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THE SODIUM-COOLED, D₂O-MODERATED REACTOR (SDR)

A Status Report
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INTRODUCTION

This is the first status report on NDA's Sodium-Cooled, D₂O-Moderated Reactor, (SDR) Project. It is the objective of this project to install a 10 MW_e SDR power plant in the Chugach Electric Association's (CEA) system in Anchorage, Alaska by 1963. CEA is to provide the steam-electric generating portion of the plant and is to operate the plant. The Atomic Energy Commission, after having supported the design, development and construction, is to own the nuclear portion of the plant.

NDA's effort on this project has been divided into three phases:

I. Preliminary Design and Feasibility Tests, II. Final Design and Development, and III. Construction and Startup. Phase I began in January 1957 and is to end in June 1958. We are, therefore, approximately 3/4 of the way through Phase I, and we shall report to you today the results which we have achieved thus far during this period.

REACTOR DESIGN CONCEPTS

The basic features of a sodium-cooled, D_2O -moderated reactor are:

1. The moderator is D_2O at low temperature (approximately 150F) and low pressure (approximately atmospheric).
2. The reactor coolant is sodium with high exit temperature ($> 900F$) and low pressure (approximately atmospheric).
3. The fuel is natural or slightly enriched uranium.

One can conceive of a large number of different reactor designs which incorporate these basic features. Of these, we have explored several fuel arrangements such as regular lattices in a cylindrical D_2O tank, annular arrays and rectangular slab designs. We have likewise considered a variety of possible fuel-coolant tube and header configurations such as top- and bottom-connected bayonets, U-tubes and through tubes whose longitudinal axes are oriented vertically, horizontally or in slanted directions. From these concepts we have selected one for more detailed studies. This one may be described as follows (see Fig. 1).

The D_2O moderator is contained in a calandria, consisting of an upright cylindrical aluminum tank, penetrated by vertical aluminum tubes which are fastened to the tank top and bottom. The calandria is approximately 8.4 ft high and 10 ft in diameter. There are 120 aluminum tubes, 4 in. in diameter on 8 in. centers.

A steel fuel-coolant tube containing a cluster of steel-clad fuel elements passes through each aluminum tube. The sodium primary coolant flows upward through the fuel-coolant tubes. Sodium enters and leaves each coolant tube through individual tubes, or "pigtaills," which provide flexibility to accommodate thermal expansions. The pigtaills are collected into vertical manifolds which are connected to horizontal header pipes.

There is a gas-filled annular space between each fuel-coolant tube and its surrounding calandria tube. One or more concentric barrier tubes may be inserted into this space to provide additional mechanical walls for the separation of sodium and D_2O .

Neutron shields are located between the reactor and the header rooms to reduce the induced radioactivity in these compartments to a level which will permit access for repairs after a suitable "cool-off" period. The upper header room is covered with a gamma shield which contains plugs located above each fuel-coolant tube. It is expected that refueling will be a relatively simple operation, requiring the removal of these shield plugs and a sealing cap from the top of each fuel tube before extracting a used, radioactive fuel cluster into a shielded unloading cask.

Control rods extend into unfueled lattice positions in the calandria and operate near the low D_2O temperatures. Drive mechanisms for the rods are mounted on the top shield. Additional reactivity control may be obtained by the use of D_2O level regulation.

Some SDR characteristics are given in Fig. 2.

The process systems external to the reactor are similar to those of other plants such as the sodium systems for SRE, EBR, and SIR and the D_2O systems for NRX, NRU and the Savannah River production plants.

Our principal effort in Phase I is directed towards demonstrating the feasibility of separation of sodium and D_2O in this reactor, and of containment of the resultant reaction in the unlikely event that contact does occur. Separation can be accomplished in a number of ways. For instance, the external sodium process systems can be located on one side of the reactor while the external D_2O process systems are located on the other side. Thus, if there are any failures in these systems, there is no opportunity for the spilled sodium and D_2O to come into contact with each other. In the reactor core region, in which the two fluids must be brought into close proximity, separation of the two fluids is maintained by a series of barriers. These barriers consist of the container walls themselves (the aluminum calandria for the D_2O and the steel fuel-coolant tubes for the sodium), as well as of barrier tubes, catch pans and shields which are interposed between them. Since both fluids are at low pressure, they do not tend to burst their containers. If the barriers fail for other reasons, there are no large pressure differentials that would tend to force the two fluids into intimate contact with each other. Gas spaces within the calandria and at the top of each fuel-coolant tube provide surge volumes to cushion accidental pressure pulses.

