A STUDY TO DETERMINE
THE FEASIBILITY OF CONDUCTING AN
EPIDEMIOLOGIC INVESTIGATION OF
THE HEALTH EFFECTS OF
LOW-LEVEL IONIZING RADIATION

PHASE I REPORT

July 3, 1979 - September 1, 1979

HEALTH SYSTEMS DIVISION
Systemedics, Inc.
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INTERIM REPORT

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Health Systems Division
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INTERIM REPORT

ABSTRACT

This document is an interim report summarizing Phase I of a study designed to evaluate the feasibility of conducting an epidemiologic investigation of the health effects of exposure to low-level ionizing radiation. During Phase I of the project, we identified 173 population groups worldwide with exposure to low-level radiation. Basic descriptive information was collected on these candidate study groups. Only a small percent (11%) of the groups identified were rejected from further feasibility consideration in Phase II. Groups were not suitable for study if either they lacked personal identification information, or their radiation exposure was outside of the limits of our operational definition of low-level. Also, if a candidate population was unique and composed of relatively few subjects, it was excluded from further evaluation because of inadequate size. During Phase II we will further investigate the remaining 154 population groups to determine those most likely to provide information on the health effects of low-level radiation exposure from occupational, environmental, and medical sources.

SUMMARY

This interim report summarizes Phase I of a study designed to evaluate the feasibility of conducting an epidemiologic investigation of the health effects of exposure to low-level ionizing radiation. The two major aspects of Phase I were: (1) evaluation of the strengths and limitations of epidemiologic methods and (2) evaluation of problems specific to radiation health research, including identification of potential population groups for study.

Five types of epidemiologic research designs were identified: cohort, case-control, nested, cross-sectional, and ecological. The main emphasis in any study design for non-experimental epidemiologic research is comparability of subjects. The relative merits of different study designs, therefore, depend largely on the nature of the comparison groups and the quality of the data. Comparisons are usually made between the health experience of two groups (one group exposed to radiation and another group, not exposed), or between the exposure histories of two groups (cases and controls). The comparability of groups can be affected by biases in selection and observation of subjects. Furthermore, confounding (mixing of effects) can bias the analysis of any epidemiologic study unless proper precautions are taken both in study design and data analysis.

how abt
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dose - rate

The quality of the data depends on adequate diagnostic criteria, accurate and precise information on radiation dose, dose rate and dose fractionation, a sufficient interval between radiation exposure and potential development of delayed health effects, and adequate measurement of effect modifiers and confounding factors. In addition an epidemiologic study must include a large enough number of subjects to detect a health effect if there indeed is one. This is especially important in the context of low-level radiation because low levels of exposure generally lead to a small increase in health effects. The study size requirements for detecting such weak effects are extremely large. Thus studies of insufficient size might not detect a real health effect if it were small. Likewise, if a strong health effect were detected in a small study it would likely be incorrect, and might reflect errors in study design rather than any specific health risk from radiation.

For the purpose of evaluating potential populations for study, we adopted an operational definition of low-level radiation according to the guidelines for maximum permissible dose equivalents for occupational exposure recommended by the National Council on Radiation Protection and Measurements in 1971. In fact, most occupational and environmental radiation exposures fall far below the maximum permissible limits. We realize, however, that much can be learned from studying populations that received as much as four or five times these levels of exposure.

We assembled a list of 173 candidate study populations worldwide using three different approaches: survey of the literature, mail inquires to a variety of individuals and groups concerned with radiation protection, and review of on-going federally supported research. Population groups with radiation exposure from occupational, medical and environmental sources were identified.

Four criteria were used in Phase I for preliminary evaluation of the feasibility for epidemiologic study of each of the candidate populations. The criteria concerned: (1) the existence or potential existence of personal data, (2) the likelihood that radiation exposure was within the operational limits of low-level, yet also substantial enough to permit detection by currently available methods of dosimetry, (3) the estimated size of the population group, and (4) the extent of potential confounding effects.

Candidate populations were excluded from further consideration in Phase II if they failed to satisfy a most generous interpretation of any one of these four criteria. Of the 173 candidate groups identified worldwide, 19 (11%) were excluded from follow-up during the 60 days in Phase I.

During Phase II, we will conduct more intensive investigation of several of the most promising candidate groups. For occupational exposures, we will concentrate on medical radiation workers (professional and para-professional) and workers involved in all phases of the nuclear fuel cycle, including miners and workers in fabrications and power plants, with special attention to Three Mile Island. For environmental exposures, we plan to investigate populations exposed in areas with high natural radioactivity (such as the monazite sands in Brazil where good dosimetry is available), as well as areas with technologically-enhanced background, such as residential areas near nuclear weapons and nuclear power plants. Regular visitors to health spas such as Bad Gastein in Austria also are recommended for follow-up in Phase II. For medical exposures, the prenatal effects of maternal irradiation and the possible health effects to adults from both diagnostic or therapeutic radiation merit further investigation. Those exposed to fallout from nuclear testing were considered for study; however, the methodologic problems in dosimetry appeared to be overwhelming.

At the end of Phase II we will recommend several options for epidemiologic research. Study populations will be selected to provide data to answer one or both of the following questions:

(1) Is there any health effect from exposure to low-level ionizing radiation?

(2) What is the shape of the dose-response curve for low-level radiation?

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PREFACE

I wish to thank all the staff members and outside consultants who participated in the creation of this report. Staff members who contributed to this project are: John P. Bowen, Richard W. Clapp, Samuel J. Covino, Jr., Frederic H. Fahey, Jeanne E. Loughlin, Harley B. Messinger, Leslie T. Stayner, and Marjorie J. Titcomb. This work would not have been possible without the valuable consultation of Drs. Kenneth Kase, Henry I. Kohn, Richard Monson, and Kenneth J. Rothman.

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A STUDY TO DETERMINE THE FEASIBILITY OF CONDUCTING EPIDEMIOLOGIC INVESTIGATION OF THE HEALTH EFFECTS OF LOW-LEVEL IONIZING RADIATION

I. INTRODUCTION

This study was conducted under contract to the U.S. Nuclear Regulatory Commission. The workscope was divided into two phases: Phase I, a preliminary analysis, and Phase II, a detailed scientific consideration of feasibility and cost based on field examination of relevant population characteristics. Phase I was accomplished in two months. Thirteen months remain for completion of Phase II.

Phase I was composed of four tasks: (1) identify various methods of conducting epidemiologic research relevent to the effects of low-level ionizing radiation, (2) provide an evaluation of the strengths and limitations of epidemiologic methods to estimate the risk of health effects from exposure to low-level ionizing radiation in excess of "normal" background levels, (3) assess the likelihood that epidemiologic studies can distinguish incremental radiation-induced health effects from conditions and disorders normally occurring and identify population groups that may be suitable for study (candidate study populations), (4) determine which populations identified in Task 3 are most suitable for epidemiologic studies of the health effects of low-level ionizing radiation. Task 1 is summarized in Chapter 2; Task 2 is summarized in Chapter 3. Task 3 is summarized in Chapters 4 and 5; Task 4 can be found in Chapter 5, part C.

This document is an interim report summarizing Phase I research. A comprehensive list of candidate populations was developed. Furthermore, certain candidate populations were excluded from Phase II follow-up if they failed to meet any one of the basic feasibility criteria described in Section V. A.3.

II. THE NATURE OF EPIDEMIOLOGIC DATA

Epidemiology is the discipline which studies the occurrence of human illness; most epidemiologic inquiry calls for non-experimental research designs. The main emphasis in non-experimental epidemiologic research, as in experiments, is on comparability of subjects. In an experimental study, comparability is achieved without difficulty by selecting homogeneous subjects and by randomly allocating subjects to treatment groups. In non-experimental studies, comparability is often more difficult to achieve. In an observational setting (non-experimental), randomization of treatment or exposure is not possible. Epidemiologists, therefore, must seek to exert as much control as possible over which data are collected and how the data are collected and analyzed. Central to this control is making sure that comparable methods were used in collecting data from the two or more groups being compared.

A. STUDY DESIGN

Epidemiologic studies can be classified according to their design and the timing of the initiation of the study. Five types of study designs are reviewed: cohort, case-control, nested, cross-sectional, and ecologic. The timing of the study can be either retrospective or prospective. However, simply referring to a study as retrospective or prospective leads to confusion, especially in discussing retrospective cohort studies. Since retrospective and prospective are timing terms, they should not be used to designate a basic type of study.

1. Cohort Studies

A cohort study begins with a group of people without the disease under investigation. Its members are classified according to their level of exposure; then, after a certain period of time has elapsed, the diseased people within each category are counted and the rates of disease frequency are compared among exposure categories. These are sometimes called follow-up studies. The timing in a cohort study can be retrospective, prospective, or mixed (hybrid).

In a retrospective follow-up or reconstructed cohort study, the members are identified from records made sometime in the past. The period of follow-up has already occurred and the resultant health experience of the cohort can be evaluated at the time the study is initiated. In a prospective follow-up study, the study subjects do not have the disease under study at the time the study is initiated. Their health experience is followed into the future. In a hybrid (mixed) study, exposure occurred in the past and/or present and health is monitored on into the future. Thus, the total period of follow-up has not been completed when a hybrid study is initiated.

There are several major differences between a prospective cohort study and a retrospective cohort or hybrid cohort study:

1. Retrospective and hybrid cohort studies tend to be shorter in duration since all or part of the follow-up period has already elapsed when the study begins.
2. In a retrospective cohort study, usually much less detail on a subject's characteristics or exposures is available. In a prospective cohort study, the investigator can collect data on smoking, drinking, diet, current health, etc., whereas in a retrospective cohort study, the only information that is usually available is a rough idea of a person's history (e.g., medical record).
3. In a prospective cohort study, the investigator usually compares disease rates between two or more groups (e.g., smoker versus non-smoker, heavy drinker versus moderate drinker versus non-drinker). In a retrospective cohort study, there frequently is no formal comparison group. Instead, mortality or morbidity rates for the exposed group are compared to such rates for the general population.
4. In prospective cohort studies, it is today's exposures that are being evaluated; in retrospective cohort studies, the exposures of perhaps 30 to 50 years ago are being evaluated.

An important advantage of prospective follow-up studies is that they afford the investigator more control over the data that is being collected. One can usually closely evaluate the quality of the data as well as specify the exact nature of the data being collected. However, prospective studies are both more costly and time-consuming than retrospective studies. They frequently require many years for completion.

While there is no question that a prospective cohort study can provide more reliable data, the shortcomings of retrospective cohort studies do not render them useless. Mortality rates for general populations have been shown empirically to be useful bases of comparison. Today's exposures frequently are similar to yesterday's.

2. Case-Control Studies

Case-control studies are frequently called retrospective studies because one is looking backward from disease to exposure. In fact, they are a type of retrospective study. In a case-control study, the investigator selects persons with the disease of interest as "cases" and other persons as "controls." Not infrequently more than one disease is of interest so that there may be a number of different diseases within the case group. The controls may be either persons with other diseases or persons with no known disease. In principle, cases are persons with a specific disease and the controls are persons without that disease.

In general, case-control studies evaluate a number of exposures in relation to one disease whereas cohort studies evaluate a number of diseases in relation to one exposure. A rule of thumb is that if the disease has a long induction period and occurs infrequently, a case-control study is more efficient because persons with the disease can be sought out and selectively enrolled. Likewise, if the exposure is rare, a cohort study is more efficient because exposed persons can be selectively identified. Case-control studies tend to be done using hospital populations because that is where persons with disease are found.

Two general types of control groups are used in case-control studies: hospital controls and population controls. As emphasized earlier, epidemiologists are always concerned with comparability. Hospital cases and controls are similar in that each group consists of persons in the hospital. The type of data available and the milieu of the data gathering process tend to be comparable for both groups. However, sometimes there is the concern that a disease group is admitted to a hospital selectively. For example, persons with cancer all tend to be hospitalized, while only certain persons with arthritis enter the hospital. For a study of cancer patients, population controls may be preferable since their demographic characteristics and day-to-day habits may be more comparable to the cases. Neither type of control group is inherently preferable to the other. The choice of control group depends on the situation in a given study.

3. Nested Design

Once a cohort has been identified and followed-up, either retrospectively or prospectively, it becomes possible to conduct a case-control study within the cohort, using information on all the cases that have been assembled. Comparable controls are selected from the pool of non-diseased people in the cohort. Controls may be selected by a representative sampling procedure or they may be matched according to potential confounding factors. For example, if one wanted to study the effect of low-level radiation on leukemia, it might be desirable to select cases and controls matched on age so that age differences would not distort the case-control comparison.

The nested design can be a very cost-efficient means of conducting an epidemiologic study because the subjects have already been assembled for another study. Thus, an investigator might conduct a cohort study of nuclear power plant workers in order to evaluate the occurrence of lung cancer. At the end of the follow-up period, the investigator may find that he has collected information on an unusually large number of cases of multiple myeloma. To determine whether multiple myelomas are associated with radiation exposure, the investigator might wish to conduct a special case-control comparison (nested study).

4. Cross-Sectional Studies

In a cross-sectional study, persons are selected irrespective of their exposure or disease status. Exposure and disease are measured essentially at the same point in time. Further, the time sequence between the onset of exposure and the onset of disease cannot be inferred.

The data resulting from a cross-sectional study can be treated in the same way as data from a cohort study or case-control study. That is, disease rates can be compared between exposed and non-exposed groups, or exposure percentages can be compared between diseased and non-diseased groups. In using data from a cross-sectional study, however, it may be difficult to determine whether the exposure led to the disease or the disease led to the exposure.

The inability to establish the exposure-disease time sequence is the defining characteristic of a cross-sectional study. This characteristic often makes the interpretation of cross-sectional studies difficult. For example, suppose drug histories may be obtained on all persons entering a hospital. Disease is diagnosed at essentially the same time. In evaluating the association between aspirin use and arthritis, it should be straight-forward to establish that the disease (arthritis) led to the exposure (aspirin). However, consider diagnostic radiation and breast cancer. It is thought by some that diagnostic x-rays may lead to breast cancer. Persons with symptomatic cancer may go for repeated diagnostic x-rays. Thus, it would be difficult to establish the meaning of cross-sectional data relating x-rays to the development of breast cancer. For this reason, cross-sectional studies are relatively uncommon. In epidemiology it is desirable to determine the time sequence of the association being evaluated.

Although cross-sectional data contain no inherent misinformation, data should be carefully evaluated to determine whether or not it is indeed cross-sectional. If the time sequence between exposure and disease cannot be determined, an extra degree of caution must be maintained in interpreting any association or non-association. The passage of time may be necessary to enable the collection of data in a longitudinal manner to supplement the results of a cross-sectional study.

5. Ecologic Studies

In cohort and case-control studies, the unit of measurement is the individual. In ecologic studies, the unit of measurement is the group. Groups are classified according to their rate of exposure and their rate of disease. An ecologic study is sometimes called a correlation study because the investigator usually correlates the exposure rates with disease rates. For example, Frigerio (1) classified the U.S. population according to altitude (as a proxy measure for cosmic radiation) and correlated these exposure rates with general mortality rates and cancer-specific mortality rates for various locations.

The major shortcoming of this type of retrospective study is sometimes called the "ecologic fallacy," referring to the fact that a correlation of rates does not ensure that the exposed people were actually those who developed the disease. In the Frigerio example, the mortality and morbidity experience that was recorded might actually reflect the health experience of recent immigrants. Where these people were diagnosed or where they died may have been different from where they spent most of their lifetime.

Because ecologic studies use the group as the unit of measurement, they are not useful in instances where confounding effects may be difficult to control in the analysis. When the effects are likely to be small, as in the study of low-level radiation, substantial confounding is more likely to be present. For regulatory purposes, it is essential to distinguish between the effects of radiation and other carcinogenic exposures.

B. MEASURES OF EFFECT

There are two types of effect measures: absolute measures (differences in rates) and relative measures (ratios of rates). Absolute measures are more revealing about the public health consequences of a given characteristic or exposure; relative risk estimates are more useful for investigating the etiology of disease. For example, consider smoking as a cause of disease. The relative risk for lung cancer given smoking is approximately ten. The relative risk for coronary disease given smoking is about two. However, the absolute effect is greater for coronary disease than for lung cancer because the incidence of coronary disease is greater. Thus more people will die from coronary disease due to smoking than from lung cancer due to smoking.

Comparative rates used in absolute and relative measures of effect are estimated according to the incidence or prevalence of a disease or condition. Data on incidence of disease and exposure come from cohort studies. Exposure incidence rates also can be estimated from case-control studies.

Incidence measures the rate of development of new cases of disease. Synonyms for incidence are incidence density and the force of morbidity. Cases that were prevalent (existing at the time the study began) would not be included in determining incidence. In case-control comparisons exposure histories should not be compared according to mean levels of exposure. This method was used in early analyses of the Hanford data (2). The uses of mean levels of exposure distorted the information because, while it appeared that excess disease occurred among workers whose mean levels of exposure were low, the excess cases actually occurred among a few workers whose exposure levels were unusually high. Information on the full range of exposures was lost by the use of means.

Data from cross-sectional studies are used to calculate the prevalence rate of a disease or condition. The prevalence rate is the number of cases divided by the total size of the study population. Prevalence rates reflect both incidence and duration of disease. Thus the incidence rate may be low while the prevalence rate is high if the disease is largely non-fatal and good treatment is available.

C. THE ART OF COMPARISON

The choice of reference groups or comparison groups is extremely important. The decision as to whether an exposure or characteristic is a cause of disease or a correlate of disease depends on the comparison. Conceptually the comparison group should refer to the absence of exposure, but this is not always meaningful. Consider whether the Japanese diet leads to an increased rate of stomach cancer. What should the comparison group be -- diet in the United States? Whereas dietary patterns in the U.S. may not lead to an increase in the rate of stomach cancer, they may lead to an increased risk of something else (coronary disease, for example).

The choice of a comparison group is especially important in studying the health effects of radiation. One cannot find a reference group that has zero exposure to ionizing radiation because varying levels of background radiation are present everywhere. A reference group should be selected to reflect levels of background radiation that are similar to the study group.

Comparison groups can be selected from within a study (internal controls), or the results can be standardized to an external group, such as the U.S. population in a given year. The use of internal controls permits comparison of disease rates according to different levels of exposure. The utility of standardized rate ratios depends on the choice of the standard. When standard rates for the U.S. are compared with disease rates for occupational cohorts, the "healthy worker effect" is usually evident. That is, the workers may appear to be experiencing less disease than the standard population. This is due to the fact that the reference group includes both sick and healthy people whereas the study group (workers) includes only people who are healthy enough to hold a job.

III. STRENGTHS AND LIMITATIONS OF EPIDEMIOLOGIC METHODS

The overwhelming limitation in any evaluation of the health effects of low-level radiation on humans is the possibility that the effect is weak. In order to detect weak effects, very large numbers of persons must be studied. Even then, it may be that weak effects simply cannot be demonstrated.

There is the added problem in non-experimental studies of disentangling any effect of low-level radiation from those effects due to other factors. Even though an association may be apparent between radiation exposure and a given health effect, it is necessary to consider alternative explanations. To the extent that data are available, analyses can be done to assess the impact of other factors. There are always additional factors that may be associated with disease but on which no information is available. It becomes a matter of judgement whether any association may be explained by these factors.

On the other hand, the basic strength of epidemiologic methods in the evaluation of the effects of low-level radiation on humans is that information is being obtained directly on people. There is no need to extrapolate from animal models. Although this advantage cannot be quantified, it is important.

The following section will describe some issues of comparability which are central to the evaluation of epidemiologic research. The quality of the data will be considered with special emphasis on dosimetry. Finally, the interpretation of epidemiologic data will be discussed.

A. COMPARABILITY

If non-comparable criteria are used to select entrants into two groups of a study, the data cannot be used to measure any postulated association between radiation exposure and disease because of selection bias. If data are collected on two groups using non-comparable methods, the data may contain incorrect information as to exposure and disease because of observation bias. Selection bias and observation bias result because of deficiencies in study design and data collection. Although not always preventable, these sources of bias should be considered in the design of a study and efforts made to minimize their effects.

1. Selection Bias

Selection bias occurs only in study design. For it to occur, the disease must have taken place at the time a person is enrolled into the study. Selection bias cannot be controlled; it must be prevented.

Consider a study where a group of persons with disease is identified and a second group of controls is selected (a case-control study). Since at the time of entrance into the study group the disease has occurred, selection bias is possible. It results from the selective admission of exposed persons into the diseased group. It may also result from the selective admission of exposed persons into the controls, of non-exposed persons into the cases or of non-exposed persons into the controls. The central feature is that different criteria relating to exposure are used for entrance into each of the two groups.

An analogous situation exists when the initial study groups are exposed and non-exposed persons (a cohort study). Selection bias may occur only in retrospective cohort studies -- those where past records are used to define the study group and disease has already occurred when individuals are entered into the study. Selection bias results if there is non-comparable admission of diseased (or non-diseased) persons into the exposed (or non-exposed) group. Note that there must be a difference in the selection criteria between the two groups in order for bias to result.

2. Observation Bias

In cohort studies, observation bias results when information on disease outcome is obtained in a non-comparable manner from exposed and non-exposed groups. In case-control studies, observation bias results when information on exposure is obtained in a non-comparable manner from cases and controls.

An obvious way to prevent observation bias in a cohort study is not to know the exposure status of study individuals when information on disease is obtained. Any errors in measurement will be made equally in members of the exposed and non-exposed groups. Likewise, in a case-control study, no observation bias is possible if neither the patient nor the data collector know the diagnosis when information on exposure is collected. This characteristic of data collection is termed blindness.

Frequently, blindness is not possible in a case-control study. The patient knows his diagnosis or the interviewer knows which patients are cases and which are controls. To minimize observation bias in such a situation, objectivity is sought in obtaining information. Questions are asked which require objective answers (closed-ended) rather than subjective answers (open-ended). While this does not prevent observation bias, it tends to minimize it.

3. Confounding

In contrast to selection and observation biases, confounding is potentially present in all data. Usually confounding can be removed by proper analytic techniques.

In evaluating an association between one variable (exposure) and a second (disease), confounding results when there exists a third variable which is a cause of the disease and also is associated with the exposure. For example, cigarette smoking is a cause of lung cancer. Also, many uranium miners smoke cigarettes. Archer *et al.* (3) looked at the relationship between uranium mining and lung cancer. An association was seen in that the rate of lung cancer in miners was higher than the rate in non-miners. However, the relationship between mining and lung cancer was confounded by cigarette smoking. When the subjects were classified according to smoking, the association between mining and development of lung cancer was present in both groups, and the incidence of lung cancer increased with increasing radiation exposure among groups with similar smoking habits. Smokers, however, appeared to have a shorter "induction-latent" period for lung cancer than non-cigarette smoking miners. Thus, in order for a third variable to be confounding, it must be associated both with exposure and disease. If some variable is associated with disease but not with exposure, or vice versa, it cannot be confounding.

If there are characteristics of persons which are associated with both radiation exposure and disease, the data relating exposure to disease may convey an appearance of association because of confounding, or a mixing of effects. Confounding is possible in all studies. In experimental studies, such bias tends to be minimized, but not necessarily controlled, because of random assignment of exposure. In non-experimental studies, however it is never possible to know the effects of confounding. All that is possible is to collect information on known or suspected confounding factors in order to measure any bias introduced. Confounding does not result from any error of the investigator.

In contrast to confounding, effect modification reflects an inherent property of biology. A variable may be an effect modifier if the outcome (effect) varies according to the variable (e.g., sex). A confounding factor may or may not be an effect modifier. An understanding of confounding and effect modification is essential in the design and analysis of epidemiologic studies.

There are procedures designed to minimize confounding both in the design of a study and during data analysis. They include randomization, matching, and stratification. When designing a study, one can plan to control for confounding by: (1) random allocation of subjects to various modes of intervention or to control groups (applies primarily to experimental studies and intervention trials), or (2) matching subjects according to potential confounding variables, such as age and sex. Matching can also be done during data analysis, although this method is generally less efficient. One cannot be assured that suitable matched controls will be available, <u>post hoc</u>; thus, information may be lost by not using <u>all the</u> data in the analysis. Stratification according to confounding factors or standardization techniques can also be used to control for confounding in the analysis of data.

B. DATA QUALITY

In epidemiologic studies, the quality of data refers to three types of data: measure of exposure (radiation), measure of outcome (disease), and measure of confounding factors. There is great variability in the quality of data on radiation. However, the value of all epidemiologic studies is limited by the power of a sample size to test for an exposure effect and to precisely estimate that effect.

In addition to adequate sample size, the 1977 UNSCEAR Report (4) lists several features that are important in evaluating the quality of data in an epidemiologic study. They are:

1) Adequate diagnostic criteria
2) Adequate information on radiation dose, dose rate, and dose fractionation *
3) Sufficient intervals between exposure and potential cancer development
4) Suitable comparison groups

We would add to their list a fifth criterion:

5) Adequate measurement of effect modifiers and potential confounding factors.

1. Power and Study Size Estimation

The study sample size must be large enough to detect an effect if there indeed is one. Power is the likelihood that the null hypothesis will be rejected if it is false. The power of a given sample size should be considered prior to beginning any epidemiologic study. Once the data have been collected, power is no longer meaningful. Instead confidence limits should be placed around the point estimate of effect to reflect the precision of the estimate. As a general rule, sample size is inversely proportional to the square of the excess risk due to exposure. Thus, "if a sample of 1,000 persons is necessary to determine the effect of a 100 rad exposure, and if that effect is proportional to dose, 100,000 persons are needed for a 10 rad exposure, and 10 million for 1 rad" (6). The following example presented by Dr. Charles Land illustrates this point with reference to breast cancer:

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* Dose rate is the speed with which a given dose of radiation is delivered. Dose fractionation is the process by which a given dose is delivered in two or more fractionations (i.e., 10 rad delivered as 10 one-rad doses) (5).

"Suppose that half of a sample of N women have received a single mammographic examination resulting in one rad average tissue dose to both breasts. Suppose the exposed and non-exposed women are otherwise comparable and suppose, for simplicity, that all were 35 years old at the time of exposure, and that there are 20 years of follow-up information with respect to breast cancer incidence for each woman. Ignoring the first 10 years as being too soon for any radiation-induced breast cancers to appear, about 1,910 breast cancers per million women per year would normally be expected during the second 10 years, plus, in the exposed, about 6 excess cancers per million per year, according to the 1972 BEIR Report.

Figure 1 shows that a sample of nearly 100 million women would be needed for statistical power of even 50%, and that for a sample of 10 million women the chances of obtaining a negative estimate are somewhat higher (25%) than the 17% chance of obtaining a statistically significant estimate at the 5% level...

Obviously a sample of 100 million women would be impractical. A case-control approach would require about 2 million breast cancer cases and controls, assuming equal proportions of exposed and non-exposed women in the population, and this is also an impractical requirement. However, if the average breast tissue doses were increased to 10 rad only 1 million women would be required, or 20,000 cases and controls, and at 100 rad only 10,000 women, or 200 cases and controls, would be needed."

There are ample statistical grounds for predicting that the large sample size requirements of studies of low-level radiation and breast cancer may preclude definitive risk estimates from epidemiologic studies, even if the risk of cancer proves to be much greater at low doses than current high dose extrapolations predict. Examples of study size requirements and other types of possible health risks are presented in Section III. B. 1.

Although such studies cannot provide definitive results, epidemiologic studies of the health effects of low-level radiation in humans should be conducted. These studies may be useful in describing the upper limits for estimates of cancer risk at given doses. For

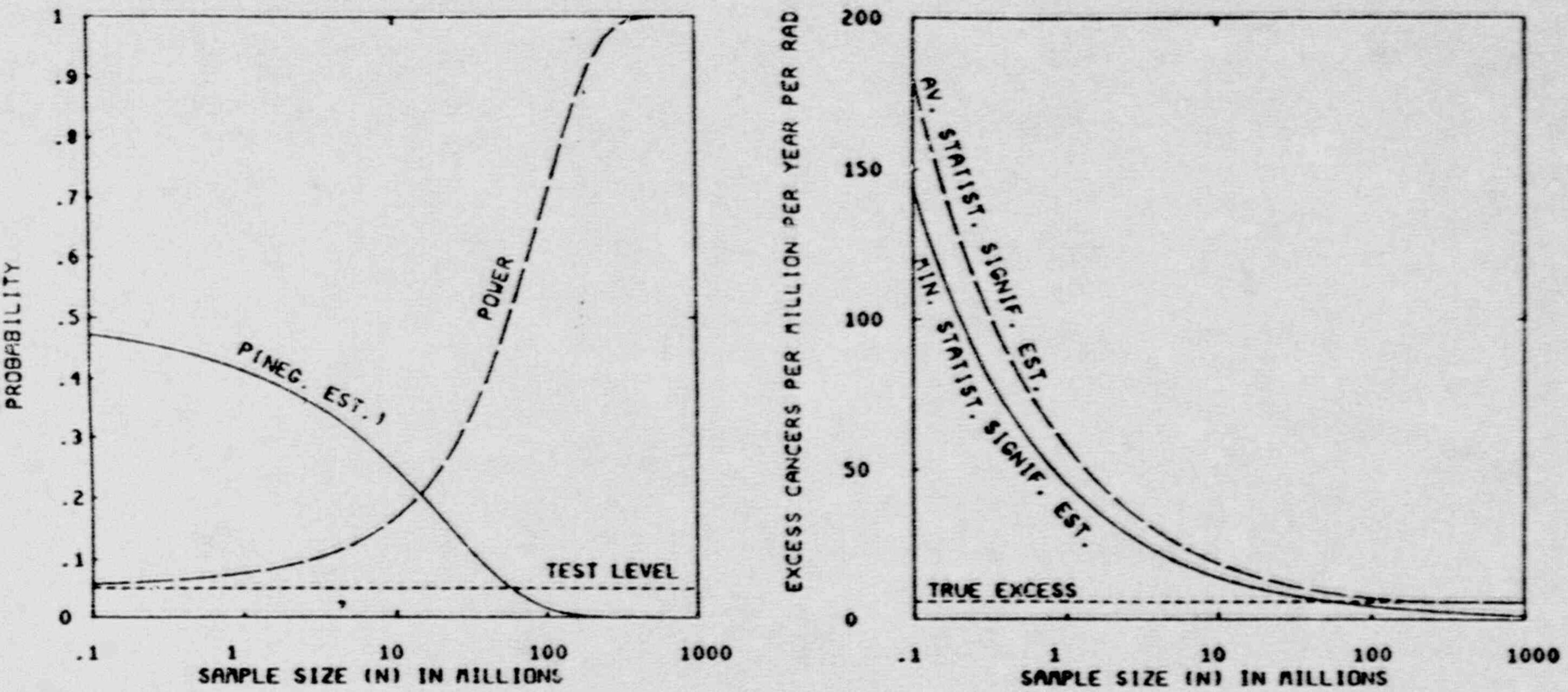


FIGURE 1

10-Year Follow-up of N/2 Nonexposed and N/2 Exposed Women
(1 Rad to Breast Tissue at Age 23, With 10-Year Latent Period)

Source: Land, Charles E.: "Strategies for Epidemiologic Research on the Effects of Low-Level Radiation," Presented at the Meeting of the American Association for the Advancement of Science, Houston, Texas, January 3-8, 1979.

example, if one or more studies of adequate size found no detectable risk of a carcinogenic effect from exposure in the 30 to 50 rad range, then it would be unlikely that a detectable risk exists at lower doses.

2. Radiation Exposure and Absorbed Dose

The quality of data on the health effects of radiation is limited by the accuracy of radiation exposure data and absorbed dose. The unit associated with exposure is the Roentgen (R).* Absorbed dose refers to the energy deposited per unit mass in some specific material of interest. The absorbed dose, although harder to measure, is probably a better indicator of the biological impact of radiation than exposure. The unit used for absorbed dose is the rad.*

Exposure to internal emitters often is expressed by the concentration of the radioactive material in the source of the activity for some period of time. For inhaled emitters this would be in units of cure hours per liter of air. In the case of the airborne emitter, radon, the unit of working level month, (WLM) is sometimes used. The working level* is an indication of the amount of alpha particle energy available from radon and its radioactive daughters per liter of air. A working level month results from being exposed to a working level for the period of a working month (170 hours).

Since various radiations are differentially effective (per rad) in causing biological effects, their equivalent doses, normalized to gamma rays, are given in terms of dose equivalent with the unit rem. The factor that describes the differential effectiveness of various types of radiation is the relative biological effectiveness (RBE). As an example, for a particular effect where the RBE for alpha particles is 10, an absorbed dose of 1 rad of alpha particles is equivalent to an absorbed dose of 10 rad of gamma rays.

As broadly used in radiation protection, the equivalent of RBE is called the quality factor. Practical quality factors are presented in Table 1.

---

* Defined in Glossary

TABLE 1

Practical Quality Factors

Radiation Type	Rounded QF
X rays, gamma rays, electrons or positrons, Energy >0.03 MeV	1
Electrons or positrons, Energy <0.03 MeV	1*
Neutrons, Energy <10 keV	3
Neutrons, Energy >10 keV	10
Protons	1-10**
Alpha particles	1-20
Fission fragments, recoil nuclei	20

*In 1966 the ICRP recommended a value of 1.7 for the QF of low energy electrons or protons. We believe that a rounded value of 1 is more commensurate with the accuracy of our knowledge and the requirements of radiation protection. (In 1969 the ICRP amended its 1966 recommendations, specifying that the QF should be taken as 1 for all β^-, β^+, e^-, γ and x radiations and for conversion electrons.)

**Use the higher value for round-off or calculate by the methods of ICRP Publication 4.

Source: National Council on Radiation Protection and Measurements, Basic Radiation Protection Criteria, NCRP Report No. 39, 1971.

Although the quality factor for any given radiation is often considered to be constant for all tissues, all dose rates, and all kinds of biological effects, the RBE, in fact, may not be constant (7,8,9,10). For this reason, the use of dose equivalent must be treated with caution since a particular quality factor may underestimate or overestimate the true dose equivalent by as much as an order of magnitude. The RBE for cancer induction by neutrons can be estimated by comparing cancer incidence from Hiroshima with that from Nagasaki, since those irradiated at Hiroshima received exposure from both neutrons and gamma rays whereas those irradiated at Nagasaki primarily received gamma rays. For both thyroid cancer and breast cancer, the RBE values are one. In contrast, the RBE values appear to be greater than unity by as much as orders of magnitude for chronic granulocytic leukemia and lung cancer (8).

It should be noted that the RBE may change with dose or dose rate, owing to the diminished effectiveness of gamma rays. Thus in going from a single dose of 10 rad to 1 rad of neutrons, the effect per unit dose will remain constant, but the effect per unit dose of gamma rays may fall, and the RBE will rise accordingly. The higher RBE of neutrons at low dosage postulated by some investigators, therefore, represents a diminished hazard from gamma rays rather than a heightened one from neutrons (9,10).

Measurements of radiation exposure and absorbed dose are limited by the accuracy of current methods of dosimetry in the low dose range. For measuring external irradiation, film badges and thermoluminescent dosimeters (TLD) represent the state-of-the-art as currently used in occupational and medical settings. As packaged, the dosimeters measure exposure to x-rays, gamma rays, and energetic beta particles. These dosimeters do not accurately measure total radiation dose because they do not measure dose to any given organ, nor do they reflect what additional radiation dose might arise from inhaled or ingested radioactivity. In the range below 0.2 rad per year, readings from these dosimeters could differ from the actual dose levels by 100%. Between 0.2 rad to 1 rad per year, the uncertainty decreases to a level of approximately 25% of the actual dose for x-ray and gamma rays in an energy range from 15 to 660 keV (11). If external exposure is complicated by the presence of beta radiation, then the uncertainty increases.

At doses above 1 rad per year, the uncertainty in dose estimation is approximately 10%. These estimates reflect the maximum accuracy of such exposure measurements. In actual use, personnel dosimeters tend to be directionally dependent and may be partially shielded from the radiation source by the wearer. Further, they measure the approximate dose to the surface of the skin, rather than the dose to internal organs. For all of these reasons, estimates of radiation dose from the dosimeter readings will tend to be inaccurate.

For absorbed dose due to internal exposures, film badges and the like will not yield dose information. Such data are obtained from either radio-analysis of urine and fecal material (12) or whole body counting (13,14). Such examinations are not routine, but their potential importance should be evaluated. Whole body counters have been used to measure the amount of an isotope in the body. The total dose to the individual can be estimated with this procedure. Radio-analysis of waste material is more difficult because of the large inter-person variation in the rate that isotopes are eliminated. There may be some records of such bio-assays for individuals with suspected internal exposure; estimating dose from this information, however, is very difficult because the accuracy of the estimate depends on what is known about the retention and excretion of radioactive material for the exposed individual.

Environmental measurements are often available for airborne radioactive concentrations and radioactivity in water. However, these measurements by themselves are not sufficient for describing population exposure. To define radiation dose to populations from these measurements would require knowledge of where individuals were in relation to measured radioactivity and the amount of time they were exposed. These considerations introduce a large uncertainty.

In the case of medical exposure, the dose per patient can be estimated from the characteristics of the machine, the exposure factors of a particular procedure, and the physical characteristics of the patients (e.g., distance from the skin to the organ of interest). In general, radiologic practice complies with FDA regulations, and hospitals have established procedures for routine examinations. It is, therefore, possible to estimate the radiologic dose for a given person provided an accurate medical history can be obtained.

An approximate dose can be estimated based on the assumption of a "typical procedure" carried out on an "average patient." However, doses from typical procedures may vary by an order of magnitude from one institution to another.

The sensitivity and accuracy of the dose measurements in the low level range affect the feasibility of studying the health effects of low-level radiation. If dosimetry is, in fact, a limiting factor in the 0 to 1 rad range, then either more accurate dosimeters should be incorporated in future studies or efforts should be concentrated on the accurate description of health effects in the 1 to 10 rad range and even in the 10 to 50 rad range in order to improve the accuracy of risk estimate extrapolation to the very low dose range.

Caution should be used in interpreting dosimetry. The demonstration of a statistical association between radiation exposure and cancer or other disease does not prove a causal relationship. The total environment must be examined in order to rule out the presence of other noxious agents which may be associated with radiation exposure.

C. INTERPRETATION OF EPIDEMIOLOGIC RESEARCH

The collection and analysis of epidemiologic data comprise the science of epidemiology. Knowledge of these methods is necessary in order to conduct epidemiologic research. Proficiency is gained primarily by practice.

The results of epidemiologic studies must be interpreted by epidemiologists and non-epidemiologists alike. It is necessary to view the results of any scientific study, epidemiologic or otherwise, in the context of other information. No one study is likely to provide a definitive answer to some question for all time. A modicum of caution must always be maintained. In the absence of a clear-cut interpretation of the data, action should be prudent and err on the side of safety.

Perhaps the best way to evaluate whether an association seen in an epidemiologic study is spurious is to replicate the study in another group with a similar exposure. Preferably, the replication should be done by another investigator in a different setting. If the results have general biologic plausibility and if similar associations are seen in different studies of different groups done by different investigators, then the belief that the associations are causal is strengthened.

IV. CAN EPIDEMIOLOGIC STUDIES DETECT THE HEALTH RISKS FROM LOW-LEVEL IONIZING RADIATION?

A. THE EPIDEMIOLOGY OF RADIATION-INDUCED DISEASES IN THE LOW-LEVEL RANGE

Probably the largest source of data on the health effects of low-level radiation comes from the Life Span Study of Japanese survivors of the atomic bombs (15). Table 2 shows the observed and expected number of neoplasms by site, listed separately for the two cities. Expected numbers were derived from data on all deaths in Japan. The sample of survivors from Nagasaki, although smaller in number, predominantly reflects the consequences of exposure to gamma radiation. In Hiroshima, there was a mixture of neutrons and gamma radiation. The estimates presented in Table 2 differ dramatically from health risks evident from much higher doses of radiation. For example, there was no detectable increase in leukemia or cancer of the thyroid. Note that the low dose risk estimates for neoplasia presented here reflect direct observation of low-dose radiation effects in humans.

More recently, Lyon *et al.* (16) reported an excess of leukemia in children in Utah counties subjected to high exposure from Nevada nuclear test fallout. However, it has not been possible to reconstruct the doses of radiation, and the statistical validity of the conclusions drawn has been questioned (17).

The health effects observed among survivors of the atomic bomb and people exposed to fallout may not accurately represent the extent of health effects that may occur to people exposed to ionizing radiation in a less dramatic way. For occupational exposures, an excess of multiple myeloma and cancer of the pancreas was noted in the study population at the Hanford nuclear facility in Washington State. However, no excess of leukemia was observed among those workers. In an re-analysis of these data, Hutchison *et al.* (18) noted in their review of Mancuso, Stewart, and Kneale's work (2) that the statistically significant association for cases of pancreatic cancer hinged on 5 of the 32 exposed cases having accumulated doses over 10 rad as compared with 1.4 such cases expected; for multiple myeloma, 3 of 8 cases had accumulated doses over 10 rad as compared with 0.4 expected. In neither case is there evidence of a graded tumor response with increasing dose; instead, there is simply an abrupt increase in the ratio of observed to expected among those with doses exceeding 10 rad.

TABLE 2

Observed and Expected Neoplasms by Site of Hiroshima and Nagasaki Residents Exposed to 1-9 rad.

1950-1974

	HIROSHIMA			NAGASAKI		
SITES	OBS.	EXP.	OBS/EXP	OBS.	EXP.	OBS/EXP
Leukemia	4	10.1	0.4	5	5.8	0.9
Thyroid	17	21.4	0.8	12	13.1	0.9
Female Breast	22	28.8	0.8	9	12.7	0.7
Trachea, Bronchus, Lung	49	52.2	0.9	20	19.8	1.0
Digestive Organs, Peritonium	318	319.5	1.0	125	125.7	1.0
Stomach	197	204.2	1.0	75	75.2	1.0
Esophagus	9	15.5	0.6	5	7.9	0.6
Cervix Uteri, Uterus	66	60.9	1.1	34	29.0	1.2
Ovary, Tube, Ligament	3	6.9	0.4	1	1.5	0.7
Bladder, Urinary	9	16.2	0.6	3	4.7	0.6
Prostate	7	11.1	0.6	3	3.4	0.9

Reference: G.W. Beebe, H. Kato, and C.E. Land: "Mortality Experience of Atomic Bomb Survivors 1950-1974," Life Span Study Report #8. Radiation Effects Research Foundation, Technical Report RERF TR 1-77.

Diagnostic medical x-rays of pregnant women have been associated with increased incidence of childhood cancers in the exposed offspring (19,20,21). Also, exposure to diagnostic radiation has been claimed to be the cause of excess leukemia in adults. However, Dr. Bross' analysis of the Tri-State Leukemia Study (22) has been strongly criticized. Boice and Land (23) pointed out that the nature of the case-control design makes it impossible to distinguish between past events that were causally related to leukemia and events consequent to the disease, e.g., where x-ray exposures reported by subjects had been given for early manifestation of disease.

Low-level ionizing radiation also has been studied as a possible cause of reproductive impairment, with decreased birth weight, microencephaly, Down's syndrome and abnormalities of the eye studied as possible consequences (24,25, 26,27). Temporary sterility in men has been noted after single doses as low as 50 rem (28). However, no studies to date show solid evidence for an association of these types of health risks and low-level radiation.

The health effects of low-level radiation exposure have not been precisely determined, because of the difficulty of identifying infrequent events that are not unique. Detecting causal relationships is further complicated by variation in background radiation. It has been estimated that background radiation averages approximately 150 mrems per year (29).

Most of what is known about the health effects of radiation comes from studies of high levels of exposure. The "classical" studies in man have dealt with the survivors of the atomic bomb explosions in Japan, populations exposed to fallout from bomb testing in the Marshall Islands, and patients who have received diagnostic or therapeutic radiation. Owing largely to the higher dose ranges in these studies, reasonably consistent estimates of increased risk have been obtained for leukemia and cancers of thyroid, female breast, lung, and bone with indications for increased risk of cancer in a variety of other tissues as well.

In addition to cancer, ionizing radiation is known to induce genetic effects including specific locus mutations and chromosomal abnormalities. From an operational point of view, genetic effects fall into two categories: germ line mutations that are induced in the parent and whose phenotypic effects are seen in the progeny, and somatic cell mutations that are induced in an individual and also observed in him. Specific locus mutations due to irradiation have not been demonstrated in germ cells of man. Large doses, of course, induce chromosome breakage and thus engender grossly abnormal germ cells that lead to an increase in the abortion rate, especially early in pregnancy. Accurate determination of the abortion rate is so difficult that it would be impractical to use an increment in abortions as an indicator of radiation damage at low level exposure. The biochemical determination of specific locus mutations is a possible line of study, owing to the development of "production line" techniques for the separation of blood proteins.

