Research Reactors

SELECTED REFERENCE MATERIAL UNITED STATES ATOMIC ENERGY PROGRAM

Research Reactors



UNITED STATES OF AMERICA

ACKNOWLEDGMENT

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VOLUME ONE

Research Reactors

Light Water Moderated

TYPE I Homogeneous—Enriched Fuel
TYPE II Heterogeneous—Enriched Fuel
TYPE III Heterogeneous—Enriched Fuel

Light Water and Oil Moderated

Heterogeneous-Enriched Fuel

Heavy Water Moderated

Heterogeneous-Enriched Fuel

Graphite Moderated

Heterogeneous-Natural Fuel

UNITED STATES OF AMERICA

GENEVA: AUGUST 1955

Foreword

Interchange of scientific and technical knowledge will greatly facilitate the work of the scientists and engineers whose skills will be devoted to the future development of the peaceful uses of atomic energy.

The United States has made available to the world's scientific community a large body of such data. In honor of this historic Conference and to stimulate further exploration and development of the beneficial applications of nuclear energy, the United States Atomic Energy Commission has prepared this special collection of technical data for the use of the delegates and the nations represented.

The purpose of this collection is to provide information concerning the ways that we have found in which fissionable materials can be put to work in nuclear reactors for research purposes and for the production of power and radioisotopes.

It is our sincere hope that this material will be of practical value to the men and women of science and engineering in whose hands the great power of the atom is becoming a benign force for world peace.

Reus L Straus

Chairman, U.S. Atomic Energy Commission

Acknowledgment

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Introduction

Within the brief span of 10 years nuclear reactors have proved themselves an indispensable research tool in a variety of fields. Up until 1953. all reactors in the United States were owned by the government and were operating on government sites. Within recent years, however, a considerable number of private research institutions and universities have planned, built, and operated research reactors on their own sites with active encouragement from the Atomic Energy Commission (AEC). In addition there are upwards of a dozen industrial firms in this country which are planning, building, or actually operating various types of nuclear reactors. A valuable backlog of reactor design and operating experience has accumulated and is available to assist groups to enter the field. On the basis of this experience, some general considerations on the uses, classifications, performance, costs, and safety problems of nuclear reactors are presented on the pages that follow.

Uses of Reactors. The practical applications of nuclear research reactors may be divided into the following categories: (1) reactor technology, (2) physics research, and (3) biomedical and industrial research.

Reactor technology. Reactors are an exceedingly useful source of neutrons for a variety of experiments in the study of reactor physics and of the properties of neutrons themselves. Reactors also provide an excellent means for studying radiation damage, giving personnel experience with radiation and the methods used for detecting and counting neutrons or gamma rays. Among the many possible reactor experiments are the following:

- 1. Critical-multiplication-approach studies.
- 2. Control-rod calibrations.
- 3. Critical behavior studies (reactor period as a function of excess reactivity).
- 4. Temperature-coefficient measurements and studies of the effect of temperature on reactivity.
 - 5. Studies of neutron-flux distribution.
- 6. Studies of the effects of neutrons on materials (radiation damage).
- 7. Shielding studies.

Physics research. Reactors are excellent tools for performing fundamental experiments in the field of physics. Studies of the fission process and measurements of neutron cross sections are among the commonly performed experiments possible with a research reactor. The following are typical examples of experiments designed to study the fission process:

- 1. Determination of neutron-energy distribution from the fission of U²³⁵.
- 2. Observation of the number and lifetimes of neutrons and the intensity of gamma rays occurring after fission.
- 3. Determination of the total energy of fission by calorimetric methods.
- 4. Measurement of the velocity distribution of the fission fragments.

Examples of neutron cross-section measurements include:

- 1. Fission, absorption, and scattering cross sections at various neutron energy levels.
- 2. Total cross section for a large number of elements by using a neutron converter in the beam hole as a fast-neutron source and a proton-recoil chamber as a neutron spectrometer.

