth the responsibilities for disposal of low-level waste by states or interstate compacts. The act states the amount of waste that certain low-level waste recipients can receive over a set time period. The amount of low-level radioactive waste generated from both pressurized and boiling water reactor types is allocated over a transition period until a local waste facility is operational.

(k) Nuclear Waste Policy Act of 1982, Title 42 U.S.C. 10101, et seq.

The *Nuclear Waste Policy Act of 1982* provides for the research and development of repositories for the disposal of high-level radioactive waste, spent nuclear fuel, and low-level radioactive waste. The act consists of three titles and several subtitles. Title I includes the provisions for the disposal and storage of high-level radioactive waste and spent nuclear fuel. Subtitle A of Title I delineates the requirements for site characterization and construction of the repository and the participation of states and other local governments in the selection process. Subtitles B,C, and D of Title I deal with the specific issues for interim storage, monitored

retrievable storage, and low-level radioactive waste.

(l) Toxic Substances Control Act

Congress enacted TSCA in 1976, to become effective January 1, 1977. The act authorizes EPA to secure information on all new and existing chemical substances and to control any of these substances determined to cause an unreasonable risk to public health or the environment.

Under earlier laws EPA had authority to control toxic substances only after damage occurred. The earlier laws did not require the screening of toxic substances before they entered the marketplace. TSCA closed the gap in the earlier laws by requiring that the health and environmental effects of all new chemicals be reviewed before they are manufactured for commercial purposes.

Determinations regarding compliance with TSCA must be made on a case-by-case basis if an activity involves the manufacture, processing, distribution in commerce, use, and/or disposal of a new or existing chemical substance or mixture that may present an unreasonable risk of injury to health or the environment. Although the definition of "chemical substances" explicitly excludes from its scope several materials that might otherwise meet the definition, including those that are regulated under other federal statues, TSCA is potentially applicable to all "chemical substances" and "mixtures" that are manufactured, imported, processed, used, distributed, and/or disposed of in the United States. By definition, TSCA-regulated chemical substances and mixtures do not include "... any source material, special nuclear material, or byproduct material (as such terms are defined in the Atomic Energy Act of 1954 and regulations issued under such Act) ...." [TSCA, Section 3(2)(B)(iv)]. Although TSCA excludes nuclear material, the TSCA-regulated portion of a mixed nuclear and regulated waste must comply with TSCA requirements. Materials that are not chemical substances or mixtures are not subject to the various requirements of TSCA.

The TSCA program is run by EPA and is not delegated to any state agency.

(m) National Environmental Policy Act

NEPA of 1969 as implemented by E.O. 11514 and E.O. 11991 established national policies and goals for the protection of the environment. NEPA aims to encourage harmony between people and the environment, to promote efforts to prevent or eliminate damage to the environment and the biosphere, and to enrich the understanding of ecological systems and natural resources important to the country.

NEPA is divided into two titles. Title I outlines a basic national charter for protection of the environment. Title II establishes the Council on Environmental Quality (CEQ). CEQ monitors the progress made toward achieving the goals set forth in Section 101 of NEPA. CEQ's duties include advising the president on environmental issues and providing guidance to other federal agencies on compliance with NEPA. Accordingly, CEQ promulgated regulations (amended in 1986) governing the NEPA process for all federal agencies.

Section 102(2) of NEPA contains "action-forcing" provisions that ensure federal agencies act according to the letter and the spirit of the law. These procedural requirements direct all federal agencies to give appropriate consideration to the environmental effects of their decision making and to prepare detailed environmental statements on recommendations or reports on proposals for legislation and other major federal actions significantly affecting the quality of the environment.

Agencies must establish specific criteria for classes of action that (1) usually require an EIS, (2) normally require an EA but do not necessarily require an EIS, and (3) require neither an EA nor an EIS (the "categorical exclusions").

If the action requires an EIS, the agency must publish a notice of intent and begin the scoping process. Then the agency prepares the draft EIS, solicits comments from affected parties and various governmental entities, and drafts the final EIS after considering the comments received. The contents of the final EIS must be considered when making a decision on the proposed action. The agency must prepare a record of decision, a concise statement of its decision discussing its choice among alternatives and the means that will be employed to mitigate or minimize environmental harm.

If the agency action does not fall within the category of actions designated as categorical exclusions or as requiring an EIS, the agency must prepare an EA. The EA determines whether an EIS is needed. If the EA determines that an EIS is not needed, the agency must issue a finding of no significant impact that briefly explains why the agency's action will not have a significant impact on the environment.

Although NEPA requires agencies to take what is known as a "hard look" at the environmental consequences of their actions, it does not force them to take the most environmentally sound alterative.

(n) Comprehensive Environmental Response, Compensation, and Liability Act

Congress passed CERCLA of 1980, also known as "Superfund" in response to a growing national concern about the release of hazardous substances to the environment. SARA, signed by President Reagan on October 17, 1986, amended many provisions of CERCLA. SARA has been the only major revision of CERCLA since its enactment in 1980.

