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INSTRUMENTATION AND CONTROLS DEVELOPMENT FOR
MOLTEN-SALT BREEDER REACTORS

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ABSTRACT

Instrumentation in use in the MSRE provides a good basis for development of the instrumentation for large molten-salt breeder reactors. The development would involve primarily the testing and improvement of existing instrument components and systems. New or much improved devices are required for measuring flows and pressures of molten salts in the fuel and blanket circulating systems. No problems are foreseen that should delay the design or construction of a breeder reactor experiment.

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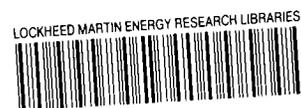
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Introduction

Operation of the Molten-Salt Reactor Experiment (MSRE) indicates that inadequate instrumentation should not become a barrier to further development of molten salt reactors. Most of the process instruments are standard industrial instruments. Some of them should be upgraded to provide the greater reliability and performance desired in a nuclear plant. The nuclear instruments are a new generation of solid state instruments. Normal evolution should provide even better equipment for future reactors. Operating experience has confirmed that some process instrument components for direct use in the molten fluoride salt are still developmental. A substantial program is required to convert those components into industrial grade instruments suitable for specification by an architect-engineer. Development of primary sensors for measuring process and nuclear variables in a highly radioactive, high temperature environment is particularly desirable.

The reference design of a molten salt breeder reactor (MSBR) is described in ORNL-3996 (Ref. 1). Criteria for a molten salt breeder experiment (MSBE) and a schedule for designing and building that reactor are presented in TM-1851 (Ref. 2). The instrumentation needed for those reactors has been examined by comparison with the MSRE and with emphasis on problems associated with heating the reactor salt systems in an oven. A program is proposed for development of instrumentation for the MSBE. The proposal does not include a discussion of control rods or other means of reactivity control; this is included in TM-1855, Component Development Program. A goal of this development is to provide instrumentation that requires only the normal improvement to be completely satisfactory for the full scale MSBR.

Instrumenting the MSBE

It is convenient and appropriate to discuss the instrumentation

of the MSBE (or any other reactor which is an extrapolation of MSRE-developed know-how) by subdividing the complete instrument system thus:

1. Nuclear instrument components and systems.
2. Process type instrument components for direct application to molten-salt loops.
3. Process type instruments required to operate auxiliaries.
4. Radiation monitoring (Health Physics) instrumentation.
5. Steam plant instrumentation.
6. Computer control and data logging.
7. Beryllium monitoring.
8. Reactivity control.
9. Component test and evaluation (new products, new methods, etc.)
10. Process radiation monitoring.

The following detailed discussion of these categories constitutes a preliminary appraisal of the anticipated development engineering needed to provide an adequately instrumented MSBE.

Nuclear Instrument Components and Systems

The MSRE employs two wide range counting channels and a BF₃ channel for startup control and unambiguous power measurement over the entire operating range of the reactor. Two linear current channels, deriving their input signals from compensated ionization chambers, are equipped with range changing devices and are used in conjunction with temperature measurements for automatic control of reactor power. Three linear level safety channels using non-compensated ionization chambers provide high flux scram signals for the safety system.

A majority of the electronic components which make up these nuclear instrument channels are ORNL's recently developed line of solid state, modular components designed specifically for reactor control and safety. The performance of these instrument

modules, as individual units, has been uniformly excellent; the performance of the sub-systems or control channels which are formed by assembling and interconnecting the modules has been equally good. These instruments, in their present state of development and measured by today's standards, are satisfactory; however, continuing engineering development is foreseen which will take advantage of the rapid and continuous evolution of instrument and control system technology. The development of new modules and circuits will be required to meet those safety and control requirements peculiar to the MSBE. In addition, it is anticipated that interfacing the modular nuclear instrumentation with non-modular process equipment will require development of special components. The use of a digital computer in the MSBE system will require development of suitable interfacing equipment in the modular line.

All neutron sensors used in the MSRE are in a water-filled penetration whose temperature does not exceed 160°F. While the presently available sensors are quite satisfactory in such an environment, they could not be used without major modification at a considerably higher temperature. Considerable development will be required to provide sensors and sensor positioning equipment capable of reliable operation in the severe temperature environment of the MSBE reactor cell. Special shielding problems appear to be unavoidable because of the presence of large amounts of highly radioactive salts circulating outside the reactor.

Although development of control rods or other means of reactivity control is not a part of the instrument development program, the requirements for nuclear instrumentation will be strongly affected by the design and performance characteristics of the reactivity control device used. To insure that satisfactory overall system performance is obtained with minimum interface equipment, these two programs must be strongly coordinated.

Process Instrument Components for Direct Application
to Molten-Salt Loops

Reliable, accurate, and reasonably priced sensors to measure flows, pressures, levels, weights and temperatures of molten salt in pipes, tubes, and tanks will be required for the MSBE.

Several developmental instruments have been in use on the MSRE with varying degrees of success. Performance of these instruments has been encouraging; however, in some cases there is need for further development to obtain improvements in performance, reduction in cost, or both. In other cases, satisfactory instrumentation is either not presently available or the type of instrumentation used on the MSRE would not be satisfactory for MSBE service. In particular, the use of the furnace type heating presently planned for MSBE reactor and drain cells would preclude the use of some devices and techniques that were used successfully on the MSRE. Also, the electrical conductivity of the MSBE salts⁽¹⁾ will have a significant effect on the type of primary sensing elements that can be used on the heated salt systems. An order of magnitude decrease in the conductivity could preclude the use of some devices presently in use on the MSRE. Conversely a significant increase in conductivity would result in better performance of existing devices and possibly permit the use of techniques (such as magnetic flowmeter) that could not be used in the MSRE.

