Written: February 24, 1970
Distributed: March 30, 1970

LA-4393
UC-80, REACTOR
TECHNOLOGY
TID-4500

LOS ALAMOS SCIENTIFIC LABORATORY
of the
University of California
LOS ALAMOS • NEW MEXICO

Loading of Sodium-Bonded Fuel Capsules

by

D. N. Dunning

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

924

CONTENTS

	<u>Page</u>
I. INTRODUCTION.....	1
II. EQUIPMENT.....	2
A. General.....	2
B. Fuel Loading and Inspection Glovebox.....	2
C. Sodium Supply Loop.....	6
D. Sodium Loading Glovebox.....	6
E. Closure Welding Glovebox.....	10
F. Sodium Bonding Equipment.....	11
III. LOADING PROCEDURE.....	12
IV. SODIUM BONDING PROCEDURE.....	13
V. NONDESTRUCTIVE TESTING.....	15
ACKNOWLEDGMENTS.....	15
REFERENCES.....	16

LOADING OF SODIUM-BONDED FUEL CAPSULES

by

D. N. Dunning

ABSTRACT

Equipment and procedures are described for assembling experimental, sodium-bonded LMFBR fuel pins and other capsules associated with the Los Alamos Scientific Laboratory (LASL) mixed carbide fuel program. Details of the system used for supplying sodium of known and controllable quality are given along with sodium analytical equipment and procedures. Also included are procedures for the handling and inspection of (U,Pu)C fuel and the bonding of fuel pellets to stainless steel cladding. Analyses of supply sodium and glovebox gas are shown.

1. INTRODUCTION

A program of in-pile and out-of-pile experiments to determine the feasibility of sodium-bonded (U,Pu)C fuel elements for LMFBR application is being pursued at the Los Alamos Scientific Laboratory (LASL). Fuel, consisting primarily of high-purity, single-phase $(U_{0.8}Pu_{0.2})C$, is fabricated at another LASL site¹ and transferred to the loading facility. This facility consists of a sodium loop, three inert-gas gloveboxes, inert-gas purification and recirculation systems, and associated mechanical and electronic equipment. Although facility development efforts have been completed and several hundred capsules of various configurations have been loaded, improvements are being made continually.

An important feature of the facility is that the contaminated fuel loading glovebox is physically separated from the uncontaminated sodium loading and welding gloveboxes. This allows use of the sodium and welding gloveboxes for a variety of tasks that do not involve plutonium, without requiring decontamination of materials or equipment leaving these boxes.

A variety of experiments are prepared in the facility. These include fuel pins for irradiation in EBR-II and in a local thermal reactor, and capsules for fuel-cladding compatibility studies, for carbon and fission product transport studies, and for solubility determinations of uranium and plutonium in sodium. High-purity sodium for these experiments is supplied from a cold-trapped, forced-convection loop maintained at an oxygen level ≤ 2 ppm. Sodium from this loop is introduced into an inert gas glovebox where the sodium either is cast into billets and extruded into rod prior to encapsulation, or is added to capsules as a liquid. Handling and transfer operations add 8 to 14 ppm oxygen to the supply sodium.

Plutonium-containing fuel is inspected and is loaded into pins or capsules within the fuel loading glovebox. A partition inside the box provides a clean volume in which the capsules or pins are handled, separate from the larger contaminated volume in which the bare fuel pellets are loaded. Transfer of capsules containing fuel, sodium, or both between the fuel box and the sodium-box welding-

box train is made in sealed, inert-gas-atmosphere cans fastened to the floors of all boxes.

II. EQUIPMENT

A. General

The room that contains the loading facility has a separate air supply system, and air is exhausted from the room through absolute filters. This ventilation system would help to prevent the spread of contamination if a spill occurred in the room. The arrangement of the loading facility is shown in Fig. 1. This facility includes three evacuable inert-gas gloveboxes, welding and sodium supply equipment, and auxiliary electronic and electrical controls. Portions of the facility are shown in Fig. 2. The boxes are constructed of Type 304 stainless steel and have Lucite windows.

The gloves are sealed to the boxes with "O" rings. Covers on the glove ports permit the evacuation and backflushing of the gloves between operations. The glove ports are designed so that gloves can be changed without introducing large amounts of air into the boxes. This arrangement has been highly satisfactory during normal operations and during glove changes.

