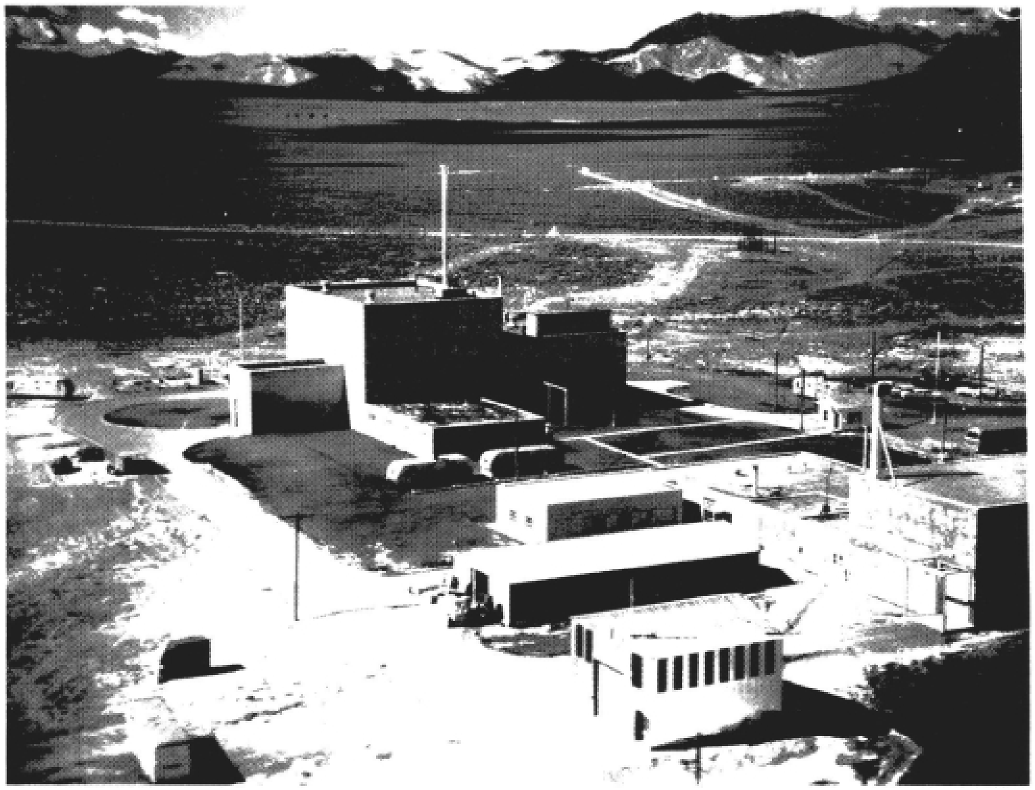
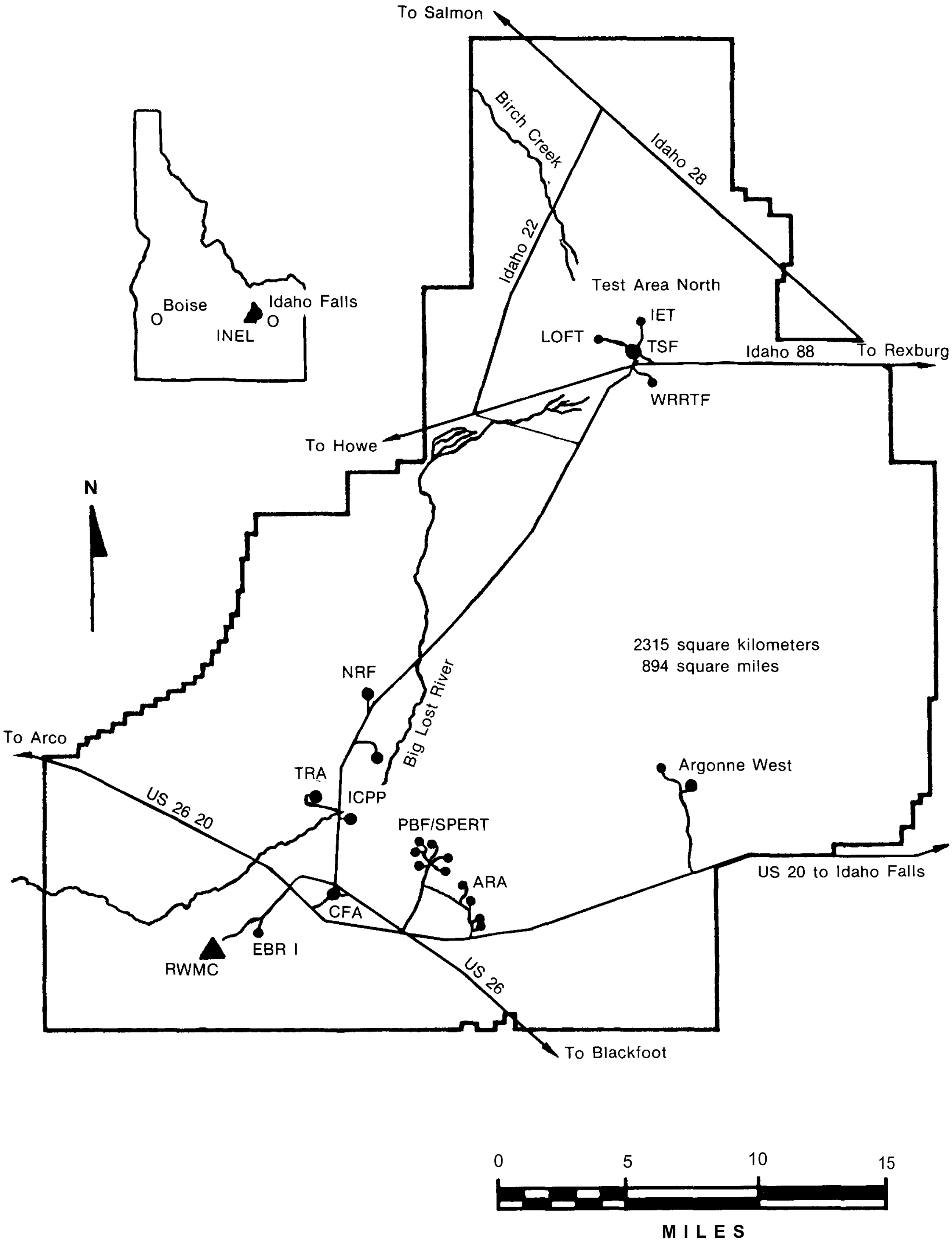
A National Historic Mechanical Engineering Landmark