It is expected that many of the problems in instrumenting the MSBE reactor systems will be common to those encountered in instrumenting the MSBE chemical processing plant. To avoid duplication of effort, the development of instrumentation for the reactor system will be coordinated with the development of instrumentation for the chemical processing plant. Techniques and instrumentation used for measurement of process variables in MSRE molten salt loops and areas where additional development may be required for the MSBE are discussed in the following paragraphs.

(1) Conductivities of MSBE salts are not presently known.

Flow Measurement

The flowrate of molten salt in the MSRE coolant salt system is measured by means of a venturi meter section. The venturi operates at system temperature and the differential pressure developed in the venturi is measured by a high-temperature, NaK-filled differential pressure transmitter. Except for some initial trouble with one of the two NaK-filled D/P transmitters installed, performance of this system has been adequate and this type of system would probably be acceptable for similar service on the MSBE.

Fuel salt flow is not measured in the MSRE because there is no acceptable flowmeter available for this service at this time. The system used for MSRE coolant salt flow measurements was not acceptable for fuel salt flow measurement because of the possibility of release of NaK into the fuel bearing salt with the resultant possibility of uranium precipitation. This consideration might not apply to the MSBE if the volume of NaK is very small in comparison with the volume of salt; however, even if this objection were removed, additional development would be required to use the venturi, NaK-filled D/P transmitter system for measurement of fuel salt flow in either the MSRE or the MSBE. The problems involved are common to those discussed under Differential Pressure Measurement.

If measurement of flow rates of fuel salt in the MSBE is required, a suitable flowmeter must be developed for this service. As mentioned previously, the present technique might be adopted if the possibility of a NaK release into the salt can be tolerated. Ultrasonic techniques offer promise for molten salt measurement. The Dynasonics Corporation is presently marketing an ultrasonic flowmeter which is capable of measuring flows in lines from one to six inches diameter. Since this instrument has piezo-electric transducers mounted on the transmitter body, it is limited to process temperatures below 500°F and is probably not suitable for use in high level nuclear radiation environment. However, a good possibility exists that these limitations can be eliminated by using the force insensitive mount techniques (developed by Aeroprojects Inc., and used in the MSRE fuel storage tank level probe) to permit the heat and radiation sensitive components to be

located outside the reactor containment and shielding. The resultant flowmeter would be capable of operating at temperatures in excess of 1300°F and would be compatible with reactor environmental conditions and containment requirements. It would be of all welded construction and would not require electrical or piping penetration of the meter body or of the containment vessel.

Other, less promising devices that should be considered for measurement of molten-salt flow are the turbine and magnetic type flowmeters. Both of these flowmeter types can be constructed for high temperature service and both have been used in liquid metal systems with varying degrees of success; however, neither has been successfully used in molten-salt service.

A turbine type flowmeter was developed for the ANP program and operated satisfactorily at 1600°F for a short period before failure. The major problem in the development of a flowmeter of this type is the high temperature physical properties of the turbine blade and bearing materials. Although the ANP development effort was not successful, it is possible that the use of improved materials now available, together with the lower MSBE temperatures might permit development of a flowmeter for MSBE service.

Magnetic flowmeters have been used extensively at high temperatures (1600°F) in liquid metal system and lower temperatures for measurement of a variety of fluid flows. This type of flowmeter could not be used in the MSRE because of consideration of containment, materials compatibility, and molten-salt conductivity. Containment and material compatibility considerations prevented the use of electrical lead-through penetrations of the meter body such as used in conventional magnetic flowmeter construction and the relatively poor (1 mho/cm) conductivity of the molten-salt prevented measurement of signal voltage at the outside surface of the meter body as is done in liquid metal flowmeters. If the conductivities of MSBE salts were found to be greater than that of the MSRE salt by a factor of 1000 or more, liquid-metal magnetic-flowmeter techniques could be used for measurement of molten-salt flow. Development of satisfactory electrical lead-through penetrations would permit development of magnetic flowmeters

for molten-salt service regardless of salt conductivity.

Salt Inventory

Inventory of the amount of molten salt in the MSRE drain and storage tanks is obtained by means of pneumatic weighing systems manufactured by the A. H. Emery Company. These systems use diaphragm type weigh cell and null balance principles and, except for some special piping connections that permit operation under conditions of varying sub-atmospheric environment pressure, are standard commercial items. This type of system is inherently radiation resistant, is not sensitive to the effects of varying ambient pressure, and is relatively insensitive to ambient temperature variations below 150°F. The basic principle of operation and method of installation are such that the sensitivity and span calibration can be checked during reactor operations at a control panel located outside the containment and the biological shield. It has the disadvantage of requiring a number of pneumatic tubing penetrations of the containment which must be guarded by safety block valves. Except for some difficulties with zero drift and with some peripheral equipment, the MSRE systems have performed acceptably. (Performance of similar systems used in the HRE-2 was also acceptable). The zero shifts are thought to be caused by changes in pipe loading rather than drift of the weigh cell system.

Although the accuracy of weighing systems may be limited by the zero shift effects produced by pipe loading, the weigh system approach appears to offer the best possibility for accurate determination of MSRE salt inventory in those applications where environmental conditions and total tank weights are such as to permit its use. Tank inventories could also be determined by measurement of level; however, this approach requires the use of corrections for tank geometry and salt density. Also, as discussed below, additional level system development would be required unless measurements of tank inventory are made under static pressure conditions and unless 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 MSBE drain tanks, and the ambient temperatures in the cells in which these tanks are located, will be such as to preclude direct use of the type of system used in MSRE for measurement of salt inventories in these tanks.

