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**A PROPOSED PROGRAM FOR THE DESIGN AND
DEMONSTRATION OF A PROTOTYPE UNDER-SODIUM
ULTRASONIC SCANNER**

**U. S. Atomic Energy Commission
Contract No. AT(11-1)-865
Project Agreement No. 14**

J. Matte, III

FEBRUARY 1968

**ATOMIC POWER
DEVELOPMENT ASSOCIATES, INC.**

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ABSTRACT

The applicability to large sodium-cooled reactors of the under-sodium ultrasonic transducer is shown to depend on the development of mechanisms suitable for accurate and versatile manipulation of the transducer within the reactor. A program of prototype design and testing is proposed to demonstrate the feasibility and desirability of such a device for eight typical applications to such reactors. The functional requirements of a prototype scanner and of a suitable demonstration test rig are presented, together with brief descriptions of initial concepts of the prototype and the test rig. Finally, the proposed program of demonstration tests is outlined, together with the basis for evaluating the prototype performance in each application.

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I. PREFACE

A. SCOPE

A program of design, procurement, and testing is proposed to demonstrate the feasibility and desirability of applying the under-sodium ultrasonic scanner to large sodium-cooled reactors for a variety of useful purposes. The program would be based on the ultrasonic transducers that have been developed and tested for the AEC by APDA and on the current state-of-the-art of under-sodium mechanism design. The principal tasks that would constitute the demonstration are the following:

- The preparation of conceptual systems' descriptions of a reactor-scale prototype of an under-sodium ultrasonic scanner and of a suitable test rig for demonstrating the scanner.
- The preparation of complete drawings and specifications for the fabrication, assembly, erection, and maintenance of the scanner prototype and the test rig.
- The preparation of detailed specifications for demonstration tests of selected typical reactor applications of the under-sodium scanner.
- The procurement and erection of the test rig in a suitable enclosure adjacent to an existing sodium loop facility that would service the demonstration test rig.
- The procurement and installation of the scanner prototype and its related equipment.
- The performance of suitable acceptance and preoperational tests of the test rig and the scanner prototype.
- The performance of demonstration tests of selected applications.
- The evaluation of the results and the significance of the demonstration tests.
- The preparation of a topical report on the demonstration and its findings, with recommendations for future applications and further development.

B. RELATIONSHIP TO OTHER PROJECTS

An instrument that would permit objects in liquid sodium to be discerned by sound waves is potentially applicable to all reactor systems that use sodium as the primary coolant. In a general sense, such an instrument is visualized as a tool to simplify maintenance and fuel handling in an opaque liquid metal. The search for more specific identification of the instrument's value to existing and future reactors of this type is part of the present work scope.

II. INTRODUCTION

As a result of extensive developmental and testing work performed to date by APDA, the feasibility, capabilities, and limitations of devices for under-sodium scanning by means of ultrasonic transducers have been demonstrated. (See Reference 1 for a summary of this work through December 1966.) Briefly, feasibility tests have demonstrated that the attenuation of sound at useful frequencies is not unacceptably high. Materials evaluation tests have demonstrated the compatibility of the transducer components with the sodium environment up to 600 F, the suitability of zirconium in sodium as an acoustic lens for focusing a sound beam, and the suitability of lead zirconate-titanate as the piezoelectric material. Finally, demonstration tests have shown the feasibility of in-sodium scanning using both A-scan and C-scan modes of operation and have yielded various performance measurements for the evaluation of a number of potential applications for the device.

The developmental work to date has defined several important parameters and requirements for the under-sodium transducer as a device ready for demonstration of potential applications. The most practical configuration for multipurpose application is the combined transmitter-receiver, rather than separate units on either side of the target object. The size of the transducer is approximately 1-1/2 inches in diameter by about 2 inches in length. Its maximum working range is about 10 feet, and its minimum range is about 1/4 inch. The maximum temperature at which the transducer can function in sodium is limited to about 600 F by the 690 F curie point of the presently tested piezoelectric crystal material, lead zirconate-titanate. The target objects to be scanned must have some surface area normal to the direction of scan or must create shadows against a normal surface of a background reflector. For accurate distance measurements, the velocity of sound in sodium must be determined, either by accurate sodium-temperature measurements or by calibration to a target of known distance.

In addition to the capabilities thus far developed and demonstrated,^{1,2} useful applications for an under-sodium scanner will require mounting the transducer on a manipulator mechanism so that the transducer can (1) be inserted and removed from the reactor vessel, (2) be moved horizontally and/or vertically within the reactor, (3) be pointed or aimed in various directions, and (4) be capable of performing some type of sweep scan motion. Problems that affect the design and that may limit the successful applications of the scanner include those peculiar to the design of precision mechanisms for operation in sodium and disturbances of transducer steadiness caused by any one of the following factors: sodium flow (required in a reactor for shut-down cooling); transducer X, Y, or Z motions; or transducer scanning motions.