Experimental Breeder Reactor I

Idaho National Engineering Laboratory

The American Society of Mechanical Engineers
June 15,1979



Location and principal features of the Idaho National Engineering Laboratory

Program

Opening Remarks	Colvin E. Jergins, Chairman, Idaho Section, ASME
Introduction of Honored Guests	Harry Reeder, Vice President, Region VIII, ASME
ASME Landmark Program	Prof. J. J. Ermenc, Chairman, National History and Heritage Committee, ASME
EBR-I Facility History	G. Kirby Whitham, Chemist, Argonne National Laboratory - West
Presentation of Plaque	Dr. Donald N. Zwiep, President, ASME
Acceptance of Plaque	John X. Combo, Deputy Manager, Idaho Operations Office, U. S. Department of Energy
Closing Remarks	David Van Haaften, Chairman, Idaho Section History and Heritage Committee, ASME

Important Dates in the History of EBR-I

1941 - 1942	Enrico Fermi and his team at the University of Chicago discover the theoretical feasibility of a breeder reactor
1946	Proposal to begin construction of EBR-I is approved by the Manhattan Engineer District
April 10, 1951	Construction complete, reactor assembly begins
August, 1951	Reactor achieves criticality (sustained chain reaction)
December 20, 1951	EBR-I lights four bulbs with the electricity produced by nuclear reaction
December 21, 1951	EBR-I supplies all the power needed for the reactor building
1953	EBR-I demonstrates the feasibility of the breeder reactor concept
1963	EBR-I begins operation with a plutonium core
December 1963	EBR-I test sequences completed
August 26, 1966	EBR-I designated a Registered National Historic Landmark
June 10, 1975	EBR-I decommissioning and decontamination complete
June 15, 1979	EBR-I designated a National Historic Mechanical Engineering Landmark

Introduction

Imagine a furnace that can change unburnable substances into perfectly good fuel — enough to replace the fuel it burns plus a little bit extra. The more fuel you burn the more fuel you create. This describes a process called fuel breeding that was first demonstrated to be technically feasible in Experimental Breeder Reactor I (EBR-I) over twenty-six years ago. This historic reactor was developed, designed, and operated by Argonne National Laboratory from 1947 through 1963. EBR-I was also the first reactor to generate usable amounts of electricity on December 20,1951, less than ten years after the world's first nuclear reactor was operated at Stagg Stadium in Chicago.

During World War II, scientists and engineers were working feverishly to achieve a controlled nuclear chain reaction as a step toward developing America's first nuclear weapon. A team led by the legendary Enrico Fermi built Chicago Pile I (CP-I) — the world's first nuclear reactor — and achieved a controlled chain reaction on December 2, 1942.

As reactor engineers gained knowledge and experience through their wartime activities, they became convinced that breeding more fuel than is consumed in a nuclear reactor was a possibility, at least theoretically. But the urgency of the wartime situation dictated that full attention be centered on the weapons program, so interest in the breeder reactor had to be put aside.

After the war, the newly established Atomic Energy Commission assigned some of the nation's nuclear skills and resources to developing peaceful uses of the atom. The large bodies of uranium ore found in the 1950's were then unknown. Uranium was in very short supply. It was therefore decided that the first prototype power reactor built would attempt to prove the theory of fuel breeding.

As a result of the requirements for a suitable site for this and other reactor projects, the National Reactor Testing Station, now the Idaho National Engineering Laboratory, was established. EBR-I was the first of more than fifty reactors to be built at this site.