The pneumatic weigh cells used in the MSRE are the largest that Emery has produced. Larger cell capacities are possible but a considerable amount of re-design 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 (leverage) systems of multiple cells with mechanical averaging, could be used to obtain large weighing capacities, considerations of space and cost may preclude the use of such techniques. Also, the 150°F maximum temperature rating of the pneumatic weigh cells precludes their use in the 1200°F ambient expected in the MSBE drain tank cells.

A number of other weighing devices are commercially available which could be used for weighing of large tanks but all of those considered to date have characteristics which preclude or seriously limit their operation under reactor environmental conditions. One weigh system, offered by a Swedish company (ASEA), has considerable promise.⁽²⁾ The load cell in this system is essentially a misdesigned transformer utilizing the magnetic anisotropy which occurs in a magnetic material under mechanical stress. 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. The standard model ASEA load cell is not suitable for extended service in high level radiation or high temperature (1200°F) environments; however, available information indicates that adequate radiation resistance could be obtained by replacement of organic electrical insulation materials with inorganic materials and that the maximum operating temperature might be extended to the point where satisfactory operation could be obtained by air cooling the load cells. However, extensive laboratory and field testing should be performed on radiation-resistant high-temperature equipment before committing the reactor system design to the use of this device.

(2) The ASEA system was seriously considered for the MSRE but a program to evaluate it was abandoned because of the press of time and procurement problems rising from the "Buy America" act.

Another promising technique (which would require development) would be the use of a NaK filled (hydraulic) 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. The principle in this case would be similar to that of the NaK-filled pressure and differential pressure cells discussed below.

In some cases it may be possible to ease the requirements on the basic weighing system by a suitable design of the reactor system. One possible, but not particularly promising approach would be to bring suspension rods through containment (with bellows seals) to weigh cells located above the biological shielding. This approach would permit the use of variety of basic weighing systems but would introduce serious structural, operational, and maintenance problems. Another more promising approach would involve weighing of a side tank rather than the entire tank. This approach would ease the problem of load cell capacity but not the ambient temperature problem. Possible problems with this approach includes 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. In any case, it is anticipated that considerable coordination of design and development will be required to obtain accurate inventory measurements.

Temperature Measurement

The temperature of heated pipes and vessels in the MSRE are measured by means of mineral-insulated, Inconel-sheathed, Chromel-Alumel thermocouples. Results of developmental tests and observation of 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 drift rate of less than $2^\circ\text{F}/\text{year}$ can be obtained at operating temperatures in the range of 0-1300°F if couples are selected and calibrated and if attention is paid to details during design, fabrication, and installation. Errors of $\pm 8^\circ\text{F}$ under static and protected conditions may result if a

standard grade of wire is used and normal installation practices are followed and errors can be even greater if the couples are exposed to moving air or are directly exposed to electrical heaters.

Since the MSBE temperatures will not be significantly greater than those encountered in the MSRE, the materials and basic techniques used for measurement of MSRE temperatures should be adequate for MSBE installations. The use of the furnace concept for heating of reactor and drain cells will, however, introduce problems which will necessitate further development of in-cell lead-wire, disconnects, and containment penetration seals. Also, if accuracies greater than those obtained in the MSRE are needed, additional development will be required. Further development effort could also be profitably applied in the areas of thermocouple attachment, investigation of the feasibility and desirability of using infra-red photography or radiation pyrometry techniques, and the measurement of small differential temperatures at elevated temperatures.

The thermocouple attachment techniques used on the MSRE would probably be satisfactory for most and possibly for all MSBE thermocouple attachments; however, the methods used on the MSRE are time consuming and costly, and small improvements in techniques could yield large dividends where large numbers of couples are required. (Over 1000 thermocouples were installed on the MSRE.)

Multiconductor, glass-insulated, silicone-impregnated, copper-sheathed thermocouple cables are used in the MSRE between the in-cell disconnects and the out-of-cell junction boxes. These cables penetrate the containment and are sealed. This sealing introduced problems because of the effort involved and because of pressure buildup produced by outgassing of the silicone-insulating materials. This type of wiring will not be useable in the MSBE if the furnace concept is used for heating the reactor and drain tank cells. The expected 1200°F ambient in these cells will require the use of inorganic insulated leadwire. Furnace heating of the cells will also require protective sheathing of all in-cell thermocouple wiring and the development of disconnect devices which are compatible with the furnace atmosphere and with remote maintenance requirements. Multiconductor, mineral-insulated, sheathed-

thermocouple cable assemblies were considered for in-cell leadwire and containment penetration service at the start of MSRE design, but this approach was abandoned because of high costs and the difficulty of fabricating satisfactory end seals. The cost of this type cable is now reduced and their use should be re-evaluated. The major problem involved in the use of mineral-insulated thermocouple cable for penetration of containments would be the development of satisfactory methods of sealing the ends of the cable. Although the development and fabrication of end seals and techniques for installation of multiconductor cable will be much more difficult than would be the case if thermocouples were brought out through individual penetrations, it is expected that the reduction in the number of penetrations, which would be obtained by using multiconductor cable will more than justify the additional cost. However, other considerations such as maintenance requirements could necessitate the use of individual penetrations. Therefore, both approaches must be considered initially.

The use of infra-red photographic and radiation pyrometry techniques offers the possibility of mapping of temperature contours on large exposed surfaces (such as the MSBE reactor vessel). On-line viewing of temperature distribution might be obtained by viewing a heated system with a closed-circuit television camera equipped with an infra-red filter. A more accurate determination of temperature profile might be obtained by mechanically maneuvering a radiation pyrometer to produce a scan pattern similar to the raster produced on a television screen. Since the feasibility of using these techniques would be strongly dependent on the physical geometry of the system viewed and of the surrounding area, investigation of feasibility and development of equipment and techniques should be performed before the start of design of the system on the facility.