An alternate concept for using a scanner in a typical sodium-cooled reactor is based on mounting the transducer at or near the gripper of an in-reactor fuel-handling mechanism. It is believed that this concept can be adequately demonstrated (and the design requirements for the fuel handler adequately defined) by tests of a scanner carried by a manipulator that is not serving as a fuel handler. This would keep the manipulator relatively uncomplicated for purposes of the proposed demonstration.

Demonstration of a complete under-sodium scanner system capable of performing useful functions in a reactor will require the design and testing of a unit much larger and more complex mechanically than any that have been attempted thus far. The transducer should be carried and manipulated by a mechanism typical in both design and size of those that would be used in reactors so that the unit could be demonstrated in one or more available facilities such as EBR-II or the Fermi plant. The demonstration should be conducted under environmental conditions typical of sodium-cooled fast reactors, although it would probably be economically desirable that the effects of operating in a high gamma radiation field be tested separately from the balance of the initial demonstration. In addition, the demonstration should permit the evaluation of a broad sampling of the various potential applications of the scanner.

The criteria for evaluating the demonstration unit should be based on determining the feasibility and desirability of applying similar or improved systems to present or future reactors for demonstrated or similar applications, particularly in connection with the LMFBR program. Such criteria would include the following: the successful demonstration of an application's purpose; the reliability in performance of function; the frequency, nature, and significance of malfunctions; the sensitivity to environmental changes; and the sophistication and cost of a prototype system.

III. APPLICATIONS TO BE DEMONSTRATED

A compilation of 18 in-reactor and 4 out-of-reactor potential applications for an under-sodium device, based on consultation with numerous specialists in sodium-cooled reactor design, is presented and discussed in Reference 1. Since some of the potential applications require greater developmental work than others but offer less valuable results, the list recommended for demonstration was shortened. Another consideration in shortening the list was the similarity in the design and performance requirements for several otherwise different applications. On this basis, the applications that have been proposed for demonstration are listed here and defined briefly.

1. Obstruction detector (sweep). Search for any subassemblies that are projecting above their normal positions in the reactor.
2. Fuel-handler calibration. Measure distances between the transducer (positioned at the fuel-handling gripper) and benchmark targets to obtain the gripper's location by triangulation. (The use of corner targets for benchmarks permits the "seeing" of targets from any direction.)
3. Subassembly identification. Read an identification mark engraved into the upper end of each fuel subassembly.
4. Subassembly orientation. Read an orientation mark engraved into the upper end of each fuel subassembly. (The identification marks, however, may give sufficient orientation information.)
5. Migratory-plug locator. Search reactor plenums or flow channels to detect, locate, and identify foreign objects that could cause flow blockage.
6. Search and retrieval. Search for lost objects or components and provide guidance during retrieval.
7. Support-plate inspection. Inspect fuel subassembly support plates for warpage by measuring offset distances from a reference plane, and inspect for cavitation damage at seal surfaces by examining for pitting.
8. Dimensional inspection. Inspect for dimensional changes occurring to in-reactor components by utilizing plate-thickness measurements, relative location measurements, or bow or warpage measurements on originally flat surfaces.

The applications proposed for demonstration require various viewing directions, transducer motions, and modes of scanning. With some applications, a limited demonstration could be performed with a reduced number of capabilities, although a demonstration of broader or more versatile applications would require a greater number of them. An analysis of the scanner capabilities is given in Table 1.

TABLE 1 - SCANNER CAPABILITY REQUIREMENTS

<u>Application</u>	<u>A-Scan</u>	<u>C-Scan</u>	<u>Viewing Direction</u>			<u>Transducer Motions</u> ⁽¹⁾				
			<u>Vertical Down</u>	<u>Horizontal</u>	<u>Oblique</u>	<u>Horizontal X</u>	<u>Horizontal Y</u>	<u>Vertical Z</u>	<u>Rotation, Horizontal Axis</u>	<u>Rotation, Vertical Axis</u>
1. Obstruction detector(sweep)	R ⁽²⁾			R						R
2. Fuel-handler calibration	R			R		R	R			R
3. Subassembly identification		R	R	R		R	R			
4. Subassembly orientation		R	R			R	R			
5. Migratory-plug locator	R	R	R	R	D ⁽³⁾	R	R	R	R	R
6. Search and retrieval	R		R	D	D	R	R	D	D	D
7. Support-plate inspection	R	R	R	R	R	R	R	R	R	R
8. Dimensional inspection	R	R	R	R	R	R	R	R	R	R

(1) Not including scanning motions

(2) R indicates required

(3) D indicates desirable

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IV. FUNCTIONAL REQUIREMENTS OF THE PROTOTYPE SCANNER

The functional requirements for a prototype under-sodium ultrasonic scanner mechanism are based on providing an adequate demonstration, in accordance with the criteria stated earlier in this report, of the eight selected applications listed in Table 1 by using a single demonstration mechanism and a variety of target simulations or mockups. In the following paragraphs, these functional requirements are outlined.