Nuclear Reactor Basics

Nuclear reactors operate by a process called fission, in which a large, heavy nucleus splits into at least two smaller nuclei. This releases relatively large amounts of energy, as well as one or more neutrons. The neutrons released in fission are important because they can cause other nuclei to undergo fission, in turn producing more neutrons to sustain a chain reaction. A chain reaction requires that, on the average, at least one of the neutrons emitted in each fission process causes another fission, although many neutrons may escape the reactor or be absorbed without causing a fission,

Neutrons can either be emitted during the fission process or afterwards, from the product nuclei. Those emitted during fission are called "prompt", while later ones are termed "delayed". Both can cause other fissions, but they have different effects on reactor kinetics.

Nuclear reactors are classed as "fast" or "thermal" reactors, depending on the relative energies of the neutrons. Fission neutrons are usually fast (having a high kinetic energy) and these are most efficient in breeder reactors. Thermal reactors use moderator materials to absorb part of the neutron energy, making the neutrons more efficient in causing fissions. The cross-section of a moderator or other material is an indication of how likely a neutron is to interact with the material as it passes through.

To control a nuclear reaction, a "poison" material (one that absorbs neutrons) such as cadmium or boron can be introduced into the reactor, decreasing the number of neutrons available to continue the chain reaction in the reactor's core, and so decreasing the reaction rate. A "scram" is a rapid shutdown of the nuclear reaction, usually accomplished by the insertion of poisoned control rods. Alternately, part of the fuel or moderator can be removed, with the same effect. In EBR-I, control was accomplished by removing fuel rods from the reactor, as necessary to maintain the desirable power level.

History of EBR-I

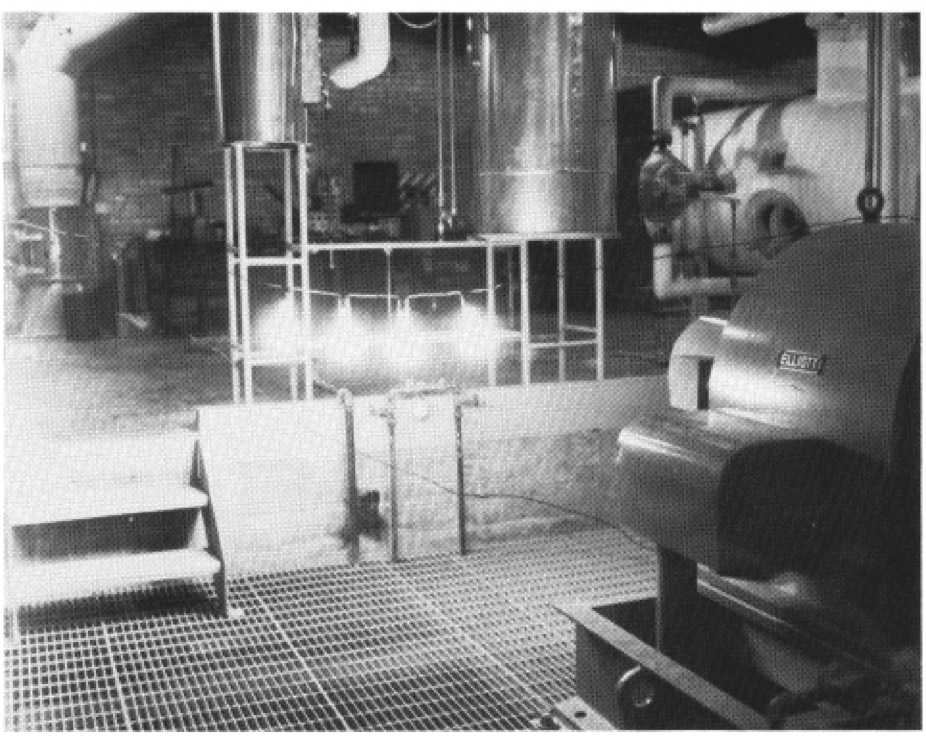
Prominent among those who envisioned fuel breeding as a promising concept were Enrico Fermi and Walter Zinn, the first director of Argonne National Laboratory. Late in 1944, Zinn, at the urging of Fermi, began planning a small-scale proof-test facility for proving the validity of the breeding principle and for evaluating the feasability of using a liquid metal as a coolant.

Their approach to the technology was simple: minimize the fraction of neutrons lost by parasitic capture to the coolant, moderator, and fuel; and maximize productive captures in massive uranium blankets. Although sophisticated neutron cross-section data were lacking at that time (circa 1943) enough information did exist to support the conclusion that parasitic neutron losses could be sharply reduced if the average neutron energy remained high. Such a requirement imposed a variety of constraints, among the most important of which was the complete absence of conventional coolant-moderator materials. Attention was accordingly drawn to liquid metal coolants, in particular to NaK (the sodium-potassium eutectic mixture). NaK had the obvious advantages of being a liquid at room temperature and having excellent heat transfer properties. Furthermore, NaK was considered nearly ideal from the viewpoint of neutron economy; it was both a poor moderating and a poor absorbing material. General plans for the facility which eventually became known as EBR-I were reasonably complete by late 1945.

