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SODIUM PLUMBING

A Review of the Unclassified Research and
Technology Involving Sodium at the Oak Ridge
National Laboratory

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ABSTRACT

The research data and the development experience relevant to sodium obtained during the period 1950 to 1953 at the Oak Ridge National Laboratory are summarized. Methods for testing the corrosion resistance of structural metals in sodium and the results of such tests are presented. The developmental work that has been done on the various components of sodium systems is described, and the relative merits of commercially available components are discussed. Cleaning, assembly, leak testing, and operating techniques and precautions are given.

ACKNOWLEDGMENT

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By William B. Cottrell and Leland A. Mann

INTRODUCTION

The physical properties of sodium and NaK are such that these liquid metals¹ are particularly suitable as high-temperature heat transfer fluids. Consequently, a new technology for the handling of these materials has been developed over the past several years by numerous installations interested in their use. While the desirability of the use of sodium (and NaK)² as a heat transfer fluid will be accepted as a priori knowledge as far as this memorandum is concerned,³ the associated technology, as employed by the Oak Ridge National Laboratory, will be described herein. This memorandum, then, will extend and supplement the information that is available in the Liquid Metals Handbook. The various aspects of sodium plumbing as practiced at ORNL, including the selection of materials and design of pumps, valves, heat exchangers, and instruments, as well as operational safety precautions and techniques, such as cleaning, filling, sampling, and repairing, are described. It is hoped that this unclassified review of the Laboratory's experience in this field will be useful to those interested in the existing and potential applications of sodium.

1. NaK is a liquid at room temperature, while sodium (mp 208°F) is not.
2. Sodium and NaK systems are sufficiently similar that, unless otherwise mentioned, whatever is said about sodium also applies to NaK.
3. Of the numerous papers on the subject, the following are recommended:
R. N. Lyon (ed.), Liquid Metals Handbook, AEC-Department of the Navy, NAVEXOS P-733 (rev.), June 1952; Liquid Sodium as a Heat Transfer Medium, E. I. DuPont de Nemours and Co., SP 23-950 (not dated); F. C. Bennett, Liquid Sodium Heat Transfer, Dow Chemical Company, NP-514 (Sept. 29, 1948).

CORROSION OF STRUCTURAL METALS

The corrosion of structural metals by liquid sodium has been covered at some length in a number of reports, including the Liquid Metals Handbook, and will not be discussed at length here. However, the subject is of such importance in determining the construction materials of sodium systems that a brief resume of the Laboratory's work will be given.

The corrosion data have been obtained, to date, from one of four types of test apparatus: static capsules, rocking capsules, thermal convection loops, and rotating shafts in pots (as well as from the operation of experimental systems). The corrosion attack is usually evaluated by one or more of several tests, with metallographic study of photomicrographs being the most significant. In addition, dimensional and weight changes of corrosion specimens, changes in composition and/or crystalline structure of the metal surface, as well as changes in the composition of the liquid metal, are recognized tests for corrosion phenomena.

The most serious attack results from the presence of oxygen in the system. It makes little difference whether the oxygen is present in the sodium as a contaminant, in the inert blanketing gas used above the sodium, or in the scale (particularly weld scale) on the container; the oxygen combines with sodium to form Na_2O , which is very corrosive. The typical result is intergranular attack of the hottest sections of the loop (since the solubility of oxygen in sodium increases with temperature). Welds are particularly susceptible to attack unless strict attention is paid to the attainment of sound, clean welds.⁴

4. See section on "Welding," p. 16.

Another corrosion mechanism occasionally experienced with sodium is mass transfer. Mass transfer may be the consequence of galvanic action, such as occurs when dissimilar metals are used with sodium, or a thermodynamic effect due to the difference in solubility of the container wall in sodium at different temperatures. Since sodium has excellent electrical conductivity (as compared to most metals), no appreciable potential can be sustained, and the galvanic mass transfer with sodium is, in general, negligible. Mass transfer due to the temperature dependence of solubility is, however, of some consequence.

Test Facilities

Four corrosion test facilities are listed in Table 1 in the order of the fluid flow rates obtained therein. The order may not be the order of severity of the test, because, in addition to flow rate, corrosion may also depend upon the temperature gradient, the presence of more than one metal, and the surface-to-volume ratio in the test capsule. Typical values for flow of sodium, temperature drops from hot to cold parts of the liquid, and surface-to-volume ratios, that is, ratio of area of metal in contact with sodium to volume of sodium, are given in Table 1 for each of the four facilities for corrosion testing of metals in contact with liquid sodium.

Table 1

Typical Conditions in Facilities for Corrosion Testing of Metals in Contact with Liquid Sodium

<u>Apparatus</u>	<u>Sodium Flow Rate (fpm)</u>	<u>ΔT ($^{\circ}F$)</u>	<u>Surface-to-Volume Ratio</u>
Static capsule	0	0	10
Rocking capsule	2	200	18
Convection loop	4	200	6.1
Rotating shaft in pot	400	0	1.2

Extreme care must be taken in the preparations for each of these tests to avoid contamination of either the container or the sodium before the system is sealed. Furthermore, it is desirable that the container be the material under test rather than a specimen of test metal enclosed in a container of another material. Use of more than one metal in a corrosion test can give rise to the phenomenon of mass transfer in which a layer of one material is deposited on the other. This type of mass transfer seriously affects the validity of the test data. Good welds appear to be as resistant as the base metal to attack by sodium and NaK, but the welds must be clean and free of inclusions which might be attacked.

The static-test capsules are prepared by the "tubulating" technique from 1/2-in.-ID tubing of the test material. The tubing is cut into approximately 7-in. lengths and cleaned. One end of each tube is crimped and heliarc welded in an inert atmosphere, and the tube is evacuated and partly filled with liquid metal. The open end of the tube is then crimped and heliarc welded. This technique for preparing test capsules was found to be entirely satisfactory; however, it would not be useful if the metals to be tested were not available in tubular form or could not be crimped and welded easily. Most of the static tests have, rather arbitrarily, been for periods of 100 hr at temperatures of 1500°F. The capsules are heated in a furnace and maintained at a constant temperature.

Similar capsules are used for the rocking tests in which one end of the capsule is mounted in a special rocking furnace. As the furnace rocks, the liquid metal moves from the end of the capsule that is in the furnace to the end of the capsule that is outside the furnace and back about 4 times per

minute. This establishes dynamic conditions with both fluid flow and a temperature gradient. While the flow rate is not so high as would be desirable in a heat transfer system, the rocking test provides a quick means for dynamic testing of many systems. The rocking tests are, in general, of 100-hr duration at a maximum temperature of 1500°F.