Size - The prototype mechanism is to be a full-scale unit of a length and diameter suitable for at least some of the selected applications in the EBR-II reactor. This will permit the disclosure of problem areas not readily apparent in reduced-scale models and will make feasible future testing of the original prototype in that reactor, if desired.

Scanner Type - The scanner system will include a combined transmitter-receiver unit that employs a metallic planospherical concave acoustic focusing lens for producing a narrow beam, as described in Reference 1. The transducer will be at the lower end of a manipulator mechanism that extends upward out of the sodium, through an inert cover gas, and through suitable seals into a normal air environment where all drive motors and instrumentation will be located.

Environment - The transducer must operate in 250 F to 600 F sodium at purity levels consistent with reactor operation. It would be desirable for the transducer to be capable of withstanding sodium temperatures from 800 F to 1000 F without damage, even though the device would not be capable of operating in that temperature range. The manipulator mechanism must be capable of operating with its lower end immersed in sodium having a high gamma flux at temperatures between 250 F and 1000 F while its upper end is in normal ambient temperature air. (The necessary seals are to be considered part of the manipulator mechanism.) Pressure within the sodium-inert gas system, which should range from 15 psig to full vacuum, will have to be tolerated by the transducer and manipulator. To the extent achievable under the foregoing requirements, the manipulator should provide a steady mounting for the transducer when acted on by the sodium flow characteristic of a shutdown reactor.

Manipulation - The transducer manipulator mechanism will be capable of moving the transducer in a horizontal plane (X and Y coordinates), in elevation (Z coordinate), 360° rotation about the vertical axis, and 90° rotation about a horizontal axis (between vertical down and horizontal). It is desirable but not necessary that A-scan sweep be possible during the foregoing motions. The X and Y movements need not be linear, i. e., rotating double

eccentric motions are acceptable. In addition to the foregoing motions, the manipulator must be capable of programmed, controlled sweep motions with a position feedback that is suitable for C-scan sweeping from a given X, Y, Z, and view direction of the transducer. These sweep motions of the transducer should not cause unacceptable vibrations of the manipulator.

Feedback - All of the required motions or position adjustments stated in the preceding paragraph should be indicated mechanically at the upper end of the manipulator mechanism by the movements or positions of the mechanical elements that drive or actuate those motions.

Steadiness - Although the requirements for steadiness of the transducer mounting cannot be unequivocally stated in advance of the demonstration, it is required that the positioning motions of the manipulator be as smooth as possible and that the effect of flow on manipulator steadiness be minimized to the extent achievable when the other requirements are met.

Instrumentation - All of the necessary instrumentation for operating, controlling, and reading both A-scan and C-scan modes of transducer operation will be provided. This includes instrumentation to indicate manipulator positions, rotational angles, and the scan status (on-off and position within sweep). The motor-drive current for each manipulator motor will also be indicated, as will the vibration of the transducer, if feasible and practicable.

V. DESCRIPTION OF THE PROTOTYPE SCANNER

The following description of a concept for a prototype scanner for demonstration of several proposed applications must be considered tentative. However, investigation has shown the arrangement to be physically possible, and the final design of the prototype can be expected to be fairly portrayed by this conceptual description.

Transducer - The transducer used in the demonstration will have a metallic housing, compatible with liquid sodium at the operating temperatures. A planospherical lens will be employed to provide a sharply focused beam of sound at a distance of approximately 4 inches from the transducer. Lead zirconate-titanate piezoelectric disks, operating at frequencies of 2.25 MHz, will provide the transmitted acoustic waves. A single electrical conductor will be used to transmit electrical energy to the piezoelectric disks.

Transducer Manipulator - The transducer manipulator, as shown in Figure 1, consists of a 24-foot-long vertical tube, 3-3/8 inches in diameter, suspended from its upper end and carrying the transducer at its lower end. This tube receives some lateral support from an external tail bearing at the lower end of a 12-foot-long guide tube. The guide tube is mounted in a double eccentric to give lateral motion up to 4 inches in any direction. The vertical tube is moved up or down by a hand wheel on a worm drive that is connected to a lead screw and is rotated by another hand wheel through a worm drive. The arrangement of these positioning devices is shown in Figure 2.