The problem of measurement of small differences in large temperatures has not been satisfactorily solved. The accuracies obtainable by using series-opposed (bucking) thermocouples, and extreme care in design and installation, are barely adequate for MSRE purposes and might be inadequate for the MSBE. There is room for a considerable amount of original work in this field. Several

commercially available, high-temperature resistance elements were tested to determine the feasibility of using such elements for precise measurements at high temperatures. Results were, in general, disappointing but the performance of one unit was sufficiently encouraging to lend support to the belief that a suitable resistance element could be developed.

A possibility exists that differential temperatures could be measured by use of ultra-sonic techniques. One company (Aeroprojects, Inc.) is presently investigating the feasibility of the ultrasonic measurement of absolute temperatures. Representatives of that company⁽³⁾ have expressed the opinion that accurate differential temperature measurements could be made by means of ultrasonic devices.

Level Measurement

Several methods have been successfully used for single point and continuous measurement of molten salt level in the MSRE. All those methods could be used in the MSBE under similar conditions; however, all have limitations which would preclude their use under certain conditions.

Continuous measurements of molten salt level in the MSRE coolant system pump bowls are made by means of "bubbler" type (dip tube) and float type level systems. Continuous measurement of molten salt level in the fuel pump bowl is also made by means of a "bubbler" type system and a future pump installation will include a float level transmitter.

Two-level, single-point measurements of molten salt level in the MSRE fuel and coolant system drain tank are made by means of conductivity type level probes. The information obtained from these probes is used to check the performance and calibration of the tank weighing systems. The probe signals operate lamps (or other binary devices) which indicate whether the level is above or below two pre-selected points.

An ultra-sonic level probe is used for single-point measurement of level in the fuel storage tank. Except that the ultrasonic probe presently installed is a one-level device, the information obtained

(3) Personal communication, Mr. Kartluke and Dr. Boyd to R. L. Moore.

from the ultrasonic probe is identical to that obtained from the conductivity type probe and is used for the same purpose.

All of the systems used for measurement of molten-salt level in the MSRE were specially developed for the service and further development or re-design would be required for other applications. The "bubbler" system is basically the simplest and most versatile method of measuring molten salt level under relatively static conditions of level and cover gas pressure. This type of system can be used for narrow or wide ranges and the vessel modifications required to install the system are simple and inexpensive. However, since the "bubbler" system performance is dependent on maintaining a gas purge flow through the dip tube, this system can only be used where the purge can be tolerated. Also, the response characteristics of this type system are dependent on the purge flow rate which, in turn, is dependent on 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 and fast variations in cover gas pressure, such as can occur in the drain tanks and pump bowl during filling and draining operations, can render the system inoperative unless accompanied by corresponding changes in purge flow rate. The desirability of using presently developed "bubbler" techniques for measurement of levels in systems containing highly radioactive liquids and gases is considerably reduced by the necessity of providing adequate means to detect and prevent the release of activity through the purge line. Development of a system wherein the purge gas would be recycled within primary and secondary containment would greatly extend the usefulness of this type of system.

The float type level system offers the best method of continuous measurement of molten salt levels over narrow ranges. This device is completely contained, has fast response, and requires only electrical penetrations of secondary containment. Present designs are limited to measurement spans less than ten inches. The span can be extended but this type of device is basically more suited to low span than to high span measurements.

The conductivity type level probe has performed well in MSRE service. With the possible exception of redesign of the tank penetration to improve containment the present probe design could be easily adapted to installations in MSBE tanks. The MSRE conductivity probe has the disadvantage of having (and requiring) thin walls in the tubes extending into the tank. This type of device is therefore not suitable for use in corrosive environments such as that in the MSRE fuel storage tank.

The output signal obtained from the MSRE conductivity probes was much greater than had been expected. Since the output signal is much greater than required the possibility exists that a more rugged and corrosion resistant single point probe could be developed (by increasing tube wall thickness) and that a continuous type conductivity probe (similar to the "I" or "J" tubes used in liquid metal systems) could be developed. An increase in the electrical conductivity of the salt (over that of the MSRE salt) would result in either better single point probe design or improved prospects of using the conductivity probes for continuous level measurement. Conversely a significant decrease in electrical conductivity could prevent the use of the conductivity probe for either single point or continuous measurement.

Except for some problems with oscillator frequency drift which caused the instrument to become inoperative, the performance of the Aeroprojects ultrasonic level probe has been dependable and accurate. Some additional development will be required in the area of main chassis electronics and packaging before this device can be considered to be a reactor grade instrument; however, the remaining problems with this instrument appear to be amenable to solution by routine re-design and development testing.

The Aeroprojects single-point ultrasonic level probe is considerably more rugged and corrosion resistant than the conductivity type probe and, when the remaining problems are solved, should be the preferred method of single-point level measurement in installations where the technique is applicable.

Aeroprojects has done some work on development of a continuous ultrasonic level probe. Such a level probe would be very useful in

molten salt systems (and in aqueous and liquid metal systems) and development of this device should be supported.

An obvious method of level measurement which should be considered for possible use in the MSBE is the direct measurement of level by the differential (head) pressure method. This method was not used in the MSRE because a suitable device for measuring differential pressure was not available. The problems associated with measurement of differential pressures in molten salt systems are discussed below.

With the possible exception of the differential (head) pressure method, all of the methods discussed above are compatible with the concept of furnace heating of reactor and drain tank cells. The float type transmitter is especially attractive since the transformer and other parts of this device not only can but are required to operate at (or near) system temperature. The conductivity and ultrasonic probes might possibly be used in a furnace atmosphere in their present form; however, some additional development work on leadwire, penetrations, and disconnects will probably be desirable.

