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**FURTHER DISCUSSION OF INSTRUMENTATION AND CONTROLS
DEVELOPMENT NEEDED FOR THE MOLTEN SALT BREEDER
REACTOR**

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ABSTRACT

Previously published information (J. R. Tallackson, R. L. Moore, and S. J. Ditto, Instrumentation and Controls Development for Molten-Salt Breeder Reactors, ORNL-TM-1856, May 1967) concerning the development and evaluation of Process instrumentation applicable to molten-salt breeder reactors (MSBR) was updated. Areas where instrumentation techniques and components tested during operation of the Molten-Salt Breeder Experiment may be applicable to the MSBR are described and recommendation for further development are stated. In this study to date, no problems are foreseen that are beyond the present state of the art.

Keywords: Development, fluid-fuel reactors, fused salts instrumentation, MSRE, MSBE, MSBR, reactors.

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1. INTRODUCTION

In a previous report,¹ Tallackson, Moore, and Ditto had discussed their evaluation of instrumentation tested during operation of the Molten Salt Reactor Experiment (MSRE) and its suitability and deficiencies for application to molten-salt breeder reactors (MSBR's).^{2,3} Many of the instrument components used successfully in the MSRE will be directly applicable to the MSBR. This report summarizes and updates the material covered in the previous (ref. 1) report. The scope of coverage is confined to process instrumentation; it does not cover nuclear instrumentation because recent advancements in the development of high temperature nuclear detectors would make such discussion premature. After these latter developments have been adequately reviewed and evaluated for application to MSBR's, they too will be reported.

2. GENERAL COMMENTS

Although it is reasonable to expect that MSBR process instrumentation will require designs beyond the present state of the art, no problems are foreseen that could not be resolved by further development of components and techniques. Many instrument components used successfully in the MSRE will be directly applicable to the MSBR. Similarly, experience being gained by the utilities industry with instrumentation of supercritical pressure steam systems will be applicable to the MSBR.

MSBR process instrumentation located outside the biologically shielded areas and not an integral part of the containment system can be conventional equipment. Some standard components, however, may require some upgrading, and a strict quality control program will be required to ensure a level of reliability and performance commensurate with MSBR requirements.

¹ J. R. Tallackson, R. L. Moore, and S. J. Ditto, Instrumentation and Controls Development for Molten-Salt Breeder Reactors, ORNL-TM-1856 (May 22, 1971).

² P. R. Kasten, E. S. Bettis, and R. C. Robertson, Design Studies of 1000-Mw(E) Molten-Salt Breeder Reactors, ORNL-3996 (August 1966).

³ R. B. Briggs, Summary of Objectives and a Program of Development of Molten-Salt Breeder Reactors, TM-1851 (June 1967).

All process instrumentation components located within the containment cells or as an integral part of the containment system must probably be considered developmental. These components are predominantly primary sensing elements for measurement of flow rates, pressures, levels, weights, and temperatures in the salt-containing pipes and vessels, in the associated purge and off-gas systems, and in the salt chemical processing facilities. Other such components are final control elements (such as off-gas control valves), leadwire and piping connections to the sensing and final control elements, remotely operated disconnects, and containment penetration seals.

Present plans to control the temperature of the reactor, drain, and steam-generating equipment by furnace heating will preclude the use of some devices and techniques that were employed successfully in the lower temperature environment of the MSRE. The physical size of the components and the space available for equipment could restrict otherwise acceptable techniques, such as weighing salt tanks, and tend to aggravate some problem areas, such as insulation shunt resistance in signal cables.

The electrical conductivity of the MSBR salts will be a significant factor in selecting the type of primary sensing elements that can be used. Although the conductivities of MSBR salts are not known with certainty, they are estimated to be about 1 mho/cm--about the same as MSRE salts. If these conductivities were an order of magnitude less, some of the MSRE devices could not be used. Conversely, if these conductivities were significantly higher, the existing devices would perform better; and possibly some techniques that could not be used in the MSRE could be used in an MSBR. For example, significantly higher conductivities would permit use of a magnetic flowmeter.