Chromosomal abnormalities have been detected in the lymphocytes of patients treated for cancer (30) and also in groups who have been exposed to the atomic bomb and examined more than 20 years later (31,32). Most recently, an increase has been reported in chromosomal aberrations in the lymphocytes of nuclear shipyard workers exposed almost exclusively to gamma rays in the range from below 1 rem to above 30 rems (33). These studies suggest that such a cytogenetic indicator might provide new information. The previous studies had indicated such a possibility, but it was considered doubtful that the method could be applied in the low level range of exposure at a practical cost. The development of automated chromosome counting and characterization methods is under way, however, and it is a possibility that in the near future such methods might be available for use in epidemiologic studies (34,35).

The traditional method used to estimate the risk to health from low-level radiation is linear extrapolation from human high dose range data. Some recent studies claim to have direct effect estimates in the low-dose range that are much higher than those derived from extrapolation (2,16,23,36). These recent claims, in turn, have been seriously questioned (17,37). Public concern as to whether the recent claims are to be accepted or rejected may affect the extent of what can be done in the future to study the subject more definitively.

A detailed evaluation of the suitability of studying various health consequences of low-level ionizing radiation will be conducted during Phase II of the project. Both somatic and genetic effects will be considered.

B. QUESTIONS FOR EPIDEMIOLOGIC RESEARCH

We recognize that the decision as to which populations merit further study will be influenced by other factors in addition to epidemiologic considerations. Therefore, we intend to provide several study recommendations in our final report. The populations selected for study should provide suitable data to answer one or both of the following questions:

(1) Is there any evidence of a health effect from low-level radiation exposure?

(2) What is the shape of the dose-response curve for low-level radiation?

It is of interest to note the different requirements necessary to answer these two questions. The first question may be answered in the absence of specific measurements of exposure. Even though data on health effects could not be related to radiation dose, it is important first to establish whether there is an increased health risk from low-level radiation. This question, although imprecise, is important in terms of public health. Consider, for example, the regulatory agency that must decide whether radioactive waste disposal sites pose a serious health risk to residents in the surrounding areas. Although no data on population exposure may be available, the question of possible risks to health still must be evaluated.

Answers to the question about the shape of the dose-response curve for low-level radiation depend largely on dosimetry. If exposure to low-level ionizing radiation does pose a serious risk to health, then it would be important to describe precisely the dose-response relationship in order to help regulatory agencies set appropriate standards for permissible levels of exposure.

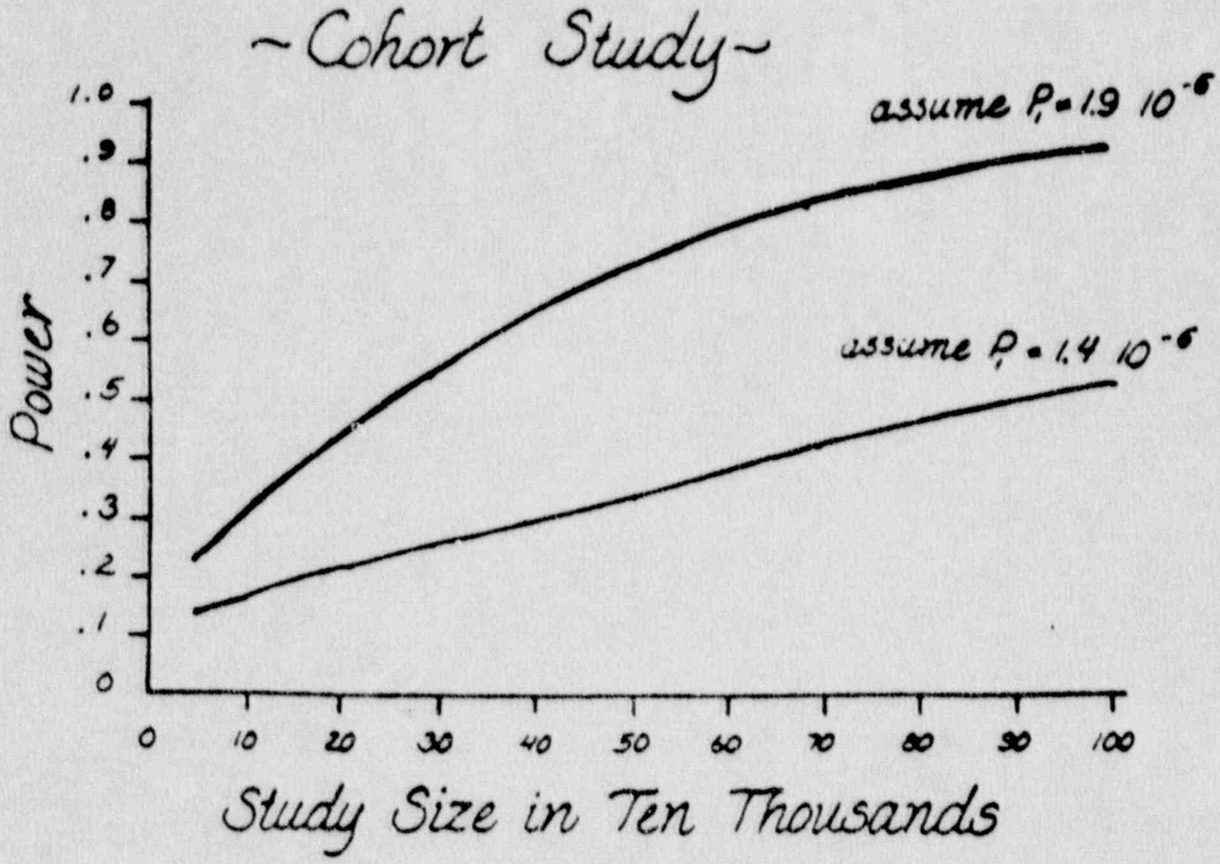
Both cohort and case-control studies might be appropriate research methods for the first research question. The second question, however, would more likely be addressed by case-control studies. Although the case-control design has certain limitations, such studies are relatively quick and inexpensive to conduct.

C. EXAMPLES OF STUDY SIZE REQUIREMENTS

We have selected two examples to illustrate the study size requirements to detect an incremental health effect due to low-level ionizing radiation. Study size requirements for cohort studies of breast cancer were presented in Section II. B.1. Below are estimates for study size requirements for cohort studies and case-control studies with different levels of power to detect a relatively small excess risk for leukemia and for gross congenital malformations. These computations were performed on a programmable calculator according to the procedure described in Rothman and Boice (38). Relative risks (RR) of 1.5 and 2 have been presented. Also note that an allocation ratio of 5:1 was used in both examples. The allocation ratio refers to the ratio of controls to cases or unexposed subjects to exposed subjects. When cases or exposed subjects are limited in number, the information yield of a study can be improved by selecting multiple controls for each case. The allocation ratio depends on the cost and availability of controls or unexposed subjects. The allocation ratio of 5:1 presented in the examples was an arbitrary selection.

The data presented in Figures 2 and 3 show power values for a range of study sizes for cohort and case-control studies of leukemia and diagnostic medical x-rays (both dental and chest). The low power of even very large cohort studies of such a rare disease makes this study design undesirable. On the other hand, the study size requirements for a case-control study are much more within the realm of possibility.

Figures 4 and 5 show power and study size relationships for cohort and case-control studies of gross congenital malformation and maternal x-rays. The parameter, P_0 (the proportion of unexposed children born with congenital malformations), was estimated from data recorded on birth and death certificates in New York State, exclusive of New York City (25). The term P_1 refers to the proportion of exposed subjects who develop disease. This estimate probably underestimated the prevalence of congenital abnormalities by using only information on gross abnormalities evident at birth.



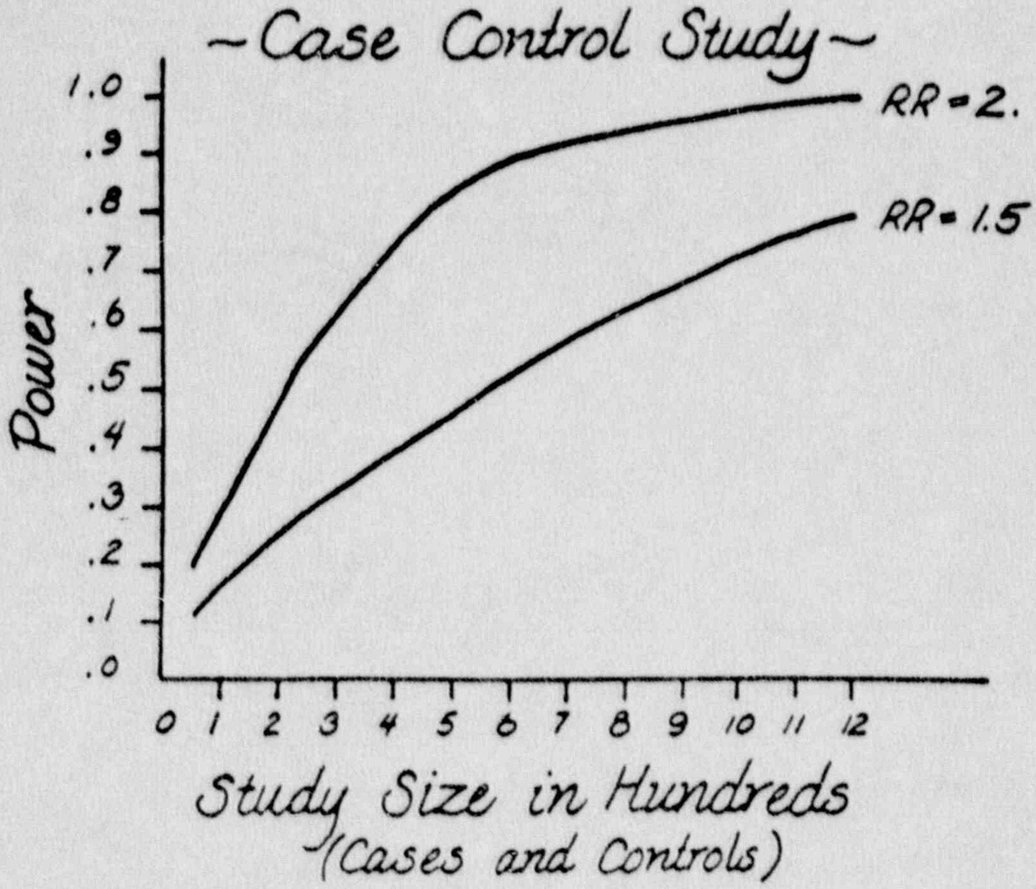
Assumptions:

- P_0 = Proportion of Unexposed who develop disease = 9.5/100,000
- Ratio of Unexposed : Exposed = 5:1
- Standard normal deviate for alpha - 1.645
- 10 year follow-up

Reference: A. Linos et al. (39).

Power & Study Size Requirements
Leukemia & Diagnostic Medical Xrays

figure 2.

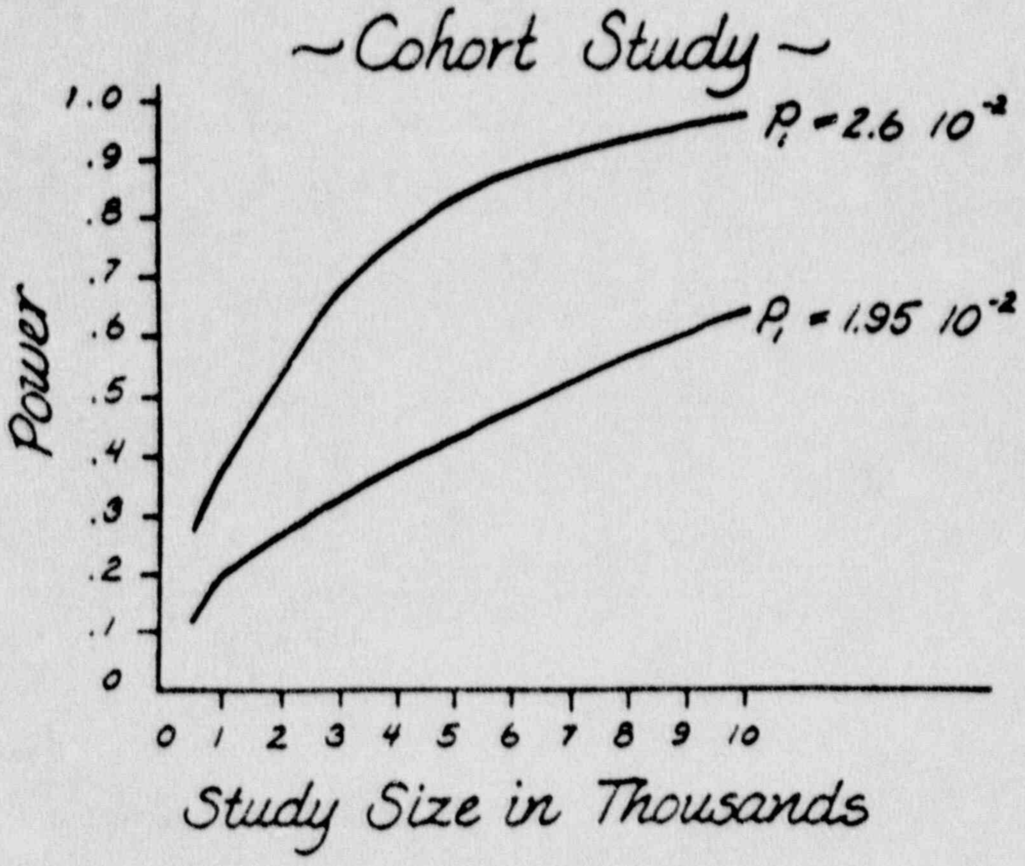


Assumptions :
- P_0 = Proportion of Controls exposed to medical
  x-rays (chest and dental) = 62/100
- Ratio of Controls : Cases = 5:1
- RR = Relative Risk
- Standard normal deviate for alpha = 1.645

Reference : Moeller (40)

Power & Study Size Requirements
Leukemia & Diagnostic Medical X-rays

figure 3.



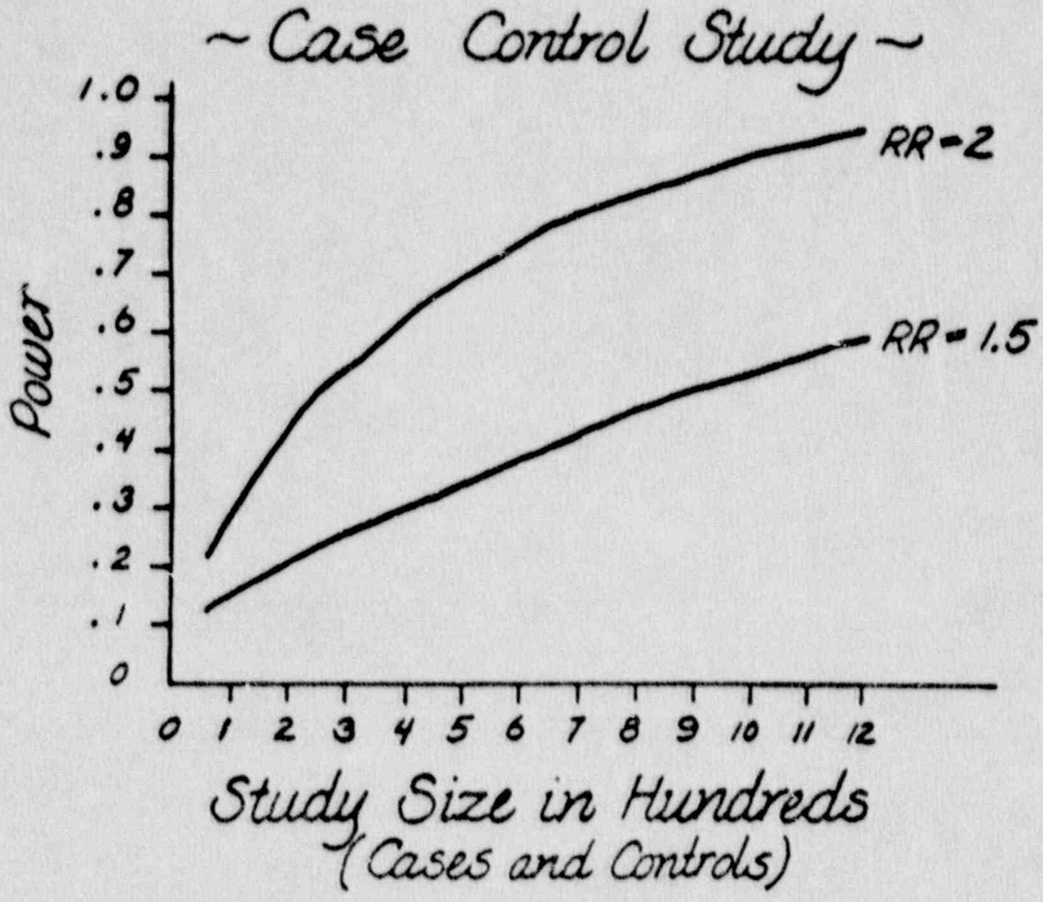
~Cohort Study~

Assumptions:

- P_0 = Proportion of Unexposed children born with congenital malformations = 13/100
- Ratio of Unexposed : Exposed = 5:1
- Standard normal deviate for alpha = 1.645

Reference: Gentry et al. (25).

Power & Study Size Requirements
Congenital Malformations & Maternal X-rays
figure 4.



Assumptions:

- P_0 = Proportion of Controls exposed to x-rays during pregnancy = 11/100
- Ratio of Controls : Cases = 5:1
- RR = Relative Risk
- Standard normal deviate for alpha = 1.645

Reference: Stewart and Kneale (41)

Power & Study Size Requirements
Congenital Malformations & Maternal X-rays

figure 5.

V. IDENTIFICATION OF CANDIDATE POPULATIONS

A. METHODS

1. Definition of Low-Level Radiation

An operational definition of "low-level" was necessary in order to define the scope of our project. We adopted operational criteria for low-level radiation according to what has been utilized by regulatory agencies as shown in Table 3. This recommendation provides maximum permissible occupational dose levels; we applied this operational definition to other populations, e.g., residential, as appropriate. We recognize that most residential and occupational radiation exposure will fall far below these limits. On the other hand, much can be learned from studying populations receiving as much as four or five times this level of exposure. Therefore, we included such populations in the list of candidate populations even when their exposures exceeded the guidelines presented in Table 3.

Although federal regulations are written in terms of quarterly and annual rates of exposure, not total exposure, we wish to emphasize that low annual dose rates can lead to relatively high cumulative exposures. Note that a person employed in the nuclear power industry from age 18 to age 50 might accumulate as much as 160 rem from his work. During Phase II, we plan to gather information on both the annual dose rate and the number of years of exposure for candidate study populations.

2. Candidate Population Selection

We assembled a list of candidate study populations using three different approaches: literature survey, mail inquiries to individuals and groups concerned with radiation protection, and review of on-going federally supported research. The literature review was restricted to studies of humans with exposures to low-level ionizing radiation. Our review was largely drawn from several recent references: a draft of the BEIR III report supplied by the Nuclear Regulatory Commission (42), the 1977 report of the United Nations Scientific Committee on the Effects of Atomic Radiation (43), and the 1979 report of Interagency Task

TABLE 3

Maximum Permissible Dose Equivalent for Occupational Exposure

Combined whole body occupational exposure

Prospective annual limit	5 rem in any one year
Retrospective annual limit	10-15 rem in any one year
Long time accumulation to age N years (Not applicable to children)	(N-18) X 5 rem

Partial body exposure

Skin	15 rem in any one year
Hands	75 rem in any one year
Forearms	30 rem in any one year
Other organs, tissues, and organ systems	15 rem in any one year
Fertile women (with respect to fetus)	0.5 rem in gestation period

SOURCE: Basic Radiation Protection Criteria, National Council on Radiation Protection and Measurements, Report No. 39, 1971.

Force on the Health Effects of Ionizing Radiation (5). The list of people whom we contacted by mail, as well as a copy of our general letter, is presented in Appendix A. A current review of on-going federally supported research on the health effects of radiation was kindly supplied to us by Dr. Lowe of the National Institutes of Health.

3. Feasibility Study Criteria

Five general areas were identified as general criteria for evaluating the feasibility of each candidate study population. These criteria are: personal data, radiation exposure data, size of the group, potential confounding factors, and suitable biological end-point for study.

The existence or potential existence of personal data is essential for an epidemiologic study of individuals. We attempted to find out if data exist that identify people exposed to low-level radiation, either healthy people or people with possible radiation-induced diseases. If no data currently exist, we considered whether it would be possible to initiate follow-up. Any candidate populations that did not appear to have personal data, nor the potential for such data collection, were excluded from Phase II of the feasibility study.

Accurate information on radiation exposure was the second criterion for feasibility evaluation. Candidate study populations were eliminated from Phase II follow-up if their exposures exceeded our operational definition of low-level. Note that in Phase II follow-up we included some populations with annual exposures that exceeded 5 rem if low dose exposures occurred at an internal organ of interest.

Further, we eliminated candidate populations whose exposures were too low to be measured by current methods of dosimetry. One approach to identifying an appropriate lower limit for detectable exposure would be to use the appropriate level of background radiation (100 mrem). However, without having conducted a thorough examination of the quality of dosimetry in the low dose range during Phase I, we chose to adopt a much more conservative lower limit as a preliminary criterion for Phase I. The EPA has directed that beginning in 1980, the dose received by any member of the public from the uranium fuel cycle shall not be more than 25 mrem whole body, 75 mrem thyroid, and

25 mrem other organs (radon and its daughters excepted) (44). Although it is not apparent how such a standard could be maintained or upheld using presently available methods of dosimetry, we selected 25 mrem as the operational limit for detectable levels of exposure in our Phase I evaluation.

It was difficult to estimate precisely the size of many of the candidate populations within the time constraints of Phase I. Therefore, we classified the groups crudely according to three categories: (1) small and unique, (2) small, not unique, and (3) large (greater than 10,000). Only population groups that were small and unique were eliminated from Phase II follow-up. Individual candidate populations that were small and similar to other groups were included in Phase II follow-up because data from such groups potentially might be pooled in a larger study.

The remaining two feasibility criteria, potential confounding factors and suitable biological end-points for study, were not evaluated in Phase I. Although they are important, they require in-depth evaluation and will be addressed more thoroughly in Phase II of this project.

B. CLASSIFICATION OF CANDIDATE POPULATIONS

Candidate populations were categorized into occupational and non-occupational groups. Occupational groups were classified into six subgroups: medicine, industry, nuclear fuel cycle, government, education, and technologically enhanced. Non-occupational groups were classified according to environmental exposures and medical exposures. Environmental populations then were categorized by the same six subgroups as the occupational populations. Medical groups were divided into exposure to diagnostic radiation and exposure to therapeutic radiation. Appropriate population registry information was included where appropriate.

C. CANDIDATE POPULATION EVALUATION

Table 4 shows the classification of candidate population groups and the referent page number. Some dose range data were estimated based on best available information; these estimated doses are followed by the notation (est.). In addition, some dose data are for general categories rather than specific populations. More specific information will be gathered in Phase II.

TABLE 4

Classification of Candidate Populations

Category	Page No.
I. OCCUPATIONAL	42
A. Medicine	42
1. Hospital/Clinic	42
a. Radionuclides	
1) Nuclear medicine technicians	
2) Radiopharmacists	
3) Radiotherapists and technicians	
4) Embalmers	
5) Hospital incinerator operators	
6) Teletherapists	
7) Nursing personnel	
b. Electronic Sources	
1) Radiologists	
2) X-ray technologists	
3) Dermatologists	
4) Dentists	
5) Cardiologists	
2. Private Practice	43
a. Radionuclides	
b. Electronic Sources	
1) X-ray technologists	
2) Radiologists	
3) Dentists	
4) Dental hygienists and assistants	
5) Veterinarians	
6) Osteopaths	
7) Chiropractors	
8) Podiatrists	
B. Industry	45
1. Industrial Radiography	45
a. Radionuclides	
1) Well loggers	
2) Non-destructive testers	
3) Gamma ray source inspectors	
2. Other Industrial	45
a. Radionuclides	
1) Sewage treatment plant workers	

TABLE 4 (cont.)

TABLE 4 (cont.)

Category	Page No.
5. Processing and Re-processing	50
a. Plutonium processing plant workers (see Appendix C)	
b. Uranium re-processing workers	
6. Transportation	51
a. High-level waste transport workers	
7. Waste	51
a. Waste disposal site workers (see Appendix D)	
8. Research and Development	51
a. Research facilities workers (see Appendix C)	
D. Government	52
1. Radionuclides	52
a. Non-destructive testers	
2. Electronic Sources	52
3. Military	52
a. Atomic veterans	
b. Nevada test site employees	
c. Weapons assembly workers	
d. Nuclear-powered ship workers	
4. Research and Development (see (Appendix B)	54
a. Research Lab. workers	
E. Education	54
1. Radionuclides	54
a. Laboratory technicians	
2. Electronic Sources	54
a. X-ray spectroscopists	
b. X-ray diffraction workers	
c. Experimental nuclear physicists	
d. Electron microscopists	

TABLE 4 (cont.)

TABLE 4 (cont.)

Category	Page No.
f. Residents and visitors to Bad Gastein, Austria	
g. Residents in high radon water areas	
h. Populations with few x-rays or radiation treatment	
i. Rural populations (Orinoco basin, Brazil)	
2. Technologically-Enhanced Natural Background	62
a. Residents near coal-fired power plants	
b. Frequent air travelers	
c. Brick or cement versus wooden housing communities	
d. Residents of phospho-gypsum houses	
3. Industry	64
a. Uranium manufacturing communities (e.g., Canonsburg, PA)	
b. Tritium manufacturing communities (e.g., Tucson, AZ)	
c. Radioactive hospital effluent communities	
d. Residents near <u>illegal</u> radioactive waste disposal sites	
4. Nuclear Fuel Cycle	65
a. Mining	
1) Uranium miners' families	
b. Milling	
1) Uranium millers' families	
2) Mill tailings communities	
3) Uranium tailings housing residents	
c. Fabrication	
1) Residents near, downwind or downstream from fabrication plants (see Appendix C)	
2) Seaweed eaters downwind from Windscale (England)	

TABLE 4 (cont.)

Category	Page No.
d. Operation	
1) Residents near nuclear power plants (see Appendix B)	
2) Visitors to nuclear plants	
e. Processing and Re-processing	
1) Residents near processing plants (see Appendix C)	
f. Transportation	
g. Waste Disposal	
1) Residents near waste disposal sites (see Appendix D)	
h. Research and Development	
1) Residents near nuclear research facilities (see (Appendix C)	
5. Government	70
a. Military fallout from Atomic Bomb or its tests	
1) Faeroe Island residents during fallout	
2) Nevada test site residents	
3) Milk-drinking children in Utah and Nevada	
4) Japanese Atomic Bomb survivors	
5) Marshall Island test site residents	
6) Fall-out residents in Utah, New York, and Minnesota	
b. Research and Development	
1) Residents near nuclear research facilities (see Appendix C)	
6. Education	72
a. Residents near, downwind or downstream from research reactors (see Appendix C)	
B. Medical	73
1. Diagnostic	73
a. Maternal pelvimetry and x-ray offspring	
b. Cardiac fluoroscopy and catheterization patients (especially children)	

TABLE 4 (cont.)

Category	Page No.
c. Scoliosis x-ray patients	
d. Urography patients	
e. Mammography patients (organ doses)	
f. Thorotrast patients	
g. Dental x-ray patients	
h. Chest x-ray screening	
i. Barium meal and enema patients (organ doses)	
j. Congenital hip dislocation and Legg-Perthe's Disease patients	
k. Neurologic x-ray patients (organ doses)	
l. Chiropracters' patients	
m. Lumbar spine screening	
n. Stomach ulcer x-ray patients (kidney dose)	
o. Multiple fluoroscopy of tuberculosis patients	
2. Therapeutic	83
a. Acne, hirsutism, and skin disease x-ray patients	
b. Thyroid cancer and thyroid disease I^{131} patients	
c. Postpartum mastitis x-ray patients	
d. Tinea capitis patients	
e. Benign gynecologic x-ray patients	
f. Ankylosing spondylitis x-ray patients	
g. Arthritis x-ray patients	
h. Thymic enlargement and upper respiratory problem patients	
i. Brachytherapy patients	
j. Radioactive implant patients' families	
k. Wearers of uranium-fabricated dentures	
l. Pacemaker patients with nuclear-powered pacemakers	
m. Polycythemia vera radioactive phosphorus patients	
n. Cervical cancer x-ray patients	
3. U.S. Tumor Registries	91

I. Occupations Population Description	Reference	Do Personal Data Exist?	Size			Radiation		Follow-Up in Phase II?			Comments
			Unique & Small	Small Not Unique	>10,000	Source of Exposure	Dose Range	No	Maybe	Yes	
A. Medicine											
1. Hospital/Clinic											
a. Radionuclides	45	Yes			X	beta, gamma sources, x-ray	Average 330 mrem/yr			X	All dose estimates from EPA Draft, Jan., 1979
1) Nuclear medicine technicians		Yes				--	--				
2) Radio pharmacists		Yes				--	--				
3) Radiotherapists and technicians		Yes				--	--				
4) Embalmers		Yes	X			beta, gamma sources		X			Handlers of radioactive cadavers
5) Hospital Incinerator Operators		?				--	--				

Population Description	Reference	Do Personal Data Exist?	Size			Radiation		Follow-Up in Phase II?			Comments
			Unique & Small	Small Not Unique	>10,000	Source of Exposure	Dose Range	No	Maybe	Yes	
6) Teletherapists											
7) Nursing personnel											
b. Electronic Sources	45	Yes			X	x-ray	330 mrad/yr			X	
1) Radiologists	46	Yes			X	x-ray	--			X	on-going study
2) X-ray technologists		Yes			X	x-ray	0-5 rad/yr (est.)			X	
3) Dermatologists	47	Yes				x-ray	--			X	on-going study
4) Dentists		Yes				x-ray	--			X	
5) Cardiologists	47	Yes				x-ray	--			X	on-going study
2. Private Practice											
a. Radionuclides	45	Yes				beta, gamma sources, x-ray	370 mrem/yr		X		many not certified; doubtful dosimetry
b. Electronic Sources	45	Yes			X	x-ray	370 mrad/yr		X		many not certified; doubtful dosimetry

Population Description	Reference	Do Personal Data Exist?	Size: Unique & Small	Size: Small Not Unique	Size: >10,000	Radiation: Source of Exposure	Radiation: Dose Range	Follow-Up in Phase II?: No	Follow-Up in Phase II?: Maybe	Follow-Up in Phase II?: Yes	Comments
1) X-ray technologists					X	x-ray	0-5 rad/yr (est.)			X	
2) Radiologists	48	Yes		X		x-ray	--			X	
3) Dentists	45	Yes			X	x-ray	180 mrad/yr			X	
4) Dental hygienists and assistants	45	Yes			X	--	--			X	
5) Veterinarians	45	Yes			X	x-ray	420 mrad/yr		X		
6) Osteopaths		Yes		X		--	--		X		
7) Chiropractors	45	Yes		X		x-ray	10 mrad/yr	X			Exposure too low to be detected
8) Podiatrists	45	Yes		X		x-ray	30 mrad/yr		X		

Population Description	Reference	Do Personal Data Exist?	Size: Unique & Small	Size: Small Not Unique	Size: >10,000	Radiation: Source of Exposure	Radiation: Dose Range	Follow-Up in Phase II?: No	Follow-Up in Phase II?: Maybe	Follow-Up in Phase II?: Yes	Comments
B. Industry											
1. Industrial Radiography											
a. Radionuclides	45	Yes		X		beta, gamma sources	440 mrem/yr		X		
1) Well-loggers		?				--	--				
2) Non-destructive testers		?				--	--				
3) Gamma ray source inspectors		?				--	--				
2. Other Industrial											
a. Radionuclides	45	Yes			X	beta, gamma sources	440 mrem/yr		X		
1) Sewage treatment plant workers		?				--	--	X			
b. Electronic Sources	45	?			X	x-ray	400 mrad/yr		X		

Population Description	Reference	Do Personal Data Exist?	Size			Radiation		Follow-Up in Phase II?			Comments
			Unique & Small	Small Not Unique	>10,000	Source of Exposure	Dose Range	No	Maybe	Yes	
1) Video display tube operators	49	No			X	x-ray	0-1700 mrad/yr	X			transient population; older machines
2) Television repairmen		?				--	--		X		
3) Seed sterilizers		?				--	--		X		
4) Airport baggage x-ray inspectors	50	Yes		X		x-ray	422 mrad/yr		X		extrapolated from NIOSH study data
5) Plasma torch operators		?				--	--		X		
3. Manufacturing and Distribution											
a. Radionuclides	45	Yes		X		beta, gamma sources	650 mrem/yr		X		
1) Smoke detector makers		?				--	--		X		
2) Radiopharmaceutical makers		Yes				--	--		X		

Population Description	Reference	Do Personal Data Exist?	Size: Unique & Small	Size: Small Not Unique	Size: >10,000	Radiation: Source of Exposure	Radiation: Dose Range	Follow-Up in Phase II?: No	Follow-Up in Phase II?: Maybe	Follow-Up in Phase II?: Yes	Comments
3) Radium dial painters	51	Yes	X			^{226}Ra	0-2,500 uCi/yr			X	on-going study; ingested dose
U.K. dial painters	52	Yes	X			^{226}Ra	--			X	on-going study in England
4) Luminizers (primarily tritium)	53	Yes	X			^{3}H	490-1,600 mrem/yr			X	
5) Radium mill workers	54	?				--	--			X	on-going study
6) Thorium alloy workers	54 55	Yes	X			--	--			X	on-going study
7) Radioactive cargo handlers	56	?		X		gamma sources, x-ray	0-446 mrad/yr		X		dose from NIOSH survey
b. Electronic sources	45	?		X		x-ray	200 mrad/yr		X		
1) Cathode ray tube makers		?				--	--				

Population Description	Reference	Do Personal Data Exist?	Size			Radiation		Follow-Up in Phase II?			**Comments**
			Unique & Small	Small Not Unique	>10,000	**Source of Exposure**	**Dose Range**	No	Maybe	Yes	
2) Klystron tube makers		?				--	--		X		
3) X-ray equipment manufacturers		?				--	--		X		
C. Nuclear Fuel Cycle											
1. Mining											
a. Uranium miners	57-64	Yes			X	alpha, radon daughters	0-10 rad/yr or 0-10 WLM/yr (est.)			X	recent mining is at low dose; registry data available and several studies on-going
2. Milling & refining	45	Yes		X		alpha, gamma, radon daughters	2-4.7 rem/yr			X	
a. Uranium millers	65, 62	Yes		X		--	--				NUREG EIS, April, 1979
b. Dye workers		?				--	--				
c. Uranium refiners	66	Yes		X		alpha, gamma radon daughters	--			X	on-going research

Population Description	Reference	Do Personal Data Exist?	Size			Radiation		Follow-Up in Phase II?			Comments
			Unique & Small	Small Not Unique	>10,000	Source of Exposure	Dose Range	No	Maybe	Yes	
3. Fabrication	45	Yes		X		alpha, gamma fission products	560 mrem/yr			X	
a. Gaseous Diffusion Plant workers		Yes			X	uranium and daughters	average 70 mrem/yr			X	current workers-5,535 .·. total probably greater than 10,000, included in DOE health & mortality study
Oak Ridge, TN	67 68	Yes			X	--	--				
Paducah, KY	68	Yes		X		--	--			X	current workforce, 2,375
Portsmouth, OH	68	Yes		X		--	--			X	
b. Feed Materials Plant workers		Yes		X		uranium and daughters	--			X	
Ashtabula, OH	68	Yes		X		--	--				
Fernald, OH	67 68	Yes		X		--	--			X	included in DOE health and mortality study

Population Description	Reference	Do Personal Data Exist?	Size			Radiation		Follow-Up in Phase II?			Comments
			Unique & Small	Small Not Unique	>10,000	Source of Exposure	Dose Range	No	Maybe	Yes	
c. Savannah River Plant workers Aiken, SC	68	Yes			X	varied	--			X	
d. Hanford Production Operations workers Richland, WA	68-71	Yes			X	varied	--			X	
e. Idaho Chemical Processing Plant workers	68	Yes		X		uranium and daughters	--			X	
4. Operation	45										
a. Nuclear power plant workers		Yes			X	primarily gamma & neutrons	760 mrem/yr			X	large pool of workers with dosimetry (See Appendix B)
5. Processing and Re-processing	45	Yes		X		--	70 - 560 mrem/yr		X		many low dose (See Appendix C)
a. Plutonium processing workers	72 73	Yes	X			--	--			X	on-going study
b. Uranium re-processing workers		?	X			--	--		X		

Population Description	Reference	Do Personal Data Exist?	Size			Radiation		Follow-Up in Phase II?			Comments
			Unique & Small	Small Not Unique	>10,000	Source of Exposure	Dose Range	No	Maybe	Yes	
6. Transportation	74	Yes		X		alpha, gamma, neutron sources	540 mrem/yr		X		doubtful dosimetry; need to determine quantification
a. High-level waste transporters		?				--	--				
7. Waste											
a. Waste disposal site workers	45	?		X		alpha, beta, gamma	--		X		See Appendix D
8. Research and Development	45	Yes			X	alpha, beta, gamma, neutrons	300 mrem/yr		X		healthy worker effect, on-going research (See Appendix B)
a. Research lab workers	67	Yes			X	--	--				

Population Description	Reference	Do Personal Data Exist?	Size			Radiation		Follow-Up in Phase II?			Comments
			Unique & Small	Small Not Unique	>10,000	Source of Exposure	Dose Range	No	Maybe	Yes	
D. Government											
1. Radionuclide workers	45	Yes		X		beta, gamma sources	400 mrem/yr		X		
a. Non-destructive testers		Yes				--	--				
2. Electronic Source workers	45 75	Yes		X		x-ray	120 mrad/yr				see section I.B.
3. Military	45	Yes			X	alpha, fission products	200 mrem/yr			X	
a. Atomic Veterans	76-78	Yes			X	alpha, fission products	0-5+rem/yr (est.)			X	limited personal data, on-going research
b. Nevada Test Site employees	68 77	Yes			X	varied - includes nuclear weapons fall-out	--			X	on-going research
c. Weapons assembly workers		Yes		X		Plutonium, uranium and their daughters	--			X	
Rocky Flats, CO	68	Yes		X							

Population Description	Reference	Do Personal Data Exist?	Size			Radiation		Follow-Up in Phase II?			Comments
			Unique & Small	Small Not Unique	>10,000	Source of Exposure	Dose Range	No	Maybe	Yes	
Pantex Plant workers TX	68	Yes		X		varied	--			X	
Pinellas Plant workers St. Petersburg, FL	68	Yes		X		neutron, others varied exposure	--			X	
Mound Facility workers Miamisburg, OH	67 68	Yes			X	varied	--			X	included in DOE health and mortality study
Y-12 Plant workers Oak Ridge, TN	67 68	Yes			X	varied	--			X	included in DOE health and mortality study
Savannah River Weapons Facility workers, Aiken, SC	68	Yes		X		tritium, possibly others	--			X	
d. Nuclear-powered ship workers	36 79 80	Yes			X	gamma, fission products	0-5 rem/yr (est.)			X	on-going research

Population Description	Reference	Do Personal Data Exist?	Size			Radiation		Follow-Up in Phase II?			Comments
			Unique & Small	Small Not Unique	>10,000	Source of Exposure	Dose Range	No	Maybe	Yes	
4. Research and Development	45	Yes			X	alpha, gamma, fission products	--			X	see above I.C.8.a.
a. Research lab workers	81 82	Yes			X	--	--			X	
E. Education											
1. Radionuclides	45	Yes			X	beta, gamma sources	270 mrem/yr	X			many transient workers
a. Laboratory technicians		?				--	--				
2. Electronic sources	45	Yes		X		x-ray	60 mrad/yr		X		
a. x-ray spectroscopists		Yes				--	--				
b. x-ray diffraction workers		Yes				--	--				
c. Nuclear physicists		Yes				--	--				
d. Electron microscopists		?				--	--				

Population Description	Reference	Do Personal Data Exist?	Size			Radiation		Follow-Up in Phase II?			Comments
			Unique & Small	Small Not Unique	>10,000	Source of Exposure	Dose Range	No	Maybe	Yes	
F. <u>Technologically-Enhanced Natural Background</u>											
1. Miners	83 84	?			X	radon daughters	bronchial epitelium dose 0-6 Rad/yr 0-6 WLM/yr (est.)		X		on-going study
a. Coal miners						--	--				
b. Hard-rock miners	85	?			X	--	--			X	Canadian study propose
c. Phosphate miners						--	--		X		
d. Lead/Zinc miners	86	?		X		--	--		X		
e. Iron miners	87	Yes		X		--	--		X		
f. Fluorspar miners	88	Yes		X		--	--		X		

Population Description	Reference	Do Personal Data Exist?	Size			Radiation		Follow-Up in Phase II?			Comments
			Unique & Small	Small Not Unique	≥10,000	Source of Exposure	Dose Range	No	Maybe	Yes	
2. Airline personnel	89	Yes			X	cosmic, beta gamma, neutron	0-1.6 rem/yr		X		no personal dosimetry
a. Pilots		Yes		X		--	--		X		
b. Flight attendants		Yes		X		--	--		X		
3. Other											
a. Fertilizer manufacturers		?				--	--		X		
b. Underground document storage workers		?				--	--		X		
c. Sailors		?				--	--		X		Less than normal background
d. Submariners		Yes				--	--		X		Less than normal background
e. Health Spa workers (Europe)		Yes		X		$^{210}\mathrm{Po}$	0.7-40 rem/yr			X	Italian feasibility study

Population Description	Reference	Do Personal Data Exist?	Size			Radiation		Follow-Up in Phase II?			Comments
			Unique & Small	Small Not Unique	>10,000	Source of Exposure	Dose Range	No	Maybe	Yes	
G. <u>Registries</u>											
1. Uranium Registry	90										
a. Uranium workers		Yes				alpha, gamma					Hanford Environmental Health Foundation
b. Uranium miners		Yes				alpha, gamma					Univ. of New Mexico
c. Uranium mill workers		Yes				alpha, gamma					NIOSH - Salt Lake City
2. Transuranium Registry	91	Yes									Hanford Environmental Health Foundation
3. Radiation workers	92	Yes				alpha, beta, gamma, x-ray, neutron					United Kingdom registry

II. Non-Occupational **Population Description**	Reference	Do Personal Data Exist?	Size			Radiation		Follow-Up in Phase II?			**Comments**
			Unique & Small	Small Not Unique	>10,000	**Source of Exposure**	**Dose Range**	No	Maybe	Yes	
A. Environmental											
1. Natural Background	93										
a. Reindeer and Caribou eaters (Eskimos and Laplanders)	43, 94-98	?			X	^{210}Pb, ^{210}Po (alpha dose) and possibly ^{137}Co through food chain (lichens to reindeer to man)	50 times normal ^{137}Cs, ^{210}Po; 4 times normal ^{210}Pb. From ^{210}Po: 4.2 mrad/yr to testes; 18 mrad/yr to liver; 5.8 mrad/yr to lung; 12 mrad/yr to Haversian canals of bones			X	**Possible pooling of sources from Finland, USSR, Sweden, Alaska and Norway**

Population Description	Reference	Do Personal Data Exist?	Size			Radiation		Follow-Up in Phase II?			Comments
			Unique & Small	Small Not Unique	>10,000	Source of Exposure	Dose Range	No	Maybe	Yes	
b. Japanese shellfish eaters	99 94	No			X	^{210}Po, ^{45}Zn, ^{60}Co and ^{54}Mn in fish flesh		X			Population hard to follow. No estimates of dose levels
c. Monazite sands residents - Residents of coastal Kerala, India	100 101 43 94	?			X	Thorium in monazite sands; possible ^{226}Ra in food	0.2-2.6 rad/yr (1.3 rad/yr from gamma, 200 mrad/yr from beta)	X			Difficult for outsiders to conduct research
Residents of Espiritos Santos, Brazil	43 94 101	?			X	Thorium in monazite sands	0.3-0.5 rad/yr			X	Medical records may not be available
Residents of Morro de Ferro, Brazil	43 94 101	?	X			Alkaline intrusions	0-1.6 rad/yr	X			Unique and small