Figure 3 shows the transducer mounting assembly at the lower end of the manipulator. The transducer is mounted in gimbals within a short housing tube. Bendix Free Flex pivots are used for gimbal bearings to minimize friction and to eliminate lost motion. The housing tube is, in turn, mounted on a horizontal-axis pivot to the lower end of the vertical tube.

Also mounted on the horizontal-axis pivot are three side-by-side drums, each actuated by a pair of steel tapes extending upward through the vertical tube. Each drum actuates one of the three modes of movement provided in the transducer mounting.

The first drum is rigidly fixed to the housing tube and thus determines the slope position of the housing tube between the limits of horizontal and downward vertical. Positive stops are provided at the limit positions for setting and verifying the correlation of the readout equipment.

The second drum is integral with a ball-end lever. Oscillating rotation of this assembly produces a "fanning" motion of the housing tube normal

to the slope plane of the tube. Fanning is possible through any angle up to 15° . Positive stops are provided just beyond the working range of the fanning angle for setting and verifying the correlation of the readout equipment.

Integral with the third drum is a side-acting cam that produces the sideways fanning of the transducer. As with the second drum, the fanning-angle range is up to 15° . This cam is also provided with positive stops for setting and verifying the correlation of the readout equipment. (An alternate arrangement of the transducer mounting to provide a parallel motion scan in place of the fanning motion is shown in Figure 4.)

Inside the vertical tube, extending upward, are the three pairs of actuating tapes and a single wire electrical lead that drives the piezoelectric disk. This electrical lead, which is a conductor insulated with magnesium oxide and sheathed in stainless steel, is arranged in a multiturn helix at the bottom of the vertical tube to provide flexibility, thereby giving minimum restraint to the transducer movements.

The outside of the vertical tube is ground and polished to obtain a seal surface. The top of the tube is sealed by the tape-driving assembly housing shown in Figure 5. Through the walls of this housing extend three pairs of rocker levers, the inner ends of which are attached to the upper ends of the three pairs of inner tapes. Sealing of the housing is maintained at the openings where the levers pass through the housing wall by means of double diaphragms with a buffer gas in between. These diaphragms are positioned near the lever pivot point for minimum flexing and are designed for easy replacement.

Outside the housing, just below the lever arms, are three tape-driving drums, each of which is connected to its corresponding pair of rocker levers by driven drums; the driven drums are made to rotate in direct relation to their corresponding driving drums.

In such a tape-drive system, provisions must be made to avoid discrepancies due to tape stretching from loading or differential temperatures or discrepancies due to lost motion or tape slack. To provide this, the rocker lever fulcrums are spring loaded (upward) in integral pairs. Since both legs of each pair of tapes are of approximately equal length, subjected to the same temperatures, and equally loaded (considering the friction and inertia of the transducer mounting assembly as negligible) and since the spring take-up movements are equal for any pair, the relation between the driving and driven tape drums should be independent of all these factors. Knurled spring-adjusting nuts are provided so that the spring load for each pair of tapes can be maintained at whatever value proves most effective.

A dial, graduated through 90° , is provided on the shaft of the tape-driving drum that controls the transducer manipulator slope or inclination

angle. A friction lock is also provided to maintain the dial setting. In changing the transducer slope, however, it is desirable that all three driven drums revolve in unison, since otherwise compensations must be made in the fanning drives. To accomplish this each of the driving drums for fanning is mounted on the carrier shaft of a bevel-gear differential so that the drum can be rotated by either of two independent inputs. One of these inputs is connected through a gear train to the inclination dial shaft. Hence, dial rotation actuates all three tape systems in unison.

The two fanning drives are similar to each other and are located on each side of the drive housing. They are connected to their respective differential inputs by miniature chain and sprockets. Each drive is composed of an electric motor with a shaft encoder and a gear-reduction unit, all of which is assembled on a common baseplate. This construction will make the drive easy to remove as a unit, particularly in the event that it is desired to test alternate drive mechanisms.

Instrumentation for the Scanner Mechanism - All transducer motions, including the scanner sweep motions, are driven from above, and these motions are sensed and indicated from the positions of the upper ends of the various drives. X and Y positions are indicated by vernier azimuth circles of the double eccentric mounting (subject to revision if motor drives are added), the Z position is indicated on a linear scale with a vernier, the transducer-slope angle is indicated on a 90° graduated dial with a vernier, and the transducer-azimuth angle is converted to a digital signal and indicated on the control panel. The sweep motions and phase relationship are also encoded and indicated digitally.

Instrumentation for the Transducer - A pulse generator-transmitter will be used to synchronize and to transmit electrical pulses to the piezoelectric disks. A receiver, a Transigate, and a digital amplifier will accept reflected signals. The electronic equipment will have carrier frequencies of 2.25 MHz, 5.0 MHz, and 10.0 MHz.