Development of other equipment and techniques, such as an electrical penetration into salt-containing pipes and vessels, would undoubtedly lead to improved instrumentation and new ideas for development. Some development will also be required to adapt MSRE control components to the high pressures and temperatures in some portions of the MSBR.

3. TEMPERATURE MEASUREMENT

The materials and techniques that were used for measurement of MSRE temperatures should be adequate for most MSBR applications, although furnace heating of the MSBR reactor cell will create new problems that might require further development. It is expected that much of the test data and equipment procurement standards being developed in the LMFBR thermometry program will be applicable to the selection and development of instrumentation for MSBR temperature measurement.

The reactor cell temperature of $\sim 1000^{\circ}\text{F}$ will require development of in-cell leadwire, disconnects, and containment penetration seals. Additional development will be required to obtain greater measurement accuracy and to ensure long-term (30-year) performance. Development effort could also be profitably applied to methods of thermocouple attachment, to an investigation of radiation pyrometry techniques, and to measurement of small differential temperatures at elevated temperatures.

Although the performance of MSRE thermocouples was very encouraging,⁴ improved measurement accuracy and drift stability are needed. Measurement of small differences between two high temperatures was not satisfactorily accomplished. The accuracy obtained with series-opposed (bucking) thermocouples and extreme care in design and installation was generally adequate for MSRE purposes, but, without further development, it might be only marginal for the MSBR.

The temperatures of heated pipes and vessels in the MSRE were measured by mineral-insulated, Inconel-sheathed, Chromel-Alumel thermocouples. Results of developmental tests and observation of the field performance of this type of thermocouple indicate that an initial (hot junction) measurement accuracy of $\pm 2^{\circ}\text{F}$ and a long-term (noncumulative) drift rate of less than $2^{\circ}\text{F}/\text{year}$ can be obtained at operating temperatures in a range from 0 to 1300°F if (1) the thermocouples are carefully selected and calibrated, (2) attention is paid to details during design, fabrication, and installation, and (3) strict quality control is maintained. In particular, the materials must be handled and assembled with cleanliness, the composition of the insulation must be controlled to specified values, and the grade and homogeneity of the thermocouple wire materials must be carefully controlled. To obtain highest accuracy, the design of the sensors and their installation must protect them against stray radiative and convective heat sources which might result in heat transfer to or from the sensor and, thus, biased measurements.

There is a good possibility that improved accuracy of both absolute and differential measurements of high temperatures in molten-salt systems can be obtained by using ceramic-insulated platinum resistance thermometers. Several companies have recently marketed resistance thermometers rated for operation at MSBR temperatures and higher. Several thermometers rated at 850°C (1562°F) were tested at ORNL for stability.⁵ Although the calibration shifts were excessive in initial thermal cycle tests, it was later demonstrated that these shifts would be decreased to acceptable levels by operating the thermometers at the maximum rated temperature for more than one week. Although the results obtained after high-temperature stabilization

⁴ Molten-Salt Reactor Program Semiannual Progress Report for Period Ending August 31, 1967, ORNL-4191, pp. 22-24, 47.

⁵ Molten-Salt Reactor Program Semiannual Progress Report for Period Ending August 31, 1968, ORNL-4344, pp. 94-95.

were encouraging, more data are needed to determine the long-term stability of these devices. The LMFBR Thermometry Program at ORNL includes plans for repeating and expanding these tests.