Population Description	Reference	Do Personal Data Exist?	Size			Radiation		Follow-Up in Phase II?			Comments
			Unique & Small	Small Not Unique	>10,000	Source of Exposure	Dose Range	No	Maybe	Yes	
d. Residents in high altitude areas (Denver, parts of the Andes Mountains, etc.)	43 101	?			X	Cosmic radiation and cosmogenic nuclides	0.2-0.4 rad/yr		X		Confounding from anoxia
e. Residents in areas of high granite content (Northern New England, Ireland)	102-104	?			X	Uranium daughter content in Conway granite	145 mrad/yr		X		Small gradient of differences between areas. Low areas have 130 mrad/yr
f. Residents and visitors to Bad Gastein, Austria	94 101	?			X	High radon levels in ground water and thermal gallery	8-20 times normal radon exposure External exposure: 100-180 mrad/yr			X	May be difficult to define population of interest

Population Description	Reference	Do Personal Data Exist?	Size			Radiation		Follow-Up in Phase II?			Comments
			Unique & Small	Small Not Unique	>10,000	Source of Exposure	Dose Range	No	Maybe	Yes	
g. Residents of high radon water areas Helsinki, Finland area	101	?			X	^{222}Rn, ^{226}Ra, ^{228}Ra and U in ground water	0-30 mrad/yr to lung				Lung cancer may be good end point
Iowa and Illinois high radon areas	101 105 106	?			X	^{226}Ra	8-30 pCi/l		X		Water-softening devices may remove much of ^{226}Ra.
h. Populations without x-ray or radiation treatment											
Mormons		Yes			X				X		Church members do not smoke but 35% live in Utah and may get some diagnostic x-rays
Seventh Day Adventists		?			X				X		Church members do not smoke

Population Description	Reference	Do Personal Data Exist?	Size			Radiation		Follow-Up in Phase II?			Comments
			Unique & Small	Small Not Unique	> 10,000	Source of Exposure	Dose Range	No	Maybe	Yes	
Christian Scientists		No			X	No diagnostic x-rays Uniquely low exposure		X			Have expressed lack of cooperation with any study
1. Rural Populations Orinoco Basin, Brazil		No			X	Only natural background	70-100 mrad/yr	X			No confounding by medical radiation exposure
2. Technologically-enhanced Natural Background											
a. Residents near coal-fired power plants	43 107 108	?			X	226_{Ra} in coal ash; [illegible]10_{Pb}, Th, and U	4×10^{-17} in air; 2×10^{-3} man-rad per MW(e) yr			X	Alpha activity may be higher than from nuclear plants; good model for effluents from reactors
b. Frequent air travellers	43	?			X	External gamma and neutrons from cosmic rays	300-400 μrad/hr at 12 km			X	May be difficult to identify population of interest

Population Description	Reference	Do Personal Data Exist?	Size			Radiation		Follow-Up in Phase II?			Comments
			Unique & Small	Small Not Unique	>10,000	Source of Exposure	Dose Range	No	Maybe	Yes	
c. Residents of cement or brick houses	43 109 110	?			X	Internal 222_{Rn} exposure	0.03-6 $p^{Ci}/_{l}$ 222_{Rn} conc.; 0.135 mrad/hr		X		Dose depends specifically on content of walls, time spent inside, ventilation, breating rate, etc.
d. Residents of phosphogypsum houses	43	?			X	222_{Rn} and daughters, external 226_{Ra}	0.2 $p^{Ci}/_{1}$ 222_{Rn} conc.; 7 mrad/hr external 226_{Ra}		X		Same problems as above
e. Smokers	43 111 112	?			X	Internal lung dose from 210_{Po}	50-80 mrad/yr to basal cell layer of bronchial epithelium	X			Confounded by other toxic substances

Population Description	Reference	Do Personal Data Exist?	Size			Radiation		Follow-Up in Phase II?			Comments
			Unique & Small	Small Not Unique	>10,000	Source of Exposure	Dose Range	No	Maybe	Yes	
3. Industry											
a. Uranium Manufacturing Communities (e.g. Canonsburgh, PA.)	113	?			X	External from uranium Internal - Rn to daughters			X		No estimates of possible exposure
b. Tritium Manufacturing Communities (e.g. Tucson, Ariz.)	114	?		?		Internal Beta from ^3H			X		No personal dosimetry data available; very low doses
c. Radioactive hospital effluent areas		?				External exposure	Very low	X			Shortlived isotopes
d. Residents near dumps used by industries dealing with radioactive substances (e.g. NY state)	115	No		?		External exposure from dumped materials	low	X			These dumps are generally "illegal" making research difficult

Population Description	Reference	Do Personal Data Exist?	Size			Radiation		Follow-Up in Phase II?			Comments
			Unique & Small	Small Not Unique	>10,000	Source of Exposure	Dose Range	No	Maybe	Yes	
4. Nuclear Fuel Cycle											
a. Mining											
Uranium Miners' Families		?			X	Exposure to U-238 dust brought home by miners	?	X			Dose probably too low
b. Milling											
1) Uranium Millers' Families		?	X			Exposure to U-238 dust brought home by millers	?	X			Unique and small
2) Residents of Mill Tailing Communities	43 116 118	?			X	External from isotopes in the piles Internal from emanating Rn-222 and daughters in air and water	In one km radius of plant- 50 mrad per person per MW(e)y			X	

Population Description	Reference	Do Personal Data Exist?	Size			Radiation		Follow-Up in Phase II?			Comments
			Unique & Small	Small Not Unique	>10,000	Source of Exposure	Dose Range	No	Maybe	Yes	
(2. cont.)						mostly through food chain					
3) Residents of Mill Tailings Homes	43 116	?				Internal from emanating Rn-222 and daughters (inhalation)					
c. Fabrication											
1) Fabrication plant communities (e.g. Windscale, U.K.)	119	?			X	Effluents (both gaseous and liquid) from plants	Low			X	See Appendix C
2) Seaweed eaters down coast from Windscale	43 120	?	X			Internal exposure in food chain (isotopes accumulate in seaweed)	0.4-0.7 rad/yr	X			May have higher exposures than others in the area but still within allowable limits

Population Description	Reference	Do Personal Data Exist?	Size			Radiation		Follow-Up in Phase II?			Comments
			Unique & Small	Small Not Unique	>10,000	Source of Exposure	Dose Range	No	Maybe	Yes	
g. Waste management sites											
1) DOE Waste sites other than those doing reprocessing		?			X	Possible leakage	Very low			X	See Appendix D
Maxey Flats, KY	126	?			X	^{90}Sr, ^{3}H in run-off	0-50 mrem/yr whole body; 0-155 mrem/yr to skeleton			X	Leakage has been noted
West Valley, N.Y.		?			X				X		
h. Research and Development											
1) Residents near R.&D. facilities		?			X						See Appendix C

Population Description	Reference	Do Personal Data Exist?	Size			Radiation		Follow-Up in Phase II?			Comments
			Unique & Small	Small Not Unique	>10,000	Source of Exposure	Dose Range	No	Maybe	Yes	
d. Operation											
Nuclear Plant Communities	43				X	Gaseous effluents (gamma dose)	<10 mrad/yr			X	Low dose but large pop.
(Three Mile Island PA.)	121						80 mrad is maximum average is 1.5 mrad			X	Best possible population data around a nuclear reactor. Worth studying because of accidental release of radioactivity
(Saxton, PA)	122	?			X	External and Internal exposure due to uncontrolled gaseous release	----				Similar to above
Visitors to reactors	108				X	External exposure	less than 10 mrad	X			Dose too low to study

Population Description	Reference	Do Personal Data Exist?	Size			Radiation		Follow-Up in Phase II?			Comments
			Unique & Small	Small Not Unique	>10,000	Source of Exposure	Dose Range	No	Maybe	Yes	
e. Reprocessing and Plutonium fabrication communities	119										
Savannah River, S.C., Hanford, WA, Idaho Falls, ID		?			X	Pu and ^3H effluents	0-10^{-4} man-rad per MW(e)yr.			X	No significant mortality difference near Savannah River; Hanford has best environmental data
Rocky Flats, CO residents	123 124	?			X	Pu effluents	----			X	May have good environmental data
Palamares, Spain residents	125		X			Pu release		X			Too small
f. Transportation											

Population Description	Reference	Do Personal Data Exist?	Size			Radiation		Follow-Up in Phase II?			Comments
			Unique & Small	Small Not Unique	>10,000	Source of Exposure	Dose Range	No	Maybe	Yes	
5. Government											
a. Military											
1) Residents of Faeroe Islands	43	?			X	Higher levels of (I-131) and Sr-90 from fallout	?			X	Time is right for effects to become evident; 20 years have passed since exposure
2) Residents in high fallout areas (e.g. Nevada)	16 17 127	?			X	Radio isotopes from fallout Exposure of I-131 and Sr-90 through milk and food chain	0-10 rads			X	Dosimetry Data is difficult. (Those in northern Utah received twice the dose as those in southern Utah.)
Milk-drinking children of Utah and Nevada		?			X	I-131, Sr-90 in milk (taken into grass, eaten by cow)	Up 100 rad Thyroid dose		X		Probably have higher exposure to I-131 in fallout, children may be more sensitive to carcinoginisis

Population Description	Reference	Do Personal Data Exist?	Size			Radiation		Follow-Up in Phase II?			Comments
			Unique & Small	Small Not Unique	>10,000	Source of Exposure	Dose Range	No	Maybe	Yes	
b. Research and Development											
1) Residents near research labs (Oak Ridge, Los Alimos, Argonas, Lawrence Livermore, Brookhaven)	134	?			X	Effluents (gas & liquid) from research reactors and other facilities	Very low		X		See Appendix C
6. Education											
Residents near accelerators or research reactors (or down river)		?			X	Accelerator or effluents from reactor	Very low from accelerator and low from reactor <10 rad/yr	X			

Population Description	Reference	Do Personal Data Exist?	Size			Radiation		Follow-Up in Phase II?			Comments
			Unique & Small	Small Not Unique	>10,000	Source of Exposure	Dose Range	No	Maybe	Yes	
B. <u>Medical</u>											
1. <u>Diagnostic</u>											
Prenatal x-ray exposure											
a. (37) Northeast U.S. maternity hospitals 1947-1954	20	?			X	x-ray in utero	dose may be est. from # of films			X	Records are old but may still exist. Only a 1% sample was abstracted at time of 1962 study
Oxford Survey Data from 1953 - present England	135 136	Yes		X		x-ray in utero	200-460 mrad			X	Ongoing Research - A. Stewart, United Kingdom 8513 cases and matched controls

Population Description	Reference	Do Personal Data Exist?	Size			Radiation		Follow-Up in Phase II?			Comments
			Unique & Small	Small Not Unique	>10,000	Source of Exposure	Dose Range	No	Maybe	Yes	
Jefferson Davis Hospital Houston, TX (U.S.)	137	Yes		X		x-ray in utero	1035 mrad for two std films 1 AP 1 R lateral 1860 mrad for those with greater than the two std films			X	study data from 1972 should still be available (61 cases exposed)
Baltimore, MD Hospitals U.S. 1947-1967	21	?			X	x-ray in utero	--			X	Data may still be available No dosimetry given
TRI-STATE LEUKEMIA POPULATION N.Y. State } Minn/St. Paul } U.S. Baltimore } 1959-1962	138 139 140	Yes		X		x-ray in utero	--			X	319 cases; 884 controls No dosimetry given

Population Description	Reference	Do Personal Data Exist?	Size			Radiation		Follow-Up in Phase II?			Comments
			Unique = Small	Small Not Unique	≥10,000	Source of Exposure	Dose Range	No	Maybe	Yes	
											Ongoing Research - M. Meyer, Johns Hopkins University Ongoing Research - Roney and Chase BRH
b. Cardiac Catheterization Children's Hospital, Boston U.S. 1950's -	141 43	Yes		X		x-ray	60-70 rad adult skin dose			X	Personal Communication Dr. Bill Caldicott Dept. Radiology Children's Hospital, Boston, MA Good possibility of accurate dose estimates Larger group may be coordinated through American Heart Assoc.

Population Description	Reference	Do Personal Data Exist?	Size			Radiation		Follow-Up in Phase II?			Comments
			Unique & Small	Small Not Unique	≥10,000	Source of Exposure	Dose Range	No	Maybe	Yes	
c. Scoliosis Patients	141	Yes		X		x-ray	--		X		Personal Communication Dr. Bill Caldicott, Dept. Radiology Children's Hospital, Boston, MA International Scoliosis Society
d. Urology Patients Prague, Czechoslovakia	142	?		X		x-ray	1-4 rad skin dose			X	
U.S.	43	Yes		X			--				20.7 exams per 1000 persons in U.S.
Sweden	43						730 mrad whole body 38 mrad thyroid 1.2 rad skin dose				

Population Description	Reference	Do Personal Data Exist?	Size			Radiation		Follow-Up in Phase II?			Comments
			Unique & Small	Small Not Unique	>10,000	Source of Exposure	Dose Range	No	Maybe	Yes	
e. Mammography Patients	43 143	Yes			X	x-ray	skin dose 2-7.8 rad per exam (usually 2 films) breast dose 1-2 rad per exposure			X	Biological End Point: breast cancer
f. Thorotrast Patients 1928-1950	144	Yes			X	x-ray alpha Thorium-232 contrast medium	Avg yearly dose liver 25 rad lung 2-20 rad bone 7 rad marrow 9 rad kidney 0.4 rad			X	Most are high-dose, but lung, bone and kidney may be acceptably low dose
Denmark	145 146										
Portugal	147 148 149										
Germany	150-153										
Japan	154-156										
U.S.	157 158										

Population Description	Reference	Do Personal Data Exist?	Size			Radiation		Follow-Up in Phase II?			Comments
			Unique & Small	Small Not Unique	>10,000	Source of Exposure	Dose Range	No	Maybe	Yes	
g. Dental x-ray Patients	43	Yes			X	x-ray	whole body 2.9 mrad gonad .01 mrad thyroid 2-9 mrad lung .1 mrad breast .5 mrad skin .4 rad (per exposure)		X		May be possible to get records of films and estimate doses 300 exams per 1000 persons
h. Chest x-ray Screening	22 159 160	Yes			X	x-ray	(per exam) whole body 30 mrad gonad $<$3 mrad thyroid 17 mrad breast 55 mrad lung 80 mrad skin 140 mrad			X	Dosimetry often just # of films. Most hospital admissions for surgery require chest x-ray TB screening 251 exams per 1000 population - U.S.

Population Description	Reference	Do Personal Data Exist?	Size			Radiation		Follow-Up in Phase II?			Comments
			Unique & Small	Small Not Unique	>10,000	Source of Exposure	Dose Range	No	Maybe	Yes	
i. Barium Meal and Enema Patients	43	Yes			X	x-ray	<u>Meal</u> bone marrow 0.35-0.53 rad skin 1.5-2 radiograph 2 rad fluoroscopy <u>Enema</u> bone marrow .75-.95 rad skin 1.5 rad radiograph 20 rad fluoroscopy			X	Possible gonadal dose
j. Congenital Hip Dislocation and Legg-Perthes Disease x-ray Patients	141	Yes		X		x-ray	--		X		Personal Communication Dr. Bill Caldicott, Radiologist, Children's Hospital, Boston, MA Possible gonadal dose

Population Description	Reference	Do Personal Data Exist?	Size			Radiation		Follow-Up in Phase II?			Comments
			Unique & Small	Small Not Unique	>10,000	Source of Exposure	Dose Range	No	Maybe	Yes	
k. Neurologic x-ray Patients						x-ray	whole body 970 mrad gonad 10 mrad			X	Low doses to brain, spinal cord
Sweden - angiography	43	?		X			Active marrow 1500 mrad thyroid 300 mrad breast 10 mrad lung 10 mrad skin 1.0 rad (per exam)				
U.S. - CT scan	161	Yes		X			CT four scan exam intracranial 1.7-2.67 rad entrance dose 1.9-3.44 rad eye lens 0.23-2.81 rad				
l. Chiropractor's Patients		?		X		x-ray	--	X			Exposure data probably not available

Population Description	Reference	Do Personal Data Exist?	Size			Radiation		Follow-Up in Phase II?			Comments
			Unique & Small	Small Not Unique	>10,000	Source of Exposure	Dose Range	No	Maybe	Yes	
m. Lumbar Spine Exams	43	Yes			X	x-ray	Bone marrow 347 mrad per exam			X	U.S. (1970) 18.7 exams per 1000 people Gonadal dose
n. Stomach Ulcer x-ray patients	162	Yes			X	x-ray	--			X	Diagnostic for ulcers and cancer Ongoing research - M. Sakka *et al.* Japan
o. Multiple Fluoroscopy of Tuberculosis Patients						x-ray				X	
Massachusetts U.S. 1930-1954	163 164 165 166 167 42 168	Yes		X			before 1948 51.2 R/min or 12.75 R/15 sec film after 1948 24.1 R/min avg. 1.5 rad to both				High dose because of large number of exams per person. Lung dose a possibility for study. Ongoing Research - R. Monson and F. Davis Harvard School of Public Health

Population Description	Reference	Do Personal Data Exist?	Size: Unique & Small	Size: Small Not Unique	Size: >10,000	Radiation: Source of Exposure	Radiation: Dose Range	Follow-Up in Phase II?: No	Follow-Up in Phase II?: Maybe	Follow-Up in Phase II?: Yes	Comments
(o. cont)	169						breasts per exam Avg of 100 exams				Ongoing Research - J. Boice, NCI
Nova Scotia, Canada 1920-1950	170 171	Yes		X			4-20 rad per exam 600-1200 rad total			X	
Ontario, Canada	172	?		X			4-20 rad per exam			X	
Toronto, Canada	173	Yes		X			17 rad to breast total			X	
All Canada Study	174 175	Yes			X					X	

Population Description	Reference	Do Personal Data Exist?	Size			Radiation		Follow-Up in Phase II?			Comments
			Unique & Small	Small Not Unique	>10,000	Source of Exposure	Dose Range	No	Maybe	Yes	
2. Therapeutic											
a. Acne Treatment U.S. (50) Dermatology Offices	176 177	?		X		x-ray	--	X			Possible low dose to breast, thyroid No information on number of treatments Current study by Simon, *et al*, at Mt. Sinai School of Med.
b. Iodine - 131 Therapy Cleveland, OH 1946-1968	178 179	Yes			X	Iodine - 131 gamma	administered dose 1-25 mCi Avg. dose 10 mCi whole body dose 11-13 rad bone marrow 7-16 rad			X	Cooperative thyrotoxicosis therapy follow-up study

Population Description	Reference	Do Personal Data Exist?	Size			Radiation		Follow-Up in Phase II?			Comments
			Unique & Small	Small Not Unique	>10,000	Source of Exposure	Dose Range	No	Maybe	Yes	
c. Treatment for Post-Partum Mastitis Rochester, NY U.S. 1940-1955	180 166 167	Yes		X		x-ray 50-1065 R to single breast 35-875 R to both breasts	--			X	Mostly high dose - other organs as lung thyroid may have had lower dose
Sweden	181	Yes		X			1 or 2 to 4000 rads				

Population Description	Reference	Do Personal Data Exist?	Size			Radiation		Follow-Up in Phase II?			Comments
			Unique & Small	Small Not Unique	>10,000	Source of Exposure	Dose Range	No	Maybe	Yes	
d. X-ray Epilation for Tinea Capitis						x-ray				X	Thyroid, pituitary, eye received low dose
NYU Skin and Cancer Unit 1940-1959 U.S.	182 183 184 185 186	Yes		X			Scalp 450-850 rad Brain 70-175 rad 140 rad avg. Thyroid 6 rad Pituitary 49 rad Eye 47 rad Parotid 39 rad Midneck 21 rad				Ongoing Research - R. Albert, N.Y. University
Israel 1949-1960	187 188 189 190	Yes		X			Scalp 350-400 rad Brain 140 rad Thyroid <9 rad			X	Ongoing Research - B. Modan et al Israel

Population Description	Reference	Do Personal Data Exist?	Size: Unique & Small	Size: Small Not Unique	Size: >10,000	Radiation: Source of Exposure	Radiation: Dose Range	Follow-Up in Phase II?: No	Follow-Up in Phase II?: Maybe	Follow-Up in Phase II?: Yes	Comments
e. Therapy for Benign Gynecologic Diseases										X	Problem of confounding with predisposing factors
Roswell Park, NY 1930-1940 U.S.	191 192 43	Yes		X		x-ray Ra-226 alpha, gamma	av. 4000 rad at 2 cm				Possible low dose to other organs
United Kingdom 1940-1960 (3 studies)	193 194 195	Yes		X		x-ray	pelvis for induced sterility 500-1000 rad marrow 134 rad			X	

Population Description	Reference	Do Personal Data Exist?	Size			Radiation		Follow-Up in Phase II?			Comments
			Unique & Small	Small Not Unique	>10,000	Source of Exposure	Dose Range	No	Maybe	Yes	
f. Ankylosing Spondylitis Patients 1935-1954 United Kingdom	42 196 197	Yes			X	x-ray	single course patients (rads spine marrow 214 esoph. 306 stomach 67-89 colon 57 pancreas 90 bronch. 197 sp. cord 698 kidney 46 bladder 31			X	Possible low dose organs
g. Patients Injected with Ra-224 for Spondylitis or TB or Arthritis						Ra-224 alpha, gamma 18 μCi/kg					Bone marrow, kidney and breast may be low dose Pool populations for study

Population Description	Reference	Do Personal Data Exist?	Size			Radiation		Follow-Up in Phase II?			Comments
			Unique & Small	Small Not Unique	> 10,000	Source of Exposure	Dose Range	No	Maybe	Yes	
Germany 1948-1951	198 199 200	Yes		X			skeletal dose 200 rad liver < 200 rad bone 50-60 rad 250-300 μCi			X	
France 1964 -	201	Yes		X			spondylitics 560-1680 μCi arthritic joints 28-616 μCi			X	
h. Irradiated Head and Neck for Upper Respiratory Problems, Thymic Enlargement	202 203 183 204 205	Yes		X		x-ray one course of treatment gave 750-900 R to nasopharynx	--			X	Possibility of low dose organs as breast
Michael Reese Hosp Chicago, Ill. U.S. 1940-1950's						Intranasal Radium Capsules alpha, gamma	--				Ongoing Research - [illegible] Cohen, Chicago, Illinois Ongoing Research - J. Boice, NCI

Population Description	Reference	Do Personal Data Exist?	Size			Radiation		Follow-Up in Phase II?			Comments
			Unique & Small	Small Not Unique	>10,000	Source of Exposure	Dose Range	No	Maybe	Yes	
i. Brachytherapy Patients									X		
Austria		Yes		X		Ra-226 alpha, gamma	420 rad total to fetus				Only one documented case - involved healthy, exposed fetus Doses to other organs may be low
U.S.		Yes		X			--				
j. Implant Patients Families	206 207	Yes		?		Internal Iodine - 131 gamma			X		
Plymouth, Devon, England						External x-ray	<20 to 270 mrad		X		

Population Description	Reference	Do Personal Data Exist?	Size: Unique & Small	Size: Small Not Unique	Size: >10,000	Radiation: Source of Exposure	Radiation: Dose Range	Follow-Up in Phase II?: No	Follow-Up in Phase II?: Maybe	Follow-Up in Phase II?: Yes	Comments
k. Wearers of Uranium-Fabricated Dentures	43	?			?	U-238 Beta	3 rad to basal cell layer of mouth per year		X		
l. Nuclear Powered Pacemakers		?				?	--		X		Possible fluoroscopy during insertion
m. Polycythemia Vera Patients	208	?	X			P-32 Beta 4 mCi per treatment (may get 4 treatments per year)	--	X			Systemic exposure Very rare disease
n. Cervical Cancer Patients	209 210	Yes		X		x-rays Radium implants Ra-226 gamma	4000-6000 rad to cervix for treatment			X	Possibility of low organ doses. Ongoing Research - G. Hutchison, Harvard School of Public Health

U.S. Tumor Registries

Location	Area Covered	Duration	Sponsor	Contact Person
Connecticut	Statewide	35 yrs.	NCI	Dr. John Flamery
Iowa	Statewide	6 yrs.	NCI	Dr. Peter Isaacson
New Mexico	Statewide	6 yrs.	NCI	Dr. Charles Key
Utah	Statewide	6 yrs.	NCI	Dr. Joseph Lyon
Rocky Mountain States	MT, ID, WY Parts of CO, NV, AZ, OR	6 yrs.	Utah Health Dept.	Dr. Joseph Lyon
Hawaii	Islands	6 yrs.	NCI	Dr. Larry Piet
Puerto Rico	Islands	6 yrs.	NCI	Dr. Isidro Martinez
San Francisco/Oakland	SMSA	6 yrs.	NCI	Dr. Don Austin
Detroit	SMSA	6 yrs.	NCI	Dr. Michael Brannon
Atlanta	SMSA	6 yrs.	NCI	Dr. Margery Child
New Orleans	SMSA	6 yrs.	NCI	Dr. Edward Cremens
New York	Statewide excluding NYC (incidence only)	----	State Health Dept.	--------
New Jersey	Statewide (incidence only)	----	State Health Dept.	--------
Massachusetts	Regions and Hospitals	----	Mass. General Hosp. & others	Ms. Joan Pardo, HEW Reg. Cancer Control
Texas, Pennsylvania Delaware, et al.	----	Being Developed	NCI	Dr. John Young, NCI Surveillance Network Coordinator

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208. E. Rubenstein and D.D. Federman, in Medicine, Sec. 5 Hematology, Scientific American, NY, 1979. Available from Scientific American Publishing, NY.

209. C.A.F. Joslin, C. Eng, C.W. Smith et al, "The Treatment of Cervix Cancer Using High Activity Cobalt-60 Sources," British Journal of Radiology 45:257-270 (1972). Available from public technical libraries.

210. "Risk of Leukemia in Patients Receiving Radiotherapy for Cervical Cancer," HEW/NCI on-going research, Dr. George Hutchison, Harvard School of Public Health, Dept. of Epidemiology, Boston, MA 02115.

APPENDIXES

APPENDIX A

Mail Inquiry
and
List of Addresses

Appendix A contains a sample of the general letter we sent to individuals and groups concerned with radiation protection. The sample letter is followed by a list of people to whom it was sent. Contacts in the United States and foreign contacts are listed separately.

equifax
HEALTH SYSTEMS DIVISION 100 MAIN STREET READING MASS 01867 (617) 942-0051
SYSTEMEDICS INC

July 18, 1979

Dear Colleague:

We are conducting a feasibility study to determine populations at risk of adverse health effects from low-level ionizing radiation. This feasibility study is supported by a contract from the Nuclear Regulatory Commission. Any subsequent epidemiologic investigations that might result from our study probably will be conducted by other Federal agencies.

In order to establish a comprehensive list of all the potential groups who might be studied, we are asking a wide range of individuals and organizations concerned about environmental radiation to suggest candidate populations. We are interested in occupational and residential populations, medically exposed (diagnostic or therapeutic) groups and other potential populations who might have exposure to low-level ionizing radiation (less than approximately 12 rems annual exposure). We are also interested in acquiring information on any groups that may have had exposure to uniquely low levels of radiation, especially those lower than normal background.

Would you please look at the enclosed sheet and fill in any categories about which you are concerned or have some knowledge? Please use the enclosed envelope to return the list to us. We hope to complete the initial list of all candidate populations by August 15. Then we will look further into their feasibility for study as we complete Phase I of our contract.

Thank you very much for your help in this project. We look forward to hearing from you.

Sincerely,

HEALTH SYSTEMS DIVISION

Nancy a Dreyer

Nancy A. Dreyer, M.P.H., Ph.D.
Director of Epidemiologic Research

NAD: paw
Enclosure

APPENDIX

United States Contacts

Institution	Contact
Agency for International Development Office of Population DS/POP Washington, D.C.	James D. Shelton, M.D., M.P.H.
Alliance-Tallahassee Tallahassee, FL	--
American Friends Service Committee Nuclear Transportation Project High Point, NC	Mr. William Reynolds
American Friends Service Committee Rocky Flats Project Denver, CO	Ms. Pam Solo
Appalachian Laboratory for Occupational Safety and Health Morgantown, WV	Dr. James A. Merchant
Argonne National Laboratory Argonne, IL	Dr. Robert E. Rowland
Atomic Industrial Forum (AIF) Washington, D.C.	E. David Harward
Barelle Human Affairs Research Centers Seattle, Washington	Dr. James Woods
Boston Industrial Mission Cambridge, MA.	Mary Roodkowsky
Boston University Health Policy Center Boston, MA	Dr. William Bicknell
Cactus Alliance Albuquerque, NM	Jodi Bastlett-Lagorio
Childrens Hospital Medical Center Boston, MA	Dr. Helen Caldicott Dr. William Caldicott
Committee for Nuclear Responsibility San Francisco, CA	--
Critical Mass Energy Project Washington, D.C.	--

Institution	Contact
Dow Chemical Bio-Medical Research Midland, MI	Ralph R. Cook, M.D., M.P.H.
Environmental Action Foundation Washington, D.C.	--
Environmental Defense Fund Washington, D.C.	Mr. Leslie Dach
Environmental Policy Center Washington, D.C.	--
Environmental Policy Institute Radiation Health Information Project Washington, D.C.	Mr. Robert Alvarez
Friends of the Earth Washington, D.C.	Dr. David Brower
Harvard Medical School Boston, MA	Dr. David Rutstein
Harvard School of Public Health Dept. of Epidemiology Boston, MA	Dr. Brian MacMahon Dr. George Hutchison
Health Research Group Washington, D.C.	Dr. Sidney Wolfe
Institute of Environmental Medicine Laboratory for Environmental Studies Tuxedo, NY	Dr. Merril Eisenbud
International Brotherhood of Electrical Workers Washington, D.C.	Mr. Charles Pillard
International Brotherhood of Teamsters Health and Safety Department Washington, D.C.	Mr. Stephen J. McDougall
The Johns Hopkins School of Hygiene and Public Health Environmental Health Engineering Division Baltimore, MD	Dr. K. Kawata Charles E. Billings, Ph.D. Dr. Cornelius Kruse
The Johns Hopkins School of Hygiene and Public Health Department of Epidemiology Baltimore, MD	Dr. Abraham M. Lilienfeld Genevieve M. Matanoski, M.D., Dr.P.H.

Institution	Contact
The Johns Hopkins School of Hygiene and Public Health Division of Radiation Health Science Baltimore, MD	Dr. Thomas Mitchell
Massachusetts Audubon Society Lincoln, MA	Ms. Deborah Bleviss
Massachusetts Dept. of Public Health Environmental Health Division Boston, MA	Dr. Gerald Parker
Massachusetts Dept. of Public Health Office of the General Counsel Boston, MA	Mr. Gerald Rodman
Massachusetts Institute of Technology Dept. of Nuclear Engineering Cambridge, MA	Dr. Norman C. Rasmussen
Massachusetts Public Interest Research Group (Mass PIRG) Boston, MA	Mr. Frank Bove
Mobilization for Survival Philadelphia, PA	Terry Provance
Mt. Sinai Medical Center Dept. of Community Medicine New York, NY	Dr. Irving J. Selikoff Dr. Steven Blum
National Cancer Institute Environmental Epidemiology Branch Bethesda, MD	Dr. Charles Land John D. Boice, Jr., Sc.D.
National Commission on Air Quality Washington, D.C.	Mr. Gregory J. Prang
National Council on Radiation Protection and Measurements Washington, D.C.	Dr. Warren Sinclair W. Roger Ney
National Institute of Environmental Health Sciences (NIEHS) Research Triangle Park, NC	Dr. Allen Wilcox

Institution	Contact
National Institute of Occupational Safety and Health (NIOSH) Cincinnati, OH	Mr. Robert Rinsky Ms. Sherry Selevan Mr. William E. Murray
National Institute of Occupational Safety and Health (NIOSH) Biometry Branch Cincinnati, OH	Dr. Richard Waxweiller
National Institute of Occupational Safety and Health Educational Resource Center Harvard School of Public Health Boston, MA	Dr. John M. Peters
National Research Council Medical Follow-Up Agency Washington, D.C.	Mr. Seymour Jablon
National Resources Defense Council Washington, D.C.	Mr. Arthur Tamplin
National Veterans Law Center American University College of Law Washington, D.C.	Mr. Lewis Milford
Natural Resources Defense Council, Inc. New York, NY	Dr. Louis Slesin
New York University Medical Center Dept. of Occupational Medicine New York, NY	Dr. Roy Albert
Nuclear Information and Resource Service Washington, D.C.	Ms. Betsy Taylor
Oak Ridge Associated University Medical and Health Sciences Division Oak Ridge, TN	Dr. Anthony Polednak
Oil, Chemical and Atomic Workers Washington, D.C.	Mr. Anthony Mazzochi Mr. Steve Wodka
Pennsylvania State University College of Human Development	Dr. Vilma R. Hunt
Presbyterian-University Hospital Radiation Medicine Dept. Pittsburgh, PA	Dr. Neil Wald

Institution	Contact
Scientists Institute for Public Information New York, NY	--
Sierra Club Washington, D.C.	--
Southwest Research and Information Center Albuquerque, NM	--
Task Force Against Nuclear Pollution Washington, D.C.	--
Union of Concerned Scientists Cambridge, MA	--
United States Congress Office of Technology Assessment Washington, D.C.	Joyce Lashof, M.D.
United States Dept. of Energy Office of Health and Environmental Research Washington, D.C.	Dr. Walter Weyzen
United States Dept. Health, Education and Welfare Bureau of Radiological Health Rockville, MD	John C. Villforth
United States Dept. of Labor Benefits Review Board Washington, D.C.	Ms. Sydnee Schwartz
University of California General Tumor Registry San Francisco, CA	Dr. Calvin Zippin
University of California Institute of Industrial Relations Labor Occupational Health Program	Dr. Andrea Hricko
University of Calfornia Medical Center Office of Environmental Health and Safety San Francisco, CA	Dr. Reynold Brown
University of North Carolina at Chapel Hill Department of Epidemiology	Dr. H.A. Tyroler

Institution	Contact
University of North Carolina at Chapel Hill Institute for Environmental Studies	Dr. Carl Shy
University of Pittsburgh Graduate School of Public Health	Dr. Edward P. Radford
Upper Valley Energy Coalition Lebanon, NH	John R. Krause, Jr.
Washington University Center for the Biology of Natural Systems St. Louis, MO	Dr. Barry Commoner
Women's Occupational Health Resource Center American Health Foundation	Dr. Jeanne Stellman Ms. Naomi Fatt

Foreign Contacts

Deutsches Krebsforschungzeutrum Institut fur Nucklearmedizin Heidelberg, Germany	Dr. Gerhard van Kaick
Ecole Nationale de la Sante Publique Department of Biostatistics Rennes, Brittany, France	Professor Louis M.F. Masse
Finsenlabor, Finsen Institutet Copenhagen, Denmark	Professor Dr. Mogeus Faber
Greenpeace Ltd. London, England	--
Institut National do la Sante et de la Recherche Paris, France	Professor Daniel Schwartz
Medical Research Council External Scientific Staff Radiology Unit Oxfordshire, England	R.H. Mole, B.M., F.R.C.P., F.R.C.Path.
Movement Against Uranium Mining Carlton Victoria, Fitzroy, Australia	--
National Radiological Protection Board Harwell, Didcot Oxfordshire, England	Sir Edward Pochin Dr. J.A. Reissland

Institution	Contact
Nuclear Information Network London, England	--
Scottish Campaign to Resist the Atomic Menace Edinburgh, Scotland	--
Services des Nuisances Ministere do la Sante Publique et de la Famille Brussels, Belgium	Mr. L. Baekelandt
World Information Service on Energy (WISE) Amsterdam, Netherlands	--

Other Individuals

Representative Michael Barrett
State House
Boston, MA

Dr. Howard Newcombe
Chalk River, Ontario, Canada

Dr. Phillip Sartwell
Marblehead, MA

Ms. Julieann Sum
Cambridge, MA

APPENDIX B

Nuclear Reactors Built, Being Built, or Planned in the United States as of December 31, 1977.

Prepared and Published By:

Technical Information Center
Department of Energy
TIO-8200-R37
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NUCLEAR REACTORS BUILT, BEING BUILT, or PLANNED

Map Showing Locations of U. S. Nuclear Power Plants and a Listing of the Plants by States

CIVILIAN REACTORS

- Central-Station Electric Power
- Dual-Purpose Plants
- Maritime Propulsion
- Experimental Electric Power
- Auxiliary Power (SNAP)
- Space Propulsion (Rover)
- General Irradiation Test
- High-Power Research and Test
- Safety Research and Test
- General Research
- University Research and Teaching

PRODUCTION REACTORS

- Materials Production
- Process Development

MILITARY REACTORS

- Remote-Station Power
- Propulsion (Naval)
- Developmental Power
- Test Reactors
- Research Reactors

REACTORS FOR EXPORT

- Central-Station Electric Power
- Propulsion
- General Irradiation Test
- General Research
- University Research and Teaching

CRITICAL ASSEMBLY FACILITIES

- Identification of Facilities
- Experiments and Studies

Reactor Index

STATISTICAL SUMMARY

	Operable	Being built	Planned	Shut down or dismantled
I. CIVILIAN REACTORS				
1. Power Reactors				
A. Central-Station Electric Power	67	94	50	8
B. Dual-Purpose Plants	1	2		
C. Propulsion (Maritime)				1
2. Experimental Power-Reactor Systems				
A. Electric-Power Systems	1			23
B. Auxiliary Power (SNAP)				9
C. Space Propulsion (Rover)				21
3. Test, Research, and University Reactors				
A. General Irradiation Test	3	1		3
B. High-Power Research and Test	9			4
C. Safety Research and Test	3	1		8
D. General Research	24	1	1	40
E. University Research and Teaching	54	1		9
II. PRODUCTION REACTORS				
1. Materials Production	3			10
2. Process Development	4			1
III. MILITARY REACTORS				
1. Defense Power-Reactor Applications				
A. Remote Installations	1			5
B. Propulsion (Naval)	121	28		5
2. Developmental Power				
A. Electric-Power Experiments and Prototypes				3
B. Propulsion Experiments and Prototypes	7			7
3. Test and Research				
A. Test				4
B. Research	6			3
IV. REACTORS FOR EXPORT				
1. Power Reactors				
A. Central-Station Electric Power	21	28	14	2
B. Propulsion	1			
2. Test, Research, and Teaching				
A. General Irradiation Test	4			
B. General Research	30			1
C. University Research and Teaching	26			

FOREWORD

This compilation contains unclassified information about facilities built, being built, or planned in the United States for domestic use or export as of Dec. 31, 1977, which are capable of sustaining a nuclear chain reaction. Information is presented in five parts, each of which is categorized by primary function or purpose. The major parts, namely, civilian, military, production, and export, as well as such categories as power and propulsion, are self-explanatory. Various classes of reactors within these categories are defined as follows:

CENTRAL STATION NUCLEAR POWER PLANT

A facility designed and constructed for operation on a utility system. The primary purpose of some of these plants is to demonstrate the economic and technical potential of future plants of the same general type; others, particularly those of the light-water type, are expected to be economically competitive with conventionally fueled plants in the geographic area in which they are located. (Part I, Sec. 1A)

DUAL PURPOSE PLANT

A nuclear power facility designed, constructed, and operated for more than one primary purpose, for example, the production of nuclear materials and the generation of electricity or the use of reactor thermal energy for electrical generation and process-heat applications including desalting. (Part I, Sec. 1B)

EXPERIMENTAL POWER REACTOR

A facility designed, engineered, constructed, and operated to test the technical feasibility of a concept or to provide the technical basis for a similar type nuclear power plant in a larger size. Design flexibility permits changes to prove out various aspects of reactor technology including fuel and other components. Power-conversion equipment may or may not be included as part of the facility. (Part I, Sec. 2A)

GENERAL IRRADIATION TEST REACTOR

A reactor having (1) a thermal power level exceeding 10,000 kW; (2) test loops or experimental facilities within, or in proximity to, the core; and (3) the use of nuclear radiation for testing the life or performance of reactor components as its major function. (Part I, Sec. 3A, and Part IV, Sec. 2A)

HIGH POWER RESEARCH AND TEST REACTOR

A reactor having a relatively high thermal power level (5000 kW or more) but not classed as a general irradiation test reactor. (Part I, Sec. 3B)

SAFETY RESEARCH AND TEST REACTOR

A reactor associated with a nuclear safety research or engineering-scale test program conducted for the purpose of developing basic design information or demonstrating safety characteristics of terrestrial and aerospace nuclear reactor systems. (Part I, Sec. 3C)

RESEARCH REACTOR

A reactor — excluding that located at a university — whose nuclear radiations are used primarily as a research tool for basic or applied research, and whose thermal power level is less than 5000 kW. It may include facilities for testing reactor materials. (Part I, Sec. 3D; Part III, Sec. 3B; and Part IV, Sec. 2B)

UNIVERSITY RESEARCH AND TEACHING REACTOR

A reactor located at a university and usually operated for the primary purpose of training in the operation and utilization of reactors and for instruction in reactor theory and performance. (Part I, Sec. 3E, and Part IV, Sec. 2C)

SPECIAL TEST REACTOR

A reactor designed for special testing purposes. (Part III, Sec. 3A)

CRITICAL FACILITY

A reactor capable of sustaining a nuclear chain reaction operating at extremely low power (a few watts) and designed to determine a critical mass, neutron-flux distribution, and other characteristics of a flexible arrangement of nuclear fuel, construction materials, coolant, and other reactor components. Fluid critical facilities are used to explore the critical masses of various concentrations of solutions in differing geometries. Metal critical assemblies are used to investigate the variations in heterogeneous cores. The tabulation of these facilities in Part V (pp. 37-38) excludes those which have been operated and subsequently dismantled.

The abbreviated listings in the principal nuclear contractor column refer to the technical organization assigned primary responsibility for design and/or fabrication of the reactor system. The spelled-out forms for these abbreviations as well as those for designers, shipbuilders, and facility operators, are given in the table on page 12.

Startup dates refer to the year of first criticality. Estimated startup dates based on the best available information are included for projects not yet in service. The dates for non-DOE projects are estimates announced by the sponsoring organizations. Years of initial commercial operation for power reactors are given in the tabulation on pages 6 to 11.

Reactors are listed as being *operable* under the following circumstances:

1. Federal Government reactors* when criticality is achieved.
2. Non-Federal Government reactors in the United States—when criticality is achieved, or, in the case of relatively low power systems, an operating license is issued by the Nuclear Regulatory Commission (NRC).
3. Reactors for foreign locations—when criticality is achieved.

Reactors are listed as *being built* under the following circumstances:

1. Federal Government reactors* when ground is broken, components are ordered, or construction contract is awarded.
2. Non-Federal Government reactors in the United States—when a construction permit or limited work authorization is issued by NRC.
3. Reactors for foreign locations—when an application for an export license is received by NRC or when reliable information is received relating to the fabrication of reactor components.

Reactors are listed as being *planned* under the following circumstances:

1. Federal Government reactors when publicly announced as a project planned for construction by the agency involved or the project is otherwise appropriately authorized.
2. Non-Federal Government reactors in the United States when a public announcement that includes principal contractor and reactor type is made by the sponsoring organization or an application for a construction permit is received by NRC.
3. Reactors for foreign locations when public announcement that includes principal contractor and reactor type is made or when NRC receives information that a U.S. reactor manufacturer is proceeding with preconstruction design and development on the basis of a letter of intent.

Reactors are listed as *shut down* or *dismantled* when the owner announces or verifies a decision to permanently shut down a facility and does not intend to restart the reactor. A reactor shut down owing to technical problems, extensive modifications, or refueling continues to be listed as *operable*.

The Statistical Summary on page 2 excludes critical facilities. All other categories are summarized. Shutdown and dismantled reactors in these categories are included since such facilities have made significant contributions to reactor technology.