Pressure Measurement

Pressures in the MSRE molten salt loops are obtained indirectly by measuring the pressures in gas purge or supply lines connected to drain tank and pump bowl gas spaces. The pressures measured in the MSRE are, therefore, those of the cover gas and not of the salt.

The techniques used for measurement of cover gas pressures in the MSRE may or may not be applicable to larger reactors of different design. In any event there is no pressure measuring device available that is suitable in its present form for directly measuring pressures (or differential pressures) of the fuel salt. Also the system used could be strongly effected by the method of heating of lines and vessels. The use of oven type heating would impose the additional restriction (over those encountered in the MSRE) that all components of the pressure transmitters be located outside the heated zone or be capable of operating at the temperatures present in the oven.

Measurement of cover gas pressure in the MSBE would require little additional development if the indirect methods can be used as in the MSRE. However, considerable additional development would be

required for measuring salt pressures since part or all of the pressure measuring device would have to be located within containment and biological shielding in close proximity to the pressure tap and would have to be capable of withstanding the environmental effects of temperature, radiation and varying ambient pressure.

The pressure transmitters presently used in the MSRE or equivalent devices constructed in accordance with the same specification should be adequate for measurement of cover gas pressure by the indirect method. NaK-filled pressure transmitters offer the best prospects for direct measurement of cover gas or fluid pressures in molten salt systems. Use of this type of device would require acceptance of the possibility of release of a small quantity of NaK into the system in the event of a rupture of the seal diaphragm. Also, additional development would be required to obtain adequate containment if the transmitting element is located outside of the reactor secondary containment or to reduce the environment effects of temperature, radiation, and varying ambient pressure to acceptable levels if the entire transmitter is located inside reactor secondary containment and biological shielding.

Another, less promising, approach is offered by the possibility of adapting a thermionic diode type of pressure transmitter, which is presently being developed for use in high temperature liquid metal systems, for use in molten salt systems. The progress of this and other developments in liquid metal system instrumentation should be followed to determine whether they can be applied to molten salt systems.

Differential Pressure Measurement

With the possible exception of the measurement of pressure drop across the charcoal beds, all differential pressure measurements made in the MSRE molten salt system were for the purpose of measuring flows of gas or molten salt. No direct differential pressure measurements were made in the liquid portion of the MSRE fuel salt system. The performance of the differential pressure transmitters for measuring gas flow was satisfactory and no additional development is needed in this area. As mentioned above, some difficulties were experienced

with one of the two NaK-filled differential pressure cells used for measuring salt flow during initial operations of the MSRE. The performance of the other transmitter originally installed and of the replacement for the defective transmitter has been satisfactory and this type transmitter would probably be acceptable for similar service on the MSBE. While two of the three NaK filled D/P transmitters purchased for the MSRE have performed satisfactorily, the difficulties experienced with the third transmitter and with a spare recently purchased (as well as with procurement on all four) indicate that an alternate source of supply should be developed. A NaK filled transmitter is now being offered by Barton Instrument Corporation but this instrument is not reactor grade and performance has not been tested at ORNL.

The problems associated with making direct measurement of differential pressures in the liquid-filled portion of the MSBE fuel salt are similar to those discussed above for measuring pressure under similar conditions. The main differences in the two problems are that the differential pressure transmitter is not affected by variations in ambient pressure and usually is required to measure much smaller variations in pressure. 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. For example, determination of the inventory of MSRE drain tanks by measurement of level using the NaK-filled differential pressure transmitters presently available would not be a suitable substitute for the weigh system now in use. However, if the performance of the transmitters were sufficiently improved by further development, level measurement might be considered an acceptable alternative to weighing.

As in the case of the pressure transmitters, another, but less promising, approach to the problem of direct measurement of differential pressures in molten-salt systems is offered by the thermionic diode type elements presently under development for the liquid metals program.

Process Instruments to Operate Auxiliary Sub-Systems

These are the instruments used to measure and control auxiliaries such as process and cooling water, cooling and ventilating air flows, helium purge flows, etc. In most cases, instrumenting these systems is old art and presents no problems of consequence. Exceptions arise when system containment, remote handling, entrainment of foreign matter, intense radiation, extreme temperatures, and very low flow rates enter into the design. A typical example in the MSRE is the off-gas system discussed under Gas-System Control Valves. The experimental pump loops and ETU which will be built and operated in the near future will require instruments. This instrumentation, regardless of how conventional it is, should be designed to meet the criteria and conditions anticipated for the MSBE. The improved and tested instruments should be used on the MSBE and the cost of the improvement regarded as development expense.

Health Physics Radiation Monitoring

The MSRE is equipped with three (3) general types of radiation monitoring equipment. These are:

1. Monitrons to detect sources of gamma radiation.
2. Constant air monitors to detect airborne particulate sources of gamma and beta radiation.
3. Portable beta-gamma monitors.

A total of seven monitrons are used with six of these being interconnected so that if any two monitrons indicate a high radiation level, a building evacuation alarm is produced. Four of the seven constant air monitors are also used in a similar coincidence arrangement. The evacuation alarm originating from this coincidence circuitry is also transmitted to ORNL's Laboratory Emergency Control Center where appropriate emergency actions are initiated without waiting for further instructions from the alarmed site.

Several beta-gamma monitors are used to supplement the coverage of the permanent, fixed location monitors in areas less likely to experience excessive radiation levels. The beta-gamma monitors produce a local alarm signal only and are not connected to the general evacuation alarm system.

This equipment and the way it is used represent standard design practices at ORNL. The coincidence and switching circuitry is assembled from modules developed specifically for health-physics monitoring installations. These modules are in general use at ORNL and may be interconnected to produce a wide variety of coincidence arrangements depending on the particular installation.

