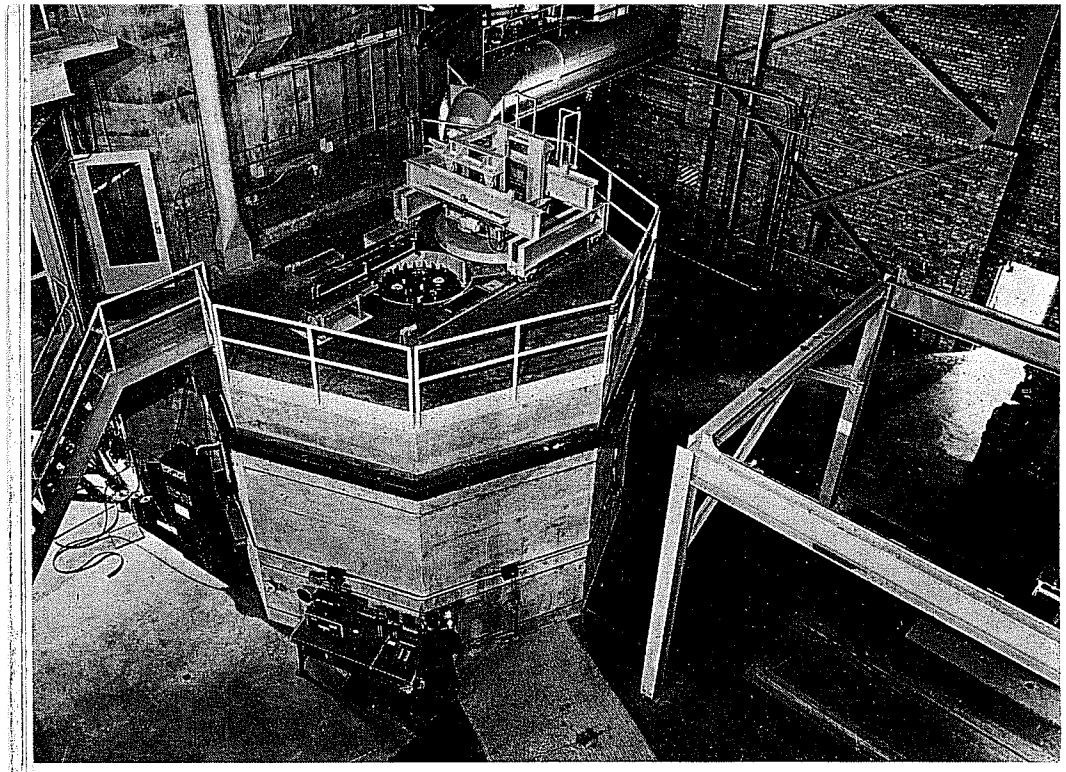
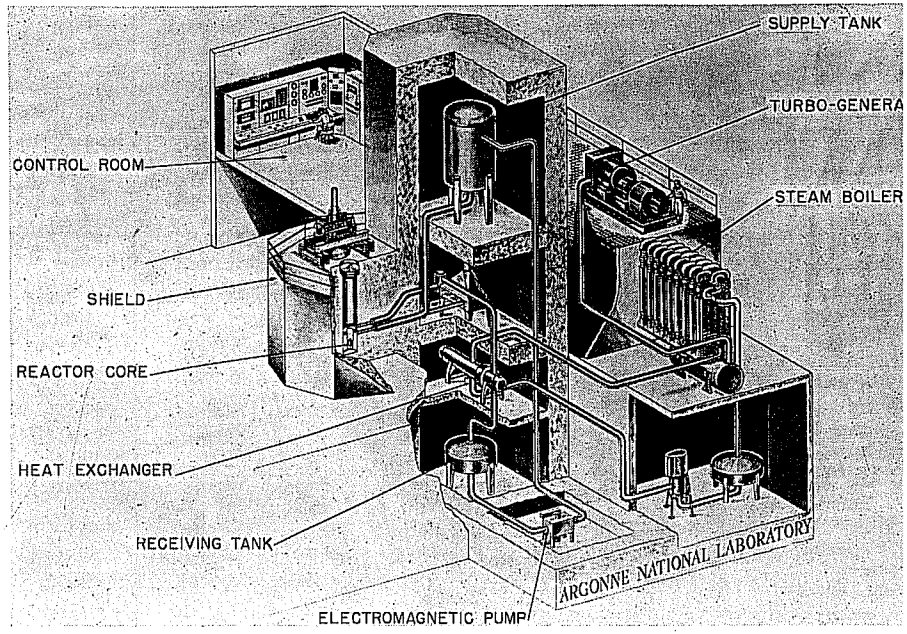
EBR-I