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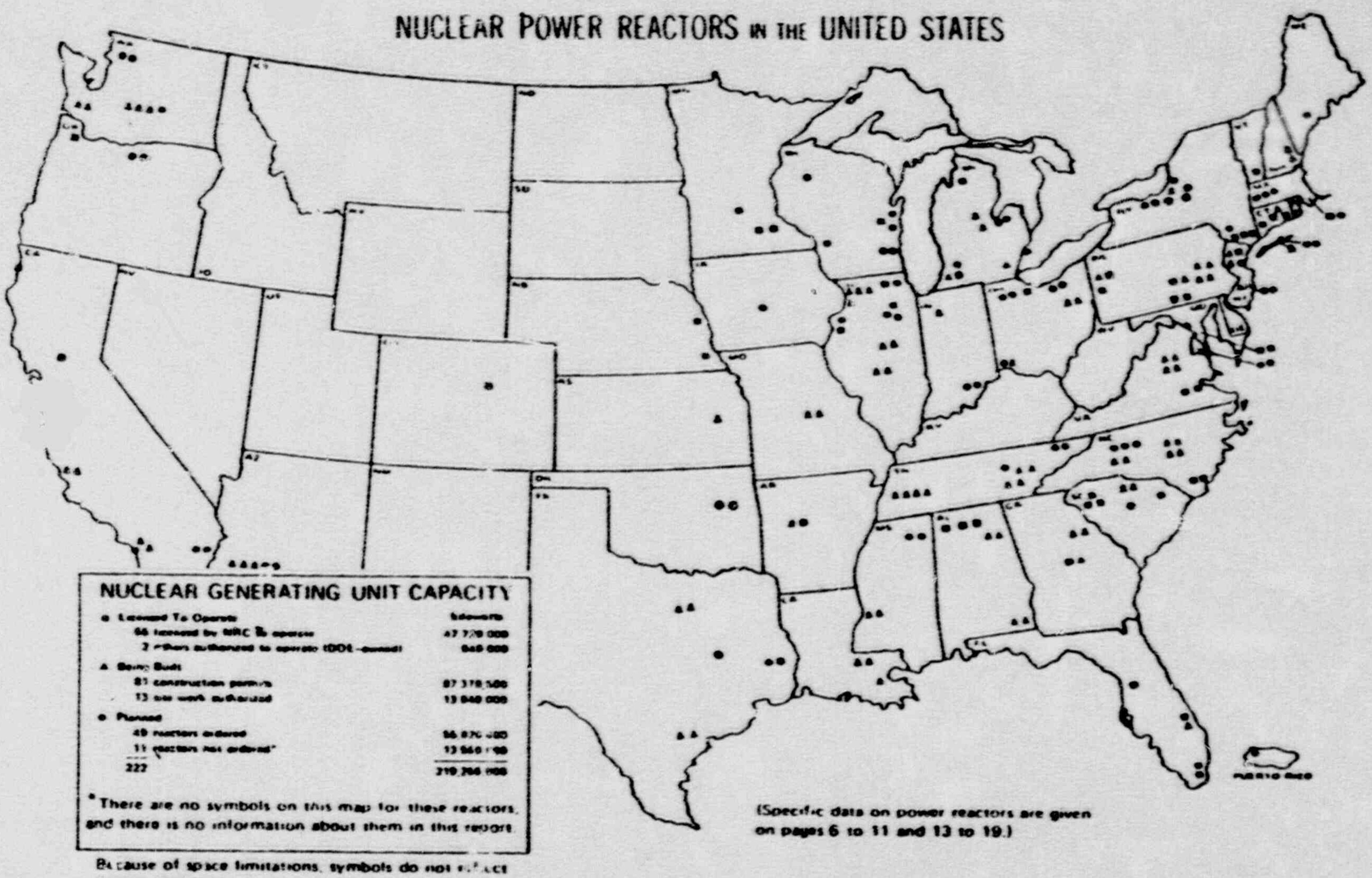
*Other than those of the Tennessee Valley Authority which are licensed by NRC and are treated in accordance with item 2.

NUCLEAR POWER REACTORS IN THE UNITED STATES



NUCLEAR GENERATING UNIT CAPACITY

	Kilowatts
● Licensed To Operate	
66 licensed by NRC to operate	47 770 000
2 others authorized to operate (DOE-owned)	848 000
▲ Being Built	
81 construction permits	87 378,500
13 site work authorized	13 840 000
● Planned	
49 reactors ordered	56 870 000
11 reactors not ordered*	13 560 000
222	219,266 000

*There are no symbols on this map for these reactors, and there is no information about them in this report.

Because of space limitations, symbols do not reflect precise locations.

(Specific data on power reactors are given on pages 6 to 11 and 13 to 19.)

COMMERCIAL NUCLEAR POWER REACTORS IN THE UNITED STATES

SITE	PLANT NAME	CAPACITY NET kW(e)	UTILITY	COMMERCIAL OPERATION
ALABAMA				
Decatur	Browns Ferry Nuclear Power Plant: Unit 1	1,065,000	Tennessee Valley Authority	1974
Decatur	Browns Ferry Nuclear Power Plant: Unit 2	1,065,000	Tennessee Valley Authority	1975
Decatur	Browns Ferry Nuclear Power Plant: Unit 3	1,065,000	Tennessee Valley Authority	1977
Dothan	Joseph M. Farley Nuclear Plant: Unit 1	820,000	Alabama Power Co.	1977
Dothan	Joseph M. Farley Nuclear Plant: Unit 2	820,000	Alabama Power Co.	1980
Scottsboro	Bellefonte Nuclear Plant: Unit 1	1,213,000	Tennessee Valley Authority	1980
Scottsboro	Bellefonte Nuclear Plant: Unit 2	1,213,000	Tennessee Valley Authority	1981
ARIZONA				
Wintersburg	Palo Verde Nuclear Generating Station: Unit 1	1,237,700	Arizona Public Service	1983
Wintersburg	Palo Verde Nuclear Generating Station: Unit 2	1,237,700	Arizona Public Service	1984
Wintersburg	Palo Verde Nuclear Generating Station: Unit 3	1,237,700	Arizona Public Service	1986
Wintersburg	Palo Verde Nuclear Generating Station: Unit 4	1,237,700	Arizona Public Service	1988
Wintersburg	Palo Verde Nuclear Generating Station: Unit 5	1,237,700	Arizona Public Service	1990
ARKANSAS				
Russellville	Arkansas Nuclear One: Unit 1	850,000	Arkansas Power & Light Co.	1974
Russellville	Arkansas Nuclear One: Unit 2	912,000	Arkansas Power & Light Co.	1978
CALIFORNIA				
Eureka	Humboldt Bay Power Plant: Unit 3	63,000	Pacific Gas & Electric Co.	1963
San Clemente	San Onofre Nuclear Generating Station: Unit 1	430,000	So. Calif. Ed. & San Diego Gas & El. Co.	1968
San Clemente	San Onofre Nuclear Generating Station: Unit 2	1,100,000	So. Calif. Ed. & San Diego Gas & El. Co.	1981
San Clemente	San Onofre Nuclear Generating Station: Unit 3	1,100,000	So. Calif. Ed. & San Diego Gas & El. Co.	1981
Diablo Canyon	Diablo Canyon Nuclear Power Plant: Unit 1	1,084,000	Pacific Gas & Electric Co.	1978
Diablo Canyon	Diablo Canyon Nuclear Power Plant: Unit 2	1,106,000	Pacific Gas & Electric Co.	1978
Clay Station	Rancho Seco Nuclear Generating Station	918,000	Sacramento Municipal Utility District	1975
Site not selected	Unit 1	1,200,000	Pacific Gas & Electric Co.	Indef.
Site not selected	Unit 2	1,200,000	Pacific Gas & Electric Co.	Indef.
Blythe	Sundesert Nuclear Plant: Unit 1	974,000	San Diego Gas & Electric Co.	1984
Blythe	Sundesert Nuclear Plant: Unit 2	974,000	San Diego Gas & Electric Co.	1986
COLORADO				
Platteville	Ft. St. Vrain Nuclear Generating Station	330,000	Public Service Co. of Colorado	1978
CONNECTICUT				
Haddam Neck	Haddam Neck Plant	575,000	Conn. Yankee Atomic Power Co.	1968
Waterford	Millstone Nuclear Power Station: Unit 1	660,000	Northeast Nuclear Energy Co.	1971
Waterford	Millstone Nuclear Power Station: Unit 2	830,000	Northeast Nuclear Energy Co.	1975
Waterford	Millstone Nuclear Power Station: Unit 3	1,156,000	Northeast Nuclear Energy Co.	1986
FLORIDA				
Florida City	Turkey Point Station: Unit 3	693,000	Florida Power & Light Co.	1972
Florida City	Turkey Point Station: Unit 4	693,000	Florida Power & Light Co.	1973
Red Level	Crystal River Plant: Unit 3	825,000	Florida Power Corp.	1977
Ft. Pierce	St. Lucie Plant: Unit 1	802,000	Florida Power & Light Co.	1976
Ft. Pierce	St. Lucie Plant: Unit 2	802,000	Florida Power & Light Co.	1983
GEORGIA				
Baxley	Edwin I. Hatch Nuclear Plant: Unit 1	786,000	Georgia Power Co.	1975
Baxley	Edwin I. Hatch Nuclear Plant: Unit 2	795,000	Georgia Power Co.	1978
Waynesboro	Alvin W. Vogtle, Jr. Plant: Unit 1	1,110,000	Georgia Power Co.	1985
Waynesboro	Alvin W. Vogtle, Jr. Plant: Unit 2	1,110,000	Georgia Power Co.	1986

COMMERCIAL NUCLEAR POWER REACTORS IN THE UNITED STATES (Continued)

SITE	PLANT NAME	CAPACITY NET kW(e)	UTILITY	COMMERCIAL OPERATION
ILLINOIS				
Morris	Dresden Nuclear Power Station: Unit 1	200,000	Commonwealth Edison Co.	1960
Morris	Dresden Nuclear Power Station: Unit 2	794,000	Commonwealth Edison Co.	1970
Morris	Dresden Nuclear Power Station: Unit 3	794,000	Commonwealth Edison Co.	1971
Zion	Zion Nuclear Plant: Unit 1	1,040,000	Commonwealth Edison Co.	1973
Zion	Zion Nuclear Plant: Unit 2	1,040,000	Commonwealth Edison Co.	1974
Cordova	Quad-Cities Station: Unit 1	789,000	Comm. Ed. Co.-Ia.-Ill. Gas & Elec. Co.	1973
Cordova	Quad-Cities Station: Unit 2	789,000	Comm. Ed. Co.-Ia.-Ill. Gas & Elec. Co.	1973
Seneca	LaSalle County Nuclear Station: Unit 1	1,078,000	Commonwealth Edison Co.	1979
Seneca	LaSalle County Nuclear Station: Unit 2	1,078,000	Commonwealth Edison Co.	1980
Byron	Byron Station: Unit 1	1,120,000	Commonwealth Edison Co.	1981
Byron	Byron Station: Unit 2	1,120,000	Commonwealth Edison Co.	1983
Braidwood	Braidwood: Unit 1	1,120,000	Commonwealth Edison Co.	1982
Braidwood	Braidwood: Unit 2	1,120,000	Commonwealth Edison Co.	1983
Clinton	Clinton Nuclear Power Plant: Unit 1	933,400	Illinois Power Co.	1981
Clinton	Clinton Nuclear Power Plant: Unit 2	933,400	Illinois Power Co.	1988
INDIANA				
Westchester	Bailly Generating Station	645,800	Northern Indiana Public Service Co.	1983
Madison	Marble Hill Nuclear Power Station: Unit 1	1,130,000	Public Service Indiana	1982
Madison	Marble Hill Nuclear Power Station: Unit 2	1,130,000	Public Service Indiana	1984
IOWA				
Palo	Duane Arnold Energy Center Unit 1	538,000	Iowa Electric Light and Power Co.	1975
Vandalia	Vandalia Nuclear Project	1,270,000	Iowa Power & Light Co.	Indef.
KANSAS				
Burlington	Wolf Creek Generating Station Unit 1	1,150,000	Kansas Gas & Electric – Kansas City P&L	1983
LOUISIANA				
Taft	Waterford Generating Station Unit 3	1,113,000	Louisiana Power & Light Co.	1981
St. Francisville	River Bend Station: Unit 1	934,000	Gulf States Utilities Co.	1983
St. Francisville	River Bend Station: Unit 2	934,000	Gulf States Utilities Co.	1985
MAINE				
Wiscasset	Maine Yankee Atomic Power Plant	790,000	Maine Yankee Atomic Power Co.	1972
MARYLAND				
Lusby	Calvert Cliffs Nuclear Power Plant: Unit 1	845,000	Baltimore Gas and Electric Co.	1975
Lusby	Calvert Cliffs Nuclear Power Plant: Unit 2	845,000	Baltimore Gas and Electric Co.	1977
Douglas Point (Utility is negotiating to cancel.)	Douglas Point Project Nuclear Gen. Station: Unit 1	1,178,000	Potomac Electric Power Co.	Indef.
Douglas Point (Utility is negotiating to cancel.)	Douglas Point Project Nuclear Gen. Station: Unit 2	1,178,000	Potomac Electric Power Co.	Indef.
MASSACHUSETTS				
Rowe	Yankee Nuclear Power Station	175,000	Yankee Atomic Electric Co.	1961
Plymouth	Pilgrim Station: Unit 1	655,000	Boston Edison Co.	1972
Plymouth	Pilgrim Station: Unit 2	1,180,000	Boston Edison Co.	1984
Montague	Montague: Unit 1	1,150,000	Northeast Utilities	1988
Montague	Montague: Unit 2	1,150,000	Northeast Utilities	1990
MICHIGAN				
Big Rock Point	Big Rock Point Nuclear Plant	72,000	Consumers Power Co.	1963
South Haven	Palisades Nuclear Power Station	668,000	Consumers Power Co.	1971
Newport	Enrico Fermi Atomic Power Plant: Unit 2	1,093,000	Detroit Edison Co.	1980
Bridgman	Donald C. Cook Plant: Unit 1	1,054,000	Indiana & Michigan Electric Co.	1975
Bridgman	Donald C. Cook Plant: Unit 2	1,060,000	Indiana & Michigan Electric Co.	1978

COMMERCIAL NUCLEAR POWER REACTORS IN THE UNITED STATES (Continued)

SITE	PLANT NAME	CAPACITY NET kW(e)	UTILITY	COMMERCIAL OPERATION
MICHIGAN (Continued)				
Midland	Midland Nuclear Power Plant Unit 1	460,000	Consumers Power Co.	1982
Midland	Midland Nuclear Power Plant Unit 2	811,000	Consumers Power Co.	1981
St. Clair County	Greenwood: Unit 2	1,200,000	Detroit Edison Co.	1987
St. Clair County	Greenwood: Unit 3	1,200,000	Detroit Edison Co.	1989
MINNESOTA				
Monticello	Monticello Nuclear Generating Plant	545,000	Northern States Power Co.	1971
Red Wing	Prairie Island Nuclear Generating Plant: Unit 1	530,000	Northern States Power Co.	1973
Red Wing	Prairie Island Nuclear Generating Plant: Unit 2	530,000	Northern States Power Co.	1974
MISSISSIPPI				
Corinth	Yellow Creek: Unit 1	1,285,000	Tennessee Valley Authority	1985
Corinth	Yellow Creek: Unit 2	1,285,000	Tennessee Valley Authority	1986
Port Gibson	Grand Gulf Nuclear Station: Unit 1	1,250,000	Mississippi Power & Light Co.	1981
Port Gibson	Grand Gulf Nuclear Station: Unit 2	1,250,000	Mississippi Power & Light Co.	1984
MISSOURI				
Fulton	Callaway Plant: Unit 1	1,120,000	Union Electric Co.	1982
Fulton	Callaway Plant: Unit 2	1,120,000	Union Electric Co.	1987
NEBRASKA				
Fort Calhoun	Ft. Calhoun Station: Unit 1	457,000	Omaha Public Power District	1973
Brownville	Cooper Nuclear Station	778,000	Nebraska Public Power District and Iowa Power and Light Co.	1974
NEW HAMPSHIRE				
Seabrook	Seabrook Nuclear Station Unit 1	1,200,000	Public Service of N.H.	1983
Seabrook	Seabrook Nuclear Station Unit 2	1,200,000	Public Service of N.H.	1985
NEW JERSEY				
Toms River	Oyster Creek Nuclear Power Plant: Unit 1	650,000	Jersey Central Power & Light Co.	1969
Forked River	Forked River Generating Station: Unit 1	1,070,000	Jersey Central Power & Light Co.	1983
Salem	Salem Nuclear Generating Station: Unit 1	1,090,000	Public Service Electric and Gas, N.J.	1977
Salem	Salem Nuclear Generating Station: Unit 2	1,115,000	Public Service Electric and Gas, N.J.	1979
Salem	Hope Creek Generating Station: Unit 1	1,067,000	Public Service Electric and Gas, N.J.	1984
Salem	Hope Creek Generating Station: Unit 2	1,067,000	Public Service Electric and Gas, N.J.	1986
Little Egg Inlet	Atlantic Generating Station: Unit 1	1,150,000	Public Service Electric and Gas, N.J.	1988
Little Egg Inlet	Atlantic Generating Station: Unit 2	1,150,000	Public Service Electric and Gas, N.J.	1990
Site not selected	1990 Unit	1,150,000	Public Service Electric and Gas, N.J.	1993
Site not selected	1992 Unit	1,150,000	Public Service Electric and Gas, N.J.	1995
NEW YORK				
Buchanan	Indian Point Station: Unit 1	265,000	Consolidated Edison Co.	1962
Buchanan	Indian Point Station: Unit 2	873,000	Consolidated Edison Co.	1973
Buchanan	Indian Point Station: Unit 3	873,000	Power Authority of State of N.Y.	1976
Scriba	Nine Mile Point Nuclear Station: Unit 1	610,000	Niagara Mohawk Power Corp.	1969
Scriba	Nine Mile Point Nuclear Station: Unit 2	1,099,800	Niagara Mohawk Power Corp.	1982
Ontario	R.E. Ginna Nuclear Power Plant: Unit 1	490,000	Rochester Gas & Electric Corp.	1970
Brookhaven	Shoreham Nuclear Power Station	819,000	Long Island Lighting Co.	1980
Scriba	James A. FitzPatrick Nuclear Power Plant	821,000	Power Authority of State of N.Y.	1975
Cementon	Greene County Nuclear Power Plant	1,212,000	Power Authority of State of N.Y.	1984
Jamesport	Jamesport 1	1,150,000	Long Island Lighting Co.	1984
Jamesport	Jamesport 2	1,150,000	Long Island Lighting Co.	1986

COMMERCIAL NUCLEAR POWER REACTORS IN THE UNITED STATES (Continued)

SITE	PLANT NAME	CAPACITY NET kW(e)	UTILITY	COMMERCIAL OPERATION
Oswego	Sterling Nuclear: Unit 1	1,150,000	Rochester Gas & Electric Corp.	1984
Site not selected	Unit 1	1,250,000	New York State Electric & Gas Co.	1988
Site not selected	Unit 2	1,250,000	New York State Electric & Gas Co.	1990
NORTH CAROLINA				
Southport	Brunswick Steam Electric Plant: Unit 1	821,000	Carolina Power and Light Co.	1977
Southport	Brunswick Steam Electric Plant: Unit 2	821,000	Carolina Power and Light Co.	1975
Cowans Ford Dam	Wm. B. McGuire Nuclear Station: Unit 1	1,180,000	Duke Power Co.	1979
Cowans Ford Dam	Wm. B. McGuire Nuclear Station: Unit 2	1,180,000	Duke Power Co.	1981
Bonsal	Shearon Harris Plant: Unit 1	900,000	Carolina Power and Light Co.	1983
Bonsal	Shearon Harris Plant: Unit 2	900,000	Carolina Power and Light Co.	1986
Bonsal	Shearon Harris Plant: Unit 3	900,000	Carolina Power and Light Co.	1989
Bonsal	Shearon Harris Plant: Unit 4	900,000	Carolina Power and Light Co.	1987
Davie County	Perkins Nuclear Station: Unit 1	1,280,000	Duke Power Co.	1985
Davie County	Perkins Nuclear Station: Unit 2	1,280,000	Duke Power Co.	1987
Davie County	Perkins Nuclear Station: Unit 3	1,280,000	Duke Power Co.	1990
Site not selected		1,150,000	Carolina Power and Light Co.	Indef.
Site not selected		1,150,000	Carolina Power and Light Co.	Indef.
Site not selected		1,150,000	Carolina Power and Light Co.	Indef.
OHIO				
Berlin Heights	Erie: Unit 1	1,260,000	Ohio Edison Co.	1986
Berlin Heights	Erie: Unit 2	1,260,000	Ohio Edison Co.	1988
Oak Harbor	Davis-Besse Nuclear Power Station: Unit 1	906,000	Toledo Edison-Cleveland El. Illum. Co.	1977
Oak Harbor	Davis-Besse Nuclear Power Station: Unit 2	906,000	Toledo Edison-Cleveland El. Illum. Co.	1985
Oak Harbor	Davis-Besse Nuclear Power Station: Unit 3	906,000	Toledo Edison-Cleveland El. Illum. Co.	1987
Perry	Perry Nuclear Power Plant: Unit 1	1,205,000	Cleveland Electric Illuminating Co.	1981
Perry	Perry Nuclear Power Plant: Unit 2	1,205,000	Cleveland Electric Illuminating Co.	1983
Moscow	Wm. H. Zimmer Nuclear Power Station: Unit 1	810,000	Cincinnati Gas & Electric Co.	1979
Moscow	Wm. H. Zimmer Nuclear Power Station: Unit 2	1,170,000	Cincinnati Gas & Electric Co.	1989
OKLAHOMA				
Inola	Black Fox Nuclear Station: Unit 1	1,150,000	Public Service of Oklahoma	1984
Inola	Black Fox Nuclear Station: Unit 2	1,150,000	Public Service of Oklahoma	1986
OREGON				
Prescott	Trojan Nuclear Plant: Unit 1	1,130,000	Portland General Electric Co.	1976
Arlington	Pebble Springs Nuclear Plant: Unit 1	1,260,000	Portland General Electric Co.	1985
Arlington	Pebble Springs Nuclear Plant: Unit 2	1,260,000	Portland General Electric Co.	1988
PENNSYLVANIA				
Peach Bottom	Peach Bottom Atomic Power Station: Unit 2	1,065,000	Philadelphia Electric Co.	1974
Peach Bottom	Peach Bottom Atomic Power Station: Unit 3	1,065,000	Philadelphia Electric Co.	1974
Pottstown	Limerick Generating Station: Unit 1	1,065,000	Philadelphia Electric Co.	1983
Pottstown	Limerick Generating Station: Unit 2	1,065,000	Philadelphia Electric Co.	1985
Shippingport	Shippingport Atomic Power Station[1]	60,000	Department of Energy	1957
Shippingport	Beaver Valley Power Station: Unit 1	852,000	Duquesne Light Co. Ohio Edison Co.	1976
Shippingport	Beaver Valley Power Station: Unit 2	852,000	Duquesne Light Co. - Ohio Edison Co.	1982
Middletown	Three Mile Island Nuclear Station: Unit 1	819,000	Metropolitan Edison Co.	1974
Middletown	Three Mile Island Nuclear Station: Unit 2	906,000	Jersey Central Power & Light Co.	1978
Berwick	Susquehanna Steam Electric Station: Unit 1	1,050,000	Pennsylvania Power and Light	1980
Berwick	Susquehanna Steam Electric Station: Unit 2	1,050,000	Pennsylvania Power and Light	1982

COMMERCIAL NUCLEAR POWER REACTORS IN THE UNITED STATES (Continued)

SITE	PLANT NAME	CAPACITY NET kW(e)	UTILITY	COMMERCIAL OPERATION
RHODE ISLAND				
Charlestown	New England Power (NEP): Unit 1	1,150,000	New England Power Co.	1984
Charlestown	New England Power (NEP): Unit 2	1,150,000	New England Power Co.	1986
SOUTH CAROLINA				
Hartsville	H.B. Robinson S.E. Plant: Unit 2	712,000	Carolina Power and Light Co.	1971
Seneca	Oconee Nuclear Station: Unit 1	887,000	Duke Power Co.	1973
Seneca	Oconee Nuclear Station: Unit 2	887,000	Duke Power Co.	1974
Seneca	Oconee Nuclear Station: Unit 3	887,000	Duke Power Co.	1974
Broad River	Virgil C. Summer Nuclear Station: Unit 1	900,000	South Carolina Electric and Gas Co.	1980
Lake Wylie	Catawba Nuclear Station: Unit 1	1,145,000	Duke Power Co.	1982
Lake Wylie	Catawba Nuclear Station: Unit 2	1,145,000	Duke Power Co.	1983
Cherokee County	Cherokee Nuclear Station: Unit 1	1,280,000	Duke Power Co.	1984
Cherokee County	Cherokee Nuclear Station: Unit 2	1,280,000	Duke Power Co.	1986
Cherokee County	Cherokee Nuclear Station: Unit 3	1,280,000	Duke Power Co.	1989
TENNESSEE				
Daisy	Sequoyah Nuclear Power Plant: Unit 1	1,148,000	Tennessee Valley Authority	[illegible]
Daisy	Sequoyah Nuclear Power Plant: Unit 2	1,148,000	Tennessee Valley Authority	[illegible]
Spring City	Watts Bar Nuclear Plant: Unit 1	1,177,000	Tennessee Valley Authori[illegible]	[illegible]
Spring City	Watts Bar Nuclear Plant: Unit 2	1,177,000	Tennessee Valley Autho[illegible]	[illegible]
Oak Ridge	Clinch River Breeder Reactor Plant	350,000	Department of Energy	[illegible]
Hartsville	A. Unit 1	1,233,000	Tennessee V[illegible] Autho[illegible]	[illegible]3
Hartsville	A. Unit 2	1,233,000	Tennessee V[illegible]thor[illegible]	[illegible]4
Hartsville	B. Unit 1	1,233,000	Tennessee V[illegible]	[illegible]83
Hartsville	B. Unit 2	1,233,000	Tennessee [illegible]hority	[illegible]8[illegible]
Site not selected	Phipps Bend, Unit 1	1,233,000	Tennessee [illegible]ority	[illegible]
Site not selected	Phipps Bend, Unit 2	1,233,000	Tennessee [illegible]rity	[illegible]
TEXAS				
Glen Rose	Comanche Peak Steam Electric Station: Unit 1	1,150,000	Texas Uti[illegible]ing Co.	[illegible]
Glen Rose	Comanche Peak Steam Electric Station: Unit 2	1,111,000	Texas Utilities [illegible]ating Co.	[illegible]3
Jasper	Blue Hills: Unit 1	918,000	Gulf States Utilities	Indef.
Jasper	Blue Hills: Unit 2	918,000	Gulf States Utilities	Indef.
Wallis	Allens Creek: Unit 1	1,150,000	Houston Lighting & Power Co.	1985
Matagorda County	South Texas: Unit 1	1,250,000	Central Power & Lt. Houston Lt. & Power	1980
Matagorda County	South Texas: Unit 2	1,250,000	Central Power & Lt. Houston Lt. & Power	1982
VERMONT				
Vernon	Vermont Yankee Generating Station	514,000	Vermont Yankee Nuclear Power Corp.	1972
VIRGINIA				
Gravel Neck	Surry Power Station: Unit 1	822,000	Virginia Electric & Power Company	1972
Gravel Neck	Surry Power Station: Unit 2	822,000	Virginia Electric & Power Company	1973
Mineral	North Anna Power Station: Unit 1	907,000	Virginia Electric & Power Company	1978
Mineral	North Anna Power Station: Unit 2	907,000	Virginia Electric & Power Company	1979
Mineral	North Anna Power Station: Unit 3	907,000	Virginia Electric & Power Company	1982
Mineral	North Anna Power Station: Unit 4	907,000	Virginia Electric & Power Company	1983
WASHINGTON				
Richland	N-Reactor/WPPSS Steam	860,000	Department of Energy	1966
Richland	WPPSS No. 1	1,250,000	Washington Public Power Supply System	1982
Richland	WPPSS No. 2	1,100,000	Washington Public Power Supply System	1980
Satsop	WPPSS No. 3	[illegible]40,000	Washington Public Power Supply System	1984
Richland	WPPSS No. 4	[illegible]	Washington Public Power Supply System	1983
Satsop	WPPSS No. 5	[illegible]40,000	Washington Public Power Supply System	1985

COMMERCIAL NUCLEAR POWER REACTORS IN THE UNITED STATES (Continued)

SITE	PLANT NAME	CAPACITY NET kW(e)	UTILITY	COMMERCIAL OPERATION
Sedro Woolley	Skagit Nuclear Project: Unit 1	1,288,000	Puget Sound Power & Light	1985
Sedro Woolley	Skagit Nuclear Project: Unit 2	1,288,000	Puget Sound Power & Light	1986
WISCONSIN				
La Crosse	La Crosse (Genoa) Nuclear Generating Station	50,000	Dairyland Power Cooperative	1969
Two Creeks	Point Beach Nuclear Plant: Unit 1	497,000	Wisconsin Michigan Power Co.	1970
Two Creeks	Point Beach Nuclear Plant: Unit 2	497,000	Wisconsin Michigan Power Co.	1972
Carlton	Kewaunee Nuclear Power Plant: Unit 1	535,000	Wisconsin Public Service Corp.	1974
Site not selected	Haven Nuclear Plant: Unit 1	900,000	Wisconsin Electric Power Co.	1987
Site not selected	Haven Nuclear Plant: Unit 2	900,000	Wisconsin Electric Power Co.	1989
Durand	Tyrone Energy Park: Unit 1	1,150,000	Northern States Power Co.	1984
PUERTO RICO				
Arecibo	North Coast Power Plant	583,000	Puerto Rico Water Resources Authority	Indef.

LIST OF CONTRACTORS, DESIGNERS, SHIPBUILDERS, AND FACILITY OPERATORS FOR WHICH ABBREVIATIONS APPEAR IN TABLES

AC	Allis-Chalmers Mfg. Co.
ACF	ACF Industries, Inc. (reactor activities absorbed by AC)
AG	Aerojet-General Corporation
AGN	Aerojet-General Nucleonics, formerly a subsidiary and now a division of Aerojet-General Corporation
AI	Atomics International, a division of Rockwell International
Alco	Alco Products, Inc. (reactor activities absorbed by AC)
AMF	AMF Atomics, Inc., a division of American Machine & Foundry Co.
ANL	Argonne National Laboratory, operated by the University of Chicago
ANPD	Aircraft Nuclear Propulsion Department, General Electric Company (name changed to Flight Propulsion Laboratory Department)
AS Inc.	American Standard Inc.
BAC	Bendix Aviation Corp.
Bethlehem	Shipbuilding Division, Bethlehem Steel Co. (now Quincy Division, General Dynamics Corp.)
Bettis	Bettis Atomic Power Laboratory, operated by Westinghouse Electric Corporation
Blaw-Knox	Blaw-Knox Co.
BNL	Brookhaven National Laboratory, operated by Associated Universities, Inc.
BNW	Battelle - Northwest, a division of Battelle Memorial Institute
B&R	Burns & Roe, Inc.
B&W	Babcock & Wilcox Co.
CL	Clinton Laboratory of the Manhattan Engineer District
Comb.	Combustion Engineering, Inc.
Convair	Convair Division, General Dynamics Corp.
Cook	Nucledyne Co., a division of Cook Electric Company
CW	Curtiss-Wright Corporation
Daystrom	Daystrom, Inc.
DOD	Department of Defense
du Pont	E. I. du Pont de Nemours & Company, Inc.
Ebasco	Ebasco Services, Inc.
EG&G ID	EG&G Idaho, Inc. (a division of EG&G, Inc.)
Electric Boat	Electric Boat Division, General Dynamics Corp.
Fluor	The Fluor Corporation, Ltd.
FW	Foster Wheeler Corp.
GA	General Atomic, a Gulf and Royal Dutch Shell Company
GD (Quincy)	Quincy Division, General Dynamics Corp.
GE	General Electric Company
GENMPO	General Electric Nuclear Materials and Propulsion Operation
GM	General Motors Corp.
GNEC	General Nuclear Engineering Corp. (became a division of Combustion Engineering, Inc., in 1962)
GSA	General Services Administration
HA	Hittman Associates
HEDL	Hanford Engineering Development Laboratory
HKF	H. K. Ferguson Co.
Hughes	Hughes Aircraft Co.
IC	Internuclear Co.
INC	Idaho Nuclear Corporation
INEL	Idaho National Engineering Laboratory
Ingalls	Ingalls Shipbuilding Corp.
Kaman	Kaman Nuclear, a division of Kaman Aircraft Corp.
KAPL	Knolls Atomic Power Laboratory, operated by General Electric Company
KE	Kaiser Engineers, a division of Henry J. Kaiser Co.
LASL	Los Alamos Scientific Laboratory, operated by the University of California
Lockheed	Lockheed Aircraft Corp.
Mare Island	Mare Island Naval Shipyard
Martin	Martin Marietta Corp.
Mason	Mason Construction Co.
Met. Lab.	Metallurgical Laboratory of the Manhattan Engineer District
NASA	National Aeronautics and Space Administration
NBS	National Bureau of Standards
Newport News	Newport News Shipbuilding & Dry Dock Co.
NRDS	Nuclear Rocket Development Station
NRL	Naval Research Laboratory
NSA	Nuclear Systems Associates
NTS	Nevada Test Site
NYSC	New York Shipbuilding Corp.
ORNL	Oak Ridge National Laboratory
PNL	Pacific Northwest Laboratory, operated by BNW
Portsmouth	Portsmouth Naval Shipyard
PPC	Phillips Petroleum Co.
PRDC	Power Reactor Development Company
P&W	Pratt & Whitney Aircraft Division, United Aircraft Corp.
RI	Rockwell International
Sandia	Sandia Laboratories, operated by Sandia Corp., a subsidiary of Western Electric Co.
San Francisco Bay	San Francisco Bay Naval Shipyard
TVA	Tennessee Valley Authority
UCLLL	University of California Lawrence Livermore Laboratory
UNC	United Nuclear Coporation, Development Division
UNI	United Nuclear Industries, Inc.
West.	Westinghouse Electric Corporation

PART 1 CIVILIAN REACTORS (DOMESTIC)

1. POWER REACTORS

A. Central-Station Electric Power

(Docket numbers for civilian reactors are listed in parentheses in the index.)

Name and/or owner	Location	Principal nuclear contractor	Type	Power[1] Unit size, net kW(e)	Reactor, kW(t)	Start-up	Shut-down
OPERABLE							
Arkansas Nuclear One, Unit 1 (Arkansas Power & Light Co.)[3]	Russellville, Ark.	B&W	Pressurized water	850,000	2,568,000	1974	
Beaver Valley Power Station, Unit 1 (Duquesne Light, Ohio Edison Co. and Pennsylvania Power Co.)[3]	Shippingport, Pa.	West.	Pressurized water	852,000	2,660,000	1976	
Big Rock Point Nuclear Plant (Consumers Power Co.)[3,4]	Big Rock Point, Mich.	GE	Boiling water	72,000	240,000	1962	
Browns Ferry Nuclear Power Plant, Unit 1 (Tennessee Valley Authority)[3]	Decatur, Ala.	GE	Boiling water	1,065,000	3,293,000	1973	
Browns Ferry Nuclear Power Plant, Unit 2 (Tennessee Valley Authority)[3]	Decatur, Ala.	GE	Boiling water	1,065,000	3,293,000	1974	
Browns Ferry Nuclear Power Plant, Unit 3 (Tennessee Valley Authority)[3]	Decatur, Ala.	GE	Boiling water	1,065,000	3,293,000	1976	
Brunswick Steam Electric Plant, Unit 1 (Carolina Power & Light Co.)[3]	Southport, N. C.	GE	Boiling water	821,000	2,436,000	1976	
Brunswick Steam Electric Plant, Unit 2 (Carolina Power & Light Co.)[3]	Southport, N. C.	GE	Boiling water	821,000	2,436,000	1975	
Calvert Cliffs Nuclear Power Plant, Unit 1 (Baltimore Gas & Electric Co.)[3]	Lusby, Md.	Comb.	Pressurized water	845,000	2,570,000	1974	
Calvert Cliffs Nuclear Power Plant, Unit 2 (Baltimore Gas & Electric Co.)[3]	Lusby, Md.	Comb.	Pressurized water	845,000	2,570,000	1976	
Cooper Nuclear Station (Nebraska Public Power District and Iowa Power & Light Co.)[3]	Brownville, Nebr.	GE	Boiling water	778,000	2,381,000	197	
Crystal River Plant, Unit 3 (Florida Power Corp.)[3]	Red Level, Fla.	B&W	Pressurized water	825,000	2,452,000	1977	
Davis-Besse Nuclear Power Station, Unit 1 (Toledo Edison Co. and Cleveland Electric Illuminating Co.)[3]	Oak Harbor, Ohio	B&W	Pressurized water	906,000	2,772,000	1977	
Donald C. Cook Nuclear Plant, Unit 1 (Indiana and Michigan Electric Co.)[3]	Bridgman, Mich.	West.	Pressurized water	1,054,000	3,250,000	1975	
Donald C. Cook Nuclear Plant, Unit 2 (Indiana and Michigan Electric Co.)[3]	Bridgman, Mich.	West.	Pressurized water	1,060,000	3,250,000	1978	
Dresden Nuclear Power Station, Unit 1 (Commonwealth Edison Co.)[3]	Morris, Ill.	GE	Boiling water	200,000	700,000	1959	
Dresden Nuclear Power Station, Unit 2 (Commonwealth Edison Co.)[3]	Morris, Ill.	GE	Boiling water	794,000	2,527,000	1970	
Dresden Nuclear Power Station, Unit 3 (Commonwealth Edison Co.)[3]	Morris, Ill.	GE	Boiling water	794,000	2,527,000	1971	
Duane Arnold Energy Center, Unit 1 (Iowa Electric Light & Power Co., Central Iowa Power Cooperative, and Corn Belt Power Cooperative)[3]	Palo, Iowa	GE	Boiling water	538,000	1,593,000	1974	
Edwin I. Hatch Nuclear Plant, Unit 1 (Georgia Power Co.)[3]	Baxley, Ga.	GE	Boiling water	786,000	2,436,000	1974	
Fort Calhoun Station, Unit 1 (Omaha Public Power District)[3]	Fort Calhoun, Nebr.	Comb.	Pressurized water	457,000	1,420,000	1973	
Fort St. Vrain Nuclear Generating Station (Public Service Co. of Colorado)[3,4]	Platteville, Colo.	GA	High temperature	330,000	841,700	1974	
Haddam Neck Plant (Connecticut Yankee Atomic Power Co.)[3,4]	Haddam Neck, Conn.	West.	Pressurized water	575,000	1,825,000	1967	
H. B. Robinson S. E. Plant, Unit 2 (Carolina Power & Light Co.)[3]	Hartsville, S. C.	West.	Pressurized water	712,000	2,200,000	1970	
Humboldt Bay Power Plant, Unit 3 (Pacific Gas & Electric Co.)[3]	Eureka, Calif.	GE	Boiling water	63,000	240,000	1963	
Indian Point Station, Unit 1 (Consolidated Edison Co. of New York, Inc.)[3,4]	Buchanan, N. Y.	B&W	Pressurized water	265,000	615,000	1962	
Indian Point Station, Unit 2 (Consolidated Edison Co. of New York, Inc.)[3]	Buchanan, N. Y.	West.	Pressurized water	873,000	2,758,000	1973	
Indian Point Station, Unit 3 (Power Authority of N.Y.)[3]	Buchanan, N. Y.	West.	Pressurized water	873,000	3,015,000	1976	
James A. FitzPatrick Nuclear Power Plant (Power Authority of the State of New York)[3]	Scriba, N. Y.	GE	Boiling water	821,000	2,436,000	1974	
Joseph M. Farley Nuclear Plant, Unit 1 (Alabama Power Co.)[3]	Dothan, Ala.	West.	Pressurized water	829,000	2,652,000	1977	
Kewaunee Nuclear Power Plant (Wisconsin Power & Light Co., Wisconsin Public Service Co., Madison Gas & Electric Co.)[3]	Carlton, Wis.	West.	Pressurized water	535,000	1,650,000	1974	

1. POWER REACTORS (Continued)

A. Central-Station Electric Power (Continued)

Name and/or owner	Location	Principal nuclear contractor	Type	Power[1] Unit size, net kW(e)	Reactor, kW(t)	Start-up	Shut-down
La Crosse (Genoa) Nuclear Generating Station (Dairyland Power Cooperative)[3,4]	La Crosse, Wis.	AC	Boiling water	50,000	165,000	1967	
Maine Yankee Atomic Power Plant (Maine Yankee Atomic Power Co.)[3]	Wiscasset, Maine	Comb.	Pressurized water	790,000	2,440,000	1972	
Millstone Nuclear Power Station, Unit 1 (Northeast Nuclear Energy Co.)[3]	Waterford, Conn.	GE	Boiling water	660,000	2,011,000	1970	
Millstone Nuclear Power Station, Unit 2 (Northeast Nuclear Energy Co.)[3]	Waterford, Conn.	Comb.	Pressurized water	830,000	2,560,000	1975	
Monticello Nuclear Generating Plant (Northern States Power Co.)[3]	Monticello, Minn.	GE	Boiling water	545,000	1,670,000	1970	
Nine Mile Point Nuclear Station, Unit 1 (Niagara Mohawk Power Corp.)[3]	Scriba, N. Y.	GE	Boiling water	610,000	1,850,000	1969	
North Anna Power Station, Unit 1 (Virginia Electric & Power Co.)[3]	Mineral, Va.	West.	Pressurized water	907,000	2,775,000	1977	
Oconee Nuclear Station, Unit 1 (Duke Power Co.)[3]	Seneca, S. C.	B&W	Pressurized water	887,000	2,568,000	1973	
Oconee Nuclear Station, Unit 2 (Duke Power Co.)[3]	Seneca, S. C.	B&W	Pressurized water	887,000	2,568,000	1973	
Oconee Nuclear Station, Unit 3 (Duke Power Co.)[3]	Seneca, S. C.	B&W	Pressurized water	887,000	2,568,000	1974	
Oyster Creek Nuclear Power Plant, Unit 1 (Jersey Central Power & Light Co.)[3]	Toms River, N. J.	GE	Boiling water	650,000	1,930,000	1969	
Palisades Nuclear Power Station, Unit 1 (Consumers Power Co. of Michigan)[3]	South Haven, Mich.	Comb.	Pressurized water	668,000	2,212,000	1971	
Peach Bottom Atomic Power Station, Unit 2 (Philadelphia Electric Co., Public Service Electric & Gas Co., Atlantic City Electric Co., and Delmarva Power & Light Co.)[3]	Peach Bottom, Pa.	GE	Boiling water	1,065,000	3,293,000	1973	
Peach Bottom Atomic Power Station, Unit 3 (Philadelphia Electric Co., Public Service Electric & Gas Co., Atlantic City Electric Co., and Delmarva Power & Light Co.)[3]	Peach Bottom, Pa.	GE	Boiling water	1,065,000	3,293,000	1974	
Pilgrim Station, Unit 1 (Boston Edison Co.)[3]	Plymouth, Mass.	GE	Boiling water	655,000	1,998,000	1972	
Point Beach Nuclear Plant, Unit 1 (Wisconsin Electric Power Co. and Wisconsin Michigan Power Co.)[3]	Two Creeks, Wis.	West.	Pressurized water	497,000	1,518,000	1970	
Point Beach Nuclear Plant, Unit 2 (Wisconsin Electric Power Co. and Wisconsin Michigan Power Co.)[3]	Two Creeks, Wis.	West.	Pressurized water	497,000	1,518,000	1972	
Prairie Island Nuclear Generating Plant, Unit 1 (Northern States Power Co.)[3]	Red Wing, Minn.	West.	Pressurized water	530,000	1,650,000	1973	
Prairie Island Nuclear Generating Plant, Unit 2 (Northern States Power Co.)[3]	Red Wing, Minn.	West.	Pressurized water	530,000	1,650,000	1974	
Quad-Cities Station, Unit 1 (Commonwealth Edison Co. and Iowa-Illinois Gas & Electric Co.)[3]	Cordova, Ill.	GE	Boiling water	789,000	2,511,000	1971	
Quad-Cities Station, Unit 2 (Commonwealth Edison Co. and Iowa-Illinois Gas & Electric Co.)[3]	Cordova, Ill.	GE	Boiling water	789,000	2,511,000	1972	
Rancho Seco Nuclear Generating Station, Unit 1 (Sacramento Municipal Utility District)[3]	Clay Station, Calif.	B&W	Pressurized water	918,000	2,569,000	1974	
Robert Emmett Ginna Nuclear Power Plant, Unit 1 (Rochester Gas & Electric Co.)[3]	Ontario, N. Y.	West.	Pressurized water	490,000	1,520,000	1969	
Salem Nuclear Generating Station, Unit 1 (Public Service Electric & Gas Co., Philadelphia Electric Co., Atlantic City Electric Co., and Delmarva Power & Light Co.)[3]	Salem, N. J.	West.	Pressurized water	1,090,000	3,350,000	1976	