CERCLA provides for liability, compensation, cleanup, and emergency response for hazardous substances released into the environment and for the cleanup of inactive hazardous waste disposal sites. CERCLA [Section 101 (14)] defines *hazardous substances* as

> (A) any substance designated pursuant to Section 311(b)(2)(A) of the Federal Water Pollution Control Act, (B) any element, compound, mixture, solution, or substance designated pursuant to Section 102 of this act, (C) any hazardous waste having the characteristics identified under or listed pursuant to Section 3001 of the Solid Waste Disposal Act (but not including any waste the regulation of which under the

Solid Waste Disposal Act has been suspended by act of Congress), (D) any toxic pollutant listed under Section 307(a) of the Federal Water Pollution Control Act, (E) any hazardous air pollutant listed under Section 112 of the Clean Air Act, and (F) any imminently hazardous chemical substance or mixture with respect to which the Administrator has taken action pursuant to Section 7 of the Toxic Substances Control Act.

Releases of source, byproduct, or special nuclear material from a nuclear incident are excluded from CERCLA requirements if the releases are subject to the financial protection requirements of the AEA. Releases of source, special nuclear, or byproduct materials from a processing site designated by the *Uranium Mill Tailings Radiation Control Act* of 1978 are also excluded [CERCLA Section 101(22)].

CERCLA intends to provide for response to, and cleanup of, environmental problems that are not covered adequately by the permit programs of the many other environmental laws, including the CAA, CWA, SDWA, MPRSA, RCRA, and AEA. In general, if a release to the environment constitutes a "federally permitted release," as defined by Section 101(10) of CERCLA, the release is not subject to CERCLA reporting requirements. However, if the release exceeds the permitted limit for a specific substance by the reportable quantity of that substance or more, results from startup or shutdown of a process, or occurs more frequently than the permit stipulates, it is subject to CERCLA reporting requirements. Future regulations may exempt federally permitted facilities and continuous-release facilities on a case-by-case basis. Permits do not cover abandoned waste disposal sites, and these sites are clearly subject to CERCLA.

CERCLA, as amended by SARA, provides for a fund, called the Superfund, that EPA or state and local governments can use to pay for the cleanup of hazardous waste sites listed on the national priorities list (NPL). The NPL, compiled by EPA, lists those sites, including federally owned facilities, that appear to pose the most serious threats to public health or the environment. EPA determines whether to place a site on the NPL by using the hazard ranking system (HRS).

Under the HRS, pertinent data about a site are evaluated and "scored." A site may receive scores for items such as waste volume, waste toxicity, proximity to population, and distance to underground drinking water. The cleanup of sites must conform to EPA's National Contingency Plan, the operating rules for Superfund cleanups promulgated by EPA under Section 105(a)(8)(B) of CERCLA. The NPL is dynamic. As HRS studies are performed, releases and waste sites may be removed from or added to the list. As of May 31, 1994, the NPL included 1,286 final sites (150 in the federal section) and 54 proposed sites (six of which are federal sites).

If liability for the release of a hazardous substance can be firmly established, the liable or "potentially responsible party"

must pay for the cost of remedial responses. Generally, funds from the Superfund do not go toward paying for the cleanup of releases from federally owned facilities [Section 111(e)(3)] except to provide alternative water supplies in cases involving groundwater contamination outside the boundaries of a federally owned facility if the federally owned facility is not the only potentially responsible party.

Under Section 120 of CERCLA, each department, agency, and instrumentality of the United States is subject to, and must comply with, CERCLA in the same manner as any nongovernmental entity (except for requirements for bonding, insurance, financial responsibility, or applicable time period).

The Superfund process includes the following steps:

Preliminary assessment—EPA performs a preliminary assessment of a site (often a review of data without an actual site visit) to determine if further study is necessary.

Site inspection—A site inspection is an on-site investigation conducted to find out whether there is a release or potential release and to determine the nature of the associated threats.

Remedial investigation—A remedial investigation, conducted by the lead agency, determines the nature and extent of the problem presented by the release.

Feasibility study—The lead agency undertakes a feasibility study to develop and evaluate options for remedial action. The remedial investigation and feasibility study are collectively referred to as the "RI/FS."

Record of decision—After completing the RI/FS, EPA selects the appropriate cleanup option and publishes it in a public document known as the record of decision.

Remedial design—The remedial design includes the technical analysis and procedures that follow the selection of a remedy for a site.

Remedial action—The remedial action involves the actual construction or implementation of a cleanup.

In general the proposed remedy for a site must meet two threshold criteria: (1) to protect human health and the environment and (2) to comply with "applicable or relevant and appropriate requirements". Federal and/or state requirements are considered "applicable" if they are "... based upon an objective determination of whether the requirement specifically addresses a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance found at a CERCLA site" [40 CFR Part 300 (9)(1)].

CERCLA, if not reauthorized by Congress, will expire in 1995. Referred to as the Superfund Reform Act of 1994 (The Act), HR-3800 and S-1834 have emerged as the primary amending statutes on Superfund law. The major features of these bills are intended to enhance EPA's information-gathering activities; sharply limit joint and several liability as it applies to de minimis parties; limit the liability of lenders; create more flexibility within the remedy