The spaces between the barriers are filled with an inert gas. This gas also occupies the reactor and header rooms. The gas may be used for sodium preheating or for reactor afterheat removal. However, the principal purpose of this gas is to exclude oxygen from all areas in which a potential sodium- D_2O reaction hazard exists. The reason for the rigorous exclusion of oxygen may be discerned from the equations which govern the sodium- D_2O reaction. They are given in Fig. 3 (with H_2O substituted for D_2O).

The sodium-water reaction produces a half-mole of hydrogen, which in turn can react with oxygen, if it is available. The hydrogen-oxygen reaction releases an additional amount of heat and its rate is explosive in nature. Sodium can also react directly with oxygen and release 4,100 Btu/lb of sodium. These reactions are frequently demonstrated with spectacular results. We repeated these experiments to note the effects of excluding oxygen. We took some movies, which we would like to show you next:

[START FILM. In the first series of reactions you will see about a half-gram piece of sodium being dropped into water at about 120F. The flask is filled with air, so that oxygen is available for the additional reactions discussed previously. The sodium oxidizes rapidly, liberating hydrogen and heat, and eventually reaches the ignition temperature and begins to burn. The hydrogen concentration continues to build up until it reaches an explosive level, and a rapid gas phase explosion occurs.

The next series shows a similar phenomenon — the sodium oxidizes — gets hot enough to burn — the hydrogen generated explodes with the oxygen, and bits and pieces of flaming sodium are shot out of the flask.

In the next series argon is flowing through the flask, displacing the air above the water surface. The other conditions are the same — a half-gram of sodium and water at 120F. The sodium still reacts quite vigorously and liberates the hydrogen, but there is no burning of the sodium with the oxygen in the air, and there is no hydrogen-oxygen explosion.

In the next series, we got a little brave and moved in for a close-up, and you can see the glob of molten sodium reacting quietly on the surface of the water. END OF FILM.]

TESTS

Our experimental program has been focused on the problems of containing the sodium, of providing a barrier material with a low neutron absorption cross section and an ability to withstand the action of hot sodium, of developing an arrangement of this material which is mechanically adequate, and of demonstrating that an integrated barrier system can be safely operated under reactor temperature and pressure conditions.

The first experimental program is concerned with the sodium containment problem and consists mainly of producing satisfactory joints between the fuel-coolant tubes, pigtails, and associated headers. Since studies indicate that these joints are not subjected to damaging thermal shocks during reactor scrams and other severe conditions, the problem of developing a dependable sodium system resolves itself to that of subjecting typical joints to cyclic loading, at temperature, to demonstrate their ability to absorb the thermal motions experienced in the course of reactor operation. Typical joints are shown in Fig. 4, while the apparatus is shown in Fig. 5. A shaper mechanism moves the end of the pigtail in cyclic fashion. A dial gage and load cell permit obtaining information concerning the loads and deflections experienced by the test specimen. This apparatus has been testing specimens since early February.

The second experimental program concerns itself with the search for a satisfactory barrier material. Here the principal requirements are for low neutron absorption per unit resistance to hot sodium jets, reasonably good strength properties at barrier operating temperatures, and favorable fabricating properties and material costs. Since the resistance to sodium jets is the only property which is not established for most materials, an apparatus was designed which would permit subjecting 2 in. $\times$ 2 in. tabs of various materials to a 1/8 in. diameter jet of high temperature sodium for considerable periods of time. Fig. 6 shows the apparatus, which employs an electromagnetic pump, flow meter, and heater to supply hot sodium to the test chamber jet. Sodium is

directed normal to the test specimen at velocities up to 50 fps (which corresponds to the maximum expected head in the reactor).

A number of materials were screened by exposing them to the jet at 950F for a period of 15 minutes. More promising materials were then exposed at higher temperatures and for longer times. As was to be expected, stainless steels and zirconium withstood the jet very well. Graphites having vulnerable binders cracked or pulverized, depending on the amount of binder. AGOT graphite was practically undamaged, although some swelling did occur. What was not expected was that aluminum in several forms would show useful resistance. Type 1100 aluminum sheet 0.010 in. thick showed slight distortion after 15 minutes exposure at 950F. After 16 hours at 950F, 0.060 in. thick aluminum showed no attack. At higher temperatures this aluminum, having a melting point of approximately 1200F, eroded 0.060 in. in approximately 2.5 hours at 1100F, while a specimen exposed for 15 minutes at 1140F shows no visible attack. Fig. 7 shows these latter specimens. The upper specimen was actually exposed at 1100F for 3 1/2 hours. The lower specimen was exposed at 1140F for 15 minutes. In the photomicrograph, Fig. 8, it is apparent that the result observed is a product of uniform dissolution or erosion, rather than intergranular penetration.