The gloveboxes are designed to contain a helium or argon inert atmosphere during operations and to be evacuated to a pressure of approximately 1μ when idle. Gas from the boxes is exhausted to the atmosphere after passing through scrubbers and absolute filters. The purity of the inert gas is controlled with U. S. Dynamics RTL 700 repurification units. The instrumentation to measure gas purity includes Consolidated Electrodynamics Corporation (CEC) moisture monitors; Westinghouse, Thermox Probe, or Delphi oxygen meters; and a mass spectrometer. With the units in operation, gas total impurities are maintained at less than 10 ppm. A further, and probably more sensitive, check on gas purity is measurement of sodium purity after exposure to the box atmosphere. This is done routinely. In addition, pieces of extruded sodium rod are placed in all boxes during loading operations; the appearance of the sodium serves as a "quick and dirty" indicator of gas purity.

The objective of box operations is to maintain all gloveboxes in the "alpha-cold" or noncontaminated condition except for the fuel inspection and handling area of the fuel box. This enables easy

maintenance of equipment in the boxes; equipment can be removed from the boxes for repair or modification instead of requiring that these operations be done with gloves.

Fuel is transferred from the manufacturing facility to the loading box in a sealed container (Fig. 3) that couples directly to the bottom of the glove box. Sodium and open capsules containing fuel are transferred between glove boxes in special containers equipped with the same seal for coupling them to the bottoms of the glove boxes. Large cans with this same type of seal are used for removing contaminated wastes from the gloveboxes.

B. Fuel Loading and Inspection Glovebox

The fuel inspection and loading glovebox provides a work space and a capsule loading region in the same box. The work space is a plutonium-contaminated section containing a fuel pellet measuring device, a storage area, and several small furnaces. Figure 2c gives a general view of the glovebox showing glove ports, absolute filters, pressure control switches, and gas repurification equipment. The right-hand section of the box is the plutonium-contaminated region; the left-hand section is maintained uncontaminated. Plutonium pellets can be loaded through the wall between these sections without contaminating the rest of the facility. The loading procedure consists of (1) opening a ball valve in the partition, (2) passing a funnel part way through the aperture from the cold side, (3) slipping the mouth of a pin or capsule over the cold end of the funnel and pushing fuel pellets from the hot side through the funnel and into the capsule, (4) removing the loaded capsule from the funnel, (5) passing the funnel completely through the valve into the hot side, and (6) closing the valve in the partition. At the end of this sequence, the outside surface of the pin or capsule and the inside surface in the vicinity of the mouth are contamination-free. Migration of alpha contamination to these surfaces has not been observed during subsequent handling in an inert gas environment. Figure 4 shows the contaminated section of the box with the disposable loading funnel, fuel pellets, storage cans, and handling equipment. The disposable funnels, made of aluminum, provide the actual contact surface for the transfer of fuel pellets from the contaminated section of the box into the test capsules. The funnels

Fig. 1. General arrangement of the fuel loading facility.

(a) Shielded welding box, sodium loading box, sodium supply loop, and associated instrumentation.

(b) Shielded welding box, sodium loading box, and end of fuel loading box.

(c) Fuel inspection and loading box.

Fig. 2. Views of portions of the loading facility.

Fig. 3. Container for transferring fuel from fabrication site to loading facility.

Fig. 4. Contaminated side of fuel inspection and loading glovebox.

fit loosely into a 1/2-in. ball valve mounted on the wall of the box. Cross contamination is controlled by maintaining the contaminated section pressure more negative than the uncontaminated section. Because the radial gap between the fuel pellet and capsule wall is 0.010 in., pellet sizes and funnel dimensions are critical. The male end of the funnel has a 0.0015-in. wall and is a slip fit into the capsule. Figure 5 shows the uncontaminated section with the capsule-holding fixture in place.

Fig. 5. Uncontaminated portion of fuel inspection and loading box.