The years 1945 to 1949 were spent in firming up matters of nuclear and engineering design. Many difficulties appeared. In addition to a paucity of fast neutron physics data, little if anything was known about liquid metal pumping, sodium and potassium corrosion, NaK-to-water heat exchangers, and the behavior of fuel, cladding, and structural materials under hostile radiation and temperature environments. Nevertheless, design parameters were fixed on the basis of the best information available.

Construction of foundations for EBR-I was begun in November of 1949, even before Bechtel Corporation had been selected as the construction contractor. The building was completed April 10, 1951, and the reactor assembly was started in May.

Criticality was achieved in August 1951 and full power operation at 1.1 MWt was reached on December 19, 1951. On December 20, 1951, Dr. Zinn began the first historic experiment in EBR-I. The reactor was started up and the power gradually increased over a period of several hours. At 1:50 p.m. the first electricity ever generated from nuclear energy



On December 20, 1951, electricity was produced from nuclear energy for the first time. These four light bulbs are seen here as they were illuminated on this historic occasion. The electrical power was produced by Argonne National Laboratory's Experimental Breeder Reactor-I.

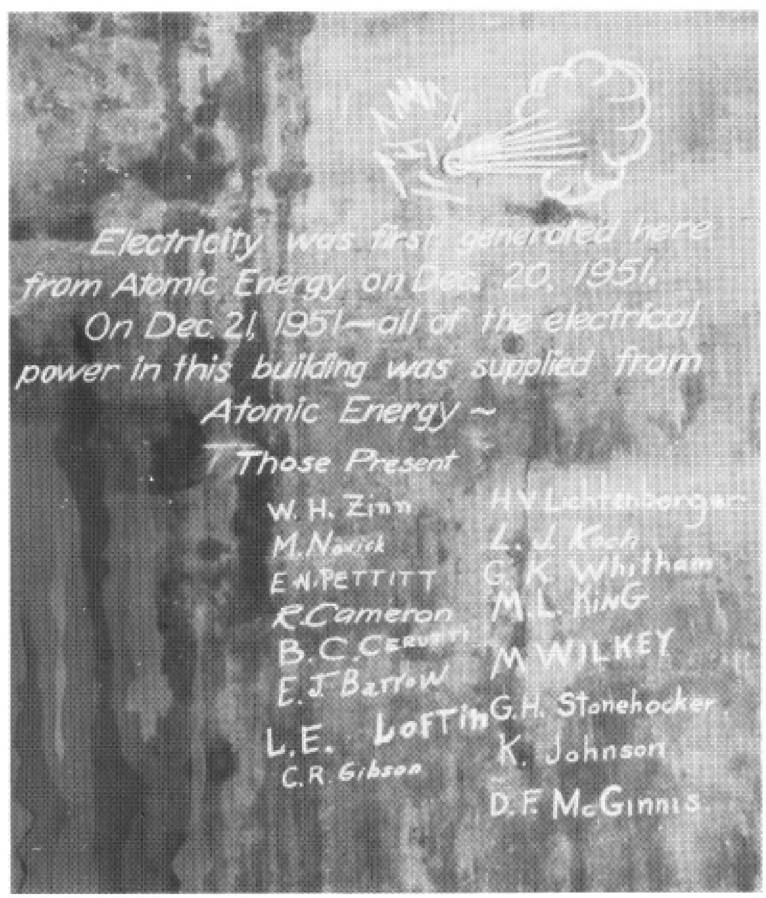
began flowing from the EBR-I turbine generator. Four light bulbs glowed brightly. The next day the experiment was repeated and sufficient electricity was generated to power the EBR-I facility.

But EBR-I's real mission was not to prove that electricity could be generated by a nuclear reactor. Instead, its chief task was to determine whether scientists theoretical calculations on fuel breeding could actually be accomplished: that more nuclear fuel could be created in a reactor than it consumed while operating. Less than a year after EBR-I generated its first electricity, Argonne scientists had the first indications that their reactor could indeed breed fuel. Then, early in 1953, a painstaking laboratory analysis showed that EBR-I was creating more than one new atom of nuclear fuel for each atom "burned." The hoped-for result was a reality.

With that kind of encouragement, it remained only to design cores that would increase the breeding ratio so that the mother reactor could not only sustain its own operation but also produce a little more to fuel its offspring. Three such improved cores were developed over the next ten years. The last of them — called Mark IV — produced 1.27 new atoms of fuel for each atom consumed. The promise of nuclear fuel breeding had become a significant fact for an energy hungry world.

EBR-I operation at full power produced about 1.2 megawatts (1.2 million watts) of heat. The critical mass on December 21, 1951, when the reactor was brought to full power, was fifty-two kilograms (114 pounds) of uranium-235 and was about the size of a football.

Following completion of the Mark-IV tests in 1963, EBR-I was shut down and decommissioned. In 1966, it was designated as a Registered National Historic Landmark by the U.S. Department of the Interior.



Argonne National Laboratory personnel present during the first generation of eletricity from nuclear energy, December 20, 1951, chalked their names on the wall of the generator room to commemorate the historic occasion.