San Onofre Nuclear Generating Station, Unit 1 (Southern California Edison and San Diego Gas & Electric Co.)[3-4]	San Clemente, Calif.	West.	Pressurized water	430,000	1,347,000	1967
Shippingport Atomic Power Station (DOE and Duquesne Light Co.)[3]	Shippingport, Pa.	West.	Pressurized water	60,000	236,600	1957
St. Lucie, Unit 1 (Florida Power & Light Co.)[3]	Fort Pierce, Fla.	Comb.	Pressurized water	802,000	2,570,000	1976
Surry Power Station, Unit 1 (Virginia Electric & Power Co.)[3]	Gravel Neck, Va.	West.	Pressurized water	822,000	2,441,000	1972
Surry Power Station, Unit 2 (Virginia Electric & Power Co.)[3]	Gravel Neck, Va.	West.	Pressurized water	822,000	2,441,000	1973
Three Mile Island Station, Unit 1 (Metropolitan Edison Co.)[3]	Middletown, Pa.	B&W	Pressurized water	819,000	2,535,000	1974
Trojan Nuclear Plant, Unit 1 (Portland General Electric Co., Eugene Water & Electric Board, and Pacific Power & Light Co.)[3]	Prescott, Oreg.	West.	Pressurized water	1,130,000	3,423,000	1975
Turkey Point Station, Unit 3 (Florida Power & Light Co.)[3]	Florida City, Fla.	West.	Pressurized water	693,000	2,200,000	1972
Turkey Point Station, Unit 4 (Florida Power & Light Co.)[3]	Florida City, Fla.	West.	Pressurized water	693,000	2,200,000	1973
Vermont Yankee Generating Station (Vermont Yankee Nuclear Power Corp.)[3]	Vernon, Vt.	GE	Boiling water	514,000	1,593,000	1972
Yankee-Rowe Nuclear Power Station (Yankee Atomic Electric Co.)[3-4]	Rowe, Mass.	West.	Pressurized water	175,000	600,000	1960
Zion Station, Unit 1 (Commonwealth Edison Co.)[3]	Zion, Ill.	West.	Pressurized water	1,040,000	3,250,000	1973
Zion Station, Unit 2 (Commonwealth Edison Co.)[3]	Zion, Ill.	West.	Pressurized water	1,040,000	3,250,000	1973
BEING BUILT						
Alvin W. Vogtle Nuclear Plant, Unit 1 (Georgia Power Co.)[3]	Waynesboro, Ga.	West.	Pressurized water	1,110,000	3,425,000	1984
Alvin W. Vogtle Nuclear Plant, Unit 2 (Georgia Power Co.)[3]	Waynesboro, Ga.	West.	Pressurized water	1,110,000	3,425,000	1985
Arkansas Nuclear One, Unit 2 (Arkansas Power & Light Co.)[3]	Russellville, Ark.	Comb.	Pressurized water	912,000	2,815,000	1978
Bailly Generating Station (Northern Indiana Public Service Co.)[3]	Westchester, Ind.	GE	Boiling water	645,000	1,931,000	1982
Beaver Valley Power Station, Unit 2 (Duquesne Light Co., Ohio Edison Co., and Pennsylvania Power Co.)[3]	Shippingport, Pa.	West.	Pressurized water	852,000	2,660,000	1982
Bellefonte Nuclear Plant, Unit 1 (Tennessee Valley Authority)[3]	Scottsboro, Ala.	B&W	Pressurized water	1,213,000	3,621,000	1980
Bellefonte Nuclear Plant, Unit 2 (Tennessee Valley Authority)[3]	Scottsboro, Ala.	B&W	Pressurized water	1,213,000	3,621,000	1981
Braidwood Station, Unit 1 (Commonwealth Edison Co.)[3]	Braidwood, Ill.	West.	Pressurized water	1,120,000	3,425,000	1981
Braidwood Station, Unit 2 (Commonwealth Edison Co.)[3]	Braidwood, Ill.	West.	Pressurized water	1,120,000	3,425,000	1982
Byron Station, Unit 1 (Commonwealth Edison Co.)[3]	Byron, Ill.	West.	Pressurized water	1,120,000	3,425,000	1980
Byron Station, Unit 2 (Commonwealth Edison Co.)[3]	Byron, Ill.	West.	Pressurized water	1,120,000	3,425,000	1982
Callaway Plant, Unit 1 (Union Electric Co.)[3]	Fulton, Mo.	West.	Pressurized water	1,120,000	3,411,000	1981
Callaway Plant, Unit 2 (Union Electric Co.)[3]	Fulton, Mo.	West.	Pressurized water	1,120,000	3,411,000	1986
Catawba Nuclear Station, Unit 1 (Duke Power Co.)[3]	Lake Wylie, S. C.	West.	Pressurized water	1,145,000	3,411,000	1981
Catawba Nuclear Station, Unit 2 (Duke Power Co.)[3]	Lake Wylie, S. C.	West.	Pressurized water	1,145,000	3,411,000	1982
Cherokee Nuclear Station, Unit 1 (Duke Power Co.)[3]	Cherokee County, S. C.	Comb.	Pressurized water	1,280,000	3,800,000	1983
Cherokee Nuclear Station, Unit 2 (Duke Power Co.)[3]	Cherokee County, S. C.	Comb.	Pressurized water	1,280,000	3,800,000	1985
Cherokee Nuclear Station, Unit 3 (Duke Power Co.)[3]	Cherokee County, S. C.	Comb.	Pressurized water	1,280,000	3,800,000	1988
Clinton Nuclear Power Station, Unit 1 (Illinois Power Co.)[3]	Clinton, Ill.	GE	Boiling water	933,400	2,894,000	1981
Clinton Nuclear Power Station, Unit 2 (Illinois Power Co.)[3]	Clinton, Ill.	GE	Boiling water	933,400	2,894,000	1987
Comanche Peak Steam Electric Station, Unit 1 (Texas Power & Light Co. and TESC & DP&LC)[3]	Glen Rose, Tex.	West.	Pressurized water	1,150,000	3,411,000	1980
Comanche Peak Steam Electric Station, Unit 2 (Texas Power & Light Co. and TESC & DP&LC)[3]	Glen Rose, Tex.	West.	Pressurized water	1,150,000	3,411,000	1982
Davis-Besse Nuclear Power Station, Unit 2 (Toledo Edison Co.)[3]	Oak Harbor, Ohio	B&W	Pressurized water	906,000	2,772,000	1985
Davis-Besse Nuclear Power Station, Unit 3 (Toledo Edison Co.)[3]	Oak Harbor, Ohio	B&W	Pressurized water	906,000	2,772,000	1987
Diablo Canyon Nuclear Power Plant, Unit 1 (Pacific Gas & Electric Co.)[3]	Diablo Canyon, Calif.	West.	Pressurized water	1,084,000	3,338,000	1978
Diablo Canyon Nuclear Power Plant, Unit 2 (Pacific Gas & Electric Co.)[3]	Diablo Canyon, Calif.	West.	Pressurized water	1,106,000	3,411,000	1978
Edwin I. Hatch Nuclear Plant, Unit 2 (Georgia Power Co.)[3]	Baxley, Ga.	GE	Boiling water	795,000	2,436,000	1978
Enrico Fermi Atomic Power Plant, Unit 2 (Detroit Edison Co.)[3]	Newport, Mich.	GE	Boiling water	1,093,000	3,293,000	1980
Forked River Nuclear Generating Station, Unit 1 (Jersey Central Power and Light Co.)[3]	Forked River, N. J.	Comb.	Pressurized water	1,070,000	3,390,000	1982

1. POWER REACTORS (Continued)

A. Central-Station Electric Power (Continued)

Name and/or owner	Location	Principal nuclear contractor	Type	Power[1] Unit size, net kW(e)	Power[1] Reactor, kW(t)	Start-up	Shut-down
Grand Gulf Nuclear Station, Unit 1 (Mississippi Power & Light Co.)[3]	Port Gibson, Miss.	GE	Boiling water	1,250,000	3,833,000	1981	
Grand Gulf Nuclear Station, Unit 2 (Mississippi Power & Light Co.)[3]	Port Gibson, Miss.	GE	Boiling water	1,250,000	3,833,000	1984	
Hartsville A, Unit 1[3]	Tennessee	GE	Boiling water	1,233,000	3,583,000	1982	
Hartsville A, Unit 2[3]	Tennessee	GE	Boiling water	1,233,000	3,583,000	1983	
Hartsville B, Unit 1[3]	Tennessee	GE	Boiling water	1,233,000	3,583,000	1982	
Hartsville B, Unit 2[3]	Tennessee	GE	Boiling water	1,233,000	3,583,000	1983	
Hope Creek Nuclear Generating Station, Unit 1 (Public Service Electric & Gas Co.)[3]	Salem, N. J.	GE	Boiling water	1,067,000	3,293,000	1983	
Hope Creek Nuclear Generating Station, Unit 2 (Public Service Electric & Gas Co.)[3]	Salem, N. J.	GE	Boiling water	1,067,000	3,293,000	1985	
Joseph M. Farley Nuclear Plant, Unit 2 (Alabama Power Co.)[3]	Dothan, Ala.	West.	Pressurized water	820,000	2,652,000	1980	
La Salle County Nuclear Station, Unit 1 (Commonwealth Edison Co.)[3]	Seneca, Ill.	GE	Boiling water	1,078,000	3,293,000	1979	
La Salle County Nuclear Station, Unit 2 (Commonwealth Edison Co.)[3]	Seneca, Ill.	GE	Boiling water	1,078,000	3,293,000	1980	
Limerick Generating Station, Unit 1 (Philadelphia Electric Co.)[3]	Pottstown, Pa.	GE	Boiling water	1,065,000	3,293,000	1983	
Limerick Generating Station, Unit 2 (Philadelphia Electric Co.)[3]	Pottstown, Pa.	GE	Boiling water	1,065,000	3,293,000	1985	
Marble Hill Nuclear Power Station, Unit 1 (Public Service Indiana)[3]	Madison, Ind.	West.	Pressurized water	1,130,000	3,425,000	1982	
Marble Hill Nuclear Power Station, Unit 2 (Public Service Indiana)[3]	Madison, Ind.	West.	Pressurized water	1,130,000	3,425,000	1984	
Millstone Nuclear Power Station, Unit 3 (Millstone Point Co.)[3]	Waterford, Conn.	West.	Pressurized water	1,156,000	3,411,000	1986	
Nine Mile Point Nuclear Station, Unit 2 (Niagara Mohawk Power Corp.)[3]	Scriba, N. Y.	GE	Boiling water	1,099,800	3,323,000	1982	
North Anna Power Station, Unit 2 (Virginia Electric & Power Co.)[3]	Mineral, Va.	West.	Pressurized water	907,000	2,775,000	1978	
North Anna Power Station, Unit 3 (Virginia Electric & Power Co.)[3]	Mineral, Va.	B&W	Pressurized water	907,000	2,631,000	1981	
North Anna Power Station, Unit 4 (Virginia Electric & Power Co.)[3]	Mineral, Va.	B&W	Pressurized water	907,000	2,631,000	1983	
Palo Verde Nuclear Generating Station, Unit 1 (Arizona Public Service Co., TG&E, STRP, PSNM, EPEC)[3]	Wintersburg, Ariz.	Comb.	Pressurized water	1,237,700	3,817,000	1983	
Palo Verde Nuclear Generating Station, Unit 2 (Arizona Public Service Co., TG&E, STRP, PSNM, EPEC)[3]	Wintersburg, Ariz.	Comb.	Pressurized water	1,237,700	3,817,000	1984	
Palo Verde Nuclear Generating Station, Unit 3 (Arizona Public Service Co., TG&E, STRP, PSNM, EPEC)[3]	Wintersburg, Ariz.	Comb.	Pressurized water	1,237,700	3,817,000	1985	
Perry Nuclear Power Plant, Unit 1 (Cleveland Electric Illuminating Co.)[3]	Perry, Ohio	GE	Boiling water	1,205,000	3,579,000	1981	
Perry Nuclear Power Plant, Unit 2 (Cleveland Electric Illuminating Co.)[3]	Perry, Ohio	GE	Boiling water	1,205,000	3,579,000	1983	
Phipps Bend, Unit 1[3]	Tennessee	GE	Boiling water	1,233,000	3,583,000	1984	
Phipps Bend, Unit 2[3]	Tennessee	GE	Boiling water	1,233,000	3,583,000	1985	
River Bend Station, Unit 1 (Gulf States Utilities Co.)[3]	St. Francisville, La.	GE	Boiling water	934,000	2,894,000	1983	
River Bend Station, Unit 2 (Gulf States Utilities Co.)[3]	St. Francisville, La.	GE	Boiling water	934,000	2,894,000	1985	
Salem Nuclear Generating Station, Unit 2 (Public Service Electric & Gas Co., Philadelphia Electric Co., Atlantic City Electric Co., and Delmarva Power & Light Co.)[3]	Salem, N. J.	West.	Pressurized water	1,115,000	3,423,000	1979	
San Onofre Nuclear Generating Station, Unit 2 (Southern California Edison Co. and San Diego Gas & Electric Co.)[3]	San Clemente, Calif.	Comb.	Pressurized water	1,100,000	3,410,000	1980	

San Onofre Nuclear Generating Station, Unit 3 (Southern California Edison Co. and San Diego Gas & Electric Co.)³	San Clemente, Calif.	Comb.	Pressurized water	1,100,000	3,410,000	1981
Seabrook Nuclear Station, Unit 1 (Public Service Co. of New Hampshire and United Illuminating Co.)³	Seabrook, N. H.	West.	Pressurized water	1,200,000	3,411,000	1983
Seabrook Nuclear Station, Unit 2 (Public Service Co. of New Hampshire and United Illuminating Co.)³	Seabrook, N. H.	West.	Pressurized water	1,200,000	3,411,000	1985
Sequoyah Nuclear Power Plant, Unit 1 (Tennessee Valley Authority)³	Daisy, Tenn.	West.	Pressurized water	1,148,000	3,423,000	1978
Sequoyah Nuclear Power Plant, Unit 2 (Tennessee Valley Authority)³	Daisy, Tenn.	West.	Pressurized water	1,148,000	3,423,000	1978
Shearon Harris Plant, Unit 1 (Carolina Power & Light Co.)³	Bonsal, N. C.	West.	Pressurized water	900,000	2,775,000	1987
Shearon Harris Plant, Unit 2 (Carolina Power & Light Co.)³	Bonsal, N. C.	West.	Pressurized water	900,000	2,775,000	1985
Shearon Harris Plant, Unit 3 (Carolina Power & Light Co.)³	Bonsal, N. C.	West.	Pressurized water	900,000	2,775,000	1989
Shearon Harris Plant, Unit 4 (Carolina Power & Light Co.)³	Bonsal, N. C.	West.	Pressurized water	900,000	2,775,000	1989
Shoreham Nuclear Power Station (Long Island Lighting Co.)³	Brookhaven, N. Y.	GE	Boiling water	819,000	2,436,000	1980
South Texas Nuclear Project, Unit 1 (Houston Lighting & Power Co., CPL, CASSA, & EPEC)³	Bay City, Tex.	West.	Pressurized water	1,250,000	3,817,000	1980
South Texas Nuclear Project, Unit 2 (Houston Lighting & Power Co., CPL, CASSA, & EPEC)³	Bay City, Tex.	West.	Pressurized water	1,250,000	3,817,000	1981
St. Lucie, Unit 2 (Florida Power & Light Co.)³	Fort Pierce, Fla.	Comb.	Pressurized water	802,000	2,570,000	1982
Sterling Power Project - Nuclear, Unit 1 (Rochester Gas & Electric Corp.)³	Oswego, N. Y.	West.	Pressurized water	1,150,000	3,411,000	1984
Susquehanna Steam Electric Station, Unit 1 (Pennsylvania Power & Light Co.)³	Berwick, Pa.	GE	Boiling water	1,050,000	3,293,000	1980
Susquehanna Steam Electric Station, Unit 2 (Pennsylvania Power & Light Co.)³	Berwick, Pa.	GE	Boiling water	1,050,000	3,293,000	1981
Three Mile Island Nuclear Station, Unit 2 (Jersey Central Power & Light Co.)³	Middletown, Pa.	B&W	Pressurized water	906,000	2,772,000	1978
Tyrone Energy Park, Unit 1 (Northern States Power Co.)³	Durand, Wis.	West.	Pressurized water	1,150,000	3,411,000	1983
Virgil C. Summer Nuclear Station, Unit 1 (South Carolina Electric & Gas Co.)³	Broad River, S. C.	West.	Pressurized water	900,000	2,785,000	1979
Waterford Generating Station, Unit 3 (Louisiana Power & Light Co.)³	Taft, La.	Comb.	Pressurized water	1,113,000	3,410,000	1980
Watts Bar Nuclear Plant, Unit 1 (Tennessee Valley Authority)³	Spring City, Tenn.	West.	Pressurized water	1,177,000	3,425,000	1979
Watts Bar Nuclear Plant, Unit 2 (Tennessee Valley Authority)³	Spring City, Tenn.	West.	Pressurized water	1,177,000	3,425,000	1979
William B. McGuire Nuclear Station, Unit 1 (Duke Power Co.)³	Cowans Ford Dam, N. C.	West.	Pressurized water	1,180,000	3,411,000	1978
William B. McGuire Nuclear Station, Unit 2 (Duke Power Co.)³	Cowans Ford Dam, N. C.	West.	Pressurized water	1,180,000	3,411,000	1980
William H. Zimmer Nuclear Power Station, Unit 1 (Cincinnati Gas & Electric Co., Columbus & Southern Ohio Electric Co., and Dayton Power & Light Co.)³	Moscow, Ohio	GE	Boiling water	810,000	2,436,000	1979
Wolf Creek (Kansas Gas & Electric Co., Kansas City Power & Light Co.)³	Burlington, Kans.	West.	Pressurized water	1,150,000	3,411,000	1982
WPPSS Nuclear Project, Unit 1 (Washington Public Power Supply System)³	Richland, Wash.	B&W	Pressurized water	1,250,000	3,600,000	1982
WPPSS Nuclear Project, Unit 2 (Washington Public Power Supply System)³	Richland, Wash.	GE	Boiling water	1,100,000	3,330,000	1980
WPPSS Nuclear Project, Unit 3 (Washington Public Power Supply System)³	Satsop, Wash.	Comb.	Pressurized water	1,240,000	3,817,000	1984
WPPSS Nuclear Project, Unit 4 (Washington Public Power Supply System)³	Richland, Wash.	B&W	Pressurized water	1,250,000	3,600,000	1984
WPPSS Nuclear Project, Unit 5 (Washington Public Power Supply System)³	Satsop, Wash.	Comb.	Pressurized water	1,240,000	3,817,000	1984
PLANNED						
Allens Creek Nuclear Plant, Unit 1 (Houston Lighting & Power)³	Wallis, Tex.	GE	Boiling water	1,150,000	3,579,000	1984
Atlantic Generating Station, Unit 1 (Public Service Electric & Gas Co. and JCP&LC & ACEC)³	Little Egg Inlet, N. J.	West.	Pressurized water	1,150,000	3,425,000	1987
Atlantic Generating Station, Unit 2 (Public Service Electric & Gas Co. and JCP&LC & ACEC)³	Little Egg Inlet, N. J.	West.	Pressurized water	1,150,000	3,425,000	1989
Black Fox Station, Unit 1 (Public Service of Oklahoma)³	Inola, Okla.	GE	Boiling water	1,150,000	3,579,000	1983
Black Fox Station, Unit 2 (Public Service of Oklahoma)³	Inola, Okla.	GE	Boiling water	1,150,000	3,579,000	1985
Blue Hills Station, Unit 1 (Gulf States Utilities)³	Jasper, Tex.	Comb.	Pressurized water	915,000	2,814,000	Indef.

1. POWER REACTORS (Continued)

A. Central-Station Electric Power (Continued)

Name and/or owner	Location	Principal nuclear contractor	Type	Power'		Start-up	Shut-down
				Unit size, net kW(e)	Reactor, kW(t)		
Blue Hills Station, Unit 2 (Gulf States Utilities)[3]	Jasper, Tex.	Comb.	Pressurized water	918,000	2,814,000	Indef.	
Carolina Power & Light, Unit 8[3]	North Carolina	B&W	Pressurized water	1,150,000		Indef.	
Carolina Power & Light, Unit 9[3]	North Carolina	B&W	Pressurized water	1,150,000		Indef.	
Carolina Power & Light, Unit 10[3]	North Carolina	B&W	Pressurized water	1,150,000		Indef.	
Clinch River Breeder Reactor Plant (DOE)[3]	Oak Ridge, Tenn.	West.	Sodium cooled fast breeder	350,000	975,000	Indef.	
*Douglas Point Project Nuclear Generating Station, Unit 1 (Potomac Electric Power Co.)[3]	Nanjemoy, Md.	GE	Boiling water	1,178,000	3,579,000	Indef.	
*Douglas Point Project Nuclear Generating Station, Unit 2 (Potomac Electric Power Co.)[3]	Nanjemoy, Md.	GE	Boiling water	1,178,000	3,579,000	Indef.	
Erie, Unit 1 (Ohio Edison Co.)[3]	Berlin Heights, Ohio	B&W	Pressurized water	1,260,000	3,760,000	1985	
Erie, Unit 2 (Ohio Edison Co.)[3]	Berlin Heights, Ohio	B&W	Pressurized water	1,260,000	3,760,000	1987	
Greene County Nuclear Power Plant (Power Authority of State of New York)[3]	Cementon, N. Y.	B&W	Pressurized water	1,212,000	3,600,000	1984	
Greenwood Energy Center, Unit 2 (Detroit Edison Co.)[3]	Michigan	B&W	Pressurized water	1,200,000	3,600,000	1987	
Greenwood Energy Center, Unit 3 (Detroit Edison Co.)[3]	Michigan	B&W	Pressurized water	1,200,000	3,600,000	1989	
Haven Nuclear Plant, Unit 1 (Wisconsin Electric Power Co., WIPS, WIPL & MAGE)[3]	Haven, Wis.	West.	Pressurized water	900,000	2,785,000	1987	
Haven Nuclear Plant, Unit 2 (Wisconsin Electric Power Co., WIPS, WIPL & MAGE)[3]	Haven, Wis.	West.	Pressurized water	900,000	2,785,000	1989	
Jamesport, Unit 1 (Long Island Lighting Co.)[3]	Jamesport, N. Y.	West.	Pressurized water	1,150,000	3,411,000	1984	
Jamesport, Unit 2 (Long Island Lighting Co.)[3]	Jamesport, N. Y.	West.	Pressurized water	1,150,000	3,411,000	1986	
Montague Nuclear Power Station, Unit 1[3]	Montague Plain, Mass.	GE	Boiling water	1,150,000	3,579,000	1988	
Montague Nuclear Power Station, Unit 2[3]	Montague Plain, Mass.	GE	Boiling water	1,150,000	3,579,000	1988	
NEP, Unit 1 (New England Power Co.)[3]	Charlestown, R. I.	West.	Pressurized water	1,150,000		1984	
NEP, Unit 2 (New England Power Co.)[3]	Charlestown, R. I.	West.	Pressurized water	1,150,000		1986	
New York State Electric & Gas, Unit 1[3]		Comb.	Pressurized water	1,250,000		Indef.	
New York State Electric & Gas, Unit 2[3]		Comb.	Pressurized water	1,250,000		Indef.	
1990 Unit (Public Service Electric & Gas Co., N. J.)[3]	Undetermined	West.	Pressurized water	1,150,000	3,425,000	1993	
1992 Unit (Public Service Electric & Gas Co., N. J.)[3]	Undetermined	West.	Pressurized water	1,150,000	3,425,000	1995	
North Coast Power Plant (Puerto Rico Water Resources Authority)[3]	Arecibo, P. R.	West.	Pressurized water	583,000	1,785,000	Indef.	
Pacific Gas & Electric Co., Unit 1[3]	California	GE	Boiling water	1,200,000	3,323,000	Indef.	
Pacific Gas & Electric Co., Unit 2[3]	California	GE	Boiling water	1,200,000	3,323,000	Indef.	
Palo Verde Nuclear Generating Station, Unit 4 (Arizona Public Service Co., TG&E, STRP, PSNM, EPEC)[3]	Wintersburg, Ariz.	Comb.	Pressurized water	1,237,700	3,817,000	1988	
Palo Verde Nuclear Generating Station, Unit 5 (Arizona Public Service Co., TG&E, STRP, PSNM, EPEC)[3]	Wintersburg, Ariz.	Comb.	Pressurized water	1,237,700	3,817,000	1990	
Pebble Springs, Unit 1 (Portland General Electric Co.)[3]	Arlington, Oreg.	B&W	Pressurized water	1,260,000	3,600,000	1985	
Pebble Springs, Unit 2 (Portland General Electric Co.)[3]	Arlington, Oreg.	B&W	Pressurized water	1,260,000		1988	

Perkins Nuclear Station, Unit 1 (Duke Power Co.)[3]	Davie County, N. C.	Comb.	Pressurized water	1,280,000	3,800,000	1984	
Perkins Nuclear Station, Unit 2 (Duke Power Co.)[3]	Davie County, N. C.	Comb.	Pressurized water	1,280,000	3,800,000	1987	
Perkins Nuclear Station, Unit 3 (Duke Power Co.)[3]	Davie County, N. C.	Comb.	Pressurized water	1,280,000	3,800,000	1989	
Pilgrim Station, Unit 2 (Boston Edison Co.)[3]	Plymouth, Mass.	Comb.	Pressurized water	1,180,000	3,456,000	1983	
Skagit Nuclear Power Project, Unit 1 (Puget Sound Power & Light Co.)[3]	Sedro Woolley, Wash.	GE	Boiling water	1,288,000	3,800,000	1985	
Skagit Nuclear Power Project, Unit 2 (Puget Sound Power & Light Co.)[3] *	Sedro Woolley, Wash.	GE	Boiling water	1,288,000	3,800,000	1986	
Sundesert Nuclear Plant, Unit 1 (San Diego Gas & Electric Co.)[3]	Blythe, Calif.	West.	Pressurized water	974,000		1984	
Sundesert Nuclear Plant, Unit 2 (San Diego Gas & Electric Co.)[3]	Blythe, Calif.	West.	Pressurized water	974,000		1985	
Vandalia Nuclear Project (Iowa Power & Light Co., Associated Electric Cooperative, Inc. and Central Iowa Power Cooperative)[3]	Iowa	B&W	Pressurized water	1,270,000		Indef.	
William H. Zimmer Nuclear Power Station, Unit 2 (Cincinnati Gas & Electric Co.)[3]	Ohio	GE	Boiling water	1,170,000		1989	
Yellow Creek, Unit 1[3]	Corinth, Miss.	Comb.	Pressurized water	1,285,000	3,817,000	1984	
Yellow Creek, Unit 2[3]	Corinth, Miss.	Comb.	Pressurized water	1,285,000	3,817,000	1985	
SHUT DOWN OR DISMANTLED							
Boiling Nuclear Superheater Power Station (AEC and Puerto Rico Water Resources Authority)[3,4]	Punta Higuera, P. R.	Comb.	Boiling water integral nuclear superheat	16,500	50,000	1964	1968
Carolinas-Virginia Tube Reactor (Carolinas-Virginia Nuclear Power Associates, Inc.)[3,4,5]	Parr, S. C.	West.	Pressure tube, heavy water	17,000	64,000	1963	1967
Elk River Reactor (AEC and Rural Cooperative Power Association)[3,4,5,6]	Elk River, Minn.	AC	Boiling water	22,000	58,200	1962	1968
Enrico Fermi Atomic Power Plant, Unit 1 (Power Reactor Development Co.)[3,4]	Lagoona Beach, Mich.	PRDC	Sodium cooled, fast	60,900	200,000	1963	1973
Hallam Nuclear Power Facility, Sheldon Station (AEC and Consumers Public Power District)[4,6]	Hallam, Nebr.	AI	Sodium graphite	75,000	240,000	1962	1964
Pathfinder Atomic Plant (Northern States Power Co.)[6]	Sioux Falls, S. Dak.	AC	Boiling water	58,500	190,000	1964	1967
Peach Bottom Atomic Power Station, Unit 1 (Philadelphia Electric Co.)[3,4]	Peach Bottom, Pa.	GA	High temperature gas cooled	40,000	115,000	1966	1974
Piqua Nuclear Power Facility (AEC and City of Piqua)[3,4,6]	Piqua, Ohio	AI	Organic cooled and moderated	11,400	45,500	1963	1966

B. Dual-Purpose Plants

OPERABLE						
N Reactor (DOE and Washington Public Power Supply System)[11]	Richland, Wash.	UNI	Graphite	8 0,000	4,000,000	1963
BEING BUILT						
Midland Nuclear Power Plant, Unit 1 (Consumers Power Co. of Michigan)[3,12]	Midland, Mich.	B&W	Pressurized water	460,000	2,468,000	1981
Midland Nuclear Power Plant, Unit 2 (Consumers Power Co. of Michigan)[3,12]	Midland, Mich.	B&W	Pressurized water	811,000	2,468,000	1980

C. Propulsion (Maritime)

Name and/or owner	Nuclear designer	Shipbuilder	Type	Maximum shaft horsepower	Power,[1] kW(t)	Start-up	Shut-down
SHUT DOWN							
Nuclear Ship SAVANNAH (Maritime Administration)[3]	B&W	NYSC	Pressurized water	22,000	80,000	1961	1971

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*Utility is negotiating to cancel.

2. EXPERIMENTAL POWER-REACTOR SYSTEMS

A. Electric-Power Systems

Name (all owned by DOE except as noted)	Designation	Location	Principal nuclear contractor	Type	Power[1] Plant, net kW(e)	Power[1] Reactor, kW(t)	Start-up	Shut-down
OPERABLE								
Experimental Breeder Reactor No. 2[1,9]	EBR-2	INEL Site, Idaho	ANL	Sodium cooled, fast	20,000	62,500	1963	
SHUT DOWN OR DISMANTLED								
Boiling Reactor Experiment No. 1	BORAX-1	INEL Site, Idaho	ANL	Boiling water	No elec.	1,400	1953	1954
Boiling Reactor Experiment No. 5	BORAX-5	INEL Site, Idaho	ANL	Boiling water, integral nuclear superheat	2,600	20,000	1962	1964
Boiling Reactor Experiments[1,3]	BORAX-2, -3, 4	INEL Site, Idaho	ANL	Boiling water	2,400	15,500	1954	1958
ESADA Vallecitos Experimental Superheat Reactor (Empire States Atomic Development Associates and General Electric Company)[3]	EVESR	Pleasanton, Calif.	GE	Light-water moderated, superheater	No elec.	17,000	1963	1967
Experimental Beryllium Oxide Reactor[1,5]	EBOR	INEL Site, Idaho	GA	Gas cooled, BeO moderated	No elec.	10,000	Terminated	
Experimental Boiling Water Reactor[3,9]	EBWR	Argonne, Ill.	ANL	Boiling water	4,500	100,000	1956	1967
Experimental Breeder Reactor No. 1[1,4]	EBR-1	INEL Site, Idaho	ANL	NaK cooled, fast	150	1,400	1951	1964
Experimental Gas Cooled Reactor[1,6]	EGCR	Oak Ridge, Tenn.	KE–AC	Gas cooled, graphite moderated	21,900	84,300	Terminated	
Experimental Organic Cooled Reactor[1,6]	EOCR	INEL Site, Idaho	Fluor–AI	Organic cooled and moderated	No elec.	40,000	Terminated	
Heavy Water Components Test Reactor	HWCTR	Savannah River Laboratory, Aiken, S. C.	du Pont	Pressurized heavy water	No elec.	61,100	1962	1964
Homogeneous Reactor Experiment No. 1	HRE-1	Oak Ridge, Tenn.	ORNL	Aqueous homogeneous solution (UO_2SO_4)	140	1,000	1952	1954
Homogeneous Reactor Experiment No. 2	HRE-2	Oak Ridge, Tenn.	ORNL	Aqueous homogeneous solution (UO_2SO_4)	300	5,200	1957	1961
Los Alamos Molten Plutonium Reactor Experiment	LAMPRE-1	Los Alamos, N. Mex.	LASL	Fast molten plutonium fueled, sodium cooled	No elec.	1,000	1961	1963
Los Alamos Power Reactor Experiment No. 1	LAPRE-1	Los Alamos, N. Mex.	LASL	Aqueous homogeneous (phosphoric acid)	No elec.	2,000	1956	1957
Los Alamos Power Reactor Experiment No. 2	LAPRE-2	Los Alamos, N. Mex.	LASL	Aqueous homogeneous (phosphoric acid)	No elec.	1,000	1959	1959
Molten Salt Reactor Experiment	MSRE	Oak Ridge, Tenn.	ORNL	Single region, graphite moderated	No elec.	8,000	1965	1969
Organic Moderated Reactor Experiment[1,4]	OMRE	INEL Site, Idaho	AI	Organic cooled and moderated	No elec.	12,000	1957	1963
Plutonium Recycle Test Reactor	PRTR	Richland, Wash.	PNL	Pressure tube, heavy-water moderated and cooled	No elec.	70,000	1960	1969
Saxton Nuclear Experimental Reactor Project (Saxton Nuclear Experimental Corp.)[3]		Saxton, Pa.	West.	Pressurized water	3,000	23,500	1962	1972

Sodium Reactor Experiment (DOE and Southern California Edison Co.)[2,3]	SRE	Santa Susana, Calif.	AI	Sodium graphite	5,700	20,000	1957	1964
Southwest Experimental Fast Oxide Reactor (Southwest Atomic Energy Associates)[3]	SEFOR	Strickler, Ark.	GE	Sodium cooled, fast		20,000	1969	1972
Ultra High Temperature Reactor Experiment	UHTREX	Los Alamos, N. Mex.	LASL	Helium cooled	No elec.	3,000	1968	1970
Vallecitos Boiling Water Reactor (General Electric Company and Pacific Gas & Electric Co.)[3]	VBWR	Pleasanton, Calif.	GE	Boiling water	5,000	33,000	1957	1963

B. Auxiliary Power (SNAP)

SHUT DOWN OR DISMANTLED								
SNAP-2 Developmental System	S2DS	Santa Susana, Calif.	AI	NaK cooled	No elec.	50	1961	1963
SNAP-2 Experimental Reactor	SER	Santa Susana, Calif.	AI	NaK cooled	No elec.	50	1959	1960
SNAP-2/10A TSF Shielding Experiment	SNAP-TSF	Oak Ridge, Tenn.	AI ORNL	NaK cooled		10	1967	1973
SNAP-8 Developmental Reactor	S8DR	Santa Susana, Calif.	AI	NaK cooled		600	1968	1969
SNAP-8 Experimental Reactor	S8ER	Santa Susana, Calif.	AI	NaK cooled	No elec.	500	1962	1965
SNAP-10A Flight System Ground Test No. 1	S10FS-1	Los Alamos, N. Mex.	AI	NaK cooled	0.5	39	1964	1964
SNAP-10A Flight System Ground Test No. 3[22]	S10FS-3	Santa Susana, Calif.	AI	NaK cooled	0.5	39	1964	1966
SNAP-10A Flight System[22]	S10FS-4	In orbit	AI	NaK cooled	0.5	39	1965	1965
SNAP-10A Flight System	S10FS-5	Oak Ridge, Tenn.	AI	NaK cooled	0.5	39	(Spare)	

C. Space Propulsion (Rover)

Name (all owned by DOE except as noted)	Designation	Location	Principal nuclear contractor	Type	Power¹ kW(t)	Year of operation	Dismantled
SHUT DOWN OR DISMANTLED							
Fuel Element Test Bed	NF-1	NRDS, Nev.	LASL	Open cycle, gaseous hydrogen	44,000	1972	1972
Fuel Element Test Reactor	Pewee-1	NRDS, Nev.	LASL	Open cycle, liquid hydrogen	514,000	1968	1968
Fuel Element Test Reactor	Pewee-2	NRDS, Nev.	LASL	Open cycle, liquid hydrogen	514,000	Indef.	1973
Ground Experimental Engine Experiment	XE-Prime	NRDS, Nev.	AG–West.	Open cycle, liquid hydrogen	1,100,000	1968	1969
Ground Experimental Engine Experiment	XE-Backup	NRDS, Nev.	AG–West.	Open cycle, liquid hydrogen	1,100,000	Indef.	1973
Nuclear Rocket Engine Reactor Experiment (NERVA)	NRX-A2	NRDS, Nev.	AG–West.	Open cycle, liquid hydrogen	1,096,000	1964	1964
Nuclear Rocket Engine Reactor Experiment (NERVA)	NRX-A3	NRDS, Nev.	AG–West.	Open cycle, liquid hydrogen	1,100,000	1965	1965
Nuclear Rocket Engine Reactor Experiment (NERVA)	NRX-A5	NRDS, Nev.	AG–West.	Open cycle, liquid hydrogen	1,120,000	1966	1966
Nuclear Rocket Engine Reactor Experiment (NERVA)	NRX-A6	NRDS, Nev.	AG–West.	Open cycle, liquid hydrogen	1,199,000	1967	1967
Nuclear Rocket Reactor Engine System Test (NERVA)	NRX-A4/EST	NRDS, Nev.	AG–West.	Open cycle, liquid hydrogen	1,155,000	1966	1966
Nuclear Rocket Reactor Experiment	Kiwi-A	NRDS, Nev.	LASL	Open cycle, gaseous hydrogen	70,000	1959	1959
Nuclear Rocket Reactor Experiment	Kiwi-A Prime	NRDS, Nev.	LASL	Open cycle, gaseous hydrogen	85,000	1960	1960
Nuclear Rocket Reactor Experiment	Kiwi-A3	NRDS, Nev.	LASL	Open cycle, gaseous hydrogen	100,000	1960	1960
Nuclear Rocket Reactor Experiment	Kiwi-B1A	NRDS, Nev.	LASL	Open cycle, gaseous hydrogen	300,000	1961	1961
Nuclear Rocket Reactor Experiment	Kiwi-B1B	NRDS, Nev.	LASL	Open cycle, liquid hydrogen	900,000	1962	1962

2. EXPERIMENTAL POWER-REACTOR SYSTEMS (Continued)

C. Space Propulsion (Rover) (Continued)

Name (all owned by DOE except as noted)	Designation	Location	Principal nuclear contractor	Type	Power,[1] kW(t)	Year of operation	Dismantled
SHUT DOWN OR DISMANTLED (Continued)							
Nuclear Rocket Reactor Experiment	Kiwi-B4A	NRDS, Nev.	LASL	Open cycle, liquid hydrogen	500,000	1962	1962
Nuclear Rocket Reactor Experiment	Kiwi-B4D	NRDS, Nev.	LASL	Open cycle, liquid hydrogen	1,000,000	1964	1964
Nuclear Rocket Reactor Experiment	Kiwi-B4E	NRDS, Nev.	LASL	Open cycle, liquid hydrogen	950,000	1964	1964
Nuclear Rocket Reactor Experiment	Phoebus 1A	NRDS, Nev.	LASL	Open cycle, liquid hydrogen	1,070,000	1965	1965
Nuclear Rocket Reactor Experiment	Phoebus 1B	NRDS, Nev.	LASL	Open cycle, liquid hydrogen	1,400,000	1967	1967
Nuclear Rocket Reactor Experiment	Phoebus 2A	NRDS, Nev.	LASL	Open cycle, liquid hydrogen	4,200,000	1968	1968

3. TEST, RESEARCH, AND UNIVERSITY REACTORS

A. General Irradiation Test

Name and/or owner	Designation	Location	Principal nuclear contractor	Operator	Type	Power,[1] kW(t)	Start-up	Shut-down
OPERABLE								
Advanced Test Reactor (DOE)	ATR	INEL, Idaho	Ebasco-B&W	EG&G-ID	Tank	250,000	1968	
Engineering Test Reactor (DOE)[2,3]	ETR	INEL, Idaho	KE-GE	EG&G-ID	Tank	175,000	1957	
BEING BUILT								
Fast Flux Test Facility (DOE)	FFTF	Richland, Wash.	HEDL	HEDL	Sodium cooled	400,000	1979	
SHUT DOWN OR DISMANTLED								
General Electric Testing Reactor[3]	GETR	Pleasanton, Calif.	Owner	Owner	Tank	50,000	1958	1977
Materials Testing Reactor (DOE)[3,4]	MTR	INEL, Idaho	ORNL-ANL-Blaw-Knox	INC	Tank	40,000	1952	1970
Plum Brook Reactor Facility (NASA)[3]	NASA-TR	Sandusky, Ohio	NASA	NASA	Tank	60,000	1961	1974
Westinghouse Testing Reactor[3]	WTR	Waltz Mill, Pa.	Owner	Owner	Tank	60,000	1959	1962

B. High-Power Research and Test

Name and/or owner	Designation	Location	Principal nuclear contractor	Type	Power,[1] kW(t)	Start-up	Shut-down
OPERABLE							
Argonne Research Reactor (DOE)	CP-5	Argonne, Ill.	ANL	Heavy water	5,000	1954	
Brookhaven High Flux Beam Research Reactor (DOE)	HFBR	Upton, N. Y.	BNL	Heavy water	40,000	1965	
Brookhaven Medical Research Reactor (DOE)	BMRR	Upton, N. Y.	Daystrom	Tank	5,000	1959	
High Flux Isotope Reactor (DOE)	HFIR	Oak Ridge, Tenn.	ORNL	Tank flux trap	100,000	1965	
National Bureau of Standards Reactor[3]	NBSR	Gaithersburg, Md.	NBS–B&R	Heavy water	10,000	1967	
Oak Ridge Research Reactor (DOE)	ORR	Oak Ridge, Tenn.	ORNL	Tank	30,000	1958	
Omega West Reactor (DOE)	OWR	Los Alamos, N. Mex.	LASL	Tank	8,000	1956	
Union Carbide Corporation Reactor[3]	UCNR	Sterling Forest, N. Y.	AMF	Pool	5,000	1961	
SHUT DOWN OR DISMANTLED							
Ames Laboratory Research Reactor (DOE)	ALRR	Ames, Iowa	AMF	Heavy water	5,000	1965	1977
Babcock & Wilcox Nuclear Development Center Test Reactor[3]	BAWTR	Lynchburg, Va	Owner	Pool	6,000	1964	1971
Brookhaven Graphite Research Reactor (DOE)	BGRR	Upton, N. Y.	HKI	Graphite	20,000	1950	1969
Industrial Reactor Laboratories, Inc.[3]		Plainsboro, N. J.	AMF	Pool	5,000	1958	1975
Sandia Engineering Reactor (DOE)	SER	Kirtland AFB, East, N. Mex.	Sandia	Tank	5,000	1961	1970

C. Safety Research and Test

Name and/or owner	Designation	Location	Principal nuclear contractor	Type	Power,[1] kW(t)	Start-up	Shut-down
OPERABLE							
Power Burst Facility (DOE)	PBF	INEL, Idaho	EG&G–ID	Open tank	Transient, 28,000	1973	
Transient Reactor Test (DOE)	TREAT	INEL Site, Idaho	ANL	Graphite	Transient	1959	
BEING BUILT							
Loss of Fluid Test (DOE)	LOFT	INEL, Idaho	EG&G–ID	Pressurized water	55,000	1978	
SHUT DOWN OR DISMANTLED							
Intrinsic Subcriticality Experiment (DOE)[3,7]	SNAPTRAN-1	Los Alamos, N. Mex.	AI	Be-reflected SNAP-10A	Transient	1968	1971
King Intense Neutron Generator (DOE)	Kinglet	Los Alamos, N. Mex.	LASL	Homogeneous	Transient	1972	1977
Kiwi–Transient Test Reactor (DOE)	Kiwi-TTR	NRDS, Nev.	LASL	Kiwi/NERVA	Transient	1965	1965
SNAP-10A Transient Test No. 2 (DOE)[3,8]	SNAPTRAN-2	INEL, Idaho	AI–PPC	Be-reflected SNAP-10A	Transient	1965	1965
SNAP-10A Transient Test No. 3 (DOE)[3,8]	SNAPTRAN-3	INEL, Idaho	PPC–AI	H_2O-reflected SNAP-10A	Transient	1964	1964
Special Power Excursion Reactor Test No. 1 (DOE)	SPERT-1	INEL, Idaho	PPC	Open tank	Transient	1955	1964
Special Power Excursion Reactor Test No. 2 (DOE)	SPERT-2	INEL, Idaho	PPC	Pressurized water	Transient	1960	1965
Special Power Excursion Reactor Test No. 3 (DOE)	SPERT-3	INEL, Idaho	PPC	Pressurized water	Transient	1958	1968
Special Power Excursion Reactor Test No. 4 (DOE)	SPERT-4	INEL, Idaho	INC	Pool	Transient	1962	1970