The Transigate will be used for both the gate generator and the gate. It will establish specific, controllable gated areas or zones within the detection distance. The gate starting point and the gate length can be varied over a range of 0.2 inch to approximately 20 feet. Reflection signals appearing within the gate will be monitored to operate visual and audible alarms. Simultaneously, the Transigate will provide a signal to the digital amplifier which, in turn, will provide a digital signal of constant amplitude for operating the C-scan recorder pen.

The output of the receiver will be supplied to one channel of a dual-trace oscilloscope, which will indicate the time separation between the transmitted pulse and the echo from a target to form an A-scan. The second channel of the oscilloscope will accept the signal from the gate generator and in-

dicating the gate wave form on the screen. With this type of display, the gate starting point and the gate length can be adjusted properly for the echo of interest.

A block diagram of the electronic system is shown in Figure 6. The equipment is available from commercial sources, and descriptions can be found in the vendor's literature.

Method of Operation - The transducer is moved horizontally (X, Y) by manual rotation of the double eccentrics on which the guide tube is mounted. Vertical motion is obtained by raising or lowering the vertical tube by means of an elevation handwheel. Rotating the vertical tube within the guide tube by means of a rotation handwheel controls the azimuth of the transducer. The slope angle is controlled by manual adjustment of the inclination dial. Continuous sweep motion of the scanner is accomplished by continuous oscillatory operation of one fanning motion drive combined with simultaneous continuous or intermittent operation of the other motion. Alternately, the sweep can be accomplished by sequential intermittent operation of these motions.

Relationship to Existing Reactors - The prototype scanner is designed so that it can be inserted into the EBR-II reactor through one of the penetrations in the inner rotating plug. It is probable that the scanner could also be employed as a maintenance tool in the Fermi reactor if this ever became desirable.

VI. FUNCTIONAL REQUIREMENTS OF THE TEST RIG

The functional requirements for a test rig are based on providing the necessary facilities and functions to permit the realistic demonstration, testing, and evaluation of the described prototype scanner under environmental conditions typical of sodium-cooled fast reactors during periods of shutdown. Descriptions of these functional requirements are given in the following.

General - The test rig will be provided as a mockup of a portion of a sodium-filled reactor vessel, suitable for use with the prototype scanner. It will have a connected loop of pumped sodium to simulate shutdown flow in a reactor, a sodium purification and service system, a variety of suitable and accessible targets, and various auxiliary equipment and instrumentation to permit testing of the scanner in each of the proposed applications listed in Table 1.

Size - The test tank should have a cylindrical reflector approximately 6 feet in radius that is located 6 feet from the transducer. The tank should be not less than 3 feet in diameter in a plane normal to the 6-foot dimension. The prototype scanner manipulator mechanism is to be mounted vertically, with the transducer capable of reaching to within one foot from the bottom of the tank. A head of 13 feet of sodium is to be maintained in the tank, but the tank itself need not be that height (i. e. , a standpipe to house the manipulator is acceptable).

Environment - The test rig will be capable of operating with the sodium circulating isothermally at 1000 F and will have adequate control and instrumentation to allow operation at any temperature between 250 F and 1000 F. The enclosure around the manipulator will be arranged to permit control of the enclosure temperature so that a regular temperature profile can be adjusted and maintained between the sodium temperature at the sodium free surface and the ambient temperature at the top of the facility.

Since sodium purity can be a significant parameter in transducer performance, the level of significant impurities will have to be measured and controlled. Although the sodium need not have lower impurity levels than normally found in sodium-cooled reactors, the measurement of the impurity levels should be as accurate as current techniques permit. Also, since it is assumed that at least intermittent cleanup of the sodium will be done, bottled nitrogen will be sufficiently pure for the cover gas. Adequate provision should be provided to prevent contamination of the test rig by air during target changes and during maintenance or shutdown periods.

Targets - Various targets that simulate actual reactor hardware will be required to evaluate the applications listed in Table 1. Where feasible, these targets should be designed to disclose not only what can be "seen" but also, the limitations or what cannot be "seen". When targets are used that do not have normal surfaces, the 6-foot-radius cylindrical reflector mentioned earlier in this section will be employed to provide a background reflection so that these targets can be examined.

Sodium Flow - The test rig will be arranged and equipped so that the target and the scanner can be subjected to flowing sodium typical of that required for reactor after-glow cooling.

Accessibility to the Interior - Easy access into the test rig for changing or adjusting targets or the reflector without system contamination should be provided. It may be economically desirable to provide for draining and vacuum distillation cleaning to give this access. A small glove box for maintenance of the transducer may also be desirable.

Instrumentation - The following system parameters should be indicated or recorded as appropriate: temperatures, pressures, levels, flow, gross impurity changes, and electrical currents or powers.