Biomedical and industrial research. Neutron flux from reactors provides the basis for many

interesting biological and industrial radiation-damage studies. Furthermore, radioactive isotopes, obtained by irradiation of samples with neutrons in a reactor, are widely used for medical, biological, and industrial research with outstanding results. Small amounts of the solution in a homogeneous reactor itself furnish excellent sources of rare isotopes. Among examples of the use of reactor neutron flux and radioisotopes for biomedical and industrial research are the following:

- Experiments to determine the biological and physical effects of thermal neutrons and hard gamma rays.
- 2. The use of radioactive tracers to follow accurately the progress of foods and minerals in plants and animals.
- Studies of fundamental blood processes, gland functions, and animal metabolism by means of radioisotopes.
- Radiation-damage studies of various materials by irradiation in a reactor.
- 5. Investigation of self-diffusion of atoms through a crystal lattice.
- 6. Irradiation of silicon and germanium crystals to investigate their electrical properties.
- Sterilization of food products by means of spent reactor fuel elements, reactor fission products, or radioisotopes.

Reactor Classification. Nuclear reactors may be classified in several different ways, depending on the type and arrangement of fuel, moderator, and coolant used and on the speed of the neutrons sustaining the fission reaction. Materials used to reduce the neutron energy, known as moderators, are primarily graphite, light water, and heavy water. Active fuel materials may be natural uranium; enriched uranium, in which the U²³⁵ fraction has been increased; plutonium (Pu²³⁹); or uranium (U²³³) resulting from fission of thorium (Th²³²). The last two are artificial, reactor-produced elements.

The arrangement of moderator and fuel provides a basis of classification. In a heterogeneous, or solid-fuel, reactor the fuel is fixed in a regular pattern (lattice) within the moderator. In a homogeneous reactor the fuel and moderator are intimately mixed in the form of a solution, whether aqueous or liquid salts or metals.

Reactors operated above minute power levels must use some form of cooling to remove the heat produced. Light-water, heavy-water, or air coolants are generally used; either natural convection or forced circulation is employed.

Reactors are further classified according to the speed or energy of the neutrons that cause fission. Neutrons of about 0.025 ev are called slow or thermal; neutrons from about 1 to 1000 ev are known as intermediate; and neutrons with energies greater than about 1000 ev are called fast. A fast reactor does not use a moderator to slow down the fission neutrons.

Finally, reactors may be classified according to their purpose. Research reactors are built primarily to supply neutrons for physical research and radioisotope manufacture. Production reactors are built to manufacture fissionable materials by conversion of nonfissionable (fertile) materials. Reactors capable of providing useful power outputs are known as power reactors.

The present volume is confined to a description of six classes of research reactors operating in the United States. These are presented in six chapters, in accordance with the following classification:

1. Light-water-moderated reactors.

Type I: Homogeneous—enriched fuel (waterboiler type). Chap. 1.

Type II: Heterogeneous—enriched fuel (pool type). Chap. 2.

Type III: Heterogeneous—enriched fuel [materials-testing reactor (MTR)]. Chap. 3.

2. Light-water- and oil-moderated reactors.

Heterogeneous—enriched fuel [nuclear-test-ing reactor (NTR)]. Chap. 4.

3. Heavy-water-moderated reactors.

Heterogeneous—enriched fuel [Argonne research reactor (CP-5)]. Chap. 5.

4. Graphite-moderated reactors.

Heterogeneous—natural fuel [Brookhaven National Laboratory (BNL)]. Chap. 6.

Performance and Costs. It is of interest to compare the performance and costs of natural-uranium research reactors with reactors using enriched fuels, since the United States has had considerable experience with both types. Some characteristics of natural-uranium research reactors

are shown in Table I-1, and equivalent data for enriched-uranium reactors are given in Table I-2.

A comparison of the performance of various reactors measured in terms of specific power and thermal-neutron flux is shown in Table I-3. The approximate cost of the reactors, not including

reaction will get out of control, that the power will rise to a very high level in an extremely short time, and that parts of the reactor will melt or even vaporize. Based on past experience, there is very little chance of any existing or proposed research reactor destroying itself as a result of such

Table I-1 Research Reactors Fueled with Natural Uranium

Designation	Date	Fuel	Moderator	Power level
CP-1	1942	6 tons U metal 40 tons U oxide	385 tons C	100 watts
CP-2	1943	10 tons U metal 42 tons U oxide	472 tons C	2 kw
X-10	1943	35 tons U metal	620 tons C	3,800 kw
CP-3	1944	3 tons U metal	6.5 tons D ₂ O	300 kw
NRX	1947	10 tons U metal	17 tons D ₂ O	30,000 kw
BNL	1950	100 tons U metal	730 tons C	30,000 kw