Design of EBR-I

The reactor consisted of three principal regions: a core, a light inner blanket that surrounded the core axially and radially, and a denser cup-shaped outer blanket.

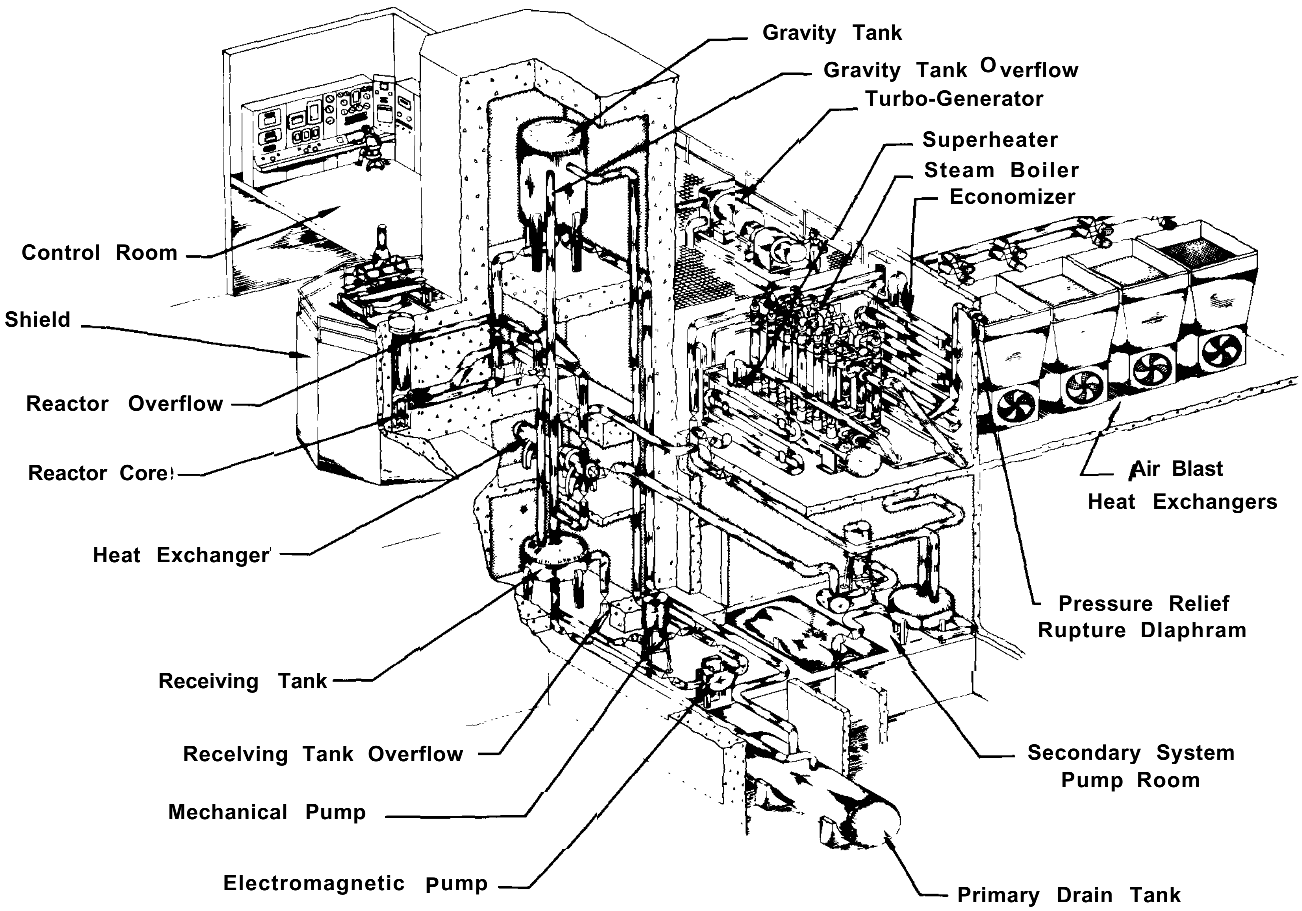
Inner blanket rods consisted of cylindrical rods of natural uranium; fuel rods were cylindrical rods of unalloyed, fully enriched, uranium metal. The outer reflector consisted of 84 one-hundred pound, keystone-shaped, steel-clad uranium bricks arranged in the form of a cup and mounted on a hydraulically driven pedestal. Separating the cup and the core was a double-walled tank system. Raising or lowering the cup provided coarse control of reactivity through the reflection of leakage neutrons, Under scram conditions the cup was dropped under gravity by releasing hydraulic pressure to the pedestal ram.

Twelve two-inch vertical holes in the cup accommodated stainless-steel-clad natural uranium rods. Eight of the twelve were positioned fully-in during operation. These were rigged to fall under spring-assisted action in the case of scram. The remaining four rods were used for fine reactivity control.

Heat generated in the cup and control/safety rods was removed by the forced circulation of air through a series of vertical holes in the reflector pieces. As it turned out, reflector cooling proved to be the factor that limited reactor power, nominally designed for 1.2 MWt. Surrounding the cup were a 19-in.-thick graphite reflector and a concrete shield approximately 9 ft. in thickness.