Metals which appear to have good corrosion resistance to sodium in the static and rocking capsule tests are then subjected to the more severe - and more elaborate - convection loop tests. The convection loops are usually fabricated of 1/2-in. pipe and are shaped roughly in the form of a parallelogram 1 ft wide and 3 ft high. When the bottom and adjacent side of the parallelogram are heated, convection forces in the contained fluid establish circulating flow that attains a velocity of 4 to 6 fpm, depending upon the temperature difference across the hot and cold sides of the parallelogram. The usual convection loop tests are for periods of 500 hr at a maximum temperature of 1500°F with a ΔT of about 200°F.

Rotating shaft tests have been employed to obtain high-velocity corrosion data, but they are inherently isothermal tests. The pot and the liquid are stationary; rotation of the shaft to which the corrosion specimens are attached causes rather high relative velocities to be obtained between the liquid and the specimen. This test has received limited application to date, largely because of the lack of a temperature gradient.

Results

It can be concluded from the tests made at ORNL, KAPL, MSA, and elsewhere that most metals satisfactorily resist corrosive attack by sodium provided the sodium is oxide free. The useful life of the metal is then dependent on the metal solubility-vs.-temperature function which controls the rate of mass

transfer. The static tests made to date show that iron, stainless steels, nickel and some nickel-base alloys (including Inconel), molybdenum, tantalum, tungsten, columbium, cobalt and some cobalt-base alloys, as well as some special alloys, are particularly suitable for use with sodium.

While some corrosion is evident in tests of some of these materials, in no case is it serious enough to prevent the extended use of these metals with sodium at temperatures up to 1000°C. Slight intergranular penetration - attributed to preferential solution - is observed with some of the stainless steels, but it is extremely shallow. In some tests in which metal specimens were contained in nickel containers, a layer of nickel was found on the specimen. This form of mass transfer is frequently evident in bi-metallic systems.

Several of the structural metals which appeared resistant to sodium in static tests have been fabricated into convection loops for additional testing. The materials which have been tested are types 304, 310, 316, 347, and 446 stainless steel, nickel, Inconel, L-605, and alloy 1010. After convection loop tests of 1000 hr duration with a hot-leg temperature of 1500°F, most stainless steels evidenced only slight, if any, intergranular attack, the heaviest attack (in all cases) being in the weld metals.

The limited data now available from the rotating-shaft tests indicate that the attack is somewhat greater than that obtained in static tests of similar metals. Specimens of Inconel and types 316, 347, and 446 stainless steel have been tested with the rotating shaft, but it should be emphasized that (except in the case of the type 347 stainless steel) these were all bimetallic systems because the pot was fabricated of type 347 stainless steel.

Although the results of convection tests cannot usually be deduced from the results of static tests because of the absence of a temperature gradient in the latter, some correlation appears to hold in tests with sodium. This is probably the result of the temperature dependence of corrosion (mass transfer) with sodium being not too important, at least with the flow rates and temperature gradients attainable in the corrosion tests made to date. It should be noted, however, that there are no data from tests with high flow rates, that is, hundreds of feet per minute, and with large ($\sim 500^{\circ}\text{C}$) temperature drops.

The tests reported above show further that there are at least two important phenomena which must be provided for in the design of any sodium heat transfer system, that is, mass transfer and the increased solubility of oxygen in sodium at high temperatures. "Galvanic mass transfer" attack can be minimized by constructing the system so that only one metallic component is in contact with the sodium. Fortunately, this does not appear to be important for all metals, particularly when the stainless steels and Inconel are involved. Solution deposition, however, is always present, but fortunately it is very small with sodium. On the other hand, corrosion resulting from the presence of Na_2O can be serious but can also be avoided. The solubility of oxygen in sodium at high temperatures is such that sodium saturated with oxygen in the temperature range of 1200 to 1500°F will contain substantially more oxygen than a system saturated at lower temperatures. The amount of sodium oxide in the system can be controlled in the original preparation and filling of the system, by purification of the gas, and by continuous removal of sodium oxide in a cold trap.

In addition to the corrosion experience reported above, the Laboratory has accumulated considerable experience in which the operation of the sodium system was the primary experiment and corrosion was of secondary interest. It has been possible to operate these sodium systems because the corrosion of almost any clean structural metal by pure sodium is so low as to be of little concern. It is imperative, however, that the system be well fabricated and well cleaned, as well as loaded and operated under controlled conditions with pure sodium (and purified inert gas), and that a cold trap be incorporated.

COMPONENTS OF SODIUM SYSTEMS

The primary components of a sodium heat transfer system are the heat exchangers and the sodium pumps. An actual system will also usually require a sump tank, a surge tank, a bypass cold trap and/or filter (discussed under "Operations"), valves, closures, heaters, insulation, and instrumentation. Each of these components is important in its own right, and the design of any liquid metal system must consider the requirements and functions of each of these components. Provision must be made for adequate instrumentation of these components. (Such instrumentation, as it is unique to liquid metals, is discussed under "Instrumentation.") A schematic view of a typical liquid metal system, without heaters and insulation, is shown in Fig. 1. Each of the individual components is discussed below. Where two or more types of a particular component have been employed to effect a particular function, an attempt is made to comparatively evaluate the various types. In view of the state of the art at the present time, an absolute appraisal is not always possible.

Joints and Closures

Closures are commonly effected in sodium systems either by welding or by using any of a number of flanged or flared joints. In general, welded joints are preferable, where not too inconvenient, since they give less trouble from leaks at high temperatures. However, strict precautions must be taken to assure sound welds. The welded joint is sometimes inconvenient in that it must be cut when it is necessary to break the joint. Insertions can be welded in and other changes and repairs can be made to existing systems, but all such changes must be made with an inert atmosphere in the system.

Fig. 1—Typical small-scale experimental sodium system.

Compression-type fittings (for example, Swagelok) have been found to be satisfactory in some applications, but insufficient testing has been done to guarantee their reliability.