Multiconductor, glass-insulated, silicone-impregnated, copper-sheathed thermocouple cables used in the MSRE between the in-cell disconnects and the out-of-cell junction boxes will not be usable in the MSBR high-temperature reactor and drain cells, and probably will not be suitable for long-term operation in areas where the radiation level is extremely high ($> 10^6$ R/hr) due to insulation degradation and the effects of radiation-induced outgassing of the silicone-insulating materials. In the MSRE, outgassing produced excessive pressure buildup in organically insulated cables that were exposed to high radiation and sealed at the containment penetration and the in-cell (disconnect) ends. Inorganic-insulated leadwire would be preferred in all high radiation areas in the MSBR and probably would be mandatory in the furnace-heated cells. In these cells protective sheathing will be required for all in-cell thermocouple wiring. Also for use in these cells, disconnect devices must be developed which will be compatible with the furnace atmosphere and remote maintenance requirements. Multiconductor, mineral-insulated, sheathed-thermocouple cable assemblies probably will be satisfactory for all in-cell leadwire and containment penetration service, but the major problem will be to develop a satisfactory method of sealing the ends of the cable. Although it would be more difficult to develop seals and techniques for installing multiconductor cable through a penetration than for installing a thermocouple through an individual penetration, the advantages to be realized from fewer penetrations required for multiconductor cables would more than justify the development cost. Other considerations, however, such as maintenance requirements and separation of safety system channels could influence the decision toward use of individual penetrations. Both methods need to be studied and evaluated in greater detail.

The thermocouple attachment techniques used for the MSRE probably will be satisfactory for the MSBR, although they were sometimes time consuming and costly. Small improvements in these techniques could yield significant dividends, because a large number of thermocouples will be required (over 1000 were installed on the MSRE).

Infrared photographic and radiation pyrometry devices might enable mapping of temperature contours of large exposed surfaces (such as the MSBR reactor vessel), possibly by use of a closed-circuit television camera equipped with an infrared filter. Such a temperature profile might be determined more accurately by mechanically maneuvering a radiation pyrometer to produce a scan pattern similar to the raster produced on a television screen. Since the feasibility of these devices would be strongly dependent on the physical geometry of the system viewed and of the surrounding area, an investigation of their feasibility and the development of equipment and techniques should be initiated early in the program. Pyrometric devices whose design is based on using the preceding principles are commercially available, and they may be adaptable to MSBR needs.

Ultrasonic devices have been applied recently to measure temperature, and some devices are now available commercially. Although we have not determined the need for such devices in the MSBR, they might be usable for special applications, such as measurement of in-core temperatures. The LMFBR Thermometry Program also includes investigation of ultrasonic sensors.

4. PRESSURE MEASUREMENT

Measurement of pressures in systems not containing molten salts or highly radioactive fluids will not present significant problems. In systems containing molten salts some pressures might be indirectly measurable with MSRE techniques and others might be directly measurable with NaK-filled transmitters. However, no pressure measuring device is available that is suitable in its present form for directly measuring pressures (or differential pressures) of the fuel salt.

In the MSRE molten-salt loops the pressures were determined indirectly by measuring the pressures in gas-purge or supply lines connected to gas spaces in the drain tanks and pump bowls. This technique will not be usable in the MSBR where gas purges cannot be tolerated or where high-frequency response is required. Additional work would be required to develop a means of directly measuring salt pressures, since part, or all, of the pressure measuring device would have to be located close to the pressure tap within the containment vessel and, thus, the device would have to withstand the effects of high temperature, radiation and a varying ambient pressure. In particular, if the reactor and appurtenances are to be heated in a furnace, then all pressure transmitter components must be located outside the heated zone or be capable of operating at the high cell temperatures.

NaK-filled pressure transmitters offer the best prospects for direct measurement of cover gas or fluid pressures in molten-salt systems. If this device is to be used, the possibility that a small amount of NaK would enter the system if the seal diaphragm breaks must be acceptable. Additional work will be required to reduce the effects of process temperature on the transmitted signal, to measure pressures > 50 psig at $> 1200^{\circ}\text{F}$, and, if the transmitting element is to be installed outside the secondary containment, to ensure adequate containment of the reactor system. If the transmitting element is to be installed inside the secondary containment, the element must be improved to reduce the environmental effects of temperature, radiation, and varying ambient pressure to acceptable levels.

Another, but less promising, way to measure pressure directly is to possibly adapt a thermionic diode type of pressure transmitter.⁶ This method is being developed

⁶ A. J. Cassano and R. E. Engdahl, "Pressure Transducer for Liquid Metal Application," pp. 165-186, Proc. Conf. Application of High-Temperature Instruments to Liquid Metals Experiments, Sept. 28-29, 1965, ANL-7100.

by others for use in high-temperature liquid-metal systems, and its progress will be followed to determine whether it can be applied to molten-salt systems.