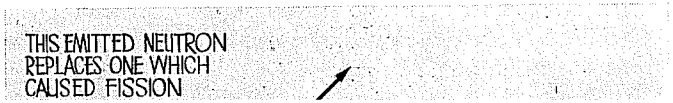


View vertically downward of the EBR-I, showing shield of the reactor and top of the reactor tank.



Cross-section conception of the EBR-I complex.

Diagrammatic illustration of the nuclear process which takes place in a breeder reactor.



Control Room of the EBR-I.

EBR-1: Its Development and Construction

by Leonard J. Koch, Reactor Engineering Division

A significant aspect of the EBR-I development relates to the state of technological development at the time. Little was known about fast reactors or liquid metal coolants and the capability for developing a broad-based technology did not exist. It was not possible to undertake a full fledged investigative program or to determine in detail the data required for such an advanced reactor concept. It was necessary to exercise judgment (and intuition) in almost every area and to proceed with faith in those judgments. EBR-I was perhaps the most "under-developed" reactor ever constructed in peace time. Its successful operation must be considered a tribute to the application of judgment and intuition when facts and knowledge were absent.

Walter H. Zinn fathered the concept and nurtured it to maturity. He set the pattern for applying basic reasoning when the facts were not available. By example rather than edict, he stimulated curiosity, caution, and the exercise of judgment.

Although there was a strong belief that fast reactors would breed, there was little experimental evidence to prove this. EBR-I was to be a "proof of principle" experiment to investigate this phenomenon. Data from critical experiments and other nuclear assemblies did not exist. It was necessary to design the reactor on the basis of very fragmentary information.

The technology of alkali-metal coolants with respect to their use as heat transfer fluids was essentially nonexistent. It was known, however, that they were highly corrosive and very reactive with water and air. Also, if the energy produced in the reactor was to be used for breeding and the generation of useful power, more had to be learned about the high temperature-heat transfer properties of these materials.

Subsequent investigation revealed that the sodium-potassium alloy (NaK) selected as the coolant was an extremely poor lubricant and considerable ingenuity would be required in the development of moving machinery to operate in the coolant. In many cases, problems that could not be solved were by-passed. The "lubrication" problem was by-passed by eliminating bearings in the rotating mechanisms, such as pumps, and the moving parts of the reactor control system were arranged external to the reactor vessel and thus out of the reactor coolant system.

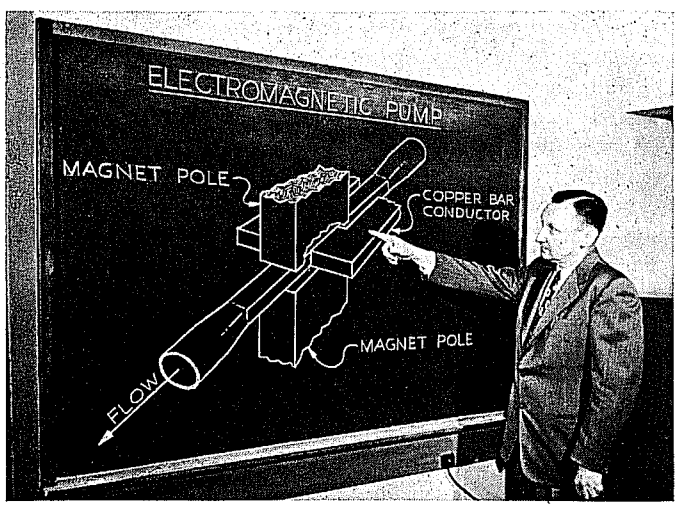
It also was necessary to terminate investigations when the first satisfactory solution was found even though it was quite probable that a better solution could be found with more time and effort.