Welding

The satisfactory welding of structural metals for high-temperature use with liquid metals is extremely important to the successful operation of the system. Poor welds, if they do not leak at once, will certainly limit the lifetime of a system and at the same time increase the corrosion as a result of the formation of weld oxides. Accordingly, exacting procedures have been established, not only for the welding procedure,⁵ but also for welders' qualifications.⁶ (The training of welders to produce high-quality work is very important.) The welding specifications are briefly described in the following:

Welding Specifications

Process	Inert-gas, shielded-arc, direct-current
Base Metal	Inconel or types 316 or 347 stainless steel
Position	Rolling horizontally, fixed vertically or fixed horizontally
Filler Metal	1/16- to 3/32-in. rod (Inco No. 62 for welding Inconel; for stainless steel use rod of same material as base metal)
Condition of Base Metal	Machined, cleaned, and unstressed
Cleaning Fluid	Trichloroethylene
Clearance in Butt Joints	3/32 to 1/8 in. with 100-deg bevel
Clearance in Lap Joints	Flush at weld
Welding Current	Direct-current electrode negative, 38 to 90 amp
Electrode	1/16- to 3/32-in. tungsten, 90-deg point
Shielding Gas Blanket	Argon, 99.8% pure; 35 cfh
Gas Blanket Beneath Weld	Helium, 99.5% pure; 4 to 12 cfh
Welding Passes	One to five
Welder's Qualifications	Welder must have passed qualification test QTS-1 within past 45 days or must have been continuously working under the qualifications given in QTS-1

5. Procedure Specifications for DC Inert Arc Welding, ORNL Metallurgy Division, PS-1 (Sept. 1952).

6. Operators Qualification Test Specification for Inert Arc Welding, ORNL Metallurgy Division, QTS-1 (Sept. 1952).

Flanged Joints

Where flanged joints must be employed, as in the parting faces of pumps, it is desirable to place the joints in as low a temperature region as possible. The bolts employed should have a thermal expansion comparable to but less than that of the gasket metal, and, even then, the flange gasket will become relaxed after repeated temperature cycles. One good combination of materials found, to date, has been stainless steel gaskets and Inconel-X bolts with stainless steel nuts. Flanged joints employing API-type oval stainless steel or soft iron gaskets in tapered grooves have been successfully employed at temperatures up to 1500°F. Other flanges that have been successfully employed are (1) flanges that use a flat copper gasket which bears against a ridge on the flange surface and (2) tapered flanges that use no gasket material.

It has been found difficult to prevent leaks through API-type oval-ring-gasket joints, although, as mentioned above, such joints have been successfully employed. Additional dependability is obtained by the use of external clamps (for example, C-clamps) which remain cool enough to retain their resilience when the flange bolts are heated above their yield temperatures. Copper gaskets should not be used if they may come in contact with sodium, since copper will be dissolved and plated out in colder parts of the system. Tapered joints without gaskets have been the most leak-free of all flanged joints.

Flared Joints

Joints have been successfully made by using flared metal tubing and by using compression-type fittings, particularly the latter. Flared joints are,

in general, suitable only for small (1/2-in.-OD) tubes, where the joint may be subjected to large sealing pressures. (Cf., Joints and Closures, above.) There is some disagreement on the suitability of the use of flared joints at any time.

Expansion Joints

Thermal expansion of pipes and equipment for use with sodium must be provided for in the design of equipment and the layout of the piping. It has not proved feasible, however, to employ expansion joints for this purpose largely because there is no suitable packing material available. Where necessary, the expansion of pipes is provided for by the "steampipe technique," that is, by using bends, or by the appropriate use of bellows.

Pumps

The only problem of consequence in pumping high-temperature sodium is that of obtaining leak-tight seals. In addition, the design of centrifugal pumps must be such that temperature changes will not impair the alignment of the shaft with the seal housing. The performance characteristics of the pump, such as head and flow, may be determined for sodium from its physical properties as readily and as accurately as for ordinary liquids. Studies have indicated that centrifugal pumps are the most efficient; however, the electromagnetic pump is attractive because it has no moving parts. Considerable effort has been expended in the development and testing of sealless pumps of two types, electromagnetic and canned rotor, and several types of shaft seals for centrifugal pumps, including gas seals and packed seals. Only the packed seal has proved to be unsuitable for use with high-temperature sodium because of excessive leakage. Each of the pumps has its particular limitations which restrict its effective use in various general applications. These basic design limitations are presented in Table 2.

Table 2Basic Limitations of Various Sodium Pumps

<u>Type of Pump</u>	<u>Limiting Characteristics</u>	<u>Development Status</u>
Electromagnetic	Low head, low efficiency, complex auxiliaries	Good
Canned Rotor	Temperature (now around 1000°F)	Poor
Gas-Sealed Centrifugal	Vertical shaft	Good
Packed-Sealed Centrifugal	High leakage	Poor

A decision as to which pump to use for a particular application can be made only after consideration of the use in question, the basic limitations of the various pumps, and the degree of reliability desired. In applications where low head is required, the electromagnetic pumps are probably preferable, even though they are the least efficient, because they are the most reliable. Application of the canned-rotor pump is presently limited by the fluid temperature, ~1000°F, imposed by the insulation on the motor windings, although this pump is otherwise generally suitable. The gas-sealed pump substitutes small gas leakage for liquid leakage but must be operated with a near-vertical shaft to maintain the liquid-gas interface. Face-type gas seals have been developed which leak extremely small amounts of gas and, in general, operate very satisfactorily. One combination of seal materials used is a highly polished Graphitar 14 ring floating between two highly polished tool steel faces, with contact being maintained by use of a bellows spring. The packed-sealed pumps, on the other hand, could be operated in any position, but at the present time no suitable packed-seal exists. It is not improbable, however, that given sufficient time for developmental work, some useful form of packed-sealed pump could be developed.

Electromagnetic Pumps⁷

Sodium and NaK both have sufficiently high electrical conductivity to be amenable to the use of an electromagnetic pump. The motivating force is achieved by passing (or inducing) a current in the fluid in a magnetic field. The charged fluid will tend to move according to Ohm's rule (in the direction $E \times H$). Since no moving parts are involved, the pump has no seal problem. Its efficiency, however, is low (although recent designs have efficiency ratings of up to 20%), but its convenience, particularly for laboratory applications, has resulted in increased use of this type of pump.