VII. DESCRIPTION OF THE TEST RIG

Since the following description of the proposed test rig is a preliminary interpretation presented in advance of any substantial design effort, it is necessarily subject to revision in concept as well as in detail.

General - All components of the test rig in contact with sodium or sodium vapor will be constructed of austenitic stainless steel (except for special-purpose details). The design, fabrication, inspection, assembly, and acceptance testing will be in accordance with approved current practice for sodium-service systems procured for AEC accounts. The test rig will be housed in an enclosed structure providing an area 13 feet by 20 feet. This structure will be built as an addition to an existing sodium test loop facility, as shown in Figure 7.

Test Tank - The test tank, as shown in Figure 8, is a horizontal cylindrical vessel 36 inches in diameter and 8 feet long, with elliptical heads on each end. Two 10-inch-diameter standpipes project upward from the tank, one at either end. One of the standpipes extends approximately 19 feet above the tank bottom, representing the height from the subassembly handling heads to the top of the rotating shield plugs in the EBR-II reactor. This standpipe has suitable valves to permit removal of the prototype scanner from the test tank without contaminating either the tank or the prototype. The other standpipe, which extends only three feet above the tank, is provided to give access inside the tank for changing or adjusting test targets. The tank also has nozzles on both the bottom and top to provide for a one-inch-diameter pumped sodium loop, a drain line, inert gas and vacuum connections, and instrumentation.

The tank and standpipes have heaters, insulation, and temperature sensors to allow operation with circulating sodium at any temperature between 250 F and 1000 F. The long standpipe is capable of being maintained with a temperature gradient declining with elevation above the tank. In addition to the design requirements in the preceding (see "General"), the tank is designed to withstand full vacuum at 800 F sodium temperature.

Inside the tank is the 6-foot-radius cylindrical reflector located at the end opposite from the prototype scanner (long standpipe). At this end, there are also appropriate support brackets to hold the targets required for the demonstration, as well as a deflector to permit variation in the flow direction of the sodium entering from the pumped loop. Another internal support bracket is located on the tank bottom to hold targets for downward-looking tests.

Conoseal joints are used in the standpipes and at a few other locations to facilitate both test operations and system maintenance.

Targets - The following descriptions of targets to be used for the demonstration tests are tentative and subject to revision. Selection and design of the targets to be used will be a necessary part of the design phase of the proposed program. Tentative target descriptions for each application are as follows:

1. Obstruction detector (sweep). A full-size mockup of the upper end of a Fermi subassembly protruding up to 2 inches above a group of neighboring subassembly handling heads. The neighboring group, which will number between 11 and 24, will be about 3 inches high. The target will be located approximately midway between the transducer and the 6-foot-radius reflector.
2. Fuel-handler calibration. Pairs of corner targets of various sizes (formed by the intersection of three mutually perpendicular planes) will be located about 30 inches apart at the opposite end of the tank from the transducer. Each corner target will be mounted so that the angles between the target planes and the beam direction will be adjustable.
3. Subassembly identification. Identification marks will be machined into the horizontal top surface of the neighboring group of Fermi-type handling heads provided for the sweep target. The group will be located below the transducer for the identification reading demonstration. It will be necessary to conceive and design a suitable identification code which provides an adequate number of different marks. For example, a three-letter code provides 17,576 different groups; however, some letters may be indistinguishable from others.
4. Subassembly orientation. An orientation mark will also be machined into the horizontal top surface of each of the sweep-target handling heads. This mark might be the identification mark itself, if numerals or letters are used. On the other hand, a separate orientation mark, such as an underscore, may be a necessary key to reading the identification mark if some other symbols are used.
5. Migratory-plug locator. Several different "foreign body" objects of a type that could possibly create coolant flow blockage will be devised. It may prove to be desirable and instructive to demonstrate the application on a two-team basis, with a target designed and installed by one team, and its location and identity established by the other team.

6. Search and retrieval. Several objects simulating typical in-reactor hardware will be placed in locations characteristic of malfunction situations such as dropping, inadvertent disassembly, etc. Such objects include a length of EBR-II subassembly wrapper tube, lengths of various-diameter tubes, and hand tools.
7. Support-plate inspection. A plate with a bowed surface of about 0.005 inch per foot of length will be installed under the transducer. This plate will have several holes of varying diameters, each having a 1/8-inch, 45° chamfer on its upper edge. Half of the perimeter of each of the chamfer surfaces will have pits machined in to simulate cavitation damage previously observed in similar cases.
8. Dimensional inspection. Several flat plate targets for thickness measurement tests will be used. Also, a sealed can of square cross section will be used, designed so the flat sides bulge at test-rig temperatures.