5. DIFFERENTIAL PRESSURE MEASUREMENT

As in measurement of pressures, the measurement of differential pressures in the MSBR will be more difficult in the systems containing molten salt and highly radioactive liquids and gases.

Except for the coolant-salt venturi pressure drop measurement (Sect. 6), no direct differential pressure measurements were made in salt-containing equipment of the MSRE. The differential pressure measurements needed to determine molten-salt levels and gas flow rates to and from the molten-salt systems were made on gas lines connected to gas spaces above the salt. The performance of the differential pressure transmitters for measuring gas flow was satisfactory. Some difficulties were experienced in measuring salt flow rates with the NaK-filled differential pressure cells during initial operations of the MSRE.⁷ The performance of some of these transmitters was satisfactory, but that of others was not, and procurement of all transmitters was difficult.

The problems associated with direct measurement of differential pressures in the liquid-filled equipment of the MSBR salt systems are similar to those associated with pressure measurement (Sect. 4); the main difference is that the differential pressure transmitter is not affected by variations in ambient pressure and usually is required to measure much smaller variations in pressures. In applications such as level measurements, where relatively small spans might be required, the effects of variations of ambient temperature, process temperature, and process pressure on the span and zero of the transmitter are of prime importance and could be the deciding factor in determining the suitability of NaK-filled differential pressure transmitters for a given application. If the performance of the transmitters were to be improved sufficiently by further development, measurement of level in the drain tanks might be considered as an acceptable alternative to weighing. Another, less promising approach to direct measurement of differential pressures in molten-salt systems is to use thermionic diode type elements presently being developed by others for the liquid metals programs.

⁷ Molten-Salt Reactor Program Semiannual Progress Report for Period Ending August 31, 1965, ORNL-3872, p. 70.

6. FLOW MEASUREMENT

Measurement of a variety of flow rates will be required in the MSBR. Most will be conventional measurements of liquid, steam, and gas flows in areas outside the fuel processing and reactor containments. Little development will be required in these applications. However, further development will be needed to obtain satisfactory measurements of salt and off-gas flows. The fuel-salt processing system may also present some special flow measurement problems.

The flow rate of molten salt in the MSRE coolant-salt system was measured by a venturi meter section operated at system temperature; the differential pressure was measured by a high-temperature, NaK-filled differential pressure transmitter. The performance was adequate, and this type of system probably would be acceptable for similar service on the MSBR. This system was not acceptable for measurement of MSRE fuel salt flows, because there was a possibility that NaK could be released into the fuel-bearing salt and possibly precipitate the uranium. This consideration might not apply to the MSBR, because the volume of NaK is very small compared with the volume of salt. Development would also be required for the venturi, NaK-filled D/P transmitter system for measurement of fuel-salt flow in the MSBR, as mentioned above.

Ultrasonic techniques offer promise for molten-salt flow measurement. A commercially available ultrasonic flowmeter is capable of measuring liquid flows in pipes from 1 to 6 in. in diameter. Since this instrument makes use of piezo-electric transducers, it probably will be necessary to use force-insensitive mount techniques (developed by Aeroprojects, Inc., and used in the level probe of the MSRE fuel storage tank) to allow the heat and radiation-sensitive components to be installed outside the reactor containment and shielding. Such a flowmeter could operate at temperatures $> 1300^{\circ}\text{F}$ and would be compatible with the environmental conditions. It would be of all-welded construction and would not require an electrical or piping penetration into the meter body or the containment vessel.

Other devices considered for measurement of molten-salt flow are the turbine and magnetic type flowmeters. Both types can be constructed for high temperature service and have been used in liquid-metal systems with varying degrees of success. Neither type has been applied to molten-salt service to date; however. The nuclear magnetic resonance type flowmeter might be applicable in the MSBR system and should be investigated. A turbine flowmeter developed for the ANP program operated satisfactorily at 1600°F for a short period before it failed. The major problem with this flowmeter is that the physical properties of the turbine blade and bearing materials must withstand high temperatures. Perhaps the improved materials now available and lower operating temperature proposed for this service would permit development of a flowmeter of this type for MSBR service.