The core and inner blanket were cooled by NaK which flowed by gravity from an elevated supply tank, upwards through the reactor, through a primary-secondary heat exchanger, and into a receiving tank. A pump, operating at a slightly higher capacity than reactor coolant flow, returned the coolant to the gravity supply tank. An overflow system connected the gravity supply tank to the receiving tank. Such a feature was beneficial in two ways: by providing a constant delivery head, and by assuring 30 min. of gravity-delivered flow following shutdown.

Heat from the secondary side of the heat exchanger was removed in two ways: through the generation of superheated steam or through a fan-cooled NaK-air heat exchanger. Under nominal full power operating conditions, enough electrical power was generated (approximately 200 kWe) to satisfy the building demand.



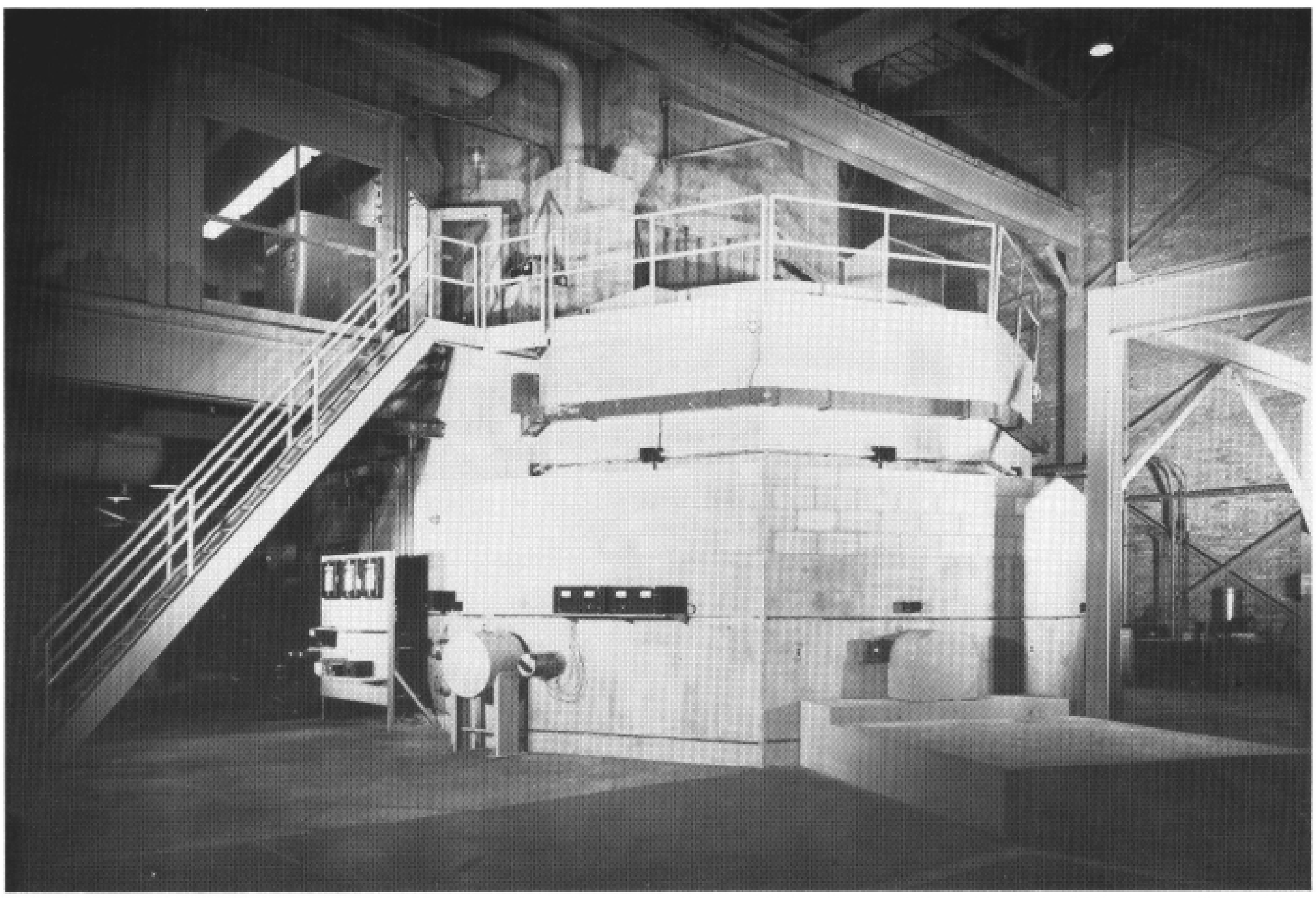
Reactor System — EBR-I

Operation of EBR—I

In the course of its useful life, EBR-I operated with four different fuel loadings. The first of these, Mark-I, was fueled with cylindrical slugs of fully enriched uranium metal contained in Type 347 stainless steel tubes. NaK in the annuli between the slugs and the tubes provided an excellent heat transfer medium. One of the principal features associated with the Mark-I loading was a gradual loss of reactivity (beyond that expected for fuel burnup). The loss was correctly attributed to axial fuel growth and after 3.5×10^6 kWt-hr of energy production, operations with this loading were terminated.