The components making up the system are, for the most part, commercially available. No unusual criteria are anticipated for the MSBE which cannot be met by using typical and available health-physics instruments; hence, no development work is foreseen.

Steam Plant Instrumentation

It has been pointed out elsewhere in this report that the steam plant which extracts power from the MSBE will be modeled after TVA's Bull Run system. Such a plant exemplifies the prevailing trend to power generation with high temperature, supercritical pressure steam.

Public utilities, TVA, and the instrument manufacturers all have strong incentives to promote and develop the instruments and techniques required to operate supercritical steam systems. ORNL is reasonably confident that, when the time arrives to design the system and to specify the steam power plant instruments, this technology will be approaching "standard practice" type of application engineering. It is fortuitous that TVA's Bull Run plant is virtually contiguous to ORNL and that they must, of necessity, develop a satisfactory plant. We expect to draw heavily on TVA experience augmented by developments elsewhere should they appear worthwhile.

It would be unwise at this time for us to dilute our efforts elsewhere by engaging in development engineering for steam system instrumentation.

The heat exchange interface between the steam plant and the molten salt may provide problems. It is too early to draw firm conclusions but it cannot be assumed that instrument design for this portion of the MSBE will be routine and conventional. Design criteria, loop and mockup tests should disclose any need to test and evaluate critical components.

Computer Control and Data Logging

MSRE instrumentation includes a digital data logger and computer which is supplementing the more conventional instruments making up the primary measurement and control system.

The data logger collects and stores information from up to 350 field-mounted instruments of all types. These instruments are scanned at 5-second intervals and selected groups of the numerical readings are automatically printed on log sheets in the appropriate engineering units once every hour, 4 hours, and 8 hours, or at any time, should the operator so request. Out-of-limit alarms are actuated if any one of the 350 data points goes beyond acceptable values in either the high or low direction. If the out-of-limit point or points are critical for good operation, the logger will scan a selected group of 64 data points continuously at a repetition rate of five times per second until the reactor system is again within its proper limits.

The system is programmed to compute a reactivity balance once every hour or upon request of the operator.

Other typical programs now in use are:

1. Heat balance,
2. Cell average temperature,
3. Salt inventory,
4. Average reactor fuel and coolant radiator outlet temperature,
5. Nuclear average temperature,
6. Reactor cell evacuation volume,
7. ΔT at fuel inlet and lower head,
8. Fuel pump ΔT and minor thermal cycles.

The machine is also programmed as a temperature controller in an experimental creep stress facility (the Surveillance Test Rig) which is installed at the reactor site. This facility simulates and follows reactor temperatures and temperature gradients in the environment surrounding the creep test specimen.

The potential application of a digital computer in the reactor control system of the MSBE will be reviewed in detail. The most important basic questions which will require early study are:

- 1) To what extent should the system be controlled by the computer,
- 2) What will be the required reliability of the digital system, and
- 3) The degree and type of back-up control to be used in the event the primary system is rendered inoperative.

Detailed answers to the first question must be deferred until preliminary reactor system design has been completed; however, one basic objective may be stated. Control functions which have been satisfactorily handled by conventional analog control devices will not be converted to computer control unless there is strong economic and technical incentive and clear evidence of technical feasibility. Some pre-specification testing of the newer digital controllers would be advantageous.

The assessment of the required reliability will also depend on what exact control functions are assigned to the computer. It is likely that high reliability will be required and consequently schemes should be investigated which will result in a system with higher reliability than can be obtained with a single computer. An example is a two computer system in which the second machine is normally occupied with logging and computation of a non-vital nature and could be called on a priority basis to serve as a controller when the main computer fails or is down for maintenance.

The basic approach to these questions and the detailed design problems in general will be much better founded within the next few months. By mid-year (FY-68) the HFIR control computer will be installed and the results of the preliminary control experiments will be available. In addition about six months of computer and interface operating experience will have been logged.

Computer control of the testing process, along with computer techniques to analyze the system loops based on the ever present process noise level, are attractive possibilities which should be explored. Such techniques, if successful, would pay off well in terms of improved reliability.

The application of the Bunker-Ramo 340 computer on the MSRE has demonstrated the desirability of providing this type of on-line

data acquisition and computation system to assist with the operation and analysis of such large complicated engineering experiments. To aid in further analysis of the benefits of on-line computers, several experiments and demonstrations are planned to gather additional information and verify some theories on the use of this type of computer for process control of reactor system auxiliary devices such as heaters, etc.

The shakedown problems experienced while putting the MSRE computer into operation suggest several areas which should be investigated prior to the application of a similar computer system on the MSBE. These potential trouble areas are all in the analog signal handling part of the system and have to do with 1) noise rejection and filtering of the input signals, 2) analog input signal commutation, and 3) generation of analog output signals. Each of these problems is primarily economic in nature and though the MSRE computer does an adequate job in these three areas, computer system costs on a larger system such as would be required for the MSBE would be very high if more economical ways to do these jobs are not found. For instance, an approximate cost to handle input signals on the MSRE computer is more than \$100 per process variable. A conservative estimate of the number of signals to be brought into a computer on the MSBE would be 2000, which emphasizes the need for finding ways to reduce the input signal handling costs.

The study of possible use of multiple small computers instead of one large computer should also be done with the actual application of one of the smallest computers to a mock-up or test stand in the early part of the MSBE program. In this way, it may be possible to avoid over-specifying or under-specifying the MSBE computer. The actual experience of applying such a computer is needed

Beryllium Monitoring

The two beryllium monitors presently in use at the MSRE are intended to detect airborne beryllium from systems not sufficiently radioactive to permit detection by activity monitoring. One is an air sampling system which requires laboratory analysis, while the other is a nearly continuous monitor in the radiator air stack.