A minimum study of corrosion and materials was made, and Type 347 stainless steel (columbium stabilized 18-8 alloy) was found to be satisfactory. On the basis of the experimental evidence and known behavior of this alloy, the most favorable composition within the normal specifications for this material were established. A major task was then undertaken for the fabrication of all of the reactor critical components from this exact alloy. This was accomplished by having a single blast furnace loading (known as a "heat") of special 347 alloy produced to our specifications. This single heat of steel was then fabricated into plate, tubes, sheet, etc., for subsequent fabrication into the variety of parts comprising the reactor vessel and all of its internals. This involved the manufacture of forgings, plate, sheet, tube rounds, tubing, etc. Many fabricators were involved, resulting in a difficult scheduling and coordinating job.

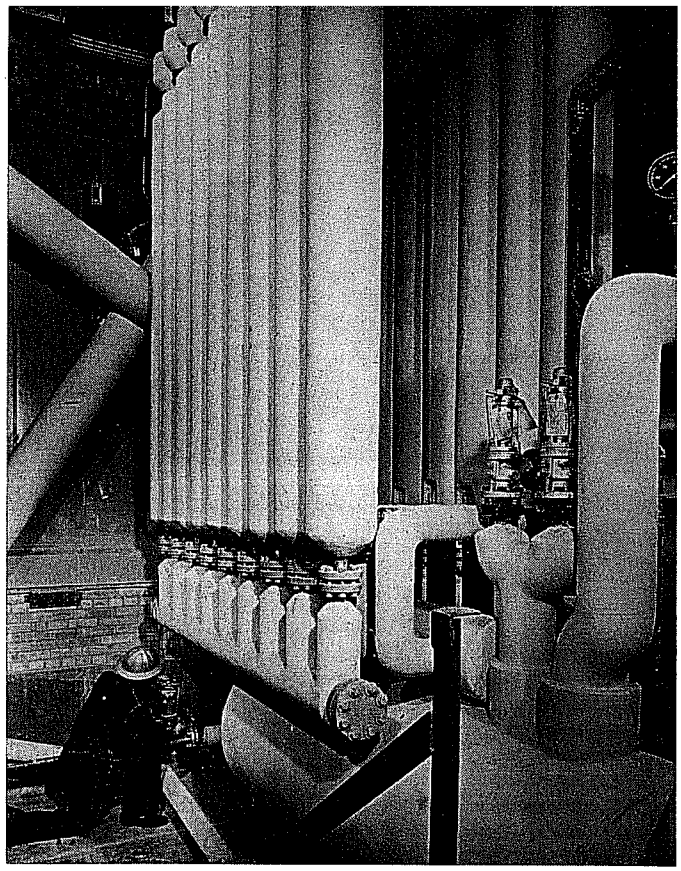
Many special developments were required—far too many to describe; however, some can be selected as typical of the variety of efforts involved.

The problem of pumping liquid NaK was a formidable one. Very little experience was available from which to draw; however, every possible avenue was exploited, including the methods used for pumping molten magnesium in foundries. It was decided that mechanical pumping and electromagnetic pumping be explored simultaneously. Because of its high electrical conductivity, it was possible to impart the pumping force directly on the fluid in an electromagnetic type of pump.

Much effort was involved in the development of pump theory and fabrication of practical units. The major difficulty confronting the use of mechanical pumps related to the "bearing problem." Although significant effort was given to the development of bearings which would function in sodium, the problem was finally circumvented by the development of



The late Arthur H. Barnes, Director of the Reactor Engineering Division at the time of his death, points to a schematic darwing of the electromagnetic pump which he, G. Kirby Whitham, now of the Idaho Division, and Fred A. Smith, now of the COO-AEC, developed for the EBR-I. A sealed, all-metal system with no moving parts, it was developed to pump the coolant (NaK) through the fast breeder reactor.



Steam generator developed at Argonne for use with EBR-I. In addition to assuring high steam generating efficiency, the generator contains unique design features which prevent mixing of the reactor's alkali metal coolant and water or steam which, in contact, react violently. Steam from this generator is conducted to a superheater from which it emerges at a temperature of 550 degrees Fahrenheit and at a pressure of 400 pounds per square inch.

"over-hung pumps" which contained no bearings in the sodium.