Magnetic flowmeters have been used extensively at high temperatures (1600°F) in liquid-metal systems and at lower temperatures for the measurement of the flow of many fluids over a fairly wide range of rates. But this type of flowmeter cannot be used for measurement of molten-salt flows in its present form because of consideration of containment, materials compatibility, and molten-salt conductivity, as follows: containment and material compatibility prevent use of electrical lead-through penetrations of the meter body such as those used in conventional magnetic flowmeter construction; and the relatively poor (1 mho/cm) conductivity of the molten salt prevents measurement of the signal voltage at the outside surface of the meter body, as is accomplished with liquid-metal flowmeters. If satisfactory electrical lead-through penetrations could be devised, then magnetic flowmeters for molten-salt service regardless of salt conductivity could be developed. There is a good possibility that such a penetration could be developed by protecting a nearly insoluble insulator material, such as beryllium oxide, with a frozen-salt film or plug.

7. LEVEL MEASUREMENT

Several methods were used successfully for single-point and continuous measurement of molten-salt levels in the MSRE system. All these methods could be used in the MSBR under similar conditions, although all have certain limitations.

Molten-salt levels in the MSRE coolant and fuel-salt pump bowls were measured continuously by bubbler (dip tube) and float level systems. A developmental pump installation included a float level transmitter. Two-level, single-point measurements of molten-salt level in the MSRE fuel and coolant system drain tank were made by conductivity level probes. With the information obtained from these probes, the performance and calibration of the tank weighing systems were checked. The probe signals operated lamps (and other binary devices) that indicated whether the level was above or below two preselected points. An ultrasonic probe was used for single-point measurement of level in the fuel storage tank. Except that it is a "one-level" device, the information obtained with the ultrasonic probe is identical to that obtained with the conductivity probe, and information from both probes was used for the same purpose.

All of the systems for measurement of molten-salt level in the MSRE were developed for a particular service, and further development or redesign would be required for other applications. The bubbler system⁸ is the simplest and the most

⁸ Molten-Salt Reactor Program Semiannual Progress Report for Period Ending Jan. 31, 1963, ORNL-3419, p. 43.

versatile method of measuring molten-salt level under relatively static conditions of level and cover-gas pressure. This system can be used for narrow or wide ranges of levels, and the vessel modifications required to install the system are simple and inexpensive. However, since performance of the bubbler system depends on a steady flow of purge gas through a dip tube, this system can be used only where the purge gas can be tolerated. Also, the response characteristics of this system depend on the purge flow rate which, in turn, depends on the supply pressure, cover-gas pressure, and other factors. In general, the low purge rate required for accurate measurement is not compatible with requirements for fast response. Fast changes of cover-gas pressure, such as can occur in the drain tanks and pump bowl during filling and draining operations, can make the system inoperative unless there are corresponding changes in the flow rate of the purge gas. A disadvantage of the bubbler technique for measurement of levels in systems containing radioactive fluids is that it is necessary to detect and prevent a release of activity through the purge line. Development of a system that would recycle the purge gas within primary and secondary containments would greatly extend the usefulness of bubbler systems.

The float level system⁹ offers the best method of continuous measurement of molten-salt levels over narrow ranges. Such a device would be completely contained, have a fast response, and require only electrical penetrations into the secondary containment. Present designs are limited to measurement spans < 10 in. Although the span probably can be increased, this device is better suited to low-span than to high-span measurements.