The air sampler uses a suction pump to draw air through filter papers located at fifteen strategically placed collecting stations. After a suitable interval for sample collection, the filter papers are spectrographically analyzed for beryllium content.

The exhaust air from the radiator stack is monitored and the results recorded almost continuously by an on-line spectrograph. This instrument, at 1-1/2 minute intervals, automatically strikes an arc in a small bypass stream of air pumped from the stack and the light output is examined photoelectrically for the characteristic line produced by beryllium.

Although the filter paper sampler has worked satisfactorily, it is limited in scope in that the information is delayed. The on-line monitor is a developmental device which has demonstrated a principle but has not provided the required degree of reliability for this type application.

The MSBE will most likely employ non-beryllium-bearing coolant salt; if so, no beryllium monitor will be needed for the reactor system. However, the ETU, the chemical processing plant, and the fuel processing facility will have large amounts of beryllium. Consequently there exists a need for a monitor having better performance than can be obtained from those presently in use. Development work will be continued toward achieving a reliable continuous on-line monitor.

Component Test and Evaluation

General

New devices are continuously appearing on the market, yet there is no general program for testing and evaluating these devices at ORNL. General Electric, Motorola, Taylor and Minneapolis-Honeywell are now offering systems which are in strong competition with the Foxboro ECI system used extensively in the MSRE. We must know more about these systems if we are to evaluate bids properly and assure ourselves that the components and instruments selected are the best choice for the job.

Electrical Control Circuit Components

Performance of all reactor systems is strongly dependent on the performance characteristics of all components of electrical control and alarm circuit. Reliability is of particular importance since the large number of control circuit components dictates that the reliability of each individual component be extremely high in order to obtain an acceptable overall system reliability. Poor system reliability will result in frequent shutdowns which in turn will result in low plant availability. To insure that adequate control component performance will be obtained a program of test and evaluation of control components is needed. The scope of this program would include testing and/or evaluation of such components as relays, control switches, wire terminals, connectors, indicator lamps, and annunciators.

Helium Flow Elements

In the MSRE, matrix type flow elements are used for measurement of gas flows and capillary tubes are used for restrictors. The performance of these devices has been very good; however, the procurement or fabrication of the devices required a great deal of engineering labor. A number of laminar flow elements are available commercially for a reasonably wide range of gas flows. These devices should be investigated to determine whether they would be an acceptable substitute for the devices now in use and whether they offer any significant advantages.

Gas-System Control Valves

Helium purge flow and cover-gas pressures in the MSRE are controlled by means of throttling valves. Due to the very low flows and pressure drops involved, the clearances in these valves are extremely small. These small clearances together with a lubricant problem were the apparent causes of trim galling which caused failures of a number of valves in MSRE service. The lubricant problem results from the need for cleanliness and from the lack of any lubricant in the dry helium which flows through the valves. Improvements have been made in valve assembly procedures which have resulted in a reduction

in the failure rate, but additional effort should be spent on developing better valves for control of small helium flows.

MSRE operating experience with the off-gas system revealed a possible future need for the suitable means to control very low flows of helium contaminated with solid particulate material and with hydrocarbons, in all phases, originating with the salt pump lubricant. It is a foregone conclusion that conventional valves and flow elements will clog and stick in this service. Unless it is certain that the MSBE will not generate similar flow and pressure control problems, a solution is required. Three lines of attack are suggested: First (and best), eliminate the problem at its source; second, develop valves which will do the job; third, develop other, and probably unorthodox, methods of handling small flows of dirty helium. Development work on these problems will be done in cooperation with the program of development and testing the off-gas system.

Temperature Scanners

A scanning system was developed for use in scanning temperatures on heated pipes and vessels in the MSRE, displaying a profile of the temperature on a cathode ray oscilloscope and producing an alarm if any temperature is outside the pre-set limits. Similar or equivalent systems will undoubtedly be desirable for the MSBE.

The performance of the MSRE system has been very satisfactory. The signals are scanned by a mercury jet commutator switch. Since the commutator switch used in the MSRE is no longer commercially available, another source of supply of switches or an alternative scanning device must be developed if this type system is used on the MSBE. The use of reed relay or transistor switches for this service offers promise and should be investigated. The use of solid state commutators or multiplexers is increasing. It is likely that all the components required to assemble a scanning system will be commercially available in the near future. In developing a suitable scanning system for the MSBE, the test loops and mockups of the reactor system can be used advantageously.

As an alternative to the MSRE type scanning system, or an improvement, the feasibility of using a computer data-logger system for scanning temperatures should be investigated. Comparison of the two methods should be based on considerations of cost and operational requirements.

Containment Penetration Seals

Electrical instrument signal penetrations in the MSRE were made by means of mineral-insulated cables; by sheathed, glass-insulated, silicone-impregnated multiconductor cables with soldered hermetic seals inside the cell and with organic seals outside the cell; and by hermetically sealed connectors welded to the containment vessels. Labor costs to install these seals were high and their performance has been marginal. The techniques used on the MSRE could be used on the MSBE if environmental conditions were similar; however, development of new techniques would probably be required if large systems were heated in an oven rather than by heaters attached to the equipment. The amount of effort required to develop satisfactory seals for contained, oven-heated, areas will be strongly dependent on the design of the containment vessel and the oven. Extensive seal development will be required unless the design is such that the oven wall is not the containment wall (i.e. unless seals can be located in a cool area). As a minimum, a different type of seal will be required for thermocouple penetrations since the type of leadwire cable used in the MSRE is not compatible with the oven heating concept. In any event, a program is needed to study and develop better methods of making electrical penetrations into the containment and to evaluate hardware.