Figure 6 is a schematic of the piping for both the inert gas and vacuum systems for this glove box. The inert-gas repurification unit has satisfactorily maintained total impurities below 10 ppm. Table I is a compilation of data obtained with a mass spectrometer on 16 gas samples taken over a six-month period. Within the ranges shown in the table, the normal amount of impurities per analysis is 6 to 7 ppm. During normal operations, the glovebox operates at a pressure between -1.0 and -0.5 in. of water.

Table I
ANALYSIS OF GAS FROM FUEL GLCVEBOX

Gas	Quantity (ppm)
H ₂ O	Not detectable
N ₂	1-3
H ₂	3-6
O ₂	1-2

A gauging device (Fig. 7), located in the inspection chamber, is used to determine physical dimensions of each fuel pellet. A closeup of the central portion of this device, with a dummy fuel pellet in the loading chute, is shown in Fig. 8. A pellet is loaded into the gauge by opening the sensing spindle and floating tailstock and rolling the pellet into position. The tailstock is closed and the pellet held in position by pressure between the spindle and tailstock.

The following measurements are then made by dial indicators which are read visually at the beginning of the cycle:

(1) Length of the fuel pellet. A dial indicator is read to nearest 0.0005 in. This indicator measures the movement of the floating tailstock as the fuel pellet is clamped in position between two rotating spindles.

(2) Flatness of the two fuel pellet end faces. Dial indicators are read to nearest 0.0001 in. for a measurement of end curvature, convex (+) or concave (-). Actuation of these indicators is by means of a small rod in the center of the hollow drive spindle (Fig. 8) as the fuel pellet is clamped in position by the floating tailstock. (All indicator settings may be calibrated or zeroed by use of a standard.)

Data obtained from three linear variable differential transformers are recorded on a 10-in., dual-channel strip chart as the pellet is moved past these sensing units at a feed rate of 25 in./min. These measurements are:

(1) Diameter of the fuel pellet is measured along a helical trace by rotating and translating the pellet between two sensing units. The signals from these two units are combined to give one trace on the strip chart. This method minimizes minor errors in the machining and assembly of gauge parts and in pellet alignment. The strip chart is

Fig. 6. Vacuum and inert gas system for fuel loading glovebox.

calibrated to read ± 0.005 in. full scale, divided in 1/10-in. divisions equal to 0.0001 in.

(2) Squareness and parallelism of the two end faces are measured with a vertical sensing unit whose output is shown as a second trace on the strip chart. The trace also shows the deviation from roundness of the fuel pellet. Figure 9 is an illustration of the readout from a typical fuel pellet.

C. Sodium Supply Loop

The sodium supply loop furnishes sodium of a known and controllable purity to the sodium box for use in capsule loadings. Figure 10 is an isometric drawing of this loop. It is constructed of Type 304 stainless steel and has a capacity of approximately 10 gal. A nickel-wound electromagnetic pump is used to provide a flow of approximately 0.5 gal/min through the loop. The sodium can be purified either by hot-trapping or cold-trapping. The present operations are conducted using only the cold trap (the

hot trap is removed from the system). The bulk sodium temperature is maintained at 325°F and the cold trap is kept at 265°F. Previous work at LASL by Rutkauskas² indicates that cold-trapping at this temperature reduces the oxygen level in the supply system to 1.5 ppm or less. Table II is a compilation of analytical data obtained on samples of solid extruded sodium representative of that loaded into EBR-II irradiation capsules.

D. Sodium Loading Glovebox

For normal operations, the sodium box contains a sodium billet casting furnace, an extrusion press, and loading fixtures. The casting furnace, as shown in Fig. 11, is used to provide a billet for the extrusion press. The sodium billets are usually 1 in. o.d. by 6 in. long or 1 in. o.d. by 12 in. long. Some pipe is usually evident in the casting, but the pipe disappears during extrusion.

Fig. 7. Device for measuring dimensions of fuel pellets.

Fig. 8. Central portion of pellet measuring device showing spindles and a dummy fuel pellet in the loading chute.

Fig. 9. Chart traces obtained during measurement of dimensions of a fuel pellet.

Fig. 10. Sodium supply loop for loading facility.