Table I-2 Research Reactors Fueled with Enriched Uranium

Designation	Date	Amount enriched U ²³⁵ in fuel	Moderator	Power level
	HIJAN A			.703
Heavy-water type:	1000	30,000	to mittelet it.	Agranda construit, regulating
CP-3'	1950	4 kg U + Al	7 tons D ₂ O	300 kw
CP-5	1953	1.3 kg U + Al	6.5 tons D ₂ O	1000 kw
Water boilers:		1000000		PROFESSION CONTRACTOR STATES SECTIONS
LOPO	1944	0.5 kg UO2SO4	H_2O	0.05 watt
HYPO	1944	0.8 kg UO ₂ SO ₄	H_2O	6 kw
SUPO	1951	0.8 kg UO ₂ SO ₄	$_{\rm H_2O}$	35 kw
North Carolina	1953	1 kg UO ₂ SO ₄	H_2O	10 kw
MTR type:		Alaba Utania	Transport to the	Local Control Control
LITR	1950	3 kg U + Al	H_2O	2000 kw
BSF	1951	3.6 kg U + Al	H ₂ O	100 kw
MTR	1952	4 kg U + Al	H_2O	30,000 kw
NTR	1951	2.5 kg U + Al	$H_2O + oil$	30 kw

fuel costs, is also listed for comparison. The cost figures in general are for the first model of each reactor and hence include some reactor- and site-development costs. The same reactors could in many cases be built at the present time at a considerably lower figure.

Safety Problems. The major hazard affecting reactor safety is the possibility that the nuclear

a runaway nuclear reaction. The water systems of enriched-fuel light-water-moderated reactors are generally designed to have a strong negative temperature coefficient, so that they tend to shut down automatically following a sudden increase in reactivity. This has been demonstrated experimentally in a number of reactors of this type. In addition, the designer of a particular reactor makes adequate provisions for automatic

interesting biological and industrial radiation-damage studies. Furthermore, radioactive isotopes, obtained by irradiation of samples with neutrons in a reactor, are widely used for medical, biological, and industrial research with outstanding results. Small amounts of the solution in a homogeneous reactor itself furnish excellent sources of rare isotopes. Among examples of the use of reactor neutron flux and radioisotopes for biomedical and industrial research are the following:

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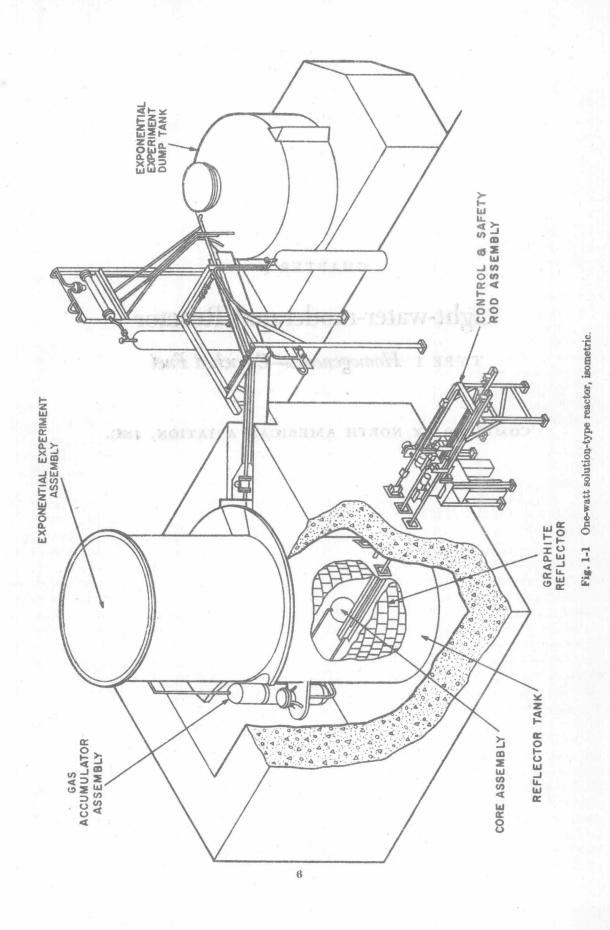
Performance and Costs. It is of interest to compare the performance and costs of natural-uranium research reactors with reactors using enriched fuels, since the United States has had considerable experience with both types. Some characteristics of natural-uranium research reactors

CHAPTER 1

Light-water-moderated Reactor

TYPE I Homogeneous—Enriched Fuel

COMPILED BY NORTH AMERICAN AVIATION, INC.



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