The Laboratory has tested and used in experimental apparatus both a commercially available EM pump (General Electric G-3) and a two-stage EM pump of local origin. The G-3 pump, as received, was limited to operation at 750°F, but it was modified to operate up to 1400°F; flows of up to 16 gpm have been obtained with heads of up to 22 psi. The two-stage EM pump was developed to provide higher (up to 90 gpm) flow rates, although the attainable heads are much lower. General Electric manufactures, on a commercial basis, several of these pumps that have flow rates of up to 30 gpm, and Allis-Chalmers recently constructed one designed for 4000 gpm at 100 psi.⁸

General Electric, G-3, EM Pump. A General Electric, alternating-current, electromagnetic pump was modified by Experimental Engineering Department personnel to utilize a flexible secondary conductor. Tests have given flows of approximately 16 gpm of sodium at 5 psi and 890°F. In a combination

7. The theory of EM pumps is treated at some length in the Liquid Metals Handbook, NAVEXOS P-733 (rev.), p. 256, June 1952.

8. M. E. LaVerne, An Improved AC Electromagnetic Pump Cell, ORNL CF 52-12-153 (Dec. 7, 1952).

performance and endurance test of a G-3 pump, performance curves were obtained at temperatures of 300, 500, and 750°F, which substantiated data supplied by General Electric, Fig. 2. The efficiency of these electromagnetic pumps increases essentially linearly from 0.5% at flows of 2 gpm to about 3% at flows of 14 gpm. Although performance curves were taken at lower temperatures, the larger part of the operation was conducted at 750°F, which was the maximum temperature recommended for the pump cell in use. The pump failed at 1000°F because a current lug melted loose from the cell wall.

In order to obtain higher temperature operation, the pump cell was redesigned to reduce the electrical resistance where the electrical leads were welded to the pump cell. The most satisfactory arrangement was one in which holes were cut in either side of the stainless steel pump throat and the nickel lugs from the current loop were welded in each of these holes by using Inconel rod. The current could then pass more directly from the nickel leads to the sodium, and there was none of the local overheating that had been experienced when the lugs were welded to the outside of the pump throat. With the new pump cell, some operation with 1400°F sodium has been obtained, and there has been extensive operation at 1300°F. A disadvantage of this arrangement is that a second base metal (nickel) is presented to the flowing sodium. (In sodium systems, however, a number of different metals can be used in the same system without serious consequence; although there is some mass transfer of nickel, it is not serious.)

Fig. 2—Performance curves for G-1 and G-3 electromagnetic pumps.

Two-Stage, Alternating-Current, EM Pump. The two-stage pump is essentially two alternating-current EM pumps in series, but it is designed with just one magnetic flux loop and one current loop, each of which intercepts the fluid path at two positions. The pump is schematically illustrated in Fig. 3.

Design calculations show that currents of the order of 7000 amp at approximately 0.5 volt are required, along with a magnetic field strength of about 4 kilogauss. The approximate size of the pump (without its supporting structure) is 30 by 27 inches. Since this pump is required to pump sodium at 1500°F, the material specified for pump cell fabrication is type 316 stainless steel. The current loop contains copper buses with nickel spacers between the copper and the stainless steel cell wall. Efficiency is improved by eliminating any magnetic material from within 3 ft of the pump.

With NaK, the pump delivery is approximately 90 gpm at approximately 10 psi; performance curves are shown in Fig. 4. The pump has given entirely satisfactory performance except for failure of a hard-soldered joint in the current loop, which was easily repaired, and the presence of excess cooling, which was removed.

Canned-Rotor Pumps

The canned-rotor pump is a sealless pumping system which employs a combination hydrodynamic and magnetic bearing. In one arrangement, two canned rotors are used with the pump (or pumps) sandwiched between them. Two turbine pumps joined together so that their suctions and discharges oppose each other have been employed in a single pumping system, but best results have been obtained with a single centrifugal pump (Fig. 5).

Fig. 3—Two-stage, alternating-current, electromagnetic pump.

Fig. 4a—Performance curves for two-stage electromagnetic pump with NaK. Input voltage to magnet loop, 125 volts. (a) NaK at 750°F.

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Fig. 4b—Performance curves for two-stage electromagnetic pump with NaK. Input voltage to magnet loop, 125 volts. (b) NaK at 1500°F.

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Fig. 5—Improved Sealless pumping system.

One canned-rotor pump tested employed two $3/4$ -hp motors modified so that machined cans having a wall diameter of about 10 mils fit snugly inside the motor stators. The motor armatures were machined to fit inside the cans with 12-mil clearance. When the system is in operation, the armatures function as journal bearings and the cans act as bearing sleeves.

A part of the pumped fluid is recirculated to help support the rotating system axially and, by acting as a hydrodynamic lubricant, to counteract any small radial loads. The thrust loads are balanced by a combination of the forces produced by (1) the recirculated fluid, (2) the magnetic fields of the motors, and (3) the pump impeller. The recirculated fluid contributes to the over-all force that balances the thrust load through the use of a valve at each recirculatory inlet; the valve may be manipulated to produce an upward pressure differential. The magnetic fields of the motors produce forces which tend to center the rotors in their respective magnetic fields. The single-entry pump impeller is mounted facing upward. This produces an additional lift on the rotating system.

A comparison of the operating characteristics of the pump (that is, head vs. flow curve) with the characteristics reported by the manufacturer of the pump impeller and housing shows that no changes are introduced in this system. The highest over-all efficiency thus far obtained is 27.3%, whereas the highest attainable if the pump is operated in the normal manner is 35.7%. Thus, it can be stated that the losses due to the cans and added windings are around 25%. For larger systems, the percentage loss would be less, inasmuch as the air-gap change would be nil and the winding losses would be about the same. It should be noted that the armature diameters of larger electric motors do not increase in proportion to the power.

The pump operated satisfactorily with NaK at temperatures up to 400°F. The limitation on operating temperature for this pump is believed to be determined by thermal damage in the motor windings. The temperature of the pumped fluid may be increased by using especially wound motor stators and/or by cooling the liquid which is fed into the motor cans. Special windings - GE class H insulation for 500°F operation and Bentley Harris No. 22 insulated wire for 1000°F operation - were tested but only limited data are available on each. The limit on operating temperature imposed by the lack of higher temperature electrical insulation is responsible for the lack of emphasis given to this pump.

Attempts were made to can the rotor elements to protect them from corrosion at high temperatures. Stainless steel has been used and found to be satisfactory, but the increase in gap caused by the 0.010-in. wall of stainless steel causes the current load to become excessive. Use of some magnetic material should protect the rotor and reduce the stator-rotor gap.