Table II
IMPURITIES IN SODIUM LOADED INTO TEST CAPSULES

Element	Impurity Concentration (ppm)
O	7-16
N	< 1
C	< 10
Li	< 3
Be	< 0.8
B	< 15
Mg	1
Al	< 3
Si	12
K	300
Ca	12
Ti	< 5
V	< 0.8
Cr	< 3
Mn	1
Fe	1
Co	< 3
Ni	< 3
Zr	< 300
Sr	< 0.8
Ag	< 0.8
Cd	< 30
Sn	< 3
Ba	< 0.8
Pb	< 5
Bi	< 5

(a) Furnace, box entry derby, and billet mold.

(b) Furnace and billet mold.

Fig. 11. Sodium billet casting furnace.

The extrusion press is designed for operation at a load of 0 to 4000 psi at a ram speed of 0 to 0.5 in./min. The hydraulic lines and all possible components are located outside the glovebox for ease of maintenance. The extrusion press is sealed to the box with a double "O"-ring seal; the space between the "O" rings is evacuated and backflushed with inert gas when the gloves are evacuated and backflushed. Figure 12 shows the hydraulic flow diagram of the components external to the glovebox. Sodium extrusions of 0.240 in. diam are normally run at a constant ram pressure of 1000 psi and constant ram speed of 0.1 in./min through a shear die having a 5° relief. Rod straightness has not been a problem. As can be seen from Fig. 13, a runout slide is located adjacent to the extrusion die and a Teflon runout table is used.

The most satisfactory method that has been found for shearing the sodium rods to length is

using a notched pair of scissors. The sodium is so sticky at these purity levels that handling is difficult; plastic-tipped tweezers are used for all handling operations.

Figure 14 is a drawing of the piping arrangement of the inert gas and vacuum systems for both the sodium loading box and the closure welding box. During normal operations, the atmosphere in the sodium loading box and closure welding box is controlled at a positive pressure of 0.25 to 0.50 in. of water and is controlled through the use of Meletron pressure switches with stainless steel bellows. The box atmosphere normally contains less than 10 ppm total impurities and is monitored by periodically withdrawing gas samples from the boxes and analyzing them with a CEC Model 21-620 mass spectrometer. These mass spectrometer data are summarized in Table III. The mass spectrometer data have correlated well with the moisture monitor (CEC Model 303) readings.

Fig. 12. Schematic of extrusion press hydraulic system.

(a) View through window on one side.

(b) View through window on opposite side of box.

Fig. 13. Views of interior of sodium loading box, showing casting furnace, extrusion press, and Teflon runout table.

Table III
ANALYSIS OF GAS FROM SODIUM LOADING BOX

Gas	Quantity (ppm)
H ₂ O	Not detectable to 2
H ₂	Not detectable
N ₂	6-7
O ₂	Not detectable

E. Closure Welding Glovebox

The capsule closure welding box, like the sodium loading box, is maintained in an "alpha-cold" or uncontaminated condition. The Type 304 stainless steel glovebox is 40 in. long by 40 in. wide by 30

in. high and is reinforced for vacuum standby operation. It contains the welding fixture, a ball valve port, and alpha transfer ports. The ball valve and alpha transfer ports are used for capsule handling and sodium melting where the capsule is too long for efficient box handling or where irradiated pellets are being loaded into capsules containing sodium. The box is shielded with lead so the closure welds can be made on capsules containing trace-irradiated fuel pellets. The facility was designed to handle irradiated fuel pellets reading up to 40 R at contact.

Figure 15 shows the welding fixture with the heliarc torch in the automatic position. The power

Fig. 14. Vacuum and inert gas system for sodium and welding high vacuum chambers.

Fig. 15. View of interior of closure welding box showing the welding fixture.

equipment used is a Vickers TIG-50 solid-state, convection-cooled welder with remote or manual current control of 0.5 to 50 A dc and controlled high frequency. For higher current requirements, a 7 to 300 A, P & H heliarc welder is used. The fixture speed is controllable in the range of 2 to 6 rpm. In the majority of the closure welds the weld fixture is used with copper chill blocks and the torch is hand-held for ease of operation.