3. TEST, RESEARCH, AND UNIVERSITY REACTORS

D. General Research

Name and/or owner	Designation	Location	Principal nuclear contractor	Type	Power,[1] kW(t)	Start-up	Shut-down
OPERABLE							
Aerotest Operations, Inc.[3]	AGNIR	San Ramon, Calif.	AGN	Pool - TRIGA core	250	1965	
Annular Core Pulsed Reactor (DOE)	ACPR	Kirtland AFB, East, N. Mex.	GA	U-Zr hydride	Transient	1967	
Argonne Thermal Source Reactor (DOE)	ATSR	Argonne, Ill.	ANL	Thermal	10	1957	
Babcock & Wilcox Lynchburg Pool Reactor[3]	LPR	Lynchburg, Va.	Owner	Pool	1,000	1958	
Biological Research Reactor (DOE)	JANUS	Argonne, Ill.	ANL	Tank	200	1964	
Bulk Shielding Reactor (DOE)[3,9]	BSR	Oak Ridge, Tenn.	ORNL	Pool	2,000	1950	
Dow Chemical Co.[3]	TRIGA-Mk I	Midland, Mich.	GA	U-Zr hydride	100	1967	
Fast Source Reactor (DOE)	AFSR	INEL Site, Idaho	ANL	Fast	1	1959	
General Atomic Company, TRIGA-MK I Prototype Reactor[3,39]	TRIGA-Mk I	La Jolla, Calif.	Owner	U-Zr hydride	250	1958	
General Atomic Company, Advanced TRIGA-Mk I Prototype Reactor[3]	TRIGA-Mk I	La Jolla, Calif.	Owner	U-Zr hydride	1,500	1960	
General Electric Nuclear Test Reactor[3]	NTR	Pleasanton, Calif.	GE	Light water	100	1957	
Health Physics Research Reactor (DOE)[34]	HPRR	Oak Ridge, Tenn.	ORNL	Fast burst	10	1962	
Livermore Pool Type Reactor (DOE)	LPTR	Livermore, Calif.	LW	Tank	3,000	1957	
Neutron Radiography Facility (DOE)	TRIGA-Mk I	Richland, Wash.	HEDL	U-Zr hydride	250	1977	
Neutron Radiography Facility (DOE)	NRAD	INEL, Idaho	ANL	Pool - TRIGA core	250	1977	
Northrop Corporate Laboratories (Space Radiation Laboratory)[3,39]	TRIGA-Mk F	Hawthorne, Calif.	GA	U-Zr hydride	1,000	1963	
Nuclear Examination Reactor (Rockwell International)[3,39]	L-85 (AE-6)	Santa Susana, Calif.	AI	Homogeneous	3	1952	
Omaha Veterans Administration Hospital[3]	TRIGA-Mk I	Omaha, Nebr.	GA	U-Zr hydride	18	1959	
Rhode Island Nuclear Science Center[3]		Fort Kearney, R. I.	GE	Pool	2,000	1964	
Rockwell International[3]	L-77	Canoga Park, Calif.	AI	Homogeneous	Neglig.	1958	
Sandia Pulsed Reactor III (DOE)	SPR-III	Kirtland AFB, East, N. Mex.	Sandia	Prompt burst	Transient	1975	
Tower Shielding Reactor No. 2 (DOE)	TSR-2	Oak Ridge, Tenn.	ORNL	Light water	1,000	1960	
U. S. Geological Survey Laboratory (Department of the Interior)[3,39]	TRIGA-Mk I	Denver, Colo.	GA	U-Zr hydride	1,000	1969	
Westinghouse Nuclear Training Center[3]		Zion, Ill.	West.		10	1972	
BEING BUILT							
Annular Core Pulsed Reactor Upgrade (DOE)	ACPR Upgrade	Kirtland AFB, East, N. Mex.	Sandia	UO_2 BeO	2000 and transient	1978	
SHUT DOWN OR DISMANTLED							
Accelerator Pulsed Fast Critical Assembly[3,43]	APFA III	La Jolla, Calif.	GA	Fast	1	1967	1973
American Standard Inc.[33]	UTR-1	Mountain View, Calif.	AS Inc.	Graphite water	Neglig.	1958	1960
Argonne CP-3, rebuilt as CP-3' (Manhattan Engineer District—DOE)	CP-3'	Palos Park, Ill.	Met. Lab.	Heavy water	300	1944	1963
Argonne Low Power Research Reactor (DOE)[39]	Juggernaut	Argonne, Ill.	ANL	Graphite water	250	1962	1970
Argonne National Laboratory (DOE)	AGN-201-108	Argonne, Ill.	AGN	Homog. solid	Neglig.	1957	1972
Argonne Nuclear Assembly for University Training (DOE)	Argonaut (CP-11)	Argonne, Ill.	ANL	Graphite water	10	1957	1972

Atomics International[3]	L-47	Canoga Park, Calif.	AI	Homogeneous	Neglig.	1957	1958
Battelle Memorial Institute[3]	BRR	West Jefferson, Ohio	AMI	Pool	2,000	1956	1974
Brookhaven Neutron Source Reactor No. 1 (DOE)	SCHIZO	Upton, N. Y.	BNL	Tank	100	1958	1970
Brookhaven Neutron Source Reactor No. 2 (DOE)	PHRENIC	Upton, N. Y.	BNL	Tank	100	1965	1970
Chicago Pile 1, rebuilt as CP-2 (Manhattan Engineer District – DOE)[3,4]	CP-2	Chicago, Ill.	Met. Lab.	Graphite	0.2 - 2	1942	1954
Curtiss-Wright Nuclear Research Laboratory of the Commonwealth of Pennsylvania		Quehanna, Pa.	Owner	Pool	1,000	1958	1966
DOE Demonstration Reactor[4,5]	Demo Reac	Oak Ridge, Tenn.	Lockheed	Pool	10	1969	1969
European - Asian Exhibit Program (DOE)[3,5]		Oak Ridge, Tenn.	Lockheed	Pool	10	1963	1969
Fast Neutron Source Reactor (DOE)	BNL FS-1	Upton, N. Y.	BNL	Fast		1967	1970
General Atomic Co. (World Agricultural Fair – U. S. Exhibit Reactor)[3,4]	TRIGA-Mk II	San Diego, Calif.	Owner	U - Zr hydride	50	1960	1960
High Temperature Lattice Test Reactor (DOE)	HTLTR	Richland, Wash.	PNL	Graphite	2	1967	1971
Illinois Institute of Technology Research Institute (Armour Research Foundation)[3]	ARR(L-54)	Chicago, Ill.	AI	Homogeneous	75	1956	1967
Kinetic Experiment on Water Boilers (Rockwell International)[3,33]	KEWB	Santa Susana, Calif.	AI	Homogeneous	Transient	1956	1967
Livermore Water Boiler (DOE)	LWB	Livermore, Calif.	AI	Homogeneous	0.5	1953	1961
Lockheed Aircraft Corp.		Dawsonville, Ga.	Lockheed	Pool	Neglig.	1960	1960
Los Alamos Fast Reactor (DOE)	Clementine	Los Alamos, N. Mex.	LASL	Fast, plutonium fuel, mercury cooled	25	1946	1953
Los Alamos HYDRO Reactor (DOE)	HYDRO	Los Alamos, N. Mex.	LASL		5 to 15	1956	1970
Los Alamos Water Boiler (DOE)	HYPO	Los Alamos, N. Mex.	LASL	Homogeneous	5.5	1944	1950
Los Alamos Water Boiler (DOE)	SUPO	Los Alamos, N. Mex.	LASL	Homogeneous	25	1950	1974
Louisiana State University Nuclear Science Center (Phillips Petroleum Co.)[3,7]	SNARE	Baton Rouge, La.	Sandia	Pool	2	1965	1966
Low Intensity Test Reactor (DOE)	LITR	Oak Ridge, Tenn.	ORNL	Tank	3,000	1950	1968
NASA Mock-Up Reactor[3]	MUR	Sandusky, Ohio	Lockheed	Light water, pool	100	1963	1973
Nuclear Effects Reactor (DOE)[3,8]	FRAN	NTS, Nev.	UCLLL/PPC	Prompt burst	Transient	1962	1970
Nuclear Effects Reactor (DOE)	KUKLA	San Diego, Calif.	UCLLL	Prompt burst	Transient	1959	1964
Oak Ridge Graphite Reactor (DOE)	X-10	Oak Ridge, Tenn.	CL	Graphite	3,500	1943	1963
Pawling Research Reactor (United Nuclear Corp.)[3]	PRR	Pawling, N. Y.	UNC	Light water	Neglig.	1958	1971
Physical Constants Test Reactor (DOE)	PCTR	Richland, Wash.	PNL	Graphite	0.1	1955	1972
Radiation Effects Reactor (Lockheed Aircraft Corp.)[3,4,5]	RER	Dawsonville, Ga.	Lockheed	Pool	3,000	1958	1970
Sandia Pulsed Reactor II (DOE)	SPR-II	Kirtland AFB, East, N. Mex.	Sandia	Prompt burst	Transient	1967	1976
Sandia Pulsed Reactor (DOE)	SPR	Kirtland AFB, East, N. Mex.	Sandia	Prompt burst	Transient	1961	1967
Shield Test and Irradiation Reactor (DOE)[4,7]	STIR	Santa Susana, Calif.	AI	Pool	1,000	1961	1972
Thermal Test Reactor No. 2 (DOE)	TTR-2	Richland, Wash.	PNL	Graphite	0.1	1955	1972
Torrey Pines, TRIGA-Mk III Reactor[3]	TRIGA-Mk III	La Jolla, Calif.	GA	U - Zr hydride	2,000	1965	1973
Tower Shielding Reactor No. 1	TSR-1	Oak Ridge, Tenn.	ORNL	Tank	500	1954	1958
UTR Test Reactor (American Radiator & Standard Sanitary Corp.)[3]		Mountain View, Calif.	Owner	Graphite/water	Neglig.	1961	1963

E. University Research and Teaching

(Footnote 3 applies to all reactors in this section except as noted.)

Name and/or owner	Designation	Location	Principal nuclear contractor	Type	Power,[1] kW(t)	Start-up	Shut-down
OPERABLE							
Brigham Young University	L-77	Provo, Utah	AI	Homogeneous	Neglig.	1967	
California State Polytechnic[34]	AGN-201-100	San Luis Obispo, Calif.	AGN	Homog. solid	Neglig.	1972	
Catholic University of America	AGN-201-101	Washington, D. C.	AGN	Homog. solid	Neglig.	1957	
Columbia University[34]	TRIGA-Mk II	New York, N. Y.	GA	U–Zr hydride	250	1977	
Cornell University[36]	TRIGA-Mk II	Ithaca, N. Y.	GA	U–Zr hydride	100	1962	
Cornell University Zero Power Reactor	ZPR	Ithaca, N. Y.	Vitro	Tank	Neglig.	1962	
Georgia Institute of Technology[45]	AGN-201-104	Atlanta, Ga.	AGN	Homog. solid	Neglig.	1957	
Georgia Tech. Research Reactor	GTRR	Atlanta, Ga.	GNEC	Heavy water	10,000	1964	
Idaho State University[33]	AGN-201P-103	Pocatello, Idaho	AGN	Homog. solid	Neglig.	1967	
Iowa State University	UTR-10	Ames, Iowa	AS Inc.	Graphite water	10	1959	
Kansas State University[36]	TRIGA-Mk II	Manhattan, Kans.	GA	U–Zr hydride	250	1962	
Manhattan College		New York, N. Y.	AMF	Tank	Neglig.	1964	
Massachusetts Institute of Technology	MITR	Cambridge, Mass.	ACF	Heavy-water reflected	5,000	1958	
Memphis State	AGN-201-108	Memphis, Tenn.	AGN	Homog. solid	Neglig.	1977	
Michigan State University[36,33]	TRIGA-Mk I	East Lansing, Mich.	GA	U–Zr hydride	250	1969	
North Carolina State University	PULSTAR	Raleigh, N. C.	AMF	Pool	1,000	1972	
Nuclear Science Center Reactor, Texas A&M University[36,44]	NSCR	College Station, Tex.	Convair	Pool - TRIGA core	1,000	1961	
Ohio State University		Columbus, Ohio	Lockheed	Pool	10	1961	
Oregon State University	AGN-201-114	Corvallis, Oreg.	AGN	Homog. solid	Neglig.	1958	
Oregon State University[36]	TRIGA-Mk II	Corvallis, Oreg.	GA	U–Zr hydride	1,000	1967	
PennState TRIGA Reactor (Pennsylvania State University)[36,44]	PSTR	University Park, Pa.	Owner	Pool - TRIGA core	1,000	1965	
Puerto Rico Nuclear Center (DOE)[47]	L-77	Mayaguez, P. R.	AI	Homogeneous	Neglig.	1959	
Purdue University		West Lafayette, Ind.	Lockheed	Pool	10	1962	
Reed College	TRIGA-Mk I	Portland, Oreg.	GA	U–Zr hydride	250	1968	
State University of New York (Western New York Nuclear Research Center, Inc.)	PULSTAR	Buffalo, N. Y.	AMF	Pool	2,000	1961	
Texas A&M University	TRIGA Conversion	College Station, Tex.	GA	U–Zr hydride	1,000	1968	
Tuskegee Institute[44]	AGN-201-102	Tuskegee, Ala.	AGN	Homog. solid	Neglig.	1957	
University of Arizona	TRIGA-Mk I	Tucson, Ariz.	GA	U–Zr hydride	250	1958	
University of California[36]	TRIGA-Mk III	Berkeley, Calif.	GA	U–Zr hydride	1,000	1966	
University of California	L-77	Santa Barbara, Calif.	AI	Homogeneous	Neglig.		
University of California[36]	TRIGA-Mk I	Irvine, Calif.	GA	U–Zr hydride	250	1969	
University of California at Los Angeles, School of Engineering and Applied Science	Educator	Los Angeles, Calif.	AMF	Graphite water	100	1960	

University of Delaware	AGN-201-113	Newark, Del.	AGN	Homog. solid	Neglig.	1958	
University of Florida	UFTR	Gainesville, Fla.	GNEC	Graphite/water	100	1959	
University of Illinois	LOPRA	Urbana, Ill.	GA	U-Zr hydride	10	1971	
University of Illinois	TRIGA Mk II	Urbana-Champaign, Ill.	GA	U-Zr hydride	1,500	1960	
University of Kansas	Model 4180	Lawrence, Kans.	BAC	Pool	10	1961	
University of Lowell		Lowell, Mass.	GI	Pool	1,000		
University of Maryland	TRIGA	College Park, Md.	AC	Tank	250	1960	
University of Michigan (Ford Nuclear Reactor)		Ann Arbor, Mich.	B&W	Pool	2,000	1957	
University of Missouri	MURR	Columbia, Mo.	Owner-IC	Tank	10,000	1966	
University of Missouri at Rolla		Rolla, Mo.	CW	Pool	200	1961	
University of New Mexico[44]	AGN-201M-112	Albuquerque, N. Mex.	AGN	Homog. solid	Neglig.	1957	
University of Oklahoma	AGN-211-102	Norman, Okla.	AGN	Homog. solid, pool	Neglig.	1958	
University of Texas[36]	TRIGA-Mk I	Austin, Tex.	GA	U-Zr hydride	250	1963	
University of Utah	TRIGA-Mk I	Salt Lake City, Utah	GA	U-Zr hydride	250	1975	
University of Utah	AGN-201-107	Salt Lake City, Utah	AGN	Homog. solid	Neglig.	1957	
University of Virginia	CAVALIER	Charlottesville, Va.	Owner		Neglig.		
University of Virginia	UVAR	Charlottesville, Va.	Owner-B&W	Pool	2,000	1960	
University of Washington	Educator	Seattle, Wash.	AMF	Graphite/water	100	1961	
University of Wisconsin[39-44]	TRIGA	Madison, Wis.	GI	Pool, TRIGA core	1,000	1960	
Virginia Polytechnic Institute	UTR-10	Blacksburg, Va.	AS Inc.	Graphite/water	100	1959	
Washington State University[39-40]	WSTR	Pullman, Wash.	GI	Pool, TRIGA core	1,000	1961	
Worcester Polytechnic Institute		Worcester, Mass.	GI	Pool	10	1959	
BEING BUILT							
Mississippi State University[33]	RRR	State College, Miss.	Owner-NSA	Homogeneous	Neglig.		
SHUT DOWN OR DISMANTLED							
Colorado State University	AGN-201-109	Fort Collins, Colo.	AGN	Homog. solid	Neglig.	1957	1974
Leland Stanford University		Palo Alto, Calif.	GL	Pool	10	1959	1974
North Carolina State University		Raleigh, N. C.	Cook	Graphite/water	10	1960	1973
Polytechnic Institute of New York[44]	AGN-201M-105	New York, N. Y.	AGN	Homog. solid	Neglig.	1967	1974
Puerto Rico Nuclear Center (DOE)[7-8]	TRIGA FLIP	Mayaguez, P. R.	GA	Pool, TRIGA core	2,000	1960	1976
University of Nevada	L-77	Reno, Nev.	AI	Homogeneous	Neglig.	1963	1974
University of Wyoming	L-77	Laramie, Wyo.	AI	Homogeneous	Neglig.	1959	1974
West Virginia University	AGN-211-103	Morgantown, W. Va.	AGN	Homog. solid, pool	Neglig.	1959	1972
William Marsh Rice University	AGN-211-101	Houston, Tex.	AGN	Homog. solid, pool	Neglig.	1959	1965

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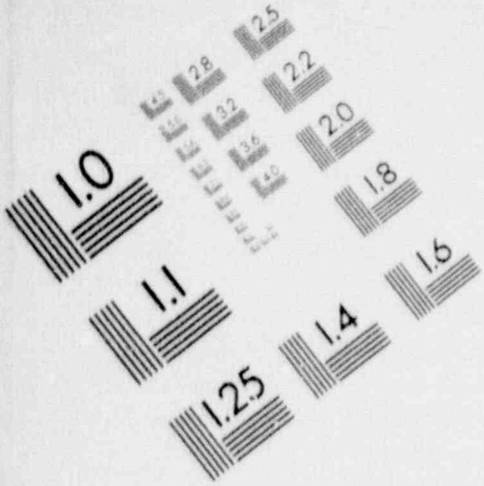
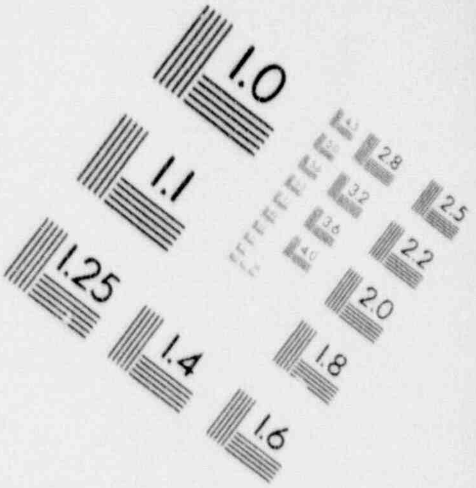
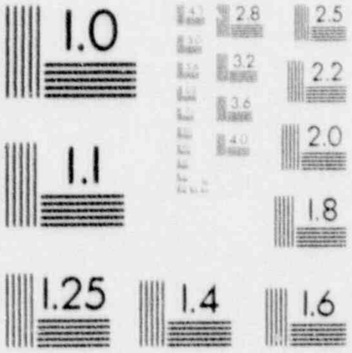
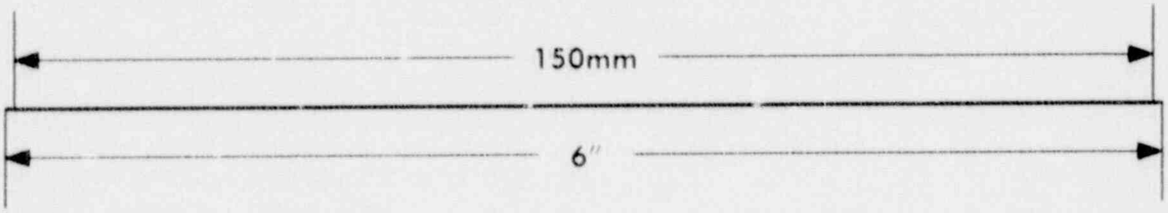
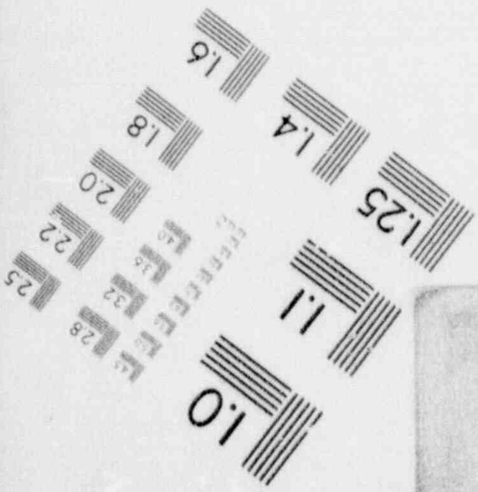
IMAGE EVALUATION
TEST TARGET (MT-3)











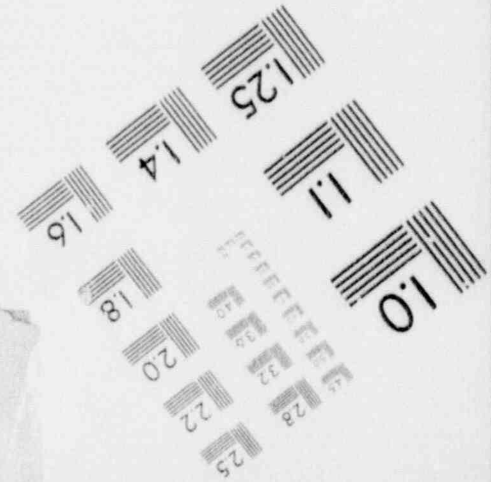


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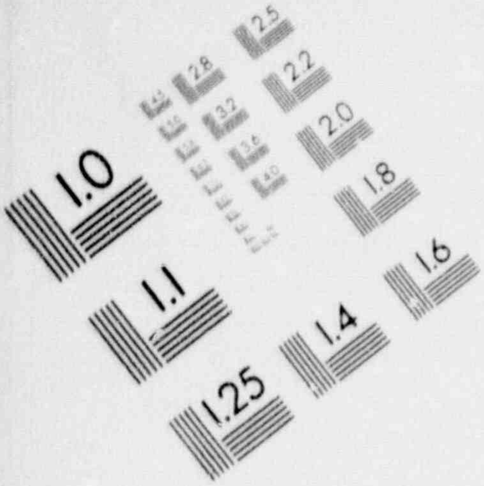
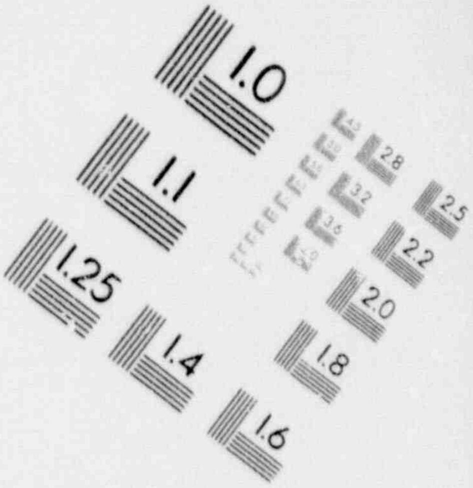
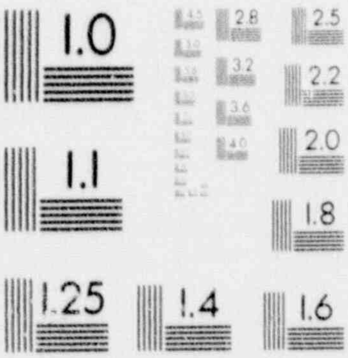
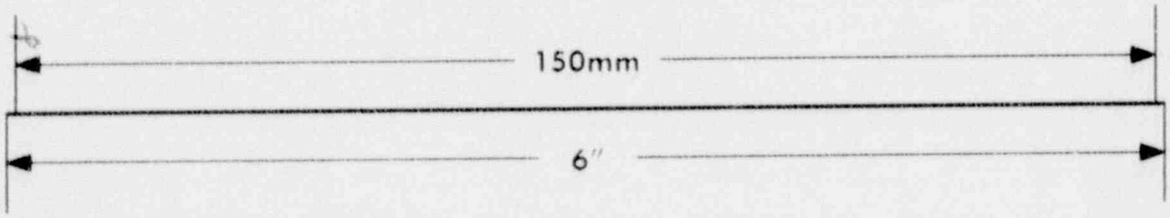
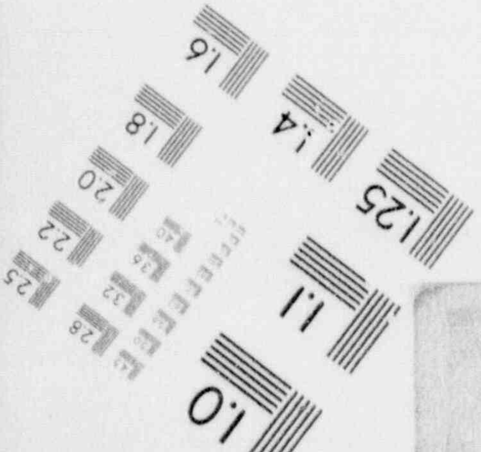
IMAGE EVALUATION
TEST TARGET (MT-3)

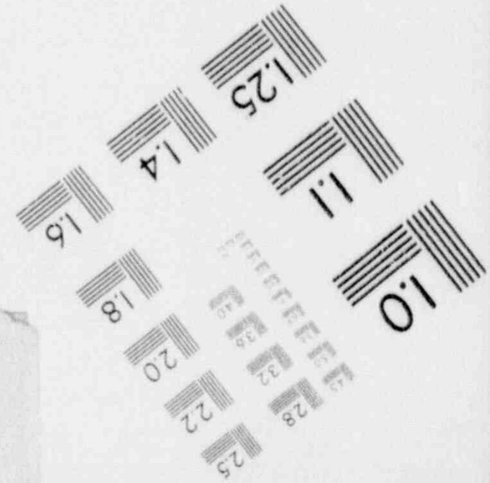












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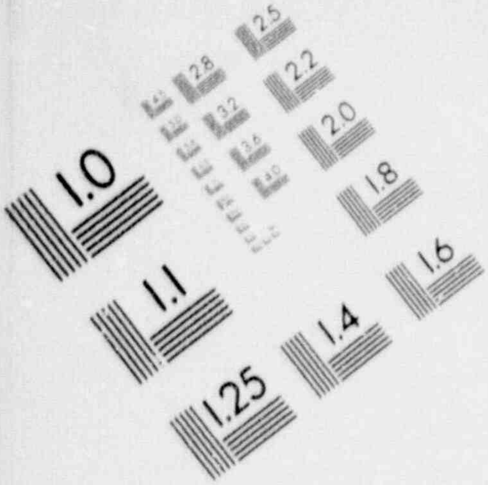

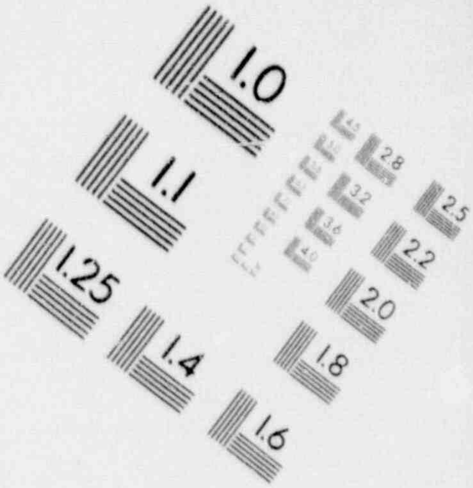

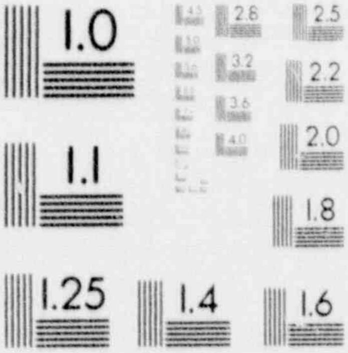

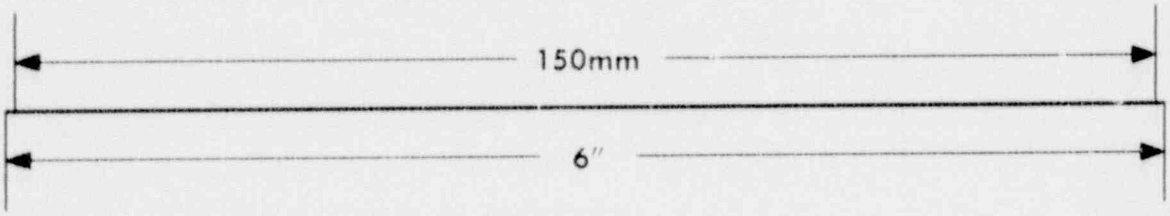

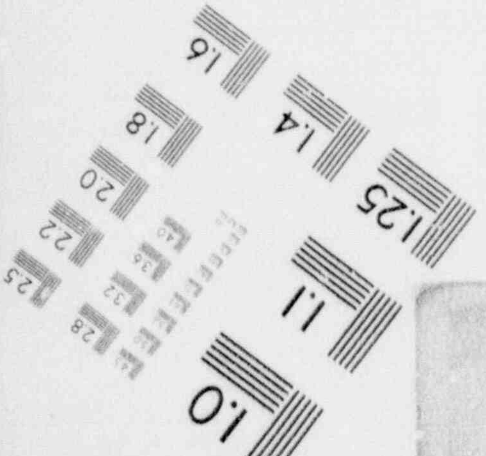

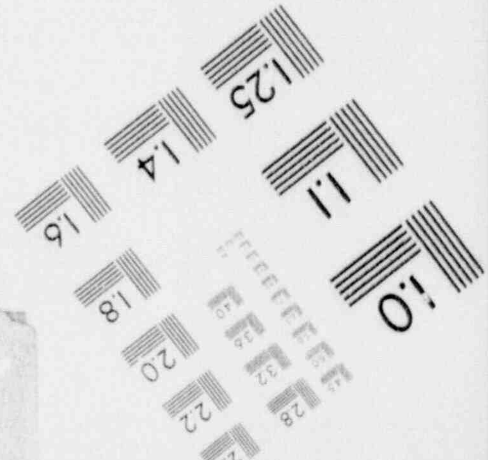

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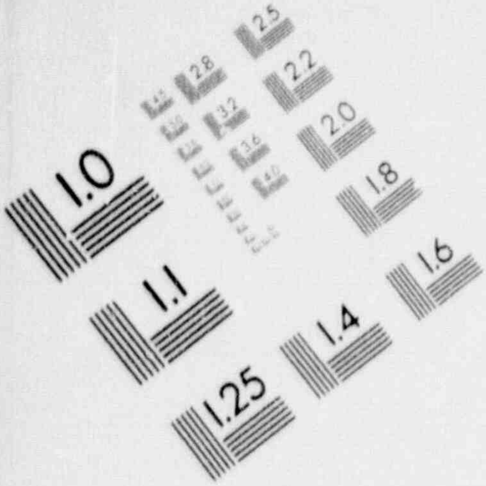

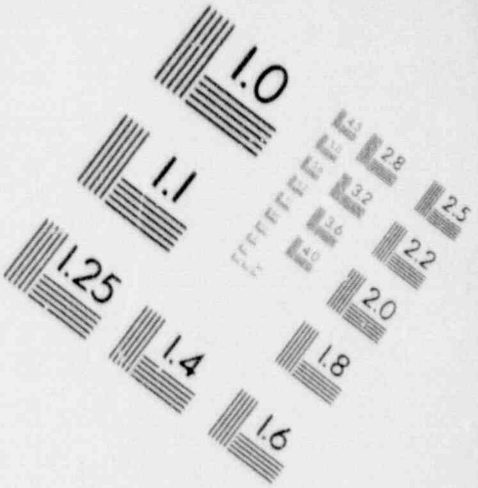

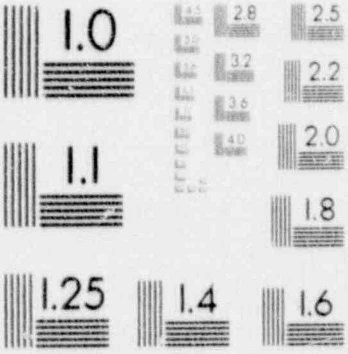

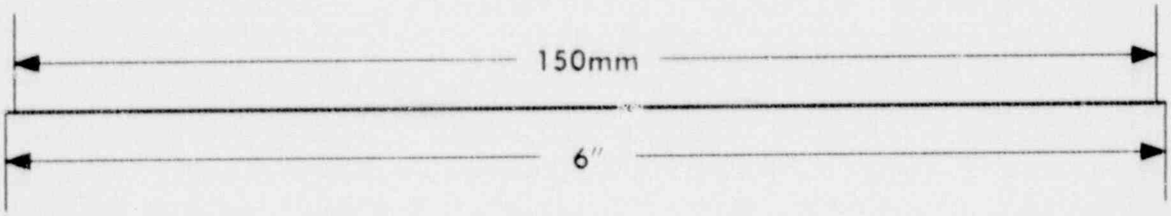

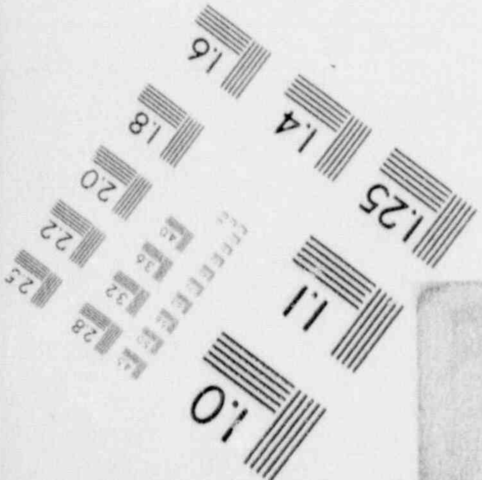

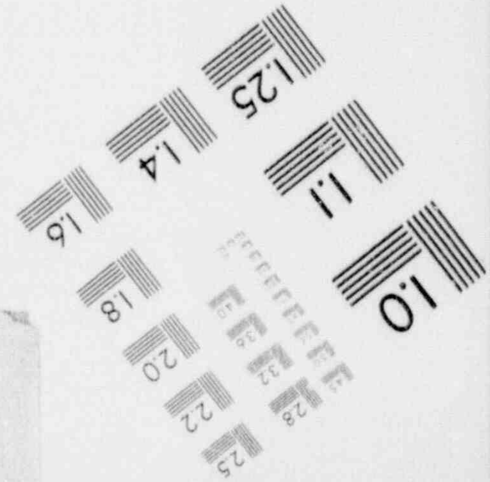

1. MATERIALS PRODUCTION

(All owned by DOE)

Designation	Nuclear designer	Type	Location	Start-up	Shut-down
OPERABLE*					
C Reactor	du Pont	Heavy water	Savannah River Plant, Aiken, S. C.	1955	
K Reactor	du Pont	Heavy water	Savannah River Plant, Aiken, S. C.	1954	
P Reactor	du Pont	Heavy water	Savannah River Plant, Aiken, S. C.	1954	
SHUT DOWN					
B Reactor	du Pont	Graphite	Richland, Wash.	1944	1968
C Reactor	GE	Graphite	Richland, Wash.	1952	1969
D Reactor	du Pont	Graphite	Richland, Wash.	1944	1967
DR Reactor	GE	Graphite	Richland, Wash.	1950	1964
F Reactor	du Pont	Graphite	Richland, Wash.	1945	1965
H Reactor	GE	Graphite	Richland, Wash.	1949	1965
KE Reactor	GE	Graphite	Richland, Wash.	1955	1971
KW Reactor	GE	Graphite	Richland, Wash.	1955	1970
L Reactor	du Pont	Heavy water	Savannah River Plant, Aiken, S. C.	1954	1968
R Reactor	du Pont	Heavy water	Savannah River Plant, Aiken, S. C.	1953	1964

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*The N Reactor, Richland, Wash., is listed on page 19; see also footnote 11.

2. PROCESS DEVELOPMENT

Name (all owned by DOE)	Designation	Location	Nuclear designer	Type	Power,[1] (kWt)	Start-up	Shut-down
OPERABLE							
Lattice Test Reactor	LTR	Savannah River Laboratory, Aiken, S. C.	du Pont	Heavy water	1	1967	
Process Development Pile	PDP	Savannah River Laboratory, Aiken, S. C.	du Pont	Heavy water	1	1953	
Savannah River Test Pile 305	SR-305	Savannah River Laboratory, Aiken, S. C.	du Pont	Graphite	1	1953	
Standard Pile	SP	Savannah River Laboratory, Aiken, S. C.	du Pont	Graphite	2 × 10	1953	
SHUT DOWN OR DISMANTLED							
Hanford 305 Test Reactor	HTR	Richland, Wash.	du Pont	Graphite	Negig.	1944	1972

1. DEFENSE POWER-REACTOR APPLICATIONS

A. Remote Installations

Name (all owned by DOD)	Designation**	Location	Principal nuclear contractor	Type	Power¹ Plant, net kW(e)	Power¹ Reactor, kW(t)	Start-up	Shut-down
SHUT DOWN OR DISMANTLED								
Portable Medium Power Plant No. 1	PM-1	Sundance, Wyo.	Martin	Pressurized water	1,000	9,370	1962	1968
Portable Medium Power Plant No. 2A**	PM-2A	Camp Century, Greenland	Alco	Pressurized water	1,560	10,000	1960	1963
Portable Medium Power Plant No. 3A	PM-3A	McMurdo Sound, Antarctica	Martin	Pressurized water	1,500	9,310	1962	1973
Stationary Medium Power Plant No. 1	SM-1	Fort Belvoir, Va.	Alco	Pressurized water	1,855	10,000	1957	1973
Stationary Medium Power Plant No. 1A**	SM-1A	Fort Greely, Alaska	Alco	Pressurized water	1,650	20,200	1962	1972
STURGIS Floating Nuclear Power Plant**	MH-1A	Gatun Lake, Canal Zone	Martin	Pressurized water	10,000	45,000	1967	1976

B. Propulsion (Naval)

Name (all owned by U. S. Navy)	Designation**	Shipbuilder	Start-up	Shut-down
OPERABLE				
USS NAUTILUS	SSN571	Electric Boat (Groton)	1954	
USS SEAWOLF*²	SSN575	Electric Boat (Groton)	1960	
USS SKATE	SSN578	Electric Boat (Groton)	1957	
USS SWORDFISH	SSN579	Portsmouth	1958	
USS SARGO	SSN583	San Francisco Bay	1958	
USS SEADRAGON	SSN584	Portsmouth	1959	
USS SKIPJACK	SSN585	Electric Boat (Groton)	1958	
USS SCAMP	SSN588	San Francisco Bay	1961	
USS SCULPIN	SSN590	Ingalls	1961	
USS SHARK	SSN591	Newport News	1960	
USS SNOOK	SSN592	Ingalls	1961	
USS PERMIT	SSN594	San Francisco Bay	1962	
USS PLUNGER	SSN595	San Francisco Bay	1962	
USS BARB	SSN596	Ingalls	1963	
USS TULLIBEE	SSN597	Electric Boat (Groton)	1960	
USS GEORGE WASHINGTON	SSBN598	Electric Boat (Groton)	1959	
USS PATRICK HENRY	SSBN599	Electric Boat (Groton)	1960	
USS THEODORE ROOSEVELT	SSBN600	San Francisco Bay	1960	
USS ROBERT E. LEE	SSBN601	Newport News	1960	
USS ABRAHAM LINCOLN	SSBN602	Portsmouth	1960	
USS POLLACK	SSN603	NYSC	1963	
USS HADDO	SSN604	NYSC	1964	
USS JACK	SSN605	Portsmouth	1965	
USS TINOSA	SSN606	Portsmouth	1963	
USS DACE	SSN607	Ingalls	1963	
USS ETHAN ALLEN	SSBN608	Electric Boat (Groton)	1961	
USS SAM HOUSTON	SSBN609	Newport News	1961	
USS THOMAS A. EDISON	SSBN610	Electric Boat (Groton)	1961	
USS JOHN MARSHALL	SSBN611	Newport News	1962	
USS GUARDFISH	SSN612	NYSC	1966	
USS FLASHER	SSN613	Electric Boat (Groton)	1966	
USS GREENLING	SSN614	GD (Quincy)	1967	
USS GATO	SSN615	GD (Quincy)	1967	
USS LAFAYETTE	SSBN616	Electric Boat (Groton)	1963	
USS ALEXANDER HAMILTON	SSBN617	Electric Boat (Groton)	1963	
USS THOMAS JEFFERSON	SSBN618	Newport News	1962	
USS ANDREW JACKSON	SSBN619	San Francisco Bay	1963	
USS JOHN ADAMS	SSBN620	Portsmouth	1964	
USS HADDOCK	SSN621	Ingalls	1967	
USS JAMES MONROE	SSBN622	Newport News	1963	
USS NATHAN HALE	SSBN623	Electric Boat (Groton)	1963	
USS WOODROW WILSON	SSBN624	San Francisco Bay	1963	
USS HENRY CLAY	SSBN625	Newport News	1963	
USS DANIEL WEBSTER	SSBN626	Electric Boat (Groton)	1964	
USS JAMES MADISON	SSBN627	Newport News	1964	
USS TECUMSEH	SSBN628	Electric Boat (Groton)	1964	
USS DANIEL BOONE	SSBN629	San Francisco Bay	1963	
USS JOHN C. CALHOUN	SSBN630	Newport News	1964	
USS ULYSSES S. GRANT	SSBN631	Electric Boat (Groton)	1964	
USS VON STEUBEN	SSBN632	Newport News	1964	
USS CASIMIR PULASKI	SSBN633	Electric Boat (Groton)	1964	
USS STONEWALL JACKSON	SSBN634	San Francisco Bay	1964	

1. DEFENSE POWER-REACTOR APPLICATIONS (Continued)

B. Propulsion (Naval) (Continued)

Name (all owned by U. S. Navy)	Designation**	Shipbuilder	Start-up
OPERABLE (Continued)			
USS SAM RAYBURN	SSBN635	Newport News	1964
USS NATHANAEL GREENE	SSBN636	Portsmouth	1964
USS STURGEON	SSN637	Electric Boat (Groton)	1966
USS WHALE	SSN638	GD (Quincy)	1968
USS TAUTOG	SSN639	Ingalls	1968
USS BENJAMIN FRANKLIN	SSBN640	Electric Boat (Groton)	1965
USS SIMON BOLIVAR	SSBN641	Newport News	1965
USS KAMEHAMEHA	SSBN642	San Francisco Bay	1965
USS GEORGE BANCROFT	SSBN643	Electric Boat (Groton)	1965
USS LEWIS AND CLARK	SSBN644	Newport News	1965
USS JAMES K. POLK	SSBN645	Electric Boat (Groton)	1966
USS GRAYLING	SSN646	Portsmouth	1969
USS POGY	SSN647	NYSC/Ingalls	1970
USS ASPRO	SSN648	Ingalls	1968
USS SUNFISH	SSN649	GD (Quincy)	1968
USS PARGO	SSN650	Electric Boat (Groton)	1967
USS QUEENFISH	SSN651	Newport News	1966
USS PUFFER	SSN652	Ingalls	1969
USS RAY	SSN653	Newport News	1967
USS GEORGE C. MARSHALL	SSBN654	Newport News	1966
USS HENRY L. STIMSON	SSBN655	Electric Boat (Groton)	1966
USS GEORGE WASHINGTON CARVER	SSBN656	Newport News	1966
USS FRANCIS SCOTT KEY	SSBN657	Electric Boat (Groton)	1966
USS MARIANO G. VALLEJO	SSBN658	San Francisco Bay	1966
USS WILL ROGERS	SSBN659	Electric Boat (Groton)	1967
USS SAND LANCE	SSN660	Portsmouth	1971
USS LAPON	SSN661	Newport News	1967
USS GURNARD	SSN662	San Francisco Bay	1968
USS HAMMERHEAD	SSN663	Newport News	1967
USS SEA DEVIL	SSN664	Newport News	1968
USS GUITARRO	SSN665	Mare Island	1972
USS HAWKBILL	SSN666	Mare Island	1970
USS BERGALL	SSN667	Electric Boat (Groton)	1969
USS SPADEFISH	SSN668	Newport News	1969
USS SEA HORSE	SSN669	Electric Boat (Groton)	1969
USS FINBACK	SSN670	Newport News	1969
USS NARWHAL	SSN671	Electric Boat (Groton)	1969
USS PINTADO	SSN672	Mare Island	1970
USS FLYING FISH	SSN673	Electric Boat (Groton)	1969
USS TREPANG	SSN674	Electric Boat (Groton)	1970
USS BLUEFISH	SSN675	Electric Boat (Groton)	1970