Gas-Sealed, Sump-Type Pumps

In the gas-sealed centrifugal pump, the difficulties of direct sealing of the liquid metal are avoided. A liquid-gas interface is maintained above the pump impeller and only a gas seal is required around the shaft. Obviously, the pump can only operate with the shaft in the near-vertical position. It does have a distinct advantage, however, in that the pump sump may also function as the system surge tank. This type of pump has proved quite reliable for high-temperature (1500°F) operation; it leaks no fluid and, with a good seal, a negligible amount of gas. The rotary gas seal consists of silver-impregnated graphite, drop-lubricated with spindle oil, operating

against hardened tool steel. The seal is satisfactory in an atmosphere containing sodium vapor, but potassium is known to react with graphite, and it is conceivable that in a NaK system the NaK vapor pressure in the gas-seal region could be sufficiently high to be of concern. It should be possible, however, to provide a cold trap between the liquid surface and the gas seal to remove such vapors should they prove to be deleterious to the seal.

While several such pumps have been constructed and operated with minor modifications, there have been only two different models - one for low (up to 12 gpm) flow rates and one for higher (up to 250 gpm) flow rates. The smaller pump has operated for several thousands of hours at temperatures up to 1500°F to test various gas seals as well as other modifications to reduce turbulence, minimize oil leakage, etc. The larger pump is in some respects a scaled-up version of the smaller one and gives every indication of operating equally satisfactorily.

Laboratory-Size Gas-Sealed Pump. A centrifugal, gas-sealed pump with 12-gpm capacity has now logged over 4000 hr of high-temperature (up to 1500°F) operation with three different gas seals - a stuffing-box seal, a rotary face seal of Graphitar 30 on hardened tool steel, and a rotary face seal of Morganite MYIF (a silver-impregnated graphite with self-lubricating properties) on hardened tool steel. The stuffing-box seals in which Teflon and graphite-impregnated asbestos were used leaked appreciable quantities of gas and required periodic maintenance. The rotary face-type seals have both proved satisfactory but the seal of Morganite MYIF is slightly preferred to that of graphite because of its self-lubricating properties. Although regular dropwise

lubrication (6 to 8 drops per day) was employed initially with the face-type seals, the lubrication was subsequently employed only when power fluctuations occurred. A drawing of a pump with an oil-flooded rotary seal employing Graphitar 30 is shown in Fig. 6. The performance of this pump is shown in Fig. 7. The many modifications which have been effected in the design of this pump include:

1. adequate clearance to level control probes to prevent electrical shorts,
2. thicker reinforced guide vanes,
3. a labyrinth between the liquid-gas interface and the gas seal,
4. liquid baffling to reduce turbulence,
5. a parting face in the pump casing above the liquid level.

250-gpm Gas-Sealed Pump. A 250-gpm gas-sealed pump similar to the laboratory model has been constructed, and tests at high temperature indicate that it is equally as satisfactory. A sectional view of this pump is shown in Fig. 8. The sump tank of this pump is designed to serve as a system surge tank, and low-temperature tests show that priming, vortexing, and fluid degassing will not be problems. The gas seal for this pump consists of an oil-flooded Graphitar ring floating between two hardened-tool-steel surfaces. The gas-seal wear faces are maintained at a low temperature during operation by circulating coolant in three different regions at or near the seal. Hydraulic tests of a mockup of this pump with water, water and glycerine, and 1,2-tetrabromoethane indicated that the design provides for stable pump operation and adequate degassing, and subsequent tests with sodium revealed no unique changes in operating characteristics at high temperatures.

Fig. 6—Laboratory-size gas-sealed centrifugal pump.

Fig. 7—Performance curve for laboratory-size gas-sealed centrifugal pump.

Fig. 8—Sump-type gas-sealed centrifugal pump.

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Packed-Sealed Pump

No work was performed with a packed-seal on a sodium pump, since no satisfactory packed-seal - even for the less demanding application as a valve-stem seal - has been developed.

Valves

As with the pumps, the most outstanding problem in the development of a valve for use with high-temperature sodium has been that of providing an adequate seal. In contrast to the pump shaft, however, the valve stem need not rotate. This permits consideration of other types of seals (such as bellows), as well as relaxation of the requirements on the seal, for example, there would be less friction heat in a valve seal than in a pump seal. With valves, however, another problem is of concern - that of self-welding of the valve face to the valve seat at high temperatures. Self-welding of the valve face to the seat seems to be best avoided by locating the valve at a point where the liquid temperature is less than 1200°F.

Two types of packed-sealed valves and a ball check valve have been tested, and a fourth valve has been proposed. The proposed valve, a canned-rotor-driven valve, was never constructed because of the extremely successful operation of the bellows type of valve. (These are available commercially from the Wm. B. Powell Company, Cincinnati, Ohio, and other manufacturers.) Of the types tested, the ball check valve operated satisfactorily, but the packed-sealed valves were not sufficiently tight or reliable.

Self-Welding Tests

Several combinations of materials have been tested to determine their self-welding properties at high temperatures in the presence of liquid sodium.

These tests included not only operation tests on actual valves under service conditions, but static tests of valve materials in sodium under load. In general, it may be concluded that there is a distinct tendency for some of the metals tested to self-weld in 1500°F sodium. Slight sticking of the valve could usually be overcome by tapping. The tendency toward sticking is a function of temperature and load, but it can be minimized by mounting the valves in the lower temperature regions.

For the static tests of self-welding of valve materials, a series of three cylinders with diameters of 1/8, 1/4, and 3/8 in. were machined from one material to be tested, and three corresponding cylinders 1/2 in. in diameter were machined from either the same or a different material. After being polished, pairs of these were placed end to end in ~1500°F sodium under a load of 75 lb for 100 hours. The results are given in Table 3.

Table 3
Static Self-Welding Tests of Valve Materials

<u>Materials</u>	<u>Results</u>
Inconel against Inconel (120 grit)	Few points of welding that broke during handling
Inconel against Inconel (polished)	Welding had just started, but pieces could be handled
Inconel against zirconium	No welding
Type 347 stainless steel against type 347 stainless steel	Few points of welding on two smallest cylinders
Stellite against Stellite	No welding in 65 hours

In addition to the above tests, the following combinations of materials have been tested under operating conditions: Inconel against Inconel, Inconel against stainless steel, Inconel against zirconium, zirconium against stainless steel, molybdenum against stainless steel. Valves constructed of the various

materials were tested in sodium for periods of over 100 hr and at temperatures of up to 1000°F. Operation consisted in a number of closings and openings, with the required torque being taken as a measure of any tendency toward welding. In the worst instance, only slight sticking was observed.