F. Sodium Bonding Equipment

For short test capsules, sodium bonding is accomplished in a resistance furnace set in an open hood (Fig. 16) connected to the plutonium exhaust system. For these capsules a two-step process is used. The first step is to heat the capsule to 600°C for 1 h. to ensure "wetting" of all surfaces. The second step in the bonding process utilizes an ultrasonic transducer silver-soldered to a nickel

Fig. 16. Bonding furnace and ultrasonic device for sodium bonding short test capsules.

solid horn to remove defects in the bond area. The solid horn is of the stepped type and has a large diameter of 1 in., a small diameter of 0.250 in., and a radius at the step of 0.250 in. The sizes were chosen by fixing the small diameter at 0.250 in. so it would seat in the bottom of the capsule and by calculating the large diameter.³ Because the Curie temperature of nickel is 358°C, the temperature of the second step in the bonding process has been limited to 300°C. Where no holddown spring is used and the capsule is short, the capsule is put in a laboratory centrifuge during cooling.

For the long EBR-II irradiation test capsules, a special centrifuge has been constructed. This is shown in Fig. 17. Attempts to bond these elements without centrifugation were generally unsatisfactory; after several heat treatments most capsules still exhibited defects in the bonds. The centrifuge not only eliminates bubbles from the sodium bonds, but also provides directional cooling to prevent shrinkage voids from forming during freezing of the sodium. Fuel chips can also be removed from the sodium bond and deposited at the bottom of the capsule by centrifugation.

III. LOADING PROCEDURE

The path followed by the fuel through the loading and bonding facilities is shown in Fig. 18. Transfer of fuel from the LASL fabrication facility and between the two gloveboxes in the loading

facility is accomplished in special transfer cans. These cans are designed to provide both a method of transferring fuel from a fabrication glovebox to a loading glovebox without either alpha or air contamination problems and also to provide a leaktight transfer can maintainable at a 2×10^{-9} Torr level. Figure 3 is a schematic drawing of the can as it is being used on a daily basis in the facility. Both the fuel transfer and the uncontaminated handling modes are illustrated. Fuel pellets (nominally 0.26 in. diam by 0.25 in. high) are obtained from the fuel fabrication facility in small sealed cans. Each pellet is in a numbered depression in a tray, and a spring prevents movement (and possible chipping) of the pellets inside the can during transfer. The cans are filled with an inert gas to prevent oxidation of the pellets.

These sealed cans are introduced into the fuel inspection glovebox by placing them in a fuel transfer can and coupling the transfer can to the bottom of the box. The transfer can is evacuated and back-filled with helium before it is opened to the box interior. The small sealed cans are opened as the pellets are needed.

Fig. 17. Centrifuge used in bonding EBR-II test capsules.

Fig. 18. Path of fuel through fuel loading and bonding facilities.

The dimensions of each pellet are determined with the pellet measuring device. Pellets that do not meet specifications for a particular capsule are retained for possible use in other tests. Records of pellet dimensions are kept for later use in the determination of irradiation-induced swelling of the fuel. The pellets are also inspected visually to determine that they are intact.

Fuel pellets are loaded into capsules of many different shapes and sizes. Several of the most commonly used capsules are shown in Fig. 19. The normal loading procedure is to push a loading funnel into an opened ball valve from the uncontaminated side of the glovebox. The pellets are pushed through the funnel into a capsule. After all capsules are loaded, the funnel is pulled through the wall into the contaminated area for later disposal and the ball valve is closed. If the sodium was loaded prior to the fuel loading, the capsule is then capped and transferred to the weld box for final closure welding. If the next operation is loading the sodium, the capsule is transferred to the sodium box.

In the sodium loading box, the casting furnace, associated lines, and box entry derby are preheated to 325°F. The casting furnace is filled from the

bottom; billet length is monitored visually. A Nupro metering valve is used to control the flow. After the proper billet length is achieved, sodium flow is stopped and the furnace is opened to freeze the sodium. The billet is then removed from the casting furnace and assembled in the extrusion press. Sodium rods of 0.240-in. diam are extruded onto a Teflon runout table.

The sodium is measured, cut to length, weighed, and inserted into the capsule through a loading funnel. The sodium loading funnel has a shorter male section than the fuel loading funnel so there is no pickup of alpha contamination on the funnel in those cases where the fuel pellets are loaded first. The top cap is inserted into place after sodium loading. The capsule is transferred to the welding box and the final closure weld is made with a hand-held heliarc torch. The capsule is then removed from the welding box and monitored to ensure that the exterior is free from alpha contamination. A helium leak detector is used as a preliminary check of weld integrity.