Valuable information was derived from the Mark-I loading. Measurements of the breeding ratio demonstrated conclusively the feasibility of breeding. Although a value of only 1.01 ± 0.05 was established it was clear that higher values could be achieved by reducing neutron leakage and by fueling the core with plutonium 239.

The operational control of the Mark-I loading also confirmed the theoretical prediction that neutronic behavior of both fast and thermal systems under certain conditions should be identical. Other important contributions appeared in the forms of realistic tests of fast reactor instrumentation, the production of "super-pure" plutonium in the outer blanket, and the demonstation that NaK, a liquid metal, posed no problems for pumping both centrifugally and electromagnetically.



Interior of the Experimental Breeder Reactor, showing lights on, indicating that the reactor is in operation, doing its dual job: "breeding" fissionable materials, and, in the process, creating heat that can be converted into electrical energy.

To study the effects of alloying on radiation resistance, a second loading, Mark-II, consisting of uranium -2% zirconium metallic alloy was installed in February 1954. As expected, the inclusion of zirconium significantly enhanced the radiation resistance of the fuel. Reactivity losses were found to be consistent with burnup considerations; no anomalies were encountered as with the Mark-I loading.

A peculiarity shared by the Mark-I and Mark-II loadings was a tendency for reactor power to oscillate whenever core temperature or coolant flow was varied rapidly. Although the origin of the instability was obscure, circumstantial evidence pointed to the complex coupling of two dominant feedback effects: one prompt and positive; and the other strongly delayed and negative. To investigate these matters, the final phase of the experimental program for Mark-II was devoted to an analysis of reactor performance under various conditions of power and flow. Upon completion of these experiments, operation of the reactor was to be terminated and the plant placed in standby status. A planned transient test with the main coolant flow stopped demonstrated the existence of a prompt positive power coefficient and led to an unintentional partial meltdown of the core.

As a consequence of the melt-down incident, considerable concern was expressed for the safe operation of future fast-breeder reactors. To prove there was nothing intrinsically unsafe in the operation of a fast reactor the damaged core was replaced with one (Mark-III) specifically designed and sufficiently versatile to study in detail feedbacks originating from fuel, coolant and structural expansions. As the result of a comprehensive experimental test program it was concluded that those features responsible for the instability noted in earlier loadings could be completely eliminated by rather elementary changes in mechanical design.

The fourth and final loading in EBR-I was fueled entirely with metallic plutonium, with a small (1.25 wt %) inclusion of aluminum. The use of plutonium introduced a variety of problems that required scrutiny prior to loading and operation. Although many problems were of a conventional nature, others were complicated by physical, chemical and neutronic properties peculiar to plutonium. The low melting point of the fuel, its tendency to deform under stress, and its toxcity, constituted sources of potential hazard not encountered in uranium 235 fueled systems.

Benefits derived from the operation of EBR-I with plutonium fuel included the following: the assurance that there is nothing inherently hazardous in the operation of a plutonium fueled system, and proof that the breeding ratio of a plutonium-fueled system can significantly exceed that of a system fueled with uranium 235. In a series of intensive experiments, a value of 1.27 ± 0.08 was measured.

EBR-I's Contribution to the Development of Nuclear Power

EBR-I was a pioneer facility in the full sense of the word. It brought dreams to reality and it turned theories into accomplishments. Not the least of these was the production of electricity from nuclear energy.

EBR-I's major contribution was its demonstration of the feasibility of breeding more fuel than the reactor consumed. Fast neutron power breeder reactors have potentially high neutron economy; i.e., for each atom of uranium-235 fuel that is split (fissioned) by one neutron, an average of 1.2 to 1.3 atoms of plutonium are created in the surrounding uranium-238 blanket. Plutonium can then be extracted and fabricated into fuel. In effect, uranium-238 is being converted to plutonium fuel. The long-term effect of a fast breeder cycle of this type is to extend a hundredfold or more our uranium resources, which in their natural state contain only 7/10 of one percent of the fissionable uranium-235.

In 1963, the reactor was operated with a core of plutonium, which emits more neutrons per fission than uranium, and measurements following this operation indicated a breeding ratio of 1.27 to one. This operation with a plutonium core also was a significant contribution to the nuclear power program; eventually breeder reactors would have to be operated as "true breeders" using plutonium fuel to produce more plutonium. Although the nuclear characteristics of plutonium differ from those of uranium, EBR-I operated smoothly and reliably with a plutonium core and thus gave reactor engineers further assurance that the fast breeder could be the "reactor of the future."

EBR-I was operated for more than half a million thermal kilowatt-hours with the plutonium core before the reactor was decommissioned at the end of 1963. Overall, EBR-I was operated at a power level of about one megawatt thermal from 1951 through 1963.