Sodium System - An existing loop will be extended to the test tank to allow sodium to be pumped through the test tank, entering at either of two locations on the tank bottom and exiting by way of the scanner standpipe, as shown in Figure 8. A pump will circulate sodium through the tank and the loop. The loop extension will probably be 1-inch pipe size except for a length of 2-inch pipe size between the highest point in the loop and a point near the intake of the pump. The enlarged portion of the loop will provide an automatic level control of the sodium in the scanner standpipe, insensitive to variations in the pumping head. The drain tank will be large enough to hold the total sodium inventory of the test rig. In addition, the existing equipment should include a clean-up loop that contains a cold trap and a plugging meter. An economizer should be installed on the cold trap to facilitate temperature regulation.

Nitrogen System - Nitrogen will be the reference cover gas for the test rig, although helium or argon could be used. The nitrogen supply and piping system will serve both to supply nitrogen to the various cover gas spaces in the test rig and to equalize the gas pressure in separated spaces as required.

Instrumentation - Conventional sodium-system instrumentation will be used to measure system temperatures, pressures, levels, and sodium flow rates. Electric power consumption of the pump and the system's heaters will be indicated, and instrumentation of the sodium clean-up and nitrogen systems will be typical of current practice.

Method of Operation - A typical demonstration run would consist of the following sequence of major operations (assuming the rig has been pre-

viously in service, and has been cleaned and opened to air for target changes and transducer inspection).

1. Move the transducer in its standpipe from the service glove box to the test tank and make up the Conoseal joint. Reconnect the transducer's instrument leads.
2. Adjust target(s) within the test tank. Close and seal the access standpipe.
3. Purge the test tank and heat the test tank and sodium system.
4. Refill the pumped sodium loop by pressurizing the drain tank and opening the necessary valves.
5. Circulate sodium through the clean-up loop until specified sodium purity is obtained. Adjust system temperatures during cleanup as appropriate.
6. Open the transducer standpipe valves and lower the transducer to operating elevation in the test tank.
7. Conduct a demonstration test run. The target may be adjusted during the run by gland-sealed tools operated through a purged chamber installed on the valve on the short standpipe.
8. Raise the transducer out of the test tank and close the standpipe valves.
9. Disconnect the transducer's instrument leads, open the standpipe Conoseal, move the standpipe to the service glove box, and seal it to the box. Install high-vacuum closure on standpipe valve on the test tank.
10. Drain the sodium system into the drain tank and close the drain valves. Draw a high vacuum on the test tank through the condenser, raise the system temperature isothermally above 750 F to distill the residual sodium into the hold-up tank. Valve off the vacuum and nitrogen systems and cool the test tank to ambient.
11. Open the test tank to air for target changes, preparatory to the next demonstration run. Perform any required inspection or maintenance on the transducer in the inerted service glove box.

Relationship to Existing Reactors - Since the prototype scanner is sized and designed so that it could be inserted and tested in the EBR-II reactor, the test rig is similarly sized to simulate the vertical dimensions, sodium

depth, etc., of that reactor, and most of the targets to be employed are simulations of components of that reactor. It is believed that the results of these demonstrations can be applied to other sodium-cooled reactors now existing or to future reactors similar in size and characteristics. A modest amount of extrapolation of the demonstration results would be required to apply the results to the ultimate breeder reactors envisaged by the LMFBR program.

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VIII. TEST AND EVALUATION PROGRAM

The program to test a prototype under-sodium scanner and to evaluate the results of that testing is presented here in brief, tentative form. Preparation of detailed test specifications is understood to be a necessary and important part of the test program and therefore would be undertaken early in the scanner demonstration program.

Design of Prototype and Test Rig - The scanner prototype and the test rig for its demonstration will be separated into systems (scanner, manipulator, test tank, sodium system connections, etc.), and a conceptual system description will be written for each system and for the complete demonstration package. These system descriptions will provide an approved reference statement (in greater detail than provided by this proposal) of the required functions and design basis for each system for use in the actual design of the hardware and in planning the test program.

Complete drawings will be prepared for each system of the scanner prototype and the test rig, as required for fabrication, assembly, erection, and maintenance. Suitable specifications will be prepared covering materials, methods of fabrication and erection, and quality control.

Erection and Systems Testing - As part of this demonstration program, the test rig will be erected within an enclosing structure (see Figure 7) on a selected site, and the prototype scanner installed in the test rig. After the completion of acceptance tests that are required by the specifications to indicate compliance by vendors and fabricators, necessary preoperational tests will be run to check out the systems designs.