Temperature Alarm Switches

A number of alarm, interlock, and control actions in the MSRE are accomplished by means of bi-stable magnetic amplifier-type switch modules that were manufactured by Electra Systems, Inc. A considerable amount of trouble was experienced with these devices during initial operation of the MSRE. Investigations showed that several defects

existed in the modules and modifications were made in all modules.

At this time, the performance of the modules is being observed to determine whether all causes of troubles have been eliminated. Regardless of the results of these observations, there is need for significant improvement in the design of sensitive switches of this general type. For example, a sensitive switch providing a null balance type high impedance input with cold junction compensation should be made available. Since Electra Systems does not offer the unit anymore, we should develop other sources of supply. For critical service, a unit constructed using the input stage of a Foxboro EMF/I converter and components of the Foxboro ECI switch would be preferable to the Electra Systems module.

The MSRE has disclosed a general need for improved small signal limit switching devices of this general type. These switches should be capable of being used with input signals in the millivolt and milliamperere region; operate consistently and reliably on small signal changes and be relatively insensitive to changes in line voltage and ambient temperature. For example, on-off limit switching in the MSRE is desirable over a 25°F or less temperature increment at average temperatures of 1200°F. This is only a 2% change and represents a severe challenge to existing methods. As a very minimum, a program to evaluate the state of the art as it is developing is needed.

Process Radiation Monitoring

The radiation level of many flows which enter or leave the MSRE containment are continuously monitored. These are lines carrying helium, off gas, cooling water, etc., and should a monitored line indicate excessive radiation, the usual control system action is to close block valves as required.

A typical arrangement calls for two or more ion chambers in a lead shield around the pipe being monitored. Where system safety is involved this redundancy is carried all the way from the ion chamber through the control system output action. When on-line testing without system perturbation is required, the redundancy is two out of three.

The signals from the ion chambers are amplified by vacuum tube electrometers whose outputs are used for alarm and control signals. The foregoing is representative of standard radiation monitoring practice today, but it is not one which is exploiting the relatively recent advances in solid state electronics. It has the merit that it is relatively immune to large overload signals but the disadvantage that frequent calibration and reference point checking is required.

Based on experience at the MSRE, a substantial program to improve process radiation monitoring methods and components is under way. The advent of reliable solid state current sensors has enabled the design of a system using the pulse mode of operation of G-M tubes, thereby eliminating the need for frequent reference level calibration and permitting long, uninterrupted cable runs to a central control area. A prototype has been built and laboratory tested. Complete engineering drawings and specifications are available. This pulse mode equipment appears to be particularly attractive where reliability is the primary consideration but its performance must be verified by field testing. The materials of construction of the probe, however, limit the environmental temperature to approximately 70°C for the sensor.

For critical applications involving high temperatures, high radiation levels, and wide variations in radiation levels, the ion chamber-current mode instruments will still be used. Modernization by conversion from vacuum tube to solid state electrometers and provision for analogue to digital output conversion is required. The need for better ceramic to metal seals and their application to ion chambers has been established. Better vacuum seals, coaxial connectors and radiation resistant high temperature cabling methods are required to provide economical, low maintenance, long lived, process radiation monitoring systems for the future.

Waste Effluent Monitoring

Some high level, intermediate level and low level aqueous wastes will be produced at the MSBE site. Standard practices will be used for

handling these wastes. Standard monitoring instrumentation such as that in common use at ORNL should be adequate. Gaseous effluent (off-gas and cell ventilation) will be disposed of through a stack. Standard packages for disposal stacks are available and will be used, but the nature of the installation would seem to make the final development of an additional device necessary.

The present scheme is to pass a sample of stack gas through a paper filter, a charcoal trap and a clean shielded volume in succession. Each of the devices is continuously monitored by a β - γ detector and the filter is also continuously monitored for alpha activity. This scheme separates the effluent material into a particulate component, a volatile component (adsorbable on charcoal) and a component which is rare gas. In case of a burst of activity, this system furnishes the first information as to the source and the extent of the incident. A sample taken directly from the stack is next analyzed in a lab for more definite information. The laboratory analysis may take an hour or longer before this information is available, however, and it is highly recommended that the development of a system using a detector at the top of the stack and a multichannel analyzer be completed. This will allow essentially instantaneous analysis of the effluent gas and is a necessary addition to the stack monitoring equipment for this project.

Estimate of Cost of Development Program

An estimate of the cost of the development is shown in Table 1.

Table 1. Estimate of Costs for Instrument Development

	FY-1968	1969	1970	1971	1972	1973	1974	1975
	(costs in thousands of dollars)							
Containment penetration seals	20	25	20	10	5	2	2	2
Helium control valves	15	15	13	10	10	1	1	1
Test and evaluation of process instruments	40	50	45	25	20	20	20	20
Level instruments	60	85	75	35	10	10	10	10
Pressure and differential pressure instruments	30	38	37	16	3	3	3	3
Ultrasonic flowmeter	15	35	32	15	5	5	5	5
Salt inventory systems	25	25	20	10	5	2	2	2
Temperature measuring instruments	50	60	50	25	12	3	3	3
Temperature scanner	5	30	25	12	5	3	3	2
Nuclear instruments	35	35	30	20	20	20	20	20
Test and evaluation of power plant instruments	0	0	6	10	10	5	5	5
Computer control and data logging systems	18	18	16	10	10	10	10	10
Beryllium monitoring	10	10	8	5	5	5	5	5
Process radiation monitoring	<u>20</u>	<u>40</u>	<u>20</u>	<u>10</u>	<u>5</u>	<u>5</u>	<u>5</u>	<u>5</u>
Total	343	466	397	213	125	94	94	93

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