Name (all owned by U. S. Navy)	Designation**	Shipbuilder	Start-up	Shut-down
USS BATON ROUGE	SSN689	Newport News	1977	
USS PHILADELPHIA	SSN690	Electric Boat (Groton)	1976	
USS MEMPHIS	SSN691	Newport News	1977	
USS OMAHA	SSN692	Electric Boat (Groton)	1977	
USS ENTERPRISE (8 reactors)	CVN65	Newport News	1960	
USS NIMITZ (2 reactors)	CVN68	Newport News	1974	
USS DWIGHT D. EISENHOWER (2 reactors)	CVN69	Newport News	1977	
USS CARL VINSON (2 reactors)	CVN70	Newport News	1977	
USS LONG BEACH (2 reactors)	CGN9	Bethlehem	1961	
USS BAINBRIDGE (2 reactors)	CGN25	Bethlehem	1962	
USS TRUXTUN (2 reactors)	CGN35	NYSC	1967	
USS CALIFORNIA (2 reactors)	CGN36	Newport News	1973	
USS SOUTH CAROLINA (2 reactors)	CGN37	Newport News	1974	
USS VIRGINIA (2 reactors)	CGN38	Newport News	1976	
USS TEXAS (2 reactors)	CGN39	Newport News	1977	
Deep Submergence Research Vehicle	NR-1	Electric Boat (Groton)	1969	
BEING BUILT				
CINCINNATI	SSN693	Newport News		
GROTON	SSN694	Electric Boat (Groton)		
BIRMINGHAM	SSN695	Newport News		
NEW YORK CITY	SSN696	Electric Boat (Groton)		
INDIANAPOLIS	SSN697	Electric Boat (Groton)		
BREMERTON	SSN698	Electric Boat (Groton)		
JACKSONVILLE	SSN699	Electric Boat (Groton)		
DALLAS	SSN700	Electric Boat (Groton)		
LA JOLLA	SSN701	Electric Boat (Groton)		
PHOENIX	SSN702	Electric Boat (Groton)		
BOSTON	SSN703	Electric Boat (Groton)		
BALTIMORE	SSN704	Electric Boat (Groton)		
Submarine	SSN705	Electric Boat (Groton)		
Submarine	SSN706	Electric Boat (Groton)		
Submarine	SSN707	Mare Island		
Submarine	SSN708	Electric Boat (Groton)		
Submarine	SSN709	Electric Boat (Groton)		
Submarine	SSN710	Ingalls		
SAN FRANCISCO	SSN711	Electric Boat (Groton)		
Submarine	SSN712	Ingalls		
Submarine	SSN713	Ingalls		
Submarine	SSN714	Electric Boat (Groton)		
Submarine	SSN715	Electric Boat (Groton)		
OHIO	SSBN726	Newport News		

USS BILLFISH	SSN676	Electric Boat (Groton)	1970	
USS DRUM	SSN677	Mare Island	1971	
USS ARCHERFISH	SSN678	Electric Boat (Groton)	1971	
USS SILVERSIDES	SSN679	Electric Boat (Groton)	1971	
USS WILLIAM H. BATES	SSN680	Ingalls	1972	
USS BATFISH	SSN681	Electric Boat (Groton)	1972	
USS TUNNY	SSN682	Ingalls	1973	
USS PARCHE	SSN683	Ingalls	1974	
USS CAVALLA	SSN684	Electric Boat (Groton)	1972	
USS GLENARD P. LIPSCOMB	SSN685	Electric Boat (Groton)	1974	
USS L. MENDELL RIVERS	SSN686	Newport News	1974	
USS RICHARD B. RUSSELL	SSN687	Newport News	1974	
USS LOS ANGELES	SSN688	Newport News	1976	
MICHIGAN	SSBN727	Newport News		
Submarine	SSBN728	Electric Boat (Groton)		
Submarine	SSBN729	Electric Boat (Groton)		
Submarine	SSBN730	Electric Boat (Groton)		
MISSISSIPPI (2 reactors)	CGN40	Newport News		
ARKANSAS (2 reactors)	CGN41	Newport News		
SHUT DOWN OR DISMANTLED				
SEAWOLF Sodium Reactor**		Electric Boat (Groton)	1957	1959
USS TRITON (2 reactors)	SSN586	Electric Boat (Groton)	1959	1968
USS HALIBUT	SSN587	San Francisco Bay	1959	1976
USS SCORPION**	SSN589	Electric Boat (Groton)	1960	1968
USS THRESHER**	SSN593	Portsmouth	1961	1963

2. DEVELOPMENTAL POWER

A. Electric-Power Experiments and Prototypes

Name (all owned by DOE)	Designation**	Location	Principal nuclear contractor	Type	Power* Plant, net kW(e)	Power* Reactor kW(t)	Start-up	Shut-down
SHUT DOWN OR DISMANTLED								
Gas Cooled Reactor Experiment	GCRE	INEL Site, Idaho	AGN	Gas cooled, light water moderated	No elec.	2,200	1960	1962
Mobile Low Power Plant No. 1	ML-1	INEL Site, Idaho	AGN	Gas cooled, light water moderated	300	3,300	1961	1965
Stationary Low Power Plant No. 1	SL-1	INEL Site, Idaho	ANL	Boiling water	300	2,200	1958	1961

B. Propulsion Experiments and Prototypes

Name (all owned by DOE)	Designation	Location	Principal nuclear contractor	Type	Power,* kW(t)	Start-up	Shut-down
OPERABLE							
Destroyer Reactor Prototype	D1G	West Milton, N. Y.	GE	Pressurized water		1962	
Large Ship Reactor Prototype (2 reactors)	A1W	INEL Site, Idaho	West.	Pressurized water		1958	
Modifications and Additions to Reactor Facility	MARF	West Milton, N. Y.	GE	Pressurized water		1976	
Natural Circulation Test Plant	S5G	INEL Site, Idaho	West.	Pressurized water		1965	
Small Submarine Reactor Prototype	S1C	Windsor, Conn.	GE	Pressurized water		1959	
S1W Reactor Facility	S1W	INEL Site, Idaho	West.	Pressurized water		1953	
Submarine Advanced Reactor Prototype	S3G	West Milton, N. Y.	GE	Pressurized water		1958	
SHUT DOWN OR DISMANTLED							
Aircraft Reactor Experiment	ARE	Oak Ridge, Tenn.	ORNL	Molten salt	1,500	1954	1954
Experimental Propulsion Test Reactor	TORY IIA	NTS, Nev.	UCLLL	Air cooled	150,000	1960	1961
Experimental Propulsion Test Reactor**	TORY IIC	NTS, Nev.	UCLLL	Air cooled	600,000	1964	1964
Heat Transfer Reactor Experiment No. 1	HTRE-1	INEL Site, Idaho	ANPD	Air cooled	20,000	1956	1957
Heat Transfer Reactor Experiment No. 2	HTRE-2	INEL Site, Idaho	ANPD	Air cooled	14,000	1957	1961
Heat Transfer Reactor Experiment No. 3	HTRE-3	INEL Site, Idaho	ANPD	Air cooled	32,000	1958	1961
Submarine Intermediate Reactor Mark A	S1G	West Milton, N. Y.	GE	Sodium		1955	1957

3. TEST AND RESEARCH

A. Test

Name and/or owner	Designation	Location	Principal nuclear contractor	Type	Power,[1] kW(t)	Start-up	Shut-down
SHUT DOWN OR DISMANTLED							
Aerospace Systems Test Reactor (USAF)	ASTR	Fort Worth, Tex.	Convair	Light water	10,000	1954	1971
Ground Test Reactor (USAF)	GTR	Fort Worth, Tex.	Convair	Pool	10,000	1953	1973
Nuclear Engineering Test Reactor (USAF)	NETR	Dayton, Ohio	Maxon AC	Tank	10,000	1965	1970

B. Research

Name and/or owner	Designation	Location	Principal nuclear contractor	Type	Power,[1] kW(t)	Start-up	Shut-down
OPERABLE							
Aberdeen Pulsed Reactor Facility (Ballistic Research Laboratories, USA)	APRF	Aberdeen, Md.	UNC	Bare, fast, prompt burst	10	1968	
Armed Forces Radiobiology Research Institute (DASA, DOD)[2,3,4]	AFRRI	Bethesda, Md.	GA	U-Zr hydride	100	1962	
Fast Burst Reactor Facility (Army Missile Test and Evaluation Directorate, USA)	FBRF	White Sands, N. Mex.	Kaman	Bare, fast, prompt burst	10	1964	
Nuclear Effects Reactor (DOE)	Super KUKLA	NTS, Nev.	UCLLL	Prompt burst	Transient	1964	
Thermal Test Reactor No. 1 (DOE)	TTR-1	Schenectady, N. Y.	KAPL	Graphite	10	1951	
SHUT DOWN OR DISMANTLED							
Army Materials Research Reactor (Army Materials and Mechanics Research Center, USA)[3]	AMRR	Watertown, Mass.	BAC	Pool	5,000	1960	1970
Diamond Ordnance Radiation Facility (Harry Diamond Laboratories, USA)[3,4]	DORF	Forest Glen, Md.	GA	TRIGA-MK I	250	1961	1977
Naval Research Reactor (USN)[3]	NRR	Washington, D. C.	NRL	Pool	1,000	1956	1970
Walter Reed Research Reactor (Walter Reed Army Institute of Research, USA)[3]	WRRR	Washington, D. C.	AI	Homogeneous	50	1962	1970

1. POWER REACTORS[4,5]

A. Central-Station Electric Power

Name and/or owner	Location	Principal nuclear contractor	Type	Power: Plant, net KW(e)	Power: Reactor, KW(t)	Start up	Shut down
OPERABLE							
France, Franco-Belgian Society for Nuclear Energy of Ardennes, SENA	Givet (near Chooz)	West.	Pressurized water	305,000	1,040,000	1967	
Germany, Kahl Nuclear Power Station (Rhine-Westphalia Power Co., RWE)	Kahl-am-Main	GE	Boiling water	15,600	60,000	1961	
Germany, Kernkraftwerk-RWE-Bayernwerk, KRB	Gundremmingen (near Gunzburg)	GE	Boiling water	237,000	801,000	1967	
India, Tarapur Nuclear Power Station, Unit 1	Tarapur (north of Bombay)	GE	Boiling water	200,000	707,000	1969	
India, Tarapur Nuclear Power Station, Unit 2	Tarapur (north of Bombay)	GE	Boiling water	200,000	707,000	1969	
Italy, Garigliano Nuclear Power Station (Project ENEL of SENN)	Punta Fiume (on Garigliano River)	GE	Boiling water	150,000	506,000	1964	
Italy, Project Enrico Fermi of SELNI, Edisonvolta (ENEL)	Trino Vercellese	West.	Pressurized water	260,000	825,000	1965	
Japan, Fukushima Station, Unit 1 (Tokyo Electric Power Co.)	Futaba, Fukushima Pref.	GE	Boiling water	439,000	1,380,000	1971	
Japan, Fukushima Station, Unit 2 (Tokyo Electric Power Co.)	Futaba, Fukushima Pref.	GE	Boiling water	760,000	2,381,000	1974	
Japan, Japan Power Demonstration Reactor (JAERI)	Tokai-Mura, Ibaragi Pref.	GE	Boiling water	12,000	90,000	1963	
Japan, Mihama Nuclear Power Station, Unit 1 (Kansai Electric Power Co.)	Mihama, Fukui Pref.	West.	Pressurized water	320,000	1,031,000	1970	
Japan, Takahama, Unit 1 (Kansai Electric Power Co.)	Takahama, Fukui Pref.	West.	Pressurized water	780,000	2,440,000	1974	
Japan, Tsuruga Nuclear Power Plant (Japan Atomic Power Company, JAPCO No. 1)	Tsuruga, Fukui Pref.	GE	Boiling water	340,000	1,070,000	1970	
The Netherlands, Dodewaard (GKN)	Dodewaard, Betuwe	GE	Boiling water	52,000		1968	
Spain, Jose Cabrera Nuclear Power Plant, Unit 1	Almonacid de Zorita	West.	Pressurized water	153,000	510,000	1969	
Spain, Santa Maria de Garona Nuclear Power Plant (Centrales Nucleares del Norte SA, Nucleonor)	Near Burgos	GE	Boiling water	440,000	1,381,000	1971	
Sweden, Ringhals, Unit 2 (Swedish State Power Board)	Goteborg	West.	Pressurized water	822,000	2,440,000	1975	
Switzerland, Beznau, Unit 1 (Nordostschweizerische Kraftwerke AG)	Dottingen	West.	Pressurized water	350,000	1,130,000	1969	
Switzerland, Beznau, Unit 2 (Nordostschweizerische Kraftwerke AG)	Dottingen	West.	Pressurized water	350,000	1,130,000	1972	
Switzerland, Muhleberg (Bernische Kraftwerk AG)	Muhleberg (near Bern)	GE	Boiling water	306,000	947,000	1972	
BEING BUILT							
Brazil, Central Electrica de Furnas	Angra Dos Reis	West.	Pressurized water	626,000	1,882,000	1978	
Italy, Caorso Nuclear Station (ENEL)	Piacenza Cremona	GE	Boiling water	822,000	2,651,000	1977	
Japan, Fukushima Station, Unit 6 (Tokyo Electric Power Co.)	Futaba, Fukushima Pref.	GE	Boiling water	1,135,000	3,293,000	1979	
Japan, Ohi Nuclear Power Plant, Unit 1 (Kansai Electric Power Co.)	Ohi Fukui Pref.	West.	Pressurized water	1,120,000	3,423,000	1978	
Japan, Ohi Nuclear Power Plant, Unit 2 (Kansai Electric Power Co.)	Ohi Fukui Pref.	West.	Pressurized water	1,120,000	3,423,000	1978	
Japan, Tokai-Mura, Unit 2 (Japan Power Co.)	Tokai-Mura, Ibaragi Pref.	GE	Boiling water	1,080,000	3,293,000	1977	
Korea, Ko-Ri, Unit 1 (Korea Electric Power Co.)	Ko-Ri (near Pusan)	West.	Pressurized water	564,000	1,724,000	1977	
Korea, Ko-Ri, Unit 2 (Korea Electric Power Co.)	Ko-Ri (near Pusan)	West	Pressurized water	605,000	1,882,000	1983	
Mexico, Laguna Verde Station, Unit 1	Laguna Verde	GE	Boiling water	660,000	1,931,000	1980	
Mexico, Laguna Verde Station, Unit 2	Laguna Verde	GE	Boiling water	660,000	1,931,000	1981	
The Philippines, Republic of, Bagac Nuclear Power Project (National Power Corp.)	Luzon	West.	Pressurized water	626,000	1,886,000	1982	
Spain, Almaraz, Unit 1 (Union Electricas, S. A.)	Almaraz	West.	Pressurized water	902,000	2,696,000	1978	
Spain, Almaraz, Unit 2 (Union Electricas, S. A.)	Almaraz	West.	Pressurized water	902,000	2,696,000	1979	

1. POWER REACTORS[a,5] (Continued)

A. Central-Station Electric Power (Continued)

Name and/or owner	Location	Principal nuclear contractor	Type	Power[c] Plant, net kW(e)	Power[c] Reactor, kW(t)	Start-up	Shut-down
BEING BUILT (Continued)							
Spain, Cofrentes, Unit 1 (Hidroelectrica Espanola, S. A.)	Cofrentes	GE	Boiling water	975,000	2,894,000	1980	
Spain, Fesca, Asco, Unit 1	Asco	West.	Pressurized water	902,000	2,696,000	1979	
Spain, Fesca, Asco, Unit 2	Asco	West.	Pressurized water	902,000	2,696,000	1979	
Spain, Lemoniz, Unit 1 (Iberduero, S. A.)	Lemoniz	West.	Pressurized water	902,000	2,696,000	1978	
Spain, Lemoniz, Unit 2 (Iberduero, S. A.)	Lemoniz	West.	Pressurized water	902,000	2,696,000	1979	
Sweden, Ringhals, Unit 3 (Swedish State Power Board)	Goteborg	West.	Pressurized water	912,000	2,783,000	1977	
Sweden, Ringhals, Unit 4 (Swedish State Power Board)	Goteborg	West.	Pressurized water	912,000	2,783,000	1980	
Switzerland, Leibstadt (Kernkraftwerk Leibstadt)	Leibstadt	GE	Boiling water	940,000	3,012,000	1980	
Taiwan, Chin-shan, Unit 1 (Taiwan Power Co.)	Chin-shan	GE	Boiling water	610,000	1,775,000	1978	
Taiwan, Chin-shan, Unit 2 (Taiwan Power Co.)	Chin-shan	GE	Boiling water	610,000	1,775,000	1979	
Taiwan, Kuosheng, Unit 1 (Taiwan Power Co.)	Wanli Hsiean	GE	Boiling water	992,000	2,894,000	1981	
Taiwan, Kuosheng, Unit 2 (Taiwan Power Co.)	Wanli Hsiean	GE	Boiling water	992,000	2,894,000	1982	
Taiwan, Maanshan 1 (Taiwan Power Co.)	Heng-chun	West.	Pressurized water	907,000	2,785,000	1983	
Taiwan, Maanshan 2 (Taiwan Power Co.)	Heng-chun	West.	Pressurized water	907,000	2,785,000	1984	
Yugoslavia (Savske Electrane)	Krsko	West.	Pressurized water	615,000	1,882,000	1980	
PLANNED							
Egypt, EFAPP-1	West of Alexandria	West.	Pressurized water	600,000		1982	
Italy, ENEL-5 [Ente Nazionale per l'Energia Electtrica (ENEL)]		West.	Pressurized water	952,000	2,775,000	1984	
Italy, ENEL-6, Unit 1	Montalto di Castro	GE	Boiling water	982,000	2,894,000	1983	
Italy, ENEL-7 [Ente Nazionale per l'Energia Electtrica (ENEL)]		West.	Pressurized water	952,000	2,775,000	1984	
Italy, ENEL-8, Unit 2	Montalto di Castro	GE	Boiling water	982,000	2,894,000	1984	
Korea, Ko-Ri, Unit 3 (Korea Electric Power Co.)	Ko-Ri (near Pusan)		Pressurized water	900,000		1984	
Korea, Ko-Ri, Unit 4 (Korea Electric Power Co.)	Ko-Ri (near Pusan)		Pressurized water	900,000		1935	
Spain, Santillan, Unit 1 (Electra de Viesgo)	Santillan (Santander)	GE	Boiling water	972,000	2,894,000	1983	
Spain, Sayago (Iberduero, S. A.)	Sayago Zomora	West.	Pressurized water	1,000,000	2,785,000	1982	
Spain, Valdecaballeros, Unit 1 (HE. Sevillana de Electricidad)	Valdecaballeros, Badajos	GE	Boiling water	974,000	2,894,000	1980	
Spain, Valdecaballeros, Unit 2 (HE. Sevillana de Electricidad)	Valdecaballeros, Badajos	GE	Boiling water	974,000	2,894,000	1981	
Spain, Vandellos, Unit 2 (ENHER)	Falset, Tarragona	West.	Pressurized water	920,000	2,785,000	1981	
Switzerland, Graben (Bernische Kraftwerke AG)	Graben	GE	Boiling water	1,140,000	3,579,000	1985	
Switzerland, Kaiseraugst (Kernkraftwerke Kaiseraugst AG)	Kaiseraugst (near Basel)	GE	Boiling water	915,000	2,894,000	1982	

B. Propulsion

Name	Owner	Designer	Designation	Type	Start-up	Shut-down
OPERABLE						
S5W for HMS DREADNOUGHT	Great Britain	West.	S5W	Pressurized water	1962	

2. TEST, RESEARCH, AND TEACHING

A. General Irradiation Test

Owner	Location	Principal nuclear contractor	Type	Power,[3] kW(t)	Start-up	Shut-down
OPERABLE						
Japan, Japan Atomic Energy Research Institute	Tokai-Mura, Ibaragi Pref.	AMF	Heavy water, CP-5	10,000	1960	
Netherlands, Reactor Center	Petten	AC	Tank (MTR)	45,000	1961	
South Africa, Atomic Energy Board	Pelindaba (near Pretoria)	AC	Tank	20,000	1965	
Sweden, Atomic Energy Company	Studsvik	AC	Tank (MTR)	5,000	1960	

B. General Research

Owner	Location	Principal nuclear contractor	Type	Power,[3] kW(t)	Start-up	Shut-down
OPERABLE						
Australia, Atomic Energy Commission	Lucas Heights, New South Wales	AS Inc.	UTR-10	15	1961	
Austria, Seibersdorf Research Center	Seibersdorf	AMF	Pool	5,000	1960	
Colombia, Colombian Institute of Nuclear Affairs	Bogotá	Lockheed	Pool	20	1965	
Denmark, Atomic Energy Commission (DR-1)	Riso	AI	L-55	2.0	1957	
Germany, Brown Boveri/Krupp[4,7]	Julich	AI	L-77A	0.01	1967	
Germany, Society for the Utilization of Nuclear Energy in Shipbuilding and Navigation, Inc.	Geesthacht	B&W	Pool	5,000	1958	
Greece, Atomic Energy Commission	Athens	AMF	Pool	1,000	1961	
Indonesia, Institute for Atomic Energy	Bandung	GA	TRIGA-Mk II	1,000	1964	
Israel, Atomic Energy Commission	Nahal Soreq	AMF	Pool	5,000	1960	
Italy, Center for Military Application of Nuclear Energy	Near Pisa	B&W	Pool	5,000	1963	
Italy, National Committee for Nuclear Energy	Ispra	AC	Heavy water, tank	5,000	1959	
Italy, National Committee for Nuclear Energy	Padua	AMF	Pool	Neglig.	1971	
Italy, National Committee for Nuclear Energy	Rome	GA	TRIGA-Mk II	1,000	1960	
Italy, SORIN Nuclear Center	Saluggia	AMF	Pool	7,000	1959	
Japan, Japan Atomic Energy Research Institute[3*]	Tokai-Mura	GA	TRIGA-ACPR	300	1975	
Korea, Atomic Energy Research Institute	Seoul	GA	TRIGA-Mk II	250	1962	
Korea, Atomic Energy Research Institute	Seoul	GA	TRIGA-Mk III	2,000	1972	
Mexico, National Commission for Nuclear Energy[3*]	Salazar	GA	TRIGA-Mk III	1,000	1968	
Pakistan, Atomic Energy Commission	Islamabad	AMF	Pool	5,000	1965	
Philippines, National Science Development Board	Quezon City	GE	Pool	1,000	1963	
Portugal, Nuclear Energy Board	Sacavém	AMF	Pool	1,000	1961	
Switzerland, Institute for Reactor Research[4*]	Wuerenlingen	ORNL	Pool	5,000	1957	
Thailand, Office of Atomic Energy for Peace[3*,4*]	Bangkok	GA	TRIGA-MK III	2,000	1977	
Turkey, Atomic Energy Commission	Istanbul	AMF	Pool	1,000	1962	

2. TEST, RESEARCH, AND TEACHING (Continued)

B. General Research (Continued)

Owner	Location	Principal nuclear contractor	Type	Power,[1] kW(t)	Start-up	Shut-down
OPERABLE						
Venezuela Institute for Scientific Research	Caracas	GE	Pool	3,000	1960	
Yugoslavia, Josef Stefan Nuclear Institute[38]	Podgarica	GA	TRIGA-Mk II	250	1966	
Zaire (Regional Center for Nuclear Studies)	Kinsha	GA	TRIGA-Mk II	1,000	1959	
SHUT DOWN OR DISMANTLED						
Denmark, Atomic Energy Commission (DR-2)	Riso	FW	Tank	5,000	1958	1975
Japan, Japan Atomic Energy Research Institute	Tokai-Mura, Ibaragi Pref.	AI	L-54	50	1957	1969
Spain, Nuclear Energy Board	Moncloa	GE	Pool	3,000	1958	1970
West Berlin, City of (Institute for Nuclear Research)	West Berlin	AI	L-54	50	1958	1970

C. University Research and Teaching

Owner	Location	Principal nuclear contractor	Type	Power,[1] kW(t)	Start-up	Shut-down
OPERABLE						
Austria, Vienna Polytechnic Institute[38]	Vienna	GA	TRIGA-Mk II	250	1962	
Brazil, University of Minas Gerais	Belo Horizonte	GA	TRIGA-Mk I	250	1960	
Brazil, University of São Paulo	São Paulo	B&W	Pool	5,000	1957	
Canada, McMaster University	Hamilton, Ont.	AMF	Pool	5,000	1959	
China, Republic of (National Tsing-Hua University)	Hsinchu	GE	Pool	1,000	1961	
Congo, Republic of the (University of Lovanium)[78]	Kinshasa	GA	TRIGA-Mk I	1,000	1959	
Finland, Institute of Technology[38]	Helsinki	GA	TRIGA-Mk II	250	1962	
Germany, Association for Radiation Research[38, 77]	Munich	GA	TRIGA-Mk III	1,000	1972	
Germany, Institute for Nuclear Medicine[77]	Heidelberg	GA	TRIGA-Mk I	250	1966	
Germany, Johannes Gutenberg University of Mainz[38]	Mainz	GA	TRIGA-Mk II	100	1965	
Germany, Medical College of Hanover[75]	Hanover	GA	TRIGA-Mk I	250	1972	
Germany, Technical University of Munich	Munich	AMF	Pool	2,500	1957	
Iran, University of Tehran	Tehran	AMF	Pool	5,000	1967	
Italy, University of Milan	Milan	AI	L-54	50	1959	
Italy, University of Palermo	Palermo	AGN	201-110	Neglig.	1960	
Italy, University of Pavia[38]	Pavia	GA	TRIGA-Mk II	250	1965	
Japan, Kinki University	Osaka	AS Inc.	UTR-10	Neglig.	1961	
Japan, Musashi University	Kawasaki, Kanagawa Pref.	GA	TRIGA-Mk II	100	1963	
Japan, Rikkyo University	Yokosuka, Kanagawa Pref.	GA	TRIGA-Mk II	100	1961	
Netherlands, Delft Technical University[73]	Delft	AMF	Pool	2,000	1963	
Switzerland, University of Basel[73]	Basel	AGN	211-100	Neglig.	1958	
Switzerland, University of Geneva[74]	Geneva	AGN	201-211	Neglig.	1958	
United Kingdom, Queen Mary College, London University	London	AS Inc.	UTR-B	100	1965	

United Kingdom, Scottish Research Reactor Center	East Kilbride	AS Inc.	UTR-100	300	1963	
Uruguay, University of Montevideo[77]	Montevideo	Lockheed	Pool	1,000	1973	
SHUT DOWN OR DISMANTLED						
Germany, Universities of Frankfurt and Darmstadt	Frankfurt	AI	L-54	50	1958	1968

PART V CRITICAL ASSEMBLY FACILITIES

1. IDENTIFICATION OF FACILITIES

Abbreviation	Name and location of facility	Operator	No. of cells	No. of control panels
ANL	Argonne National Laboratory (DOE), Argonne, Ill.	ANL	2	2
ANL-IDAHO	Argonne National Laboratory, Idaho Division (DOE), INEL Site, Idaho	ANL	1	1
ARMF-I	Advanced Reactivity Measurement Facility (DOE), INEL Site, Idaho	EG&G–ID	1	1
ATRC	Advanced Test Reactor Critical Facility (DOE), INEL Site, Idaho	EG&G–ID	1	1
Bettis	Bettis Atomic Power Laboratory (DOE), Pittsburgh, Pa.	West.	3	3
CFRMF	Coupled Fast Reactor Measurement Facility (DOE), INEL Site, Idaho	EG&G–ID	1	1
CX-10	Critical Facility-10, Lynchburg Research Center (DOE), Lynchburg, Va.	B&W	2	1
ETRC	Engineering Test Reactor Critical Facility (DOE), INEL Site, Idaho	EG&G–ID	1	1
KAPL	Knolls Atomic Power Laboratory (DOE), Schenectady, N. Y.	GE	5	5
LASL	Los Alamos Scientific Laboratory (DOE), Los Alamos, N. Mex.	LASL	3	3
Lockheed	Lockheed Aircraft Co., Critical Facility for RFR, Dawsonville, Ga.[3]	Owner	1	1
OR-CEF	Oak Ridge Critical Experiment Facility (DOE), Oak Ridge, Tenn.	UCC-ND	3	3
ORNL-PCA	Pool Critical Assembly, BSF Pool (DOE), Oak Ridge, Tenn.	ORNL	1	1
PNL-CML	Critical Mass Laboratory (DOE), Richland, Wash.	BNW	1	1
Rensselaer	Rensselaer Polytechnic Institute, Troy, N. Y.[3]	Owner	1	1
RFP-NSF	Nuclear Safety Facility, Rocky Flats Plant (DOE), Colo.	RI	1	1
UNC	United Nuclear Corporation, Development Division, Pawling, N. Y.[4]	Owner	4	3

2. IDENTIFICATION OF EXPERIMENTS AND STUDIES

A. Civilian

Facility	Subject of current experiment or study	Designation	Start-up
OPERABLE			
ANL	Basic fast reactor studies and mock-up for LMFBR	ZPR-6	1963
ANL[74]	Basic fast reactor studies and mock-up for LMFBR	ZPR-9	1967
ANL-IDAHO	Basic fast reactor studies and mock-up for LMFBR	ZPPR	1969
Bettis	LWB physics[79]	LWBCC	1963
CML	Plutonium criticals	Solution	1961
CX-10	Close storage of spent reactor fuel	SSRF	1977

2. IDENTIFICATION OF EXPERIMENTS AND STUDIES (Continued)

A. Civilian (Continued)

Facility	Subject of current experiment or study	Designation	Start-up
INEL, ARMF-I	Reactor-physics constants and reactivity changes caused by test-reactor irradiation	ARMF-I	1960
INEL, ATRC	ATR physics, core-loading and core-design measurements	ATRC	1964
INEL, CFRMF	Studies of differential cross sections to test calculational methods	CFRMF	1968
INEL, ETRC	ETR physics, core-loading and core-design measurements	ETRC	1957
LASL, Kiva I	Cold critical for gas core reactor studies	PCA	1974
LASL, Kiva I	Flexible split table assembly	Honeycomb	1956
LASL, Kiva III	Cold critical for instrumentation testing	Parka	1963
OR-CEF, Building 9213, Cell W	HFIR core reactivity measurements		1950
ORNL-PCA, Building 3010	Physics research on reactivity effects	PCA	1958
PNL-CML	Plutonium criticals	Horizontal	1961
Rensselaer	Critical experiment-assembly		1966
UNC	Proof test facility	PTF	1967

B. Military

Facility	Subject of current experiment or study	Designation	Start-up
OPERABLE			
Bettis	Surface-ship physics''	SS-CF	1957
Bettis	High-temperature physics and mock-up	HTTF	1959
KAPL	Full core physics experiment	FCPE	1970
KAPL	Flexible critical experiments	FPR	1956
KAPL	Cold water experiments	CWA	1958
KAPL	High-temperature high-pressure physics and mock-up	PTR	1958
KAPL	Cold water reactor test assembly	CWTA	1960
Lockheed	RER core configurations	CERF	1958
LASL, Kiva II	Critical-configuration safety and neutronic tests	Comet	1952
LASL, Kiva II	Plated bare-plutonium sphere	Jezebel	1954
LASL, Kiva II	Spherical metal cores in thick metal reflector	Flattop	1957
LASL, Kiva II	U(10)-metal cylinder in thick metal reflector	Big Ten	1972
LASL, Kiva III	Fast neutron irradiation, pulse capability	Godiva-IV	1967
RFP-NFS	Critical-configuration safety tests	Horizontal	1965
RFP-NFS	Critical-configuration safety tests	Vertical	1965
RFP-NFS	Critical-configuration safety tests	Solution	1965
RFP-NFS	Critical-configuration safety tests	Tank	1965

FOOTNOTES

1. Power-capacity figures are based on the best available information. In all instances thermal capacity of the nuclear reactor is given; the electrical output, when shown, is the net electrical capacity of the power plant. For reactors being built or planned, plant capacity is rounded to the nearest hundred kilowatts. Where a plant has a stretch capacity, the initial capacity is given until the stretch value is approved.
2. The first core for the Shippingport station began power operation in 1957. The second core began power operation in 1965 and operated until shutdown in 1974. The Shippingport station now has a light water breeder reactor (LWBR) core which went critical on Aug. 26, 1977. The station with the LWBR core installed was released for routine commercial power generation on Dec. 2, 1977.
3. This facility is regulated by the Nuclear Regulatory Commission and has been issued an operating license (or authorization) or a construction permit, or an application for same has been submitted.
4. This project is under the Power Demonstration Program.
5. In the Consolidated Edison Indian Point Station, the 615,000 kW(t) is increased by an oil fired superheater to produce 265,000 kW(e) net.
6. The Hallam Nuclear Power Facility was shut down in September 1964 due to moderator can failures. In August 1965 its contract with Consumers Public Power District for operation of the nuclear plant was terminated. In May 1966 CPPD turned down their option to purchase the plant. In June 1966 announcement was made for deactivation and dismantling of the nuclear facility.
7. The last CVTR shutdown occurred Jan. 24, 1967. A license amendment issued June 14, 1967, authorizes CVNPA to possess but not operate the CVTR.
8. The dismantlement program for the Piqua Nuclear Power Facility was completed in February 1969.
9. The Pathfinder Plant has been shut down since November 1967. On Sept. 9, 1968, Northern States Power Company announced plans to install gas-fired boilers for operation the summer of 1969.
10. The Elk River Reactor was shut down due to technical problems in February 1968; in March 1971, it was announced that arrangements had been made with RCPA for the dismantling and removal of this facility.
11. N Reactor, a DOE-owned reactor for production of special nuclear materials, also produces steam that is supplied to the adjacent electric generating plant, owned and operated by Washington Public Power Supply System (WPPSS). Initial electric-power generation began Apr. 8, 1966. Gross power output of 800 MW(e) utilizing N Reactor steam was achieved on Dec. 9, 1966, and gross generation of 860 MW(e) was achieved in 1972.
12. Midland Unit 1 supplies 3,625,000 pounds per hour of process steam, and Unit 2 supplies 425,000 pounds per hour.
13. This facility was originally built and operated in 1954 as the Boiling Reactor Experiment No. 2 (BORAX-2). With the addition of a turbogenerator, it operated during 1955 as BORAX-3 and on July 17, 1955, produced sufficient electricity to light and power Arco, Idaho—a U.S. first. BORAX-4, a further modification, operated from December 1956 to June 1958 when the experiment was shut down.
14. OMRE demonstrated the technical and economic feasibility of using liquid hydrocarbon terphenyls as coolant and/or moderator.
15. The EBOR reactor experiment was terminated in December 1966 prior to the completion of construction.
16. In a trial run on Dec. 21 and 22, 1951, EBR-1 generated the world's first electric power from nuclear energy and was the first to demonstrate, in July 1953, the feasibility of breeding and the compatibility with breeding economy of sodium–potassium alloy as a liquid metal coolant. It operated with a plutonium-bearing core (Mark IV) from November 1962 to December 1963. The reactor was decommissioned and dismantled early in 1964. The facility was dedicated as a historic landmark Aug. 26, 1966. It is open to the public June 14 to September 15 annually, beginning in 1975.
17. SRE operated at 20 MW(t) until shut down in February 1964 for modification to permit an increase in power level to 30 MW(t). On Dec. 2, 1966, deactivation of SRE was announced.
18. The LCCR project was terminated in January 1966 prior to the completion of construction.
19. EOCR construction was terminated in December 1962. The facility was mothballed prior to operation.
20. The EBWR achieved 100,000 kW(t) on Nov. 11, 1962. Operation of EBWR in the Boiling Water Program was closed out in December 1962. The reactor was used in support of the Plutonium Recycle Program and attained criticality using plutonium as its principal fuel on Sept. 22, 1965. In support of that program, it operated at power levels as high as 70,000 kW(t). Operation in that program was completed in June 1967.
21. This reactor was shut down in 1975 because of a lack of programmatic support and is in standby condition.
22. S10FS-4 operated in orbit during April–May 1965. Operation terminated unexpectedly after 43 days at power, probably owing to a sequence of failures of electrical components of the spacecraft with resulting spurious commands shutting down the reactor. An identical ground-test unit, S10FS-3, operated successfully for more than a year before being shut down in 1966.
23. Reactor shut down in 1973 for modifications and insertion of Sodium Loop Safety Facility (SLSF) loop. Operation resumed in 1975.
24. In August 1958 the MTR was operated with an experimental plutonium core at power levels up to 30,000 kW(t). It demonstrated the ability of plutonium fuel elements to perform satisfactorily in a high-flux research or test reactor. Operation as a test reactor was terminated on June 30, 1969, and a ^{240}Pu (Phoenix) core run in FY 1970. Reactor decommissioned in 1974.
25. The SNAPTRAN series of experiments was designed to develop, in a land based environment, safety information on space auxiliary power reactors through excursion testing at various temperatures and rates of reactivity insertion. The destructive experiments approach the maximum credible accidents postulated for SNAP reactor systems.
26. Footnote deleted.
27. This reactor is basically the same as the SNAP-10A Transient Test Reactor No. 1 (SNAPTRAN-1) that operated at Idaho National Engineering Laboratory (INEL) from 1963–1965. It was moved from INEL to its present location in the SNAP Environmental Test Facility. It was used there to evaluate the effects of separated ^{155}Gd as a burnable poison and as a shutdown agent in the event of water immersion. It was defueled in 1971 and placed on standby. The reactor was transferred to Los Alamos, N. Mex., in 1973.
28. The BSR-2, which became operable in 1959, is a stainless-steel-UO$_2$ core that can be used alternately in the same facility with BSR-1 (aluminum-alloy core).

FOOTNOTES (Continued)

29. Ownership of this reactor was transferred to North American Rockwell in December 1971 and was redesignated the Nuclear Examination Reactor or L-85 rather than AE-6. The AE-6, also designated WBNS, was built and first operated at Downey, Calif. It was moved to Santa Susana in 1956.
30. This TRIGA reactor is capable of being pulsed and of steady-state operation.
31. The HPRR was previously operated in the Nevada BREN facility. It is now installed in the Dosimetry Applications Research Facility.
32. The KEWB reactor was operated by AI from 1956 to 1967 as the Kinetic Experiment on Water Boilers.
33. This reactor was operated in the USAEC Atoms for Peace Exhibit in Vienna, Austria, in June 1963; in Belgrade, Yugoslavia, in September 1963; in Madrid, Spain, in April 1964; in Lisbon, Portugal, in April 1965; in Utrecht, Netherlands, in March 1966; in Dublin, Ireland, in September–October 1966; Ankara, Turkey, in April–May 1967; Tehran, Iran, in November–December 1967; Taipei, Taiwan, in April–May 1968; Seoul, Korea, in September–October 1968; Manila, Philippines, in February–March 1969; and Bucharest, Romania, in October 1969. The reactor instrumentation has been shipped to Howard University, Washington, D.C., and the fuel is currently in storage at Oak Ridge pending shipment to Howard University.
34. In 1943 the Manhattan Engineer District disassembled Chicago Pile 1 and rebuilt it at Palos Park, Ill., as Chicago Pile 2. CP-2 had a thermal power level of 10 kW.
35. This reactor was shipped abroad for exhibition purposes in the USAEC Atoms for Peace Exhibit in the Tokyo International Trade Fair in 1959, and in Cairo, Egypt, and Lahore, Pakistan, in 1960.
36. This TRIGA-MK II was operated at the New Delhi World Agricultural Fair in 1960. It has been dismantled for storage in California by Gulf Oil Corporation.
37. In 1965 and 1966 this reactor was operated at Sandia, N. Mex., as SNARE. Prior to that time it operated at INEL as the Shield Test Pool Reactor (Susie) in the Aircraft Nuclear Propulsion Program from 1959 to 1962. It was shut down in 1966 and transferred to Louisiana State University in June 1966, where it was never assembled.
38. Until mid-1967 FRAN was operated by UCLLL at the Nevada Test Site, and until 1970 it was operated in the former ML-1 reactor area at INEL. In mid-1970 it was transferred back to UCLLL.
39. After the assembly and operation of this reactor in the government exhibit at Geneva in September 1958, it was dismantled and returned to ANL, where it was rebuilt as a 250-kW(t) Juggernaut.
40. The RER was previously used in the terminated Aircraft Nuclear Propulsion Program. A license authorizing Lockheed to operate the reactor as a commercial facility was issued in July 1962, and in August 1962 the USAF transferred the facility to the General Services Administration. Lockheed acquired title to the facility in March 1965.
41. This reactor was previously designated STF for SNAP Shield Test Facility.
42. The APFA-III was previously operated as the KUKLA Prompt Critical Assembly at Lawrence Radiation Laboratory at Livermore, Calif.
43. This reactor was formerly called the Latin American Demonstration Reactor and was operated initially in São Paulo, Brazil, in October 1969. It is currently in storage at Oak Ridge.
44. AGN-201-102 was operated at Oklahoma State University, Stillwater, Okla., from 1957 until transferred to Tuskegee Institute in 1972.

    AGN-201-104 operated at the University of Akron (Ohio) from 1957 until transferred to the Georgia Institute of Technology in 1967.
46. AGN-201-112 was operated at the University of California, Berkeley, beginning in 1957. The University of New Mexico filed an application in April 1966 for transfer and reconstruction of the reactor at a site on its campus. The reactor achieved criticality at the University of New Mexico on Oct. 7, 1966.

intact, for use in successive locations. The second capital letter indicates the power range as measured by design capacity for continuous operation; L (low), 100 to 1000 kW(e); M (medium), 1000 to 10,000 kW(e); and H (high), 10,000 kW(e) or more. Arabic numerals indicate order in which plants having the same mobility and power characteristics are initiated. If not followed by an additional letter, the designation indicates a prototype or pilot plant. The last capital letter (when present) indicates the alphabetical order in which field plants of a specific type are initiated.

58. The MH-1A was installed in the STURGIS (formerly the Liberty Ship CHARLES H. CUGLE) at Mobile, Ala. Acceptance testing was performed at Fort Belvoir, Va., from April 1967 to June 27, 1967, when the Army accepted the plant from the Contractor. In late July 1968 the plant was deployed to Gatun Lake, Panama Canal Zone, and began producing power to the Panama Canal power grid on Oct. 5, 1968.
59. The PM-2A was shut down on July 9, 1963, and dismantled during April–June 1964. The reactor vessel was then used at INEL for NDT (nil ductility transition temperature) investigations of materials that had been subjected to long-term irradiation. Defects were sequentially introduced into the vessel wall during a series of tests involving pressure and temperature conditions which exceeded the range permitted in operating nuclear power plants. The final test on Nov. 15, 1966, resulted in a brittle fracture under conditions even more severe than those which had been previously predicted to cause failure. The test program confirmed laboratory data on the adequacy of reactor-operating limitations to prevent brittle fracture of a pressure vessel.
60. The Army made the determination to shut down the SM-1A because the plant's demonstration and R&D missions had been successfully completed and because of the ready availability of cheaper conventional power at the site.
61. The abbreviations used here are defined as follows: SSN, Submarine (Nuclear Propulsion); SSBN, Fleet Ballistic Missile Submarine (Nuclear Propulsion); DLGN, Guided Missile Frigate (Nuclear Propulsion) (all DLGNs were redesignated CGN on July 1, 1975); CGN, Guided Missile Cruiser (Nuclear Propulsion); CVAN CVN, Aircraft Carrier (Nuclear Propulsion).
62. The USS SEAWOLF, originally commissioned with a sodium-cooled reactor in March 1957, was recommissioned with a pressurized water reactor on Sept. 30, 1960.
63. The USS THRESHER (SSN593) was lost in the Atlantic on Apr. 10, 1963. The USS SCORPION (SSN589) was lost in the Atlantic on May 21, 1968.
64. The TORY IIC was successfully tested at full design power during May 1964. Subsequent to cancellation of the Pluto program on July 1, 1964, the reactor was placed in the Pluto disassembly building at NTS for storage. In 1974 the reactor was transferred to the NERVA disassembly area for disassembly.
65. In addition to the export power reactors listed, Westinghouse provided the design and furnished nuclear components, including fuel elements, control rods, and instrumentation for the 11.5-MW(e) Belgium BR-3 pressurized-water reactor at Mol.
66. JAERI is being rebuilt as a 90-kW(t) boiling-water research reactor (JPDR-II).
67. This L-77 reactor was operated in the commercial exhibit of the 1958 International Conference in Geneva and in the USAEC Atoms for Peace Exhibits in Beirut, Lebanon, in October 1961; in Athens, Greece, in May 1962; and in Bangkok, Thailand, in November 1962.
68. This is the 1955 Geneva Conference reactor rebuilt with increased power and now operating at Wuerenlingen, Switzerland.
69. The Thai research reactor (TRR-1), built by Curtiss-Wright and started up in 1962, originally operated at 1000 kW(t). In June 1975 the TRR-1 was shut down for conversion to TRR-1/M1, a TRIGA Mark III system adapted for pool installation. The TRR-1/M1, with a power level of 2000 kW(t)/2000 MW pulsing, was commissioned in November 1977.

47. The Center for Environmental and Energy Research (formerly Puerto Rico Nuclear Center).

48. The University of Wisconsin reactor has been modified for 1000 kW steady-state operation with a TRIGA-type core. Power level was 250 kW prior to modification in 1967.