IV. SODIUM BONDING PROCEDURE

For capsules loaded in this facility, the fuel pellets must be at the bottom of the capsule and a sodium bond must be achieved between the fuel pellets

and capsule wall. The requirements of the sodium bond are that the fuel pellets and the capsule wall be bonded or "wetted" with sodium and there be no voids in the sodium. Two different procedures are used, depending on the capsule length.

Short test capsules are heated to 600°C for 1 h in a resistance furnace to ensure "wetting" of all surfaces. The capsules are then placed in a laboratory centrifuge and centrifuged during cooling to room temperature. Each capsule is then heated to 300°C for 1 h with an ultrasonic transducer operating against the bottom. Final cooling is again performed while the capsule is centrifuged.

Long (36 in.) EBR-11 capsules are bonded in a separate facility, but the procedure is similar. The difference in fuel stack height of approximately 1 in. in short capsules to 14-1/2 in. in the EBR-II test capsules required a modified procedure. The problem in the longer capsules is to freeze a long tube of sodium 14-1/2 in. long that varies in thickness from 0 to 0.020 in. and an outside diameter of 0.300 in. with no defects such as bubbles or voids in the sodium. In addition, any chips that have come off the corners of the fuel pellets must be moved to the bottom of the capsule. After a considerable development effort, the following procedure is used to eliminate all defects in the sodium bond within the nondestructive test limit of 0.020 in.

(a) Heat the fuel element in the centrifuge and centrifuge per Table IV.

(b) Heat capsules from the top down to 600°C and hold for 1 h.

(c) Heat capsule from the top down and repeat Step 1.

Table IV
OPERATING CONDITIONS FOR BONDING CENTRIFUGE

Fuel Stack Position	Time to Freeze (min)	Temperature at Start of Centrifuging (°C)
Top	11	280
Middle	5	230
Bottom	1.5-2 (Est.)	150

V. NONDESTRUCTIVE TESTING

The following tests are done on the capsules:

(a) Radiography to determine fuel position, sodium level, voids in the sodium bond, and weld integrity.

(b) Eddy-current and ultrasonic tests to determine cladding defects, voids in the sodium bond, and shrinkage voids.

(c) Helium leak checks to determine weld integrity.

(d) Visual inspection.

(e) Measurements of fuel, cladding, and capsule to determine diametral and axial dimensions and warpage.

An eddy-current inspection is used primarily to detect voids in the sodium. Two axially positioned eddy-current coils are placed near the rotating capsule. The coils are connected differentially so that a zero output signal is received when they sample areas of equal conductance. Calculations based on the conductivities of the capsule materials indicate that a frequency of about 250 Hz should be sensitive to defects in the sodium bonds. This system was tested utilizing a brass tube with various size holes drilled in it. This tube was inserted in a 0.010-in.-thick stainless steel tube. The test indicated that a 0.020-in.-diam hole could be detected and this standard is run just prior to each capsule test.

In addition to the above sensitivity checks on equipment, capsules that tests showed had voids and "nonwet" areas were destructively inspected by stripping off the cladding and observing the bond area. All "nonwet" areas and void indications are verified in this manner. Capsules that nondestructive tests indicated had no defects also were stripped and in no case were any defects found.

ACKNOWLEDGMENTS

This facility requires the talents and time of many persons for successful operation. In particular, L. L. Marriott, J. W. Woolsey, C. R. Winkelman, J. O. Barner, and J. A. Bridge contributed daily operation time and considerable skill at design and fabrication of component parts. The technical assistance and guidance provided by R. H. Perkins and J. C. Clifford are appreciated and necessary.

REFERENCES

1. "Quarterly Status Report on the Advanced Plutonium Fuels Program, April 1 to June 30, 1968, and Second Annual Report, FY 1968," LA-3993-MS, Los Alamos Scientific Laboratory (1968).
2. V. J. Rutkauskas, "Determination of the Solubility of Oxygen in Sodium by Vacuum Distillation," LA-3879, Los Alamos Scientific Laboratory, Sept. 17, 1968.
3. J. R. Frederick, Ultrasonic Engineering, Wiley, (1965), pp. 87-91.