It is most significant that in actual practice the valve seat and valve face are as-received stock items (usually stainless steel) and no untoward troubles are experienced from self-welding when the valves are located in low (1200°F) temperature points in the system. Since the self-welding tests have not been fully satisfactory, more tests are planned with the above-mentioned and other materials at various temperatures.

Packed-Sealed Valves

An attempt was made to find a valve-stem packing material for use in a sodium system. Only little success was experienced, however, and the tests were discontinued when other types of seals proved adequate for the pump as well as for the valve. The materials tested and the results of each test are given in Table 4.

Table 4

Results of Tests of Packing Materials for Valve-Stem Seals

<u>Packing Material</u>	<u>Result</u>
Amosite asbestos	Held sodium for 21 hr at 1500°F under 15-psi pressure before leaking
Graphite powder	Leaked sodium at 600°F under 10-psi pressure
Met-L-X	Held sodium for 2 hr at 1500°F under 15-psi pressure before leaking
Lead-mill slag	Held sodium for 10 days at 1500°F under 15-psi pressure; no leaks occurred before experiment was terminated
Nickel metal powder	Held sodium for 10 days at 1500°F under 15-psi pressure; no leaks occurred before experiment was terminated
Soda ash	Leaked sodium at 1300°F under 10-psi pressure

Ball Check Valve

A ball check valve has been successfully operated to transfer high-temperature fluids at 1400°F. As the name implies, the valve permits unidirectional flow of the liquid and is operated by fluid pressure, Fig. 9. The balls were constructed of type 440 (passivated) stainless steel, and the housing and fittings were of type 316 stainless steel. There was some slight evidence of the balls sticking in the open position, but, in all cases, increased pressure or slight tapping of the valve corrected this condition.

Bellows-Sealed Valves

The most satisfactory valve-stem seal for sodium or NaK is a bellows seal. This type of seal incorporates a bellows with a nonrotating valve stem; that is, only motion parallel to the valve stem is permitted. Since there is no opening to seal, there is no fluid leakage. The bellows merely compresses or expands as the valve stem moves in or out. Bellows seals are normally operated with a single bellows filled with liquid; the most dependable results, however, are assured by the use of a double-bellows arrangement in which the region between the two bellows is filled with trapped gas, as illustrated in Fig. 10.

Commercially available bellows seal valves are now routinely employed in liquid metal systems. When installed in low-temperature (1200°F) regions, there is no difficulty either from corrosion of the bellows or from self-welding of the valve face and seat. Some self-welding is experienced at higher (1500°F) temperatures, and increased torque is required for opening the valve. No difficulty is experienced with valves used for throttling at high temperatures. Among the commercially available bellows valves are those made by the Powell, Fulton Sylphon, and Crane Companies.

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Fig. 9—Ball check valve.

Fig. 10 — Bellows-sealed valve.

Canned-Rotor Valve

The use of a canned-rotor drive for valves in high-temperature fluid circuits appears to be feasible. This type of valve has not been tested under operating conditions, but tests of the operating mechanism indicate that it will operate satisfactorily. The proposed design is shown in Fig.

11. Preliminary tests indicate that a rotor constructed of a permanent magnet can be operated in a cooled, trapped-gas space with the actuating-field coil separated from the rotor by a stainless steel or Inconel can up to 1/16 in. thick. Complete control of the actuation of such a valve may be obtained by using a multiple-position rotary switch to rotate the poles of a three-phase induction-wound motor. One complete rotation of the switch causes the rotor to follow at the same speed in the direction the switch is rotating. Bearings could possibly be eliminated by mounting the rotor on a shaft having screw threads on one side of the rotor and a guide sleeve on the other to permit the rotor to travel axially in the magnetic field. Further development of this valve was suspended because of the favorable performance of the bellows valve.

Heat Exchangers

As reported in the Liquid Metals Handbook, "The design and construction of heat exchangers for liquid metals is based upon the established practice with some modifications required by the liquid-metals properties and the particular application of the heat exchanger." Although mechanical joints are widely used in conventional practice, they are not suitable for sealing liquid metal. All joints must be welded or brazed and should be of extremely high quality and soundness. High-sensitivity mass-spectrometer leak testing,

Fig. 11 — Proposed design for canned-rotor-driven valve.

or the equivalent, is recommended during various stages of construction, as well as upon completion of the heat exchanger.

"One of the main advantages offered by liquid metals as heat-transfer fluids is their high heat-transfer rates which permit the transfer of a large quantity of heat in a comparatively small volume. In many applications of liquid-metal heat exchangers, compactness is an extremely important consideration. To take full advantage of the high liquid-metal heat-transfer coefficients, it is necessary to select tube materials of high conductivity and minimum wall thickness consistent with the strength requirements. In a liquid-metal/liquid-metal heat exchanger, particularly, the wall resistance is an appreciable percentage of the total resistance to heat transfer. It follows that an appreciable temperature drop and thermal stress will occur in the wall."

The design and performance of heat exchangers are dependent, to a large extent, on the particular application in view. A sodium heat exchanger for some particular applications may be designed according to standard practice using the known values for the physical properties of sodium and the conventional structural metals. The Laboratory has initiated tests of both liquid-to-liquid and liquid-to-air heat exchangers. The designs of both of these types of heat exchangers have emphasized compactness and have employed all-brazed (or welded) construction. In neither of these designs was special provision made for differential thermal expansion within the heat exchanger, although this was a consideration in the design. There is sufficient flexibility in the tube bundle arrangements to accomodate such distortions as may arise.

A liquid-to-liquid heat exchanger employing NaK as both the primary and secondary fluid was operated for over 3000 hr at temperatures below 1200 and 1500°F. The heat exchanger consisted of a tube bundle arrangement and employed countercurrent flow. Both types 347 and 304 stainless steel tubes with 19.5- and 16-mil walls, respectively, were used, and the tube-to-header joints were effected by cone-arc welding,⁹ as well as by microbrazing. After the test, two tube failures were discovered in the microbrazed tube-to-header joints. It was concluded, however, that these failures were due to vibration and the etching effect which the circulating NaK had on the tubes in the hot zones. The failures were encouraged by the embrittlement of the 16-mil-wall type 304 stainless steel tubes. No fractures were detected in the 19.5-mil-wall type 347 stainless steel microbrazed tube-to-header joints. One bad joint was found in the cone-arc-welded header which was probably due to faulty fabrication prior to welding.