49. The Nuclear Science Center Reactor at Texas A&M University has been modified for 1000-kW steady-state operation with a TRIGA-type core. Power level was 100 kW prior to modification in 1968.

50. In 1967 the original MTR type core of the Washington State University reactor was replaced by a modified TRIGA-type core and control system, and the steady-state power level was increased from 100 to 1000 kW(t).

51. From 1955 to 1965 the Penn State reactor was operated as a 200-kW(t) pool-type reactor fueled with MTR type elements.

52. The AGN-201P-103 was operated at San Ramon, Calif., by Aerojet-General Corporation from 1957 to 1966. In April 1967 Idaho State University applied for a license to operate the reactor at Pocatello, Idaho.

53. The core of the Michigan State University reactor operated in the University of Illinois TRIGA facility from 1960 until transferred in 1968.

54. California State Polytechnic College, San Luis Obispo, Calif., in December 1971 received a permit to relocate AGN-201-100 and operate it on CSPC campus. The unit previously was operated starting in 1958 at the Naval Postgraduate School, Monterey, Calif.

55. This reactor was originally operated by North Carolina State University as the Raleigh Research Reactor (RRR). It was transferred in March 1966 to Mississippi State University for reactivation. The RRR was dismantled by N. C. State in 1963.

56. In 1957–1962, AGN-201M-105 was owned and operated by the National Naval Medical Center, Bethesda, Md. Title to the reactor was transferred to New York University early in 1964. A license to operate was issued in April 1967.

57. Reactors in the Army Power Program are identified by symbolic nomenclature to reflect mobility characteristics, power range, development sequence, and field sequence. The first capital letter indicates mobility characteristics: S (stationary operation), not designed for subsequent relocation; P (portable), semimobile stationary operation, capable of being dismantled and reassembled for use in successive locations; and M (mobile), capable of being moved intact, or virtually

70. The TRIGA reactor was operated at the 1958 International Conference in Geneva prior to shipment to the University of Lovanium. It began operating at the University of Lovanium in June 1959. It is the first reactor to be operated on the African continent.

71. This reactor was sold through Gulf Oil licensee, Gutehoffnungshuette Sterkrade A.E.

72. The Netherlands research reactor was originally operated at the Amsterdam International Exhibition in June 1957; major portions of the exhibition reactor system were used to fabricate the present reactor.

73. This reactor was operated in the International Science Section of the Brussels International Exhibition, Apr. 15 to Oct. 1, 1958, prior to transfer to the University of Basel.

74. The AGN-201-111 was operated first in the USAEC Atoms for Peace Exhibit in Rome, Italy, in July 1958 and later in the commercial exhibit of the 1958 International Conference in Geneva prior to transfer to the University of Geneva.

75. Prior to its sale to the University of Montevideo in 1966, this reactor was part of the USAEC Exhibit Program. It was in Buenos Aires, Argentina, in the fall of 1960; in Rio de Janeiro, Brazil, in the spring of 1961; in Lima, Peru, in the fall of 1961; in Mexico City in the spring of 1962; in Santiago, Chile, in the fall of 1962; in Bogotá, Colombia, in the spring of 1963; and in Montevideo, Uruguay, in the fall of 1963. The unit became operational in 1972.

76. Zero-power experiments of historical interest previously conducted in ANL facility cells include the NAUTILUS core design (ZPR-1), the Savannah River reactor design (ZPR-2), and a series of fast-neutron studies (ZPR-4) and interactions between two basic systems (ZPR-5). The following experiments have been performed in the ZPR-7 facility: thorium, uranium, deuterium criticals (THUD), and a series of flux-trap criticals for the Argonne High Flux Research Reactor.

77. The cell has one control panel for two pits. Experiments may be operated in either pit but not in both simultaneously.

78. This reactor was operated at the Puerto Rico Nuclear Center from 1960 to October 1976. It was converted to the TRIGA-FLIP in 1972. It has been moved to the Neutron Radiography Facility at the National Engineering Laboratory in Idaho.

79. The EBR-II reactor has recently become a major irradiation facility for the LMFBR program.

REACTOR INDEX

[REACTORS FOR EXPORT not included in the index (see pages 33 to 36).]

(Docket numbers for civilian reactors are listed in parentheses in the index.)

REACTOR INDEX (Continued)

REACTOR INDEX (Continued)

REACTOR INDEX (Continued)

NUCLEAR SAFETY

A bimonthly technical progress review which is published by the U. S. Nuclear Regulatory Commission and U. S. Department of Energy in cooperation with the Nuclear Safety Information Center, Oak Ridge National Laboratory. This journal digests and evaluates the latest findings in its area of nuclear technology and science, with the aim of meeting the needs of industry and government for concise summaries of developments.

Primary emphasis is on safety in reactor design, construction, and operation. However, safety considerations in reactor fuel fabrication, spent-fuel processing, nuclear waste disposal, handling of radioisotopes, and environmental effects of these operations are also treated.

Nuclear Safety may be purchased from the Superintendent of Documents, U. S. Government Printing Office, Washington, D. C. 20402, at $11.00 per year (six issues); $3.50 additional for foreign handling. (Single copy price is $2.40; $0.60 additional for foreign handling.)

ENERGY RESEARCH ABSTRACTS (ERA)

A semimonthly publication prepared by the Technical Information Center of the U. S. Department of Energy (DOE). Provides abstracts and indexing for all scientific and technical reports, journal articles, conference papers and proceedings, books, patents, theses, and monographs originated by DOE, its laboratories, energy centers, and contractors.

Subject matter includes DOE's research, development, demonstration and technical programs resulting from its broad charter for energy systems, conservation, safety, environmental protection, physical research, and biology and medicine. *ERA* also covers other U. S. Government-sponsored energy information and the international literature on reactor technology, waste processing and storage, and fusion technology. Also covered is nonnuclear information obtained from foreign governments under agreements for cooperation.

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APPENDIX C

U.S. Department of Energy
Research and Development and Field Facilities

The following summary includes U.S. Department of Energy facilities which are involved in some way with the radiation sciences. These facilities are grouped according to the following headings:

PRODUCTION, TESTING, AND FABRICATION FACILITIES

- Nuclear Materials Production Facilities
- Weapons Testing and Fabrication Complex

RESEARCH AND DEVELOPMENT FACILITIES

- Multiprogram Laboratories
- Program-Dedicated Facilities

DISBANDED FACILITIES

The information in the Summary includes the name and location of the facility, a brief description on what is done at that facility, available information on current and total workforce, and length of time in operation. The information reported in this summary was taken from DOE Research and Development and Field Facilities (# DOE/ER-0029) and Expanded Study of the Effects of Exposure to Low-Level Ionizing Radiation (by the MITRE Corporation, Technical Report # MTR-8018).

APPENDIX C

Production, Testing, and Fabrication Facilities

Name of Facility	Nuclear Materials Production Facilities Description	Workforce*		Date Established	Years in Operation*
		Current	Total		
Oak Ridge, TN	Gaseous Diffusion Plant (Union Carbide Corp.)	5,535	--	1943	35
Paducah, KY	Gaseous Diffusion Plant (Union Carbide Corp.)	2,375	--	1952	26
Portsmouth, OH	Gaseous Diffusion Plant (Goodyear Atomic Corp.)	2,996	8,000	1953	25
Ashtabula, OH	Feed Materials Plant (Reactive Metals, Inc.)	62	--	1952	26
Fernald, OH	Feed Materials Plant (National Lead of OH)	533	—	1953	25
Savannah River Plant Aiken, SC	-Fuel Fabrication (including Pu) (duPont) -Isotope production in nuclear reactors -Chemical separation of reactor products -Waste management -Heavy water extraction	7,500	—	1950	28
Hanford Production Operations Richland, WA	-Fuel Fabrication (United Nuclear Inc.) (including Pu) -Reactor operations (United Nuclear Inc.) -Chemical separation (Rockwell) Chemical processing of irradiated production reactor fuel -Solidification of liquid waste (Rockwell) -Research on waste storage (Rockwell)	3,136 Rockwell 835 UNI	--	1944	34
Idaho Chemical Processing Plant	-Recovers uranium from irradiated Navy reactor and test reactor fuels	--	--	1953	25

*as of 1978

APPENDIX C (cont.)

Production, Testing, and Fabrication Facilities

Name of Facility	Weapons Testing and Fabrication Complex Description	Workforce *		Date Established	Years in Operation*
		Current	Total		
Nevada Test Site	-Area for testing nuclear weapons	5,200	54,000	1950	28
Kansas City Plant Kansas City, MO	-Involved in production of non-nuclear portions of nuclear weapons (Bendix)	5,561 Av.man-yrs. 1978	--	1949	29
Rocky Flats Plant Rocky Flats, CO	-Produces nuclear components of nuclear weapons including: -fabrication of plutonium and uranium alloy -plutonium recovery (1952-1975 Dow Chemical) (1975- Rockwell)	2,986 Av.man-yrs. 1978	9,000	1952	26
Pantex (Amarillo) Plant Pantex, TX	-Fabrication of high explosive and other components needed to assemble, repair and test nuclear weapons -Participate in weapons retirement (Mason & Hangar)	1,858 Av.man-yrs. 1978	4,800	1952	26
Pinellas Plant St. Petersburg, FL	-Development and production of neutron generators for nuclear weapons initiation (General Elec.) -Also manufacture electronic test equipment	1,233 Av.man-yrs. 1978	4,000	1956	22
Mound Facility Miamisburg, OH	-Wide variety of weapons production and development activities (Monsanto)	1,705 Av.man-yrs. 1978	36,000	1943	35

*as of 1978

APPENDIX C (cont.)

Production, Testing, and Fabrication Facilities

Name of Facility	Weapons Testing and Fabrication Complex Description	Workforce *		DateEstab-lished	Years in Operation*
		Current	Total		
-12 Plant Oak Ridge, TN	-Fabrication and certification of components for the nuclear weapons stockpile -Nuclear materials processing (Union Carbide)	4,911 Av.man-yrs. 1978	--	1943	35
Savannah River Weapons Facility Aiken, SC	-Extraction, separation, and recovery of tritium (DuPont)	355 Av.man-yrs. 1978	--	--	--

*as of 1978

APPENDIX C (cont.)

Research and Development Facilities

Name of Facility	Multiprogram Laboratories Description	Workforce * Current	Workforce * Total	Date Established	Years in Operation*
Ames Laboratory Ames, IA	-Basic nuclear physics research such as establishing the energy levels and states of short lived isotopes produced by fission reactions.	450	9,000	1942 or 1947	36 or 31
Argonne National Laboratories, IL Argonne National Laboratory-West ID	-Reactor development (ie-breeder) research -Biologic effects of radiation research -Basic nuclear-physics research	5,166 + 800 temp.	32,500	1946	32
Brookhaven National Laboratory Upton, NY	-Research on physical, chemical and biologic effects of radiation	3,460	15,000	1947	31
Hanford Engineering Development Laboratory Richland, WA	-Breeder reactor research -Radioactive waste management research (including Pu recovery) -Nuclear fuel cycle research	2,900	--	1970	8
Idaho National Engineering Laboratory Idaho Falls, ID (includes ID Chemical Processing Plant)	-Research in reactor fuel reprocessing -Research on breeder reactor -Navel reactor development -Waste management research	2,211	50,000	1949	29
Lawrence Berkeley Laboratory Berkeley, CA	-Nuclear medicine research -Basic nuclear science research	1,016	21,823	1931	47

*as of 1978

APPENDIX C (cont.)

Research and Development Facilities

Name of Facility	Multiprogram Laboratories Description	Workforce *		Date Established	Years in Operation*
		Current	Total		
Lawrence Livermore Laboratory Livermore, CA	-Nuclear weapons design -Nuclear waste isolation research -Biomedical & environmental effects of radiation research	2,457	30,000	1952	26
Los Alamos Scientific Laboratory Los Alamos, NM	-Nuclear weapons development -Research throughout the nuclear fuel cycle including: -surveying for Uranium -developing methods of isotopic separation -modeling reactor accident results -evaluating biomedical consequences of nuclear energy production -developing nuclear waste disposal methods	6,569	26,000	1943	35
Oak Ridge National Lab. Oak Ridge, TN	-NRC reactor safety research -Breeder reactor research -Nuclear waste disposal development -Reprocessing research -Biomedical and environmental research related to nuclear fuel cycle	2,450	--	1948	30
Pacific Northwest Laboratory Richland, WA	-Research thru entire nuclear fuel cycle especially in waste disposal	1,161	--	1956	22

*as of 1978

APPENDIX C (cont.)
Research and Development Facilities

Name of Facility	Multiprogram Laboratories Description	Workforce *		DateEstablished	Years in Operation*
		Current	Total		
Sandia Laboratories Albuquerque, NM Livermore, CA Tonophah, NV	-Used to develop and manufacture nuclear weapons - now it manufactures non-nuclear parts of nuclear weapons -Research on radioactive waste transportation & disposal -Light water reactor safety research -Waste Management research -NRC research to support safety assessment & licensing	3,140	21,633	1949	29
Savannah River Laboratory Aiken, SC	-Provides developmental and technical assistance in all areas of the nuclear fuel cycle: uranium resource evaluation, fuel fabrication, isotope production, reactor physics and engineering, fuel reprocessing, waste management, environmental monitoring, and heavy water production	968	15,300	1952	26
Energy Technology Engineering Center Canoga Park, CA	-Development work on breeder reactor -Technical assistance to NRC	164	--	1966	12

*as of 1978

APPENDIX C (cont.)

Research and Development Facilities

Program-Dedicated Facilities · Biomedical and Environmental

Name of Facility	Description	Workforce*		Date Established	Years in Operation*
		Current	Total		
Center for Energy and Environment Research San Juan, PR	-Serves as focal point for energy research in PR	202	--	1957	21
Comparative Animal Research Laboratory Oak Ridge, TN	-Originally designated to study long-term effects of radiation -Now there is de-emphasis of radiation work	86	--	1948	30
Environmental Measurements Laboratory (HASL) New York, NY	-Evaluate exposure of man to environmental radiation including natural and manmade sources	104	--	1947	31
Inhalation Toxicology Research Institute Albuquerque, NM	-Research on human health effects associated with inhalation of fission product radionuclides (and other airborne toxic substances)	222	574	1960	18
Laboratory for Energy Related Health Research formerly: Radiobiology Lab. Davis, CA	-Study biomedical effects of long-term, low-level exposures to nuclear (& fossil fuel) effluents from energy production	94	--	1958	20
Laboratory of Nuclear Medicine and Radiation Biology Los Angeles, CA	-Biomolecular and Cellular Science Division - cell damage from ionizing radiation -Environmental Biology Division - environmental effects -Nuclear Medicine Division - research in nuclear medicine	184	--	1947	31

*as of 1978

APPENDIX C (cont.)

Research and Development Facilities

Name of Facility	Program-Dedicated Facilities: Biomedical and Environmental Description	Workforce *		Date Established	Years in Operation*
		Current	Total		
Laboratory of Radiobiology San Francisco, CA	-Basic animal research	40	850	1964	14
MSU-DOE Plant Research Lab. East Lansing, MI	-Basic plant research	80	--	1964	14
Oak Ridge Assoc. Univ. Oak Ridge, TN	-Study effects of radiation on humans through different approaches including epidemiology, biochemistry, and cell biology -Maintains DOE National Accident Registry -Health & Mortality Studies	353	--	1946	32
Radiobiology Laboratory Salt Lake City, UT	-Animal Studies of acute and chronic toxic effects of various isotopes, especially alpha-emitters	62	--	1952	26
Savannah River Ecology Lab. Aiken, SC	-Research in ecologic consequences of nuclear power production	68	--	1951	27
Franklin McLean Mem.Res.Inst. Chicago, IL	-Research in Nuclear Medicine	103	--	1953	25
Univ. of Rochester Bio-Medical Laboratory Rochester, NY	-Originally part of Manhattan Project to consult on expected health hazards involved in development of A-Bomb (1943-46) -Now animal research on the effects of toxic materials associated with energy production	209	--	1943	35

*as of 1978

APPENDIX C (cont.)
Research and Development Facilities

Name of Facility	Program-Dedicated Facilities: Nuclear Development Facilities Description	Workforce *		Date Established	Years in Operation*
		Current	Total		
Princeton Plasma Physics Lab., Princeton, NJ	-Presently working on development of thermonuclear fusion	931	2,050	1951	27
Bettis Atomic Power Lab. PA, ID**	-Development of nuclear propulsion plants for the Navy (includes Shippingport Atomic Power Station, PA)	3,309	19,000	1954	24
Knolls Atomic Power Lab. Schenectady, NY (3 sites) West Milton, NY Windsor, CT	-Design and development of nuclear propulsion plants for the navy	2,936	12,000	1946	32

** Includes Idaho Chemical Processing Plant established 1953 current.

* as of 1978

APPENDIX C (cont.)

Research and Development Facilities

Name of Facility	Program Dedicated Facilities: Physical Research Facilities Description	Workforce *		Date Established	Years in Operation*
		Current	Total		
Bates Linear Accelerator Facility Cambridge, MA	-Basic physical research	75		1972	6
Fermi National Accelerator Laboratory Batavia, IL	-Elementary particle physics research -Research on using protons for cancer research	1,439	3,500	1969	9
Notre Dame Radiation Laboratory Notre Dame, IN	-Basic physical research	79		1947	31
Stanford Linear Accelerator Center	-Elementary particle physics research	1,184	12,400	1966	12
	Program Dedicated Facilities: Safeguards Facility				
New Brunswick Laboratory Argonne, IL	-Development and dissemination of improved measurement technology for nuclear materials (used to be in NJ)	56			

*as of 1978

APPENDIX C (cont.)
Disbanded Facilities

Name of Facility	Description	Workforce*		DateEstab-lished	Years in Operation*
		Current	Total		
National Guard Armory, IL	Storage				
Site A, Palos Park, IL	Waste				
University of Chicago	First Reactor				
Iowa State University	Research				
Metal Hydrides Inc., MA	Experimental Reprocessing				
Mallinckrodt Chemical, MO	Uranium Refinery				
St. Louis Airport Storage Site, MO	Storage				
Middlesex Sampling Plant (DuPont) NJ	Sampled ore from Congo				
Kellex Corp., NJ	Research -(Vitro)				
Middlesex Landfill Site, NJ	Waste Dump				
Acid Pueblo Canyon, NM	Waste Dump				
Chupadera Mesa Area, NM	Waste Dump				
Lawrence Livermore Lab, NV	At Nevada Test Site		4,003	1952	26

*as of 1978

APPENDIX C (cont.)

Disbanded Facilities

Name of Facility	Description	Workforce*		Date Established	Years in Operation*
		Current	Total		
Haist Property, NY	Waste Dump, Ashland Oil Co.				
Linde Refinery	Production Plant (old)				
Seaway Industrial Park, NY	Storage				
Seneca Army Depot, NY	Storage				
Simonds Saw & Steel Co.,NY	Small production				
Harshaw Chemical Co.,OH	Old Production				
Horizons, Inc., OH	Beryllium Research				
Blairsville Dumpsite, PA	Waste?				
Vitro Refinery, PA (Cannonsburgh Industrial Park)	Small waste recovery/experimental refinery				
Conserv. Inc. FL	?				
Gardiner Inc. FL	?				
Blockson Chemical Co., IL	?				
Universal Cyclops, Inc.,PA	?				

*as of 1978

APPENDIX D
Waste Management Sites in the U.S.

The following section is an inventory of radioactive waste storage and disposal activities in the U.S. These lists include:

I. Commercially operated burial sites which are managed by private industry in accordance with Federal and State regulations.

II. Department of Energy (DOE) managed disposal and storage facilities.

A. Other than High-Level Radioactive Waste Disposal Sites.

B. High-Level Radioactive Waste Storage Sites.

C. Other than High-Level Radioactive Waste Storage Sites.

D. Transuranic Radioactive Waste Storage Sites.

III. Uranium tailings sites which are regulated either by the NRC or by certain agreement States.

Radioactive wastes within the Department of Energy have been classified into three categories: (1) high-level, (2) transuranium contaminated (atomic number greater than 92), and (3) other than high-level wastes.

High level wastes are those wastes generated from the reprocessing of spent nuclear fuelds. The transuranium contaminated wastes usually contain solid materials with greater than 10 nCi/g of long-lived alpha emitters such as plutonium. The "other than high-level wastes" include the balance of the wastes generated in the fuel cycle. This last category includes low and intermediate level wastes. The classification used was adopted from NUREG 0527, currently in press.

An attempt was made to make this inventory as comprehensive as possible, although it is by no means a complete listing of radioactive waste management activities in the U.S. Notably, at the time of this report no information was available on commercial radioactive waste storage. In addition, it is probable that information on some inactive waste disposal sites may be lacking.

This information has been compiled from the following references which are keyed to the tables:

(1) Holcomb, W.F., "A Summary of Shallow Land Burial of Radioactive Wastes at Commercial Sites Between 1962 and 1976, with projections," Nuclear Safety, Vol. 19; No. 1, pp. 50-69, January - February 1978.

(2) Office of Nuclear Material Safety and Safeguards, Nuclear Regulatory Commission, "Public Comments and Task Force Responses Regarding the Environmental Survey of the Reprocessing and Waste Management Portion of the LWR Fuel Cycle (NUREG 0116)," NUREG 0216, March 1977.

(3) Nuclear Regulatory Commission, "Regulation of Federal Radioactive Waste Activities," NUREG 0527, unpublished.

(4) Environmental Protection Agency, "Radiation Protection Activities 1977," EPA-520/4-78-003, August 1978.

(5) Written Communications with John J. Linehan, Uranium Mill Licensing Section, Fuel Processing and Fabrication Branch, Division of Fuel Cycle and Material Safety, United States Nuclear Regulatory Commission.

I. COMMERCIAL WASTE DISPOSAL FACILITIES

Name of Facility and Location	Ref.	Years in Operation	M^3 Waste Volume	Ci Waste Activity	Description and Comments
Nuclear Engineering Company Beatty, NV	1,2	1962-? inactive	53,796	1.3 X 10	Low-level wastes from commercial activities.
Nuclear Engineering Company Richland WA	1,2	1965- Present	13,519	5.4×10^5	Low-level wastes from commercial activities
Nuclear Engineering Company Sheffield, IL	1,2	1967- ? inactive	68,956	4.65×10^4	Low-level wastes from commercial activities.
Nuclear Engineering Company Maxey Flats, KY	1,2	1962-1977	134,864	1.9×10^6	Low-level wastes from commercial activities. Study published in Dec. 1974 by the KY Dept. of Human Resources, concluded that the burial ground was contributing radioactivity to the local environment.
Nuclear Fuel Services West Valley, NY	1,2	1963-1975	66,521	5.4×10^5	Low-level wastes from commercial activities. Voluntarily closed in 1975 when it was discovered that H^3 and Sr^{90} was leaking from two burial trenches.
Chemical Nuclear Systems, Inc. Barnwell, SC	1,2	1971- Present	85,444	3.4×10^5	Low-level wastes from commercial activities.

II. DEPARTMENT OF ENERGY FACILITIES

II.A. Other than High-Level Waste Disposal Sites

Name of Facility and Location	Ref.	Years in Operation	M^3 Waste Volume	Ci Waste Activity	Description and Comments
Brookhaven National Laboratory Upton, NY	3			3.4(1973)	Low-level wastes from reactors, a particle accelerator, and a hot laboratory complex - low level waste is not presently being disposed there.
Feed Materials Production Center Fernald, OH	3	Active	3.3×10^2	1.03×10^3	Low-level wastes from the production of purified uranium metals and compounds from semi-pure uranium concentrate.
Hanford Reservation Richland, WA	3	1943 - Present	1.79×10^6	1.65×10^6	Solid and liquid low-level wastes from production and processing of plutonium for the weapons program, Fast Flux Test Facility, N-Dual Purpose Reactor, Lab. Services, Pilot activity on the reprocessing and solidification of commercial fuel, and the solidification and encapsulation of cesium and strontium.

II. DEPARTMENT OF ENERGY FACILITIES (cont.)

II.A. Other than High-Level Waste Disposal Sites

Name of Facility and Location	Ref.	Years in Operation	M^3 Waste Volume	Ci Waste Activity	Description and Comments
Idaho National Engineering Lab. (INEL) Idaho Falls, ID	3	1949-			Low-level wastes disposed of have been generated both on-site and off-site, from both defense and non defense programs. In addition, commercial wastes were disposed of at INEL prior to the availability of commercial sites. Several locations have been used for the disposal of wastes;
					(1) Various Ponds - INEL has eight active and seven inactive ponds. The volume and activity of these ponds has not been determined.
			1.63×10^5	7.8×10^6	(2) Radioactive Waste Management Complex - Solid low level waste has been disposed.
					(3) The Idaho Chemical Processing Plant (ICPP) - Waste Evaporator liquid waste which undergoes ion exchange treatment and is diluted with nonradioactive service water. This waste is injected into a 600-foot deep well.

II. DEPARTMENT OF ENERGY FACILITIES (cont.)

II.A. Other than High-Level Waste Disposal Sites

Name of Facility and Location	Ref.	Years in Operation	M^3 Waste Volume	Ci Waste Activity	Description and Comments
					(4) The Power Burst Facility - Low level liquid waste from this facility is pumped into 110-foot deep well.
			2.30 X 10^3	600	(5) The SL-1 Burial Ground - Solid low level waste from the SL-1 reactor.
Los Alamos Scientific Lab. Los Alamos, NM	3	1946 - Present	2.55 X 10^5	4 X 10^5	The site has been used for disposal of low level radioactive wastes from the design construction, and testing of World War II atomic bombs. A variety of special disposal operatings have been performed, ranging from the shaft burial of a few grams of tritium to the demolition and burial of whole buildings.
Lawrence Livermore Lab (LLL) Livermore, CA	3	Present	1.4 X 10^4	3.5	Solid low level waste has been generated from the design and testing of Nuclear weapons, a reactor (pool type), a linear accelerator, and in a heavy element, metalurgy and light isotope chemistry buildings

II. DEPARTMENT OF ENERGY FACILITIES (cont.)

II.A. Other than High-Level Waste Disposal Sites

Name of Facility and Location	Ref.	Years in Operation	M^3 Waste Volume	Ci Waste Activity	Description and Comments
Nevada Test Site (NTS)			2.4×10^4	3.8×10^6	Low-level wastes from nuclear testing in support of the National defense program
Oak Ridge National Laboratory (ORNL), Oak Ridge, TN	3	early 1940's	1.84×10^5	1×10^5	Originally ORNL was engaged in the Manhattan Project. Presently major facilities in the complex consist of operating reactors, particle accelerators, a transuranium processing plant, chemical processing development facilities, a biological laboratory complex, an environmental science laboratory and the Hollfield Heavy Ion Research Facility. Low-level wastes that have been disposed of have originated from ORNL activities, commercial operations and other Federal activities.
Oak Ridge Y-12 Plant Oak Ridge, TN	3	present	8.55×10^4	6.8×10^3	Low-level waste generated from the production of atomic weapon components and in fabrication support for weapon design.
Paducah Gaseous Diffusion Plant Paducah, KY	3	1950's - present	6.7×10^3	1.25×10^3	The plant enriches uranium in the isotope U-235. The low-level waste disposed originated from defense and non-defense programs.

II. DEPARTMENT OF ENERGY FACILITIES (cont.)

II.A. Other than High-Level Waste Disposal Sites

Name of Facility and Location	**Ref.**	**Years in Operation**	M^3 **Waste Volume**	Ci **Waste Activity**	**Description and Comments**
Pantex Plant Amarillo, TX	3	inactive	27	1×10^3	The plant generates low-level waste from its involvement in the defense program relating to the fabrication of high explosives and other components necessary to assemble, repair, and test nuclear weapons.
Portsmouth Gaseous Diffusion Plant Piketon, OH	3	active	9.7×10^2	6	This facility produces enriched uranium for the government and private sector. The radioactive wastes generated are from the decontamination and recovery facility. The low-level wastes disposed have originated from both defense and commercial programs.
Rocky Flats Plant (RFP) Golden, CO	3	inactive	4×10^3	very low	Low-level wastes from the production of nuclear components for the national defense program.
Sandia Laboratories - Albuquerque Albuquerque, NM	3	1945 - present	1.4×10^3	6×10^3	Low-level wastes have been generated in the research, design and development of nuclear weapons.

II. DEPARTMENT OF ENERGY FACILITIES (cont.)

II.A. Other than High-Level Waste Disposal Sites

Name of Facility and Location	**Ref.**	**Years in Operation**	**M^3 Waste Volume**	**Ci Waste Activity**	**Description and Comments**
Savannah River Plant Aiken, SC	3	1955 - present			Low-level wastes generated in the production of nuclear materials, primarily plutonium and tritium, for the defense program.
			2.53×10^5	3.88×10^6	Low-level solid wastes have been buried in pits and trenches.
					In addition liquid low-level wastes have been disposed of in seepage and retention basins.
Weldon Spring Site Weldon Spring, MO	3	1950's - 1960's	7.46×10^6	52.25	Low-level wastes generated from the refining of uranium ores for the defense program.
Oak Ridge National Laboratory Oak Ridge, TN	3				Intermediate level wastes from a number of operations concerned with the laboratories fission energy program. The wastes have been disposed of in;
		inactive	1.84×10^5	1×10^6	Pits and trenches
			5×10^3	6.26×10^5	well injection

II. DEPARTMENT OF ENERGY FACILITIES (cont.)

II.B. High Level Radioactive Waste Storage Sites

Name of Facility and Location	Ref.	Years in Operation	M^3 Waste Volume	Ci Waste Activity	Description and Comments
Hanford Richland, WA	3				The high level wastes stored have been generated in the production of plutonium for the defense program. These wastes are stored in the following locations;
		active	1.78×10^5	1.08×10^8	1) Tank Farms which contain solid and liquid wastes.
		active	105	1.50×10^8	2) B Plant which contains Sr^{90} and Cs^{137} removed from high-level radioactive wastes.
				3.1×10^7	3) Waste encapsulation and storage facility which takes wastes stored in the B plant and encapsulates and stores the Sr^{90} and Cs^{137}.
Idaho National Engineering Lab. Idaho Falls, ID	3				The high level wastes stored are from INEL activities and from other DOE sites. The wastes are stored in the following locations:
		active	8980	1.1×10^7	1) Tank Farm contains liquid wastes which originated from defense programs and test and research reactors.

II. DEPARTMENT OF ENERGY FACILITIES (cont.)

II.B. High Level Radioactive Waste Storage Sites

Name of Facility and Location	Ref.	Years in Operation	M^3 Waste Volume	Ci Waste Activity	Description and Comments
			1640	1×10^6	2) Bin Farm contains solid wastes which originated from defense programs and test and research reactors
					3) Spent Fuel which originated from nondefense programs
			100	9×10^6	4) Argonne-West National Laboratory at INEL has some HLW storage.
Savannah River Plant Aiken, SC	3		8.33×10^4	7.75×10^8	High level wastes generated in the production of nuclear materials, predominantly in the defense program.

II. DEPARTMENT OF ENERGY FACILITIES (cont.)

II.C. Other Than High-Level Radioactive Waste Storage Sites

Name of Facility and Location	Ref.	Years in Operation	M^3 Waste Volume	Ci Waste Activity	Description and Comments
Brookhaven National Lab. (BNL) Upton, NY	3	--	100	--	All of the waste stored originated from BNL activities. In addition contaminated equipment from BNL reactors is being held in storage.
Feed Materials Production Ctr. Piketon, OH	3	inactive	9×10^3	1,656	The stored low-level wastes originated in both defense and non-defense programs.
Niagara Falls Lewiston, NY		--	7.83×10^5	10	The low-level wastes stored were generated between 1944 and 1953 through processing of uranium ore at other locations. NOTE the curie values do not include any activity associated with Radium-226.
Pantex Amarillo, TX	3	active	100	1,000	The low-level wastes stored originated from the weapons program.
Savannah River Plant Aiken, SC	3	active	--	--	From its defense program, the plant has classified low-level waste stored.
Oak Ridge National Laboratory Oak Ridge, TN	3	--	1.5×10^3	1×10^6	These intermediate level wastes are sludges that have settled in tanks that supply the hydrofracture facility w/supernatant. The principal radionuclide in the study is Sr^{90}.

II. DEPARTMENT OF ENERGY FACILITIES (cont.)

II.D. Transuranic Radioactive Waste Storage Sites

Name of Facility and Location	Ref.	Years in Operation	M^3 Waste Volume	Ci Waste Activity	Description and Comments
Hanford Richland, WA	3	active	7.76 X 10^3	1.03 X 10^5	Transuranic wastes stored have been generated in production of plutonium for the defense program, & in a number of research & development facilities.
Idaho National Engineering Lab. Idaho Falls, ID	3	active	4.10 X 10^4	1.75 X 10^5	Transuranic wastes stored have been generated from the facilities activities in processing spent fuel from Government owned reactors & developing improved fuel reprocessing. In addition waste from other DOE Sites are stored there.
Las Alamos Scientific Lab. Los Alamos, NM	3	active	1.95 X 10^3	1 X 10^5	Transuranic wastes stored are primarily from on-site facilities involved in the development of plutonium technology.
Nevada Test Site Mercury, NV	3	active	184	1,060	The origin of the wastes is primarily from defense programs.
Oak Ridge National Laboratory Oak Ridge, TN	3	active	1.10 X 10^3	8.10 X 10^4	Transuranic wastes from a variety of chemical processing development facilities supporting the laboratories fission energy development mission.

II. DEPARTMENT OF ENERGY FACILITIES (cont.)

II.D. Transuranic Radioactive Waste Storage Sites

Name of Facility and Location	**Ref.**	**Years in Operation**	**M^3 Waste Volume**	**Ci Waste Activity**	**Description and Comments**
Pantex Amarillo, TX	3	active	33	low	Transuranic waste from the defense program.
Savannah River Plant Aiken, SC	3	active	2.7 X 10^4	3 X 10^5	Transuranic wastes stored are primarily from nuclear production reactors and chemical separation plants.

III. URANIUM MILL TAILINGS SITES

Site Location	Name and/or Owner	Reference	Operational Status	Years in Operation	Tons of Tailings (x106)	Land Area (acres)	Est. Workforce Current/Total	Comments
Arizona								
Tuba City		5						
Monument Valley		5						
Colorado								
Canon City	Cotter Corp.	4	active	1958-Present	1.1	35		
Durango		5						
Grand Junction		5						
Gunnison		5						
Maybell		5						
Naturita		5						
Rifle	Union Carbide	4	active	1955-Present	2.7	32		
Slick Rock		5						
Uravan	Union Carbide	4	active	1950-Present	7.0	8-		

III. URANIUM MILL TAILINGS SITES (cont.)

Site Location	Name and/or Owner	Reference	Operational Status	Years in Operation	Tons of Tailings (x106)	Land Area (acres)	Est. Workforce Current/Total	Comments
Idaho								
Lowman		5						
New Mexico								
Ambrosia Lake	Kerr, McGee Nuclear	4 5 5	active	1958-Present	25.4	200		
Blue Water	Anaconda Co.	4	active	1953-Present	15.3	250		
Churchrock	United Nuclear	4	active	1977-Present				
Moquino	Sohio	4	active	1977-Present				
Shiprock		5						
Oregon								
Lakeview		5						
SouthDakota								
Edgemont	TVA (Mine Dev.Inc.	4	active	1956-Present				

III. URANIUM MILL TAILINGS SITES (cont.)

Site Location	Name and/or Owner	Reference	Operational Status	Years in Operation	Tons of Tailings (x106)	Land Area (acres)	Est. Workforce Current/Total	Comments
Texas								
Fall City	Conoco & Pioneer Nuclear Inc.	5						
Utah								
Green River		5						
La Sal	RioAlgom Corp.	4	active	1972-Present	.74	45		
Mexican Hat		5						
Moab	Atlas Corp.	4	active	1956-Present	7	115		
Salt Lake City		5						
Washington								
Ford	Dawn Mining Co.	4	active	1956-Present	1.9	100		

III. URANIUM MILL TAILINGS SITES (cont.)

Site Location	Name and/or Owner	Reference	Operational Status	Years in Operation	Tons of Tailings ($x10^6$)	Land Area (acres)	Est. Workforce Current/Total	Comments
Wyoming								
Bear Creek	Rocky Mtn. Energy	4	active	1977-Present				
Converse County		5						
Gas Hills	Fed.Am. Partners	4	active	1959-Present	4.0	100		
Gas Hills	UT Int. Inc.	4	active	1956-Present	5.5	135		
Gas Hills	Union Carbide	4	active	1960-Present	4.0	61		
Jeffry City	Western Nuclear Inc.	4	active	1957-Present	3.0	60		
Powder River Basin	Highland Mill, ExxonUSA	4	active	1972-Present	2.2	250		
Riverton		5						

III. URANIUM MILL TAILINGS SITES (cont.)

Site Location	Name and/or Owner	Reference	Operational Status	Years in Operation	Tons of Tailings ($x10^6$)	Land Area (acres)	Est. Workforce Current/Total	Comments
Wyoming (Cont.)								
Shirley Basin	Petro-tomicsCo	4	active	1972-Present	2.2	50		
Shirley Basin	UT Int. Inc.	4	active	1971-Present	1.8	250		

GLOSSARY

Alpha Particle:	A charged particle emitted from the nucleus of an atom having a mass and charge equal in magnitude to that of a helium nucleus, i.e. two protons and two neutrons.
Beta Particle:	A charged particle emitted from the nucleus of an atom, with a mass and charge equal to that of the electron.
Brachytherapy:	Therapy at short distances with beta or gamma radiation. Implantation of placement therapy with radioactive needles, inserts, or other such applications.
Chamber, Ionization:	An instrument designed to measure a quantity of ionizing radiation in terms of the charge of electricity associated with ions produced within a defined volume.
Chamber, Pocket:	A small, pocket-sized ionization chamber used for monitoring radiation exposure of personnel. Also called a posket dosimeter.
Cosmic Rays:	High-energy particulate and electromagnetic radiations which osiginate outside the earth's atmosphere.
Curie (Ci):	The associated unit of activity. One curie equals 3.7 X 10^{10} disintegrations per second. -miciocurie, uCi = 3.7 X 10^{4} disintegrations per second. -millicurie, mCi = 3.7 X 10^{7} disintegrations per second. -picocurie, pCi = 3.7 X 10^{-2} disintegrations per second.
Decay, Radioactive:	Disintegration of the nucleus of an unstable nuclide by spontaneous emission of charged particles (alpha or beta particles) or electromagnetic radiation (gamma rays).

Decay Product (Daughter):	A nuclide resulting from the radioactive disintegration of a radionuclide, formed either directly or as a result of successive transformations in a radioactive series. A decay product may be either radioactive or stable.
Dose, Absorbed:	The energy imparted to matter by ionizing radiation per unit mass of irradiated material at the place of interest. The associated unit is the rad. One rad equals 100 ergs per gram.
Dose, Cumulative:	The total dose resulting from repeated exposures to radiation.
Dose Equivalent:	A quantity used in radiation protection. It expresses all radiations on a common scale for calculating the effective absorbed dose. It is defined as the product of the absorbed dose in rads and certain modifying factors. The associated unit is the rem.
Dose, Skin:	Absorbed dose at center of irradiated field on skin as used in radiology.
Dose, Tissue:	Absorbed dose received by tissue in the region of interest, expressed in rads.
Dose, Fractimation:	A method of administering radiation in which relatively small doses are given at particular intervals (e.g. daily).
Dose Rate:	Absorbed dose delivered per unit time.
Dosimeter:	Instrument to detect and measure accumulated radiation exposure. Examples are film badges, thermoluminescent dosimeters (TLD), and pocket chambers, as used for personnel monitoring.
Enriched Uranium:	Uranium in which the abundance of the isotope U-235 is increased above normal.

Exposure (gamma and x-ray):	A measure of the ionization produced in air by x or gamma radiation. It is the sum of the electrical charges on all ions of one sign produced in air when all electrons liberated by photons in a volume element of air are completely stopped in air, divided by the mass of the air in the volume element. The associated unit is the Roentgen.
Exposure, Acute:	Radiation exposure of short duration.
Exposure, Chronic:	Radiation exposure of long duration, either by fractionation or protraction.
Fall Out:	Radioactive debris from a nuclear detonation, which is airborne or has been deposited on the earth.
Film Badge:	A pack of photographic film which measures radiation exposure for personnel monitoring. The badge may contain two or three films of differing sensitivity and filters to shield parts of the film from certain types of radiation.
Fission, Nuclear:	A nuclear transformation characterized by the splitting of a nucleus into at least two other nuclei and the release of a relatively large amount of energy.
Fission Products:	Elements or compounds resulting from nuclear fission.
Fluorescence:	The emission of radiation of particular wavelengths by a substance as a result of absorption of radiation of shorter wavelength. Fluorescent screens will emit visible light when irradiated by ionizing radiation.
Fluoroscope:	A fluorescent screen, suitably mounted with respect to an x-ray tube for ease of observation and protection, used for indirect visualization (by x-rays) of internal organs in the body or internal structures in apparatus.

Gamma Ray:	Short wavelength electromagnetic radiation of nuclear origin (energy range of 10 KeV to 9 MeV).
Half-life:	Time required for a radioactive substance to lose 50% of its activity by decay. Each radionuclide has a unique half-life.
Hardness (x-rays):	A relative specification of the quality or penetrating power of x-rays. In general, the higher the energy, the harder the radiation.
Implant:	Encapsulated radioactive material embedded in a tissue for brachytherapy.
Ion:	Atomic particle, atom, or chemical radical bearing an electrical charge, either negative or positive.
Ionization:	The process by which a neutral atom or molecule acquires a positive or negative charge.
Isotopes:	Nuclides having the same number of protons in their nuclei, and hence the same atomic number, but differing in the number of neutrons, and therefore in the atomic mass. Almost identical chemical properties exist between isotopes of a particular element.
Kerma:	The sum of the initial kinetic energy of all charged particles liberated by indirectly ionizing particles (neutrons, gamma rays, and x-rays) in a volume, divided by the mass of matter in that volume.
Nuclear Medicine:	The use of radioisotopes as tracers in the diagnosis of disease.
Photon:	A quantized packet of electromagnetic energy.
Quality Factor:	The factor by which the absorbed dose is multiplied to obtain a quantity that expresses the effectiveness of the absorbed dose on a common scale for all ionizing radiation. The term is used for radiation protection purposes.

Rad:	The associated unit of absorbed dose equal to 100 ergs per gram (0.01 joules per kilogram) in any medium. (see Dose, Absorbed)
Radiation, Background:	Radiation arising from radioactive material other than the one directly under consideration. Natural background refers to cosmic radiation and that resulting from natural terrestrial sources.
Radiation, Ionizing:	Any electromagnetic or particulate radiation capable of producing ions, directly or indirectly, in its passage through matter.
Radioactivity:	The property of certain nuclides of spontaneously emitting particles or gamma radiation.
Relative Biological Effectiveness (RBE):	The RBE is a factor used to compare the biological effectiveness of absorbed radiation doses (i.e. rads) due to different types of ionizing radiation, more specifically, it is the experimentally determined ratio of an absorbed dose of a radiation in question to the absorbed dose of a reference radiation (generally gamma rays) required to produce an identical biological effect in a particular experimental organism or tissue.
Rem:	A special unit of dose equivalent. The dose equivalent in rem is numerically equal to the absorbed dose in rads multiplied by the quality factor. (see Dose Equivalent)
Roentgen (R):	The associated unit of exposure. One roentgen equals 2.58 X 10^{-4} coulomb per kilogram of air at standard temperature and pressure. (see Exposure)
Series, Radioactive:	A succession of nuclides, each of which transforms by radioactive disintegration into the next until a stable nuclide results. The first member is the "parent", the intermediate members are called "daughters", and the final member is called the "end product".

Soft X-rays:	Low energy x-rays that do not have much penetrating ability.
Therapy, Radiation:	The use of ionizing radiation to treat disease.
Thermoluminescent Dosimetry (TLD):	A crystalline, semiconducting dosimeter characterized by the ability to emit visible light upon heating that is proportional in amount to the radiation absorbed dose received. Typically, TLD's are made of lithium fluoride.
Tritium:	The hydrogen isotope with one proton and two neutrons (symbol: ^3H).
Working Level: (WL)	The concentration of radon such that, along with its radioactive daughters, it will result in the emission of 1.3 X 10^5 MeV of alpha activity. 100 pCil^{-1} of Rn-222 = 1WL.
Working Level:	The exposure resulting from being exposed to one working level for a period of 170 hours.
X-rays:	Penetrating electromagnetic radiations whose wavelengths are shorter than those of visible light. They are usually produced by bombarding a metallic target with fast electrons in a high vacuum. In nuclear reactions, it is customary to refer to photons originating in the nucleus as gamma rays and those originating in the extra nuclear part of the atom as x-rays.