EBR-I also pioneered the use of a liquid metal coolant. Thermal reactors utilize water or heavy water as a coolant, but water moderates the neutrons, an effect desired in today's thermal reactors but undesirable in a breeder which depends on unmoderated, fast neutrons for operation. The alternative to water seemed to be a liquid-metal coolant, and liquid sodium or sodium potassium eutectic appeared to be ideal for the purpose.

Fortunately, EBR-I, using NaK, and its successor, EBR-II, using sodium, have demonstrated that operating with sodium presents no insuperable obstacles. Maintaining sodium purity and avoiding chemical and metallurgical reactions with reactor components has also proved to be practical. In short, operation of EBR-I and EBR-II has shown that there is no practical reason to forego the advantages of sodium as a coolant. These advantages include good heat transfer, low vapor pressure at high temperatures, low neutron absorption, and the absence of a moderating effect on the energy of the neutrons.

Thus, EBR-I was truly a significant energy milestone. It opened the way to a power reactor concept that could make available a source of energy more than 2,000 times greater than the world's supply of fossil fuels. Large breeder power plants could do much to help conserve precious oil, coal, and natural gas for other uses than simply burning them to produce electricity.

First plutonium produced in EBR-I, being shown to Dr. W. H. Zinn, Argonne National Laboratory (left), by Dr. Stephen Lawroski, Director of Argonne's Chemical Engineering Division.

Acknowledgements

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This brochure was compiled and edited by Dave Van Haaften and Sue Turner, with assistance from Ivonne Ingvarsson, Kirby Whitham, and Dick Blackledge.

National Historic Mechanical Engineering Landmark Program

In September 1971 the ASME Council reactivated the Society's History and Heritage program with the formation of a National History and Heritage Committee. The overall objective of the Committee is to promote a general awareness of our technological heritage among both engineers and the general public. A charge given the Committee is to gather data on all works and artifacts with a mechanical engineering connection which are historically significant to the profession — an ambitious goal, and one achieved largely through the volunteer efforts of the Section and Division History and Heritage Committees and interested ASME members.

Accordingly, two major programs are carried out by the Sections and Divisions under the direction of the National Committee: 1) a listing of industrial operations and related mechanical engineering artifacts in local Historic Engineering Records; and 2) a National Historic Mechanical Engineering Landmark program. The former is a record of detailed studies of sites in each local area; the latter is a demarcation of local sites which are of national significance — people or events which have contributed to the general development of civilization.

In addition, the Society cooperates with the Smithsonian Institution in a joint project which provides contributions of historical material to the National Museum of History and Technology in Washington, D.C. The Institution's permanent exhibition of mechanical engineering memorabilia is under the direction of a curator, who also serves as an ex-officio member of the ASME National History and Heritage Committee.

The Experimental Breeder Reactor I (EBR-I), Idaho Falls, Idaho, is the thirty-seventh landmark to be designated since the program began in 1973. The others are:

Ferries and Cliff House Cable Railway Power House, San Francisco, CA
Leavitt Pumping Engine, Chestnut Hill Pumping Station, Brookline, MA
A.B. Wood Low-Head High-Volume Screw Pump, New Orleans, LA
Portsmouth-Kittery Naval Shipbuilding Activity, Portsmouth, NH
102-inch Boyden Hydraulic Turbines, Cohoes, NY
5000 KW Vertical Curtis Steam Turbine-Generator, Schenectady, NY
Saugus Iron Works, Saugus, MA
Pioneer Oil Refinery, Newhall, CA
Chesapeake & Delaware Canal, Scoop Wheel and Engines, Chesapeake City, MD
U.S.S. Texas, Reciprocating Steam Engines, Houston, TX
Childs-Irving Hydro Plant, Irving, AZ
Hanford B-Nuclear Reactor, Hanford, WA
Manitou and Pike's Peak Cog Railway, Colorado Springs, CO
Edgar Steam-Electric Station, Weymouth, MA
Mt. Washington Cog Railway, Mt. Washington, NH
Folsom Power House #1, Folsom, CA
Crawler Transporters of Launch Complex 39, J.F.K. Space Center, FL
Fairmount Water Works, Philadelphia, PA
U.S.S. Olympia, Vertical Reciprocating Steam Engines, Philadelphia, PA
5 Ton "Pit-Cast" Jib Crane, Birmingham, AL
State Line Generating Unit #1, Hammond, IN
Pratt Institute Power Generating Plant, Brooklyn, NY
Monongahela Incline, Pittsburgh, PA
Duquesne Incline, Pittsburgh, PA
Great Falls Raceway and Power System, Patterson, NJ
Vulcan Street Power Plant, Appleton, WI
Wilkinson Mill, Pawtucket, RI
New York City Subway System, New York, NY
Baltimore & Ohio Railroad, Baltimore, MD
Ringwood Manor Iron Complex, Ringwood, NJ
Joshua Hendy Iron Works, Sunnyvale, CA
Hacienda La Esperanza Sugar Mill Steam Engine, Manati, PR
RL-10 Liquid-Hydrogen Rocket Engine, West Palm Beach, FL
A.O. Smith Automated Chassis Frame Factory, Milwaukee, WI
Reaction-Type Hydraulic Turbine, Morris Canal, Stewartsville, NJ

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