Test Program - The test will be oriented toward evaluating the potential capability of the under-sodium scanner in each of the applications listed in Table 1. The tests will be performed in approximately the sequence listed in that table, since each application in the sequence requires more sophisticated techniques and mechanism versatility than the preceding one. A general description of the tests to be made for each application follows:

1. Obstruction detector (sweep). Using A-scan, the beam will be directed horizontally just above a group of subassembly handling heads having one subassembly projecting abnormally upward a distance adjustable from zero to two inches. It is expected that the beam will be returned by the reflector without an intervening echo except when the beam detects the upward protruding subassembly. Factors to be examined include "noise" from the normal handling heads, distance of the protruding subassembly above

normal elevation, and distance of the beam above the normal handling heads.

2. Fuel-handler calibration. Using A-scan, the beam will be rotated in a horizontal plane to locate each of two corner targets. The beam will therefore accurately indicate the distances between the transducer and the targets, thereby defining the location of the transducer with respect to the targets. This will be done with several locations (X, Y) of the transducer and with the transducer both stationary and in motion. Factors to be examined include effects of target size and orientation, methods of calibration for sodium temperature, and effects of manipulator motion.
3. Subassembly identification. Using C-scan, the transducer will sweep in a downward-looking direction to read identification markings engraved into the top of subassembly handling heads from several distances above the subassembly. Factors to be examined include the effect of distance above the handling heads, the suitability of the sweep pattern and dimensions, and the suitability of the adopted identification code.
4. Subassembly orientation. Test data for evaluating this application will be obtained during the test runs made for the preceding applications. The factors of interest are the same.
5. Migratory-plug locator. Several targets will be located on a flat shelf below the transducer to simulate "foreign body" objects that would be theoretically capable of causing coolant flow blockage such as that which occurred in the Fermi reactor. Whether using either A-scan or C-scan, the capability of the scanner to "see" such targets, to recognize them as foreign, and to describe or identify them will be among the factors of interest.
6. Search and retrieval. This test is very similar to the preceding one, but involves accurate location of targets whose identities and descriptions are known. Less versatility of the scanner may suffice for obtaining the required dimensions of target location and position.
7. Support-plate inspection. Using A-scan while pointing downward, the extent of plate warpage will be found by measuring offset distances from a reference plane established by moving the transducer in the X and Y directions only. Chamfered-hole seating surfaces will be scanned using the C-scan mode of operation while traversing the transducer around the hole centerline to determine whether the pitting characteristic of cavitation damage can be detected.

8. Dimensional inspection. Using A-scan, the thickness of several flat plates located at random angles will be measured. A gas-filled thin-walled can, sealed and supplied with an external source of pressurized argon gas, will be examined using the A-scan mode to detect and measure can-wall bulging caused by pressurizing the can. Finally, by using both A-scan and C-scan the center-to-center distance between adjacent subassembly handling heads will be determined by relating downward-looking C-scans with the transducer's X and Y coordinates and with the in-reactor transducer's coordinates by triangulation from the corner reflectors. (The latter is obtained using A-scan horizontally, as in application No. 2 above.)

Items Measured and Reported - In all test runs the following items will be measured (where applicable) and reported: A-scan and C-scan photographs; target descriptions, locations, and orientations; transducer position and direction data; target interpretation data; sodium temperatures, impurity analyses, flow rates, and flow directions; and all other systems' instrumentation data (this will be logged but not necessarily reported).

Evaluation of the Tests - The test results for each application will be evaluated to determine the feasibility and desirability of applying similar or improved under-sodium scanner systems to these or similar applications in existing reactors or in future fast reactors. The evaluations made will include considerations of the performance, or degree of success attained, in demonstrating each proposed application. This evaluation is expected to be relative or comparative, rather than a clear affirmation or rejection. All malfunctions encountered during the tests will be considered, together with any modifications that may have been generated by malfunctions, to determine whether they affect the feasibility or desirability of the proposed use. Also to be considered is the reliability, dependability, or accuracy of the scanner in executing each application. Finally, the cost of the prototype as pertinent to the features required for each application will be examined.

Based on the evaluation of each application according to the foregoing considerations, estimates will be presented of the ultimate capability of the under-sodium scanner for such applications, together with recommendations on the desirability of modifications and further development of the scanner for these and other applications.

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FIG. 1 TRANSDUCER MANIPULATOR ASSEMBLY

FIG. 2 ELEVATION, ROTATION, AND TRANSLATION DRIVE ASSEMBLY

FIG. 3 TRANSDUCER MOUNTING ASSEMBLY

FIG. 4 ALTERNATE TRANSDUCER MOUNTING — PARALLEL MOTION TYPE

FIG. 5 TAPE-DRIVING ASSEMBLY

FIG. 6 BLOCK DIAGRAM OF ELECTRONIC SYSTEM

FIG. 7 GENERAL ARRANGEMENT OF TEST FACILITY

FIG. 8 TEST FACILITY SCANNER TANK

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