A sodium-to-air radiator design employing a cross-flow, finned-tube arrangement has been operated at temperatures up to 1700°F. The radiator was assembled by microbrazing the stainless steel fins to the stainless steel tubes. Of the three radiators tested, each has had a failure termination caused by a leak at the same place in the tubes. It is possible that local stresses are set up in these tubes during the brazing operations. It is significant that the leaking sodium expands the original leak by accelerating the attack on the outer surface of the tube.

9. P. Patriarca, Cone-Arc Welding, ORNL MM-2, June 26, 1952.

Sump and Surge Tanks

Both sump and surge tanks are usually included in large liquid metal systems, although in some simple systems, one tank combines the functions of both, and in others, the surge tank is incorporated in the sump-type pump used.

The liquid metal is usually stored under an inert atmosphere (usually helium) in the sump tank to which it is transferred under gas pressure after being melted and purified in a separate tank. The sump tank is the lowest point in the system and should have temperature and pressure instrumentation, heaters, and insulation. In addition, gas pressure and bleed connections are required so that the liquid metal may be forced into the system when desired. Upon completion of a run in the system or if it is necessary to drain the system, as in the event of a leak, the liquid metal is drained into the sump tank by gravity and/or gas pressure.

The surge tank, in contrast to the sump tank, is located in the highest part of the system. It should have a level indicator and controls to indicate when the system is filled to the desired level and to maintain it in that condition. The surge tank also provides an expansion volume for the liquid sodium, which expands about 20% in the temperature range from 250 to 1500°F. Since the surge tank usually operates at the lowest pressure in the system, it precedes the pump in most applications. In any case, the temperature and the pressure within the surge tank must be such as to prevent excessive vaporization or boiling of the liquid metal, since liquid metal vapors, if present, would condense and plug the gas lines leading into the system. Similar to the sump tank, the surge tank also has gas pressure and bleed connections to facilitate loading and draining of the system. Likewise, temperature and pressure instrumentation are usually provided.

In system operation, there is considerable advantage to be gained by minimizing the number of free-liquid surfaces. In general, it will be found that the level of only one surface can be automatically regulated, and the levels of the others will follow. A shut-off valve between the sump and the system will reduce the number of surfaces.

Heaters

Systems that use NaK, in contrast to those that use sodium, have the distinct advantage that system heaters and insulation are not required, because NaK is liquid at room temperature. However, heaters and insulation are readily available which will not only bring a system to above the melting point of sodium, but which will also heat the system to temperatures well over 1000°F. A number of externally mounted, insulated, resistance-wire heaters have proved adequate, although induction heating and resistance heating may have advantages in particular applications. (It is of note in this connection that, in spite of the apparent hazard, Harwell uses steam to heat their sodium systems.)

External Heating

Several varieties of external heating units have proved satisfactory. The different heating units include (1) an integral heater and insulation assembly that can be prefabricated in the desired shape, (2) flexible heating cable that can be wrapped around the object to be heated, and (3) Calrod-type heaters that are specially constructed to have greater contact with the surface to which they are attached. The limiting temperatures of these heaters are determined by the heating elements, and they vary from 750 to 1800°F, depending upon the desired lifetime.

The integral heater and insulation assembly, which can be prefabricated in a variety of sizes, consists of a conventional "clamshell" tube-furnace heater element inserted into preformed insulation and attached by means of clamps. This assembly has resulted in a substantial saving of installation time, as well as in reduced heat loss to the ambient air. The heaters have operated more than 500 hr with filament temperatures at 1800°F without becoming detached from the insulation. Heaters of this type are preferred when assembly time is at a premium.

A flexible heating cable that can be tightly wound on surfaces of complex geometry has been used to obtain contact heating and reduction of heat-up time. This type of heater, which consists of nichrome wire covered with a double layer of special fiberglass tubular insulation, has been used successfully with a filament temperature of 1500°F. The thin insulation is superior to other types of insulation, such as ceramic beads, because it permits the wire to be more closely wound on the surface to be heated and the temperature drop from heater wire to heated surface is considerably lower.

Dies have been constructed for flattening the tubular Calrod heaters to give greater contact with the pipe to which they are attached. As modified, one side of the heater is shaped to conform to the curvature of the pipe for nearly the full length of the heater. Care must be exercised in such shaping because it decreases the volume of the heater that contains the magnesium oxide insulation and results in heater filament relocation and distortion and subsequent hot spots in operation. There is a wide variety in the quality of these heaters as produced by different commercial manufacturers. Those found most satisfactory are the Calrod heaters manufactured by the General Electric Company.

Induction Heating

High-frequency heating is advantageous as a means for rapid heating of small components. Megatherms that produce 20 kw of power at 220 kc have been modified with water-cooled coils to obtain temperatures of over 2700°C. This method provides uniform heating when the material to which heat is applied is of symmetrical geometry. On complex surfaces, however, that section closest to the coil is heated as much as 400°C higher than the rest of the material.

Resistance Heating

A method for rapid heating of constant cross section equipment is direct-resistance heating. This type of heating is superior to other types, where applicable, since the heat is generated internally at the point where it is desired, and heat conduction by means of air or other gas is eliminated. Direct-resistance heating has been used successfully for heating sections of pipe where freezing would be critical and for preheating thermal-convection loops in preparation for the filling operation. Sections of 1-in.-IPS pipe 6 ft long have been heated to 1500°F and convection loops to 2000°F for cleaning by hydrogen firing. Heating rates of the order of 100°F/min may be obtained. The uniform heating obtained and the elimination of heater failures make this method of heat application attractive.

Insulation

The most satisfactory insulating materials for use with sodium and NaK are Superex, Hi-Temp No. 19, or the lead-mill slag-wool type of insulation because of their relative inertness when in contact with these liquids. For

high-temperature (1500°F) applications it may be desirable to use a combination insulation composed of an inner layer of either Superex or Hi-Temp No. 19 thick enough to bring the interface temperature down to 1200°F and an outer layer of lead-mill or steel-mill slag wool thick enough to give the desired heat loss from the pipe. For small pipe (about 2 in.) at 1800°F , these thicknesses will be about 2 1/2 and 3 in., respectively. The basic difficulty with most insulating materials is that they react with sodium. Table 5 summarizes the tests that have been made on insulating materials exposed to sodium.