Both pump developments were successful, and as a result the EBR-I primary system contains one mechanical pump and one electromagnetic pump operating in parallel. Both are full capacity units, and normally the electromagnetic pump is operated and the mechanical pump is maintained as a stand-by. Both have functioned remarkably well and have provided essentially trouble-free service over the life of the plant.

The development of the steam generator for the EBR-I system posed another major problem. Violent reaction between NaK and water was of course well known, and it was therefore imperative that a heat exchanger be developed which would insure the absolute separation of these two fluids. This was accomplished by the development of a "triple-tube" unit consisting of a nickel-copper-nickel concentric triplex tube. A triple failure, i.e., of both nickel tubes and the copper tube, was necessary for sodium and water to come in contact. Grooves were machined in the copper tube to permit testing of the annulus and the determination of a leak of either water or sodium. These units have operated perfectly and no failure has occurred.

Of course, one of the major areas of development involved the fuel elements for the reactor. This included the fuel itself, the structural material, and the over-all assembly. At that time, unalloyed beta-treated uranium appeared to be the most suitable fuel for this application. Methods of fabrication of the cylinders of fuel were developed as well as the complex structure for permitting the close-packed assembly necessary in the reactor. Methods of forming "ribbed tubing" were necessary as well as extremely reliable weldments and locking devices, etc.

Perhaps the most interesting and difficult problems arose with respect to the problem of transferring heat from the fuel through the cladding and to the flowing coolant. The required thermal performance could be achieved only if good heat transfer could be accomplished between the fuel and the fuel tube. This could not be done metallurgically because uranium and stainless steel are incompatible and form a very poor alloy. It was decided to accomplish the heat transfer by means of a "liquid-metal bond" by filling the gap between the fuel and the tube with liquid NaK. It was determined that liquid NaK would "wet" both of these materials and would transfer the heat with very little temperature drop. A major development was then undertaken to establish the techniques for filling the tubes and insuring that they were completely filled (without bubbles or voids, etc.). It was also necessary to insure that they were filled to the proper level. Although the procedures were quite complex, they consisted of filling the tubes, containing the uranium cylinders, with NaK from a hydraulic cylinder. To insure filling to the proper level, each tube was over-filled, and then the excess removed with a special syringe. To insure that there were no voids in the annulus, the tubes were filled with radioactive NaK irradiated in CP-3. After filling, each tube was placed in a casette with X-ray film, producing a radiograph from the gamma rays emitted by the NaK itself. This would, of course, indicate any voids by virtue of under-exposure in that location. Needless to say, a large effort went into developing the technique, the resolution of the data, and the conduct of the entire operation behind shielding to protect the operators from the radioactivity.

There was considerable concern about the loss of the liquid metal bond inside of the fuel tubes, which would result in overheating of the fuel. This could occur if the fuel tubes were to leak at the bottom and the bond run out of the tube or be forced out by internal pressure. As a result, it was particularly important that pressure not build up inside of the fuel tube which could force the liquid bond out if a leak were to occur. The tubes were sealed at one-half atmosphere absolute pressure after filling. The pressure increase due to temperature in the reactor would raise this to almost atmospheric pressure. A large gas volume was provided inside of each fuel element by utilizing its long "handle," thus providing space for fission gases which might be released from the fuel during irradiation.

It was unknown to what extent pressure would increase in the fuel elements, and because this was a critical matter very ingenious pressure gauges were developed and installed in the upper end of each fuel element handle. This was extremely difficult because space limitations permitted only about ⅜-inch diameter for the pressure gauge. A gauge was finally developed which consisted of a small bellows actuated by pressure difference which in turn moved a small anvil adjacent to an electromagnet. The movement of the anvil could be measured electrically, and a system was developed whereby each of the pressure gauges was scanned continuously and the pressure recorded. It was impossible to build identical small gauges, therefore it was necessary to individually calibrate

each unit and retain the calibration. In a sense, each fuel element was made into an experimental unit.

It is interesting to note that liquid metal bonding of fuel elements has been employed since in many reactors and is a most acceptable method of providing the needed heat transfer where the fuel and the jacket cannot be metallurgically joined.