The conductivity level probe¹⁰ performed well in MSRE service. Except that redesign of the tank penetration might be necessary to improve containment and to withstand high temperature ambient conditions in furnace heated areas, the present probe design could be adapted to installation in MSBR tanks. A disadvantage of this probe is that the walls of the tube extending into the tank must be thin, which makes the tubing unsuitable in corrosive environments. Since the output signal obtained from the MSRE conductivity probes was much greater than expected, possibly a more rugged and corrosion-resistant single-point probe with a thicker tube wall could be developed. A continuous-type conductivity probe similar to those used in liquid-metal systems also has possibilities.

⁹ MSRE Design and Operations Report, Nuclear and Process Instrumentation, ORNL-TM-729, part IIB, Sect. 6.9 (in preparation).

¹⁰ Ibid., Sect. 6.10.

Recent data on the conductivity of molten salts¹¹ have led to a better understanding of the mechanisms that influence the measurement of molten-salt conductivities and to a possible explanation of the drift characteristics that have deterred development of conductivity probes for application to continuous measurement of molten-salt levels. These data indicate that it might be possible to reduce the drift rates of present developmental designs to acceptable levels by using a higher excitation frequency and phase detection techniques.

Except for some problems with oscillator frequency drift, the Aeroprojects, Inc., ultrasonic level probe¹² has been dependable and accurate. Development will be required to improve the main chassis electronics and packaging, and routine redesign and development testing should be sufficient to resolve the remaining problems. The Aeroprojects single-point ultrasonic level probe is more rugged and corrosion resistant than the conductivity type probe, and, when the remaining problems are solved, this could be the preferred device for single-point level measurement in installations where it is applicable.

Level measurement by a differential head-pressure method was not used in the MSRE because a suitable device for measuring differential pressure was not available. As discussed previously, if the performance of low-span, NaK-filled, differential pressure transmitters could be improved, this device could be considered for the MSBR.

With the possible exception of the differential (head) pressure method, all methods previously discussed would be compatible with the MSBR design concept of furnace heating the reactor and drain tank cells. The float-type level transmitter should be given great consideration, because its transformer and other parts could operate at the proposed MSBR system temperatures. Possibly, the conductivity and ultrasonic probes could be used in a furnace atmosphere in their present form; however, some additional development work on leadwire, penetrations, and disconnects will probably be needed. The effects of temperature on the transmission line characteristics of the ultrasonic level system must be investigated before further consideration can be given to use of this system in furnace-heated areas.

8. SALT INVENTORY MEASUREMENT

Measurement of the amount of salt in various MSBR systems will be required, both during operation and shutdown, because this information will be necessary

¹¹ G. D. Robbins, Electrical Conductivity of Molten Fluorides, A Review, ORNL-TM-2180 (March 26, 1968).

¹² MSRE Design and Operations Report, Nuclear and Process Instrumentation, ORNL-TM-729, part IIB, Sect. 6.11 (in preparation).

for calculating reactivity and for accounting for the amount and location of fissionable materials. Information obtained from inventory instrumentation will also be valuable and necessary aid to operation.

The molten salt in the MSRE drain and storage tanks was inventoried by pneumatic weighing systems. These systems use diaphragm-type cells and automatic force-balance (negative feedback) principles of operation. Except for special piping connections that permitted operation under varying subatmospheric environmental pressures, the weighing systems were standard commercial items. This system is not affected by radiation, is insensitive to varying ambient pressure, and is relatively insensitive to varying ambient temperature at $< 150^{\circ}\text{F}$. The basic principle of operation and method of installation of this system are such that its sensitivity and span calibration can be checked during reactor operation at a control panel outside the containment and the biological shields. A disadvantage of the system is that it requires several pneumatic tubing penetrations of the containment, and these must be guarded by safety block valves. Except for some difficulties with drift of the zero setting, which were probably due to changes in pipe loading, and with some peripheral equipment, the performance of the MSRE systems was acceptable. Although the measurement accuracy of weighing systems might be lessened by shifts of the zero setting due to pipe loading, the weighing system offers the best possibility for accurate determination of MSBR salt inventory where environmental conditions and total tank weights permit its use.