The discovery that aluminum has such good resistance to sodium at these temperatures is of considerable importance to the program. Since it is necessary for the barrier to withstand sodium only long enough to permit detection of the leak and decreasing of the sodium temperature, it is possible to use aluminum at temperatures considerably above the normal SDR operating temperature. Since the objective of this program had been accomplished testing was terminated in November.

A third program concerns itself with the study of the performance of barriers as a function of the mechanical arrangement of the material in the annular space between the fuel-coolant tube and the calandria tube. Various barrier configurations are mounted in an apparatus capable of directing jets of sodium, and/or water, at the proper sides of the barrier. Fig. 9 shows a cross sectional view of a test section designed to subject a typical barrier to simultaneous jets of sodium and water. The water-filled annular tank simulates the calandria. Incorporated in it is a nozzle which permits directing a 1/8 in. diameter water jet radially inward at the barrier. The double sleeve is a barrier which has been designed to provide a large thermal resistance between the inner wall (which could experience high temperature sodium heating), and the outer wall (which could be cooled by the water). A high thermal resistance of the barrier in the reactor is desirable to minimize heat energy losses from the sodium to the D₂O. The thermal resistance also prevents severe distortion and possible

mechanical damage to the barrier under conditions of simultaneous leakage of both fluids. The small-diameter cylinder is a sodium-filled container into which is built a nozzle and feed line which are used to direct a sodium jet radially outward against the barrier. The apparatus is operated at reactor maximum temperature conditions or higher. Other test sections permit directing sodium jets at the calandria tube and water jets at the sodium tube in the absence of a barrier. Shakedown of the apparatus has been completed and initial tests have been run.

The fourth experimental demonstration of the feasibility of the reactor concept consists of assembling and operating a system having all of the characteristic features of the sodium-barrier-water systems. Toward this end, a full-scale mockup of three coolant channels in the core of an SDR (supplied with flowing sodium and water, barriers, inter-barrier gas, leak detection devices, drip pans, etc.) has been designed and constructed. Fig. 10 shows a cross sectional view of the test section (only one coolant channel shown). Simulation of the core details of the SDR is quite faithful. Header spaces above and below the core provide at least equal opportunity for sodium leakage into the core region. Operating temperatures and pressures will be equivalent to those of the reactor. Sodium flow is used to supply heat losses to the test section, rather than to remove fission heat, with the result that only a low flow rate is required. The apparatus is instrumented to permit remote operation of the test section at a variety of simulated reactor transient and steady state conditions. Construction of this apparatus has been completed and shakedown operations are under way.

NEG. NO. 898

Fig. 1 — Reactor elevation

REACTOR POWER	40 MW
NET ELECTRIC POWER	10 MW
FUEL LOADING	7.7 TONS
FUEL ENRICHMENT	2% OR LESS
CALANDRIA HEIGHT	8.4 Ft
CALANDRIA DIAMETER	10.0 Ft
SODIUM INLET TEMPERATURE	750 F
SODIUM OUTLET TEMPERATURE	950 F
AVERAGE D ₂ O TEMPERATURE	150 F

Fig. 2 — SDR data

Fig. 3 — Sodium reactions

Fig. 4 — Pigtail-to-fuel coolant tube joints

Fig. 5 — Joint test apparatus

Fig. 6 — Single failure test apparatus

NEG. NO. 577

BEFORE

NEG. No. 903A

AFTER

NEG. No. 903E-1

1100°F, 3 hr 35 min

1100-0 aluminum specimens exposed
to 50 fps Na jet, argon atmosphere.

Specimen size $2'' \times 2'' \times \frac{1}{16}''$

NEG. No. 903H

1140°F, 15 min

Fig. 7 — Aluminum specimen before and after exposure to sodium jets

NEG. No. 903E-1

Exposed surface

1100-0 Aluminum

**Exposed to Na jet 50 fps;
1100°F; 3 hr 35 min;
argon atmosphere**

Cross section of pit, $\times 100$

NEG. No. 903E-4

Fig. 8 — Photomicrograph of aluminum specimen after exposure to sodium jet

NEG. NO. 906

Fig. 9 — Multiple failure test section

NEG. NO. 902

Fig. 10 — Mockup test section