There were, of course, many other necessary developments. A large number can be related to the intricate geometries and close tolerances resulting from the necessity for close packing of the fuel elements within the reactor. Since it was necessary that the fuel be well supported, the internal structure of the reactor represented a challenging design and fabrication problem.

Another complex area relates to the reactor control system and the external reflector of the reactor. The control rods were located in the cup-shaped reflector surrounding the reactor vessel, all mounted on a hydraulically operated elevator located immediately below the reactor. It was necessary that the cup be removable so that pie-shaped bricks, from which the reflector was fabricated, could be removed and stacked. This required accurate movement of the five-ton cup assembly to an adjacent hot lab where remotely operated machinery for "brick stacking" and other manipulations could be performed.

A third general area of development involved the various components required in the NaK circulation systems, including instrumentation, valves, etc. All of these required basic development since circulation of NaK as a heat transfer fluid was essentially unknown.

EBR-I was a "first" in the true context of a developmental project in new and uncharted areas. It was accomplished in a somewhat different administrative manner from that employed by the Laboratory for subsequent reactors. EBR-I was not the province or responsibility of a single division of the Laboratory. Although many participated in its development, the basic responsibility for the development and construction (and later its operation) was assigned to a small project group reporting directly to Walter Zinn, the Laboratory Director. Because of his personal interest, Mr. Zinn certainly was the unofficial Manager or Coordinator of the entire operation. Needless to say, his ability to exert "influence" within the entire Laboratory family was extremely helpful and contributed to the success of this undertaking.

Harold Lichtenberger, the Project Engineer, led the Project Group and assumed personal responsibility for the basic overall facilities design. He also assumed primary responsibility for directing the efforts of the Architect-Engineer (The Austin Company). The close proximity of all concerned assisted immensely in achieving the communication and getting the job accomplished. The Project Group and the Architect-Engineer forces both were housed in Building 12 at the DuPage site during the early and critical design phases.

Other members of the Project Group and their primary responsibilities included:

Leonard Koch (Associate Project Engineer), Bernard Cerutti, and Elmo Stone: Reactor Components.

Meyer Novick (Senior Engineer), Darrel McGinnis: Heat Transfer, Flow Systems, etc.

Newman Pettitt: Physics, Shielding and Instrumentation.

Reid Cameron: Fuel Element Bonding

This group transferred to Idaho and assumed responsibility for placing the plant into operation. Other groups not directly within the project, but very closely associated and interrelated, included:

Twelve who were in Idaho ten years ago when Argonne generated the first electricity from nuclear power pose in front of the historic sign chalked on wall over the turbine at the EBR-I. Of the twelve, only Leonard J. Koch of the Reactor Engineering is not a member of the Idaho Division. Front row, l to r, are Mrs. Wilma S. Mangum, Charles R. Gibson, Orin E. Marcum, G. Kirby Whitham, Meyer Novick, Milton Wilkey, Frank D. McGinnis, Mr. Koch, and Weslie E. Molen. Back row: Bernard C. Cerutti, Lester E. Loftin, and Earl J. Barrow.

Arthur Barnes, Kirby Whitham, and Fred Smith: Electromagnetic Pumps and Special Sodium Instrumentation. (Kirby Whitham also transferred to Idaho with the Project Group.)

Robert A. Noland, Arthur B. Shuck, and David E. Walker: Fuel Elements, Blanket, Metallurgical Control, and the development of fabrication techniques.

Many other groups, of course, participated and assisted in providing the "back-up" required. Because of the large amount of design performed by the Laboratory staff, a small segment of the Drafting Group which eventually became the Reactor Engineering Division Drafting Section must be included; particularly Ernest Hutter, who worked on many of the more difficult design problems and served in a sense as Mr. Zinn's personal designer; Leonard Bogorad, who scheduled the work through the drafting group and kept many items from falling into "cracks"; and Jim Shimkus, who served as the checker for most of the Argonne generated design drawings.

Similarly, much of the equipment was assembled and tested at the Laboratory. A small group of technicians was deeply involved and Otto Hillig, Clarence Edburg, Vincent Shoemaker, and Joseph Reid, along with many others, should be remembered.

The EBR-I must be recognized as a tribute to bold imagination, cooperation, and the willingness to undertake calculated risks in the absence of complete technological data. Its success is evidence of the rewards which can be obtained by employing these judiciously.