Tank inventories could also be determined by measurement of level, although this measurement requires correction for tank geometry and salt density. Also, as discussed previously, additional level system development would be required unless measurements of tank inventories are to be made under static pressure conditions and a continuous gas purge into the tanks can be tolerated. It is possible that a combination of level and weight measurements will be required to obtain a total salt inventory. Present indications are that the tare and live loads of the main MSBR drain tanks and the ambient temperatures in the cells in which these tanks are to be installed will preclude use of the MSRE system for measurement of salt inventories in these tanks.

The pneumatic weigh cells used in the MSRE were the largest that were commercially available at the time. Larger cell capacities are possible, but a considerable amount of redesign and developmental testing would be required to obtain significant increases in individual cell capacity. Although a number of "brute force" design techniques, such as beam balance systems of multiple cells with mechanical averaging, could be used to obtain large weighing capacities, considerations of space and cost may preclude their use. Also, the 150°F maximum temperature rating of the pneumatic weigh cells prevents their use at the $\geq 1000^{\circ}\text{F}$ ambient temperatures which may be present in the MSBR drain tank cell. One weigh system by a Swedish company shows considerable promise. The load cell in this system is essentially a transformer that makes use of the magnetic anisotropy in a magnetic

material under mechanical stress. The desirable features of the cell include its high load capacity, electrical output, solid-state structure, low output impedance, low sensitivity to temperature effects, and high output signal. Although the standard model load cell is not suitable for extended service in high level radiation or high temperature (1200°F) environments, information is available that indicates that adequate radiation resistance could probably be obtained by replacement of organic electrical insulation materials with inorganic materials. The maximum operating temperature might be satisfactorily extended by air cooling the load cells.

Another promising technique is the use of a NaK-filled load cell. Oil- and mercury-filled hydraulic systems having high load capacity and accuracy are commercially available. Substitution of NaK for oil should permit operation of the primary load cell at 1200°F. In this system, weight would be converted to NaK pressure, which would be transmitted via a capillary tube to a transducer located in a more hospitable environment.

One possible design would be to install vessel suspension rods through the containment overhead with bellows seals to weigh cells located above the biological shielding. Although this design would permit use of a variety of basic weighing systems, it would, however, introduce serious structural, operational, and maintenance problems. A variation would be to weigh a side tank rather than the entire tank, thereby easing the problem of load cell capacity. However, this variation would require removal of afterheat from the side tank and elimination of extraneous loads produced by stresses in piping connecting the side tank to the main tank.

9. CONTAINMENT PENETRATION SEALS

Electrical power and instrument signals were carried into MSRE containment by (1) mineral-insulated cables; (2) sheathed, glass-insulated, silicone-impregnated multiconductor cables with soldered hermetic seals inside the cell and with organic seals outside the cell; and (3) hermetically sealed connectors welded to the containment vessels. Seals were required on these cables at both ends and at the point of penetration to prevent escape of radioactive gases and particulates and to exclude moisture from the cables. Labor costs to install these seals were high. The performance of these seals was marginal. Development of new techniques will probably be required in the MSBR for furnace-heated containment areas. Extensive seal development will be required unless seals can be installed in a cool area. A seal different from that used in the MSRE will be required for thermocouple penetrations because the MSRE leadwire cable will not withstand the temperatures of furnace-heated cells.

10. GAS-SYSTEM CONTROL VALVES

Helium-purge flow and cover-gas pressures in the MSRE were controlled by throttling valves. Due to the low flow rates and pressure drops, the clearances in these valves were extremely small. These small clearances together with poor lubrication resulting from dry helium service and limitations imposed on the type and amount of lubricant that could be used were the apparent causes of trim galling that caused many of the valves to fail. The valve assembly procedures were improved, but additional work is needed to develop better valves for controlling small helium flows.

The MSRE operating experience indicated a need for a suitable means of controlling very low flow rates of helium contaminated with particulates and hydrocarbons. It is evident that similar conditions will exist in the MSBR and that conventional valves and flow elements will clog and stick in such service. Three lines of attack are suggested: (1) eliminate the contaminants, (2) develop special valves, and (3) develop other (and probably unorthodox) methods of controlling low flow rates of dirty helium.

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