TABLE 5. TESTS OF INSULATING MATERIAL EXPOSED TO SODIUM JETTED ONTO IT AT 1372°F

Type of Insulating Material	Primary Constituent	Insulation Surface Temp. (°F)	Insulation Thickness (in.)	Sodium Penetration (in.)	Effect of Sodium on Insulating Material
Johns-Manville RF 300 Thermoflex	Asbestos	1372	1		Material disintegrated
85% Magnesia Block	Magnesia	1372	1	Negligible	Material reacted with sodium
Philip-Carey Hi-Temp No. 19	Diatomaceous Silica	1100	1	1/2	Hard, black, porous substance formed
Johns-Manville Superex	Diatomaceous earth	1100	1	1/2	Hard, black, porous substance formed
Eagle-Picher DE-85 Block	Diatomaceous earth	1100	1-1/2	3/4	Black, very porous substance formed
Baldwin-Hill Monoblock	Black rock wool	1100	1-1/2	7/8	Greenish, porous cake formed that crumbled on being broken
Owens-Illinois Kaylo Block	Lime silica	1100	1-1/2	1	Black cake formed that crumbled in handling
Friedrick and Dimmock Glass Wool	Glass wool	1100	2	1/4	Fused to steel plate where in contact with sodium
Baldwin-Hill Black Rock Wool Blanket	Lead-mill slag	Not heated	2	1/4	Stuck to steel plate where sodium was burning
Philip-Carey Gray Wool Blanket	Lead, blast furnace, and phosphate slags	Not heated	2	1/4	Stuck to steel plate where sodium was burning
Philip-Carey White Wool Blanket	Blast furnace and phosphate slag	Not heated	2	1/4	Stuck to steel plate where sodium was burning
Johns-Manville Banroc Blanket	Steel-mill slag	Not heated	2	1/4	Stuck to steel plate where in contact with sodium

INSTRUMENTATION

Operation of a high-temperature forced-circulation system with liquid metals necessitates maintenance of level indication and control, accurate determination of flow rates, and reliable pressure measurements at several points in the system. Since the use of most commercially available equipment for performing these functions is limited to temperatures considerably lower than the minimum operating temperature, an extensive developmental program was carried out to either produce new instruments or to remove the temperature limitations placed on existing instrumentation. Developmental work has now progressed to the point where levels can be controlled in sodium systems with great reliability for periods extending for more than 2000 hours. Pressures and flows are reliably measured with both commercial and locally developed instrumentation. The degree of accuracy eventually attainable for all instrumentation depends upon the accuracy of the calibrating equipment. In general, several alternate means of effecting a particular measurement are available. An attempt is made, for each application, to evaluate the relative merits of the various methods.

Temperature

Thermocouples are not only suitable for measuring the high temperatures (1000 to 1500°F) attained in liquid metal systems, they are the only means seriously considered. The thermocouples may be attached to the outside of fluid containers or, where internal temperatures are desired, they may be inserted in wells.

Temperatures of up to 2000°F are measured by means of chromel-alumel thermocouples and are recorded on multipoint Brown temperature recorders.

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It has been found that the accuracy of temperature measurement depends to a great extent on the fabrication and installation of the thermocouples. Two methods of thermocouple attachment are being used: (1) pulse-welding each thermocouple wire to the outside surface of pipes or containers and (2) forming a beaded junction of the two thermocouple wires and welding this assembly to the container. In each case, the thermocouple is given additional rigidity and accuracy by tying it down with nichrome wire. With either of these methods, a temperature error is introduced if the thermocouple is not insulated from ambient air or other adjacent material. Borax has been found to form an airtight coating that prevents further oxidation.

Tests conducted with thermocouples placed in deep wells centered in the flowing stream and with other couples directly opposite on the external surface of the pipe have revealed that there is no more than a 15°F temperature drop between the internal thermocouple and that placed on the outside of a well-insulated pipe. Thermocouples made by beading the wires are accurate to within $\pm 1^{\circ}\text{F}$.

The Brown temperature recorders, if carefully adjusted, will record temperatures accurately to within $\pm 1^{\circ}\text{F}$ over the full range from 0 to 2000°F . They do, however, show a tendency to drift after extended periods of operation and thus cause errors of the order of 5°F . This tendency to drift necessitates frequent calibration of the instruments; therefore, a program for routine inspection must be set up for detecting any instrumentation errors soon after they occur.

Temperatures can be easily regulated to within a few degrees by feeding the temperature signal from the thermocouple into a temperature regulator. A number of commercially available instruments are satisfactory for this use.

Level Control

In liquid metal systems, as in other fluid systems, it is usually essential not only that the level of the liquid be known but also that the level be automatically maintained. In general, any level indicating device can be adapted to level control. However, of the many potential level indicating devices tested, only shielded probes and the variable-inductance float device have been routinely applied to automatic liquid metal level control. Table 6 summarizes the relative merits of the various methods of level control which have been considered. The methods are listed in order of suitability.

Table 6Comparison of Various Methods of Level Indication and Control

<u>Method</u>	<u>Advantages</u>	<u>Disadvantages</u>
Spark Plug	Rugged, simple	Oscillating control, vapor shorts
Variable Inductance	Continuous level indication	Maximum temperature of 1300°F
Resistance	Simple, rugged, and gives continuous level indication	Resistance fluctuations
Gas Bubbler	Sensitive, good response	Gas-line plugs
Resonant Cavity	Continuous and extremely accurate level indication	Unknown (method not tested)

Spark-Plug Level Controller

The conventional probe type of level controller consists of two or more spark plugs which operate relays or solenoids to change the pressure of the gas over the sodium when the sodium rises to short out the probe. Such a level control has proved quite satisfactory, although some difficulty was encountered because condensation on the spark-plug insulation caused shorting out of the plug. This difficulty may be minimized by mounting the spark plugs

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from special "risers" which are maintained at lower temperatures. The spark plugs normally do not give a continuous indication of the exact liquid level, and, when used to control the level, they create an oscillation between the two controlling probes. The level may, however, be readily controlled to within 1/8 inch. Commercial spark plugs with extended electrodes provide an insulated leaktight lead through a container wall.

A variation of the spark plug controller described above is one in which a single spark plug may be moved up or down to determine the height of the liquid. This method was developed by Westinghouse.

Variable-Inductance Level Controller

The variable inductance level controller consists of a float to which is attached a tapered iron core enclosed in an Inconel tube which protrudes above the liquid container. As the float rises and falls with the level of the liquid, the iron core, which is chrome plated to resist corrosion, moves up and down within an inductance coil located outside the Inconel tube. The core temperature is limited to 1300°F, that is, the curie point of the metal. (The sensing element of this level controller is similar to that of the variable-inductance, rotameter-type flowmeter which is discussed and illustrated in a following section.)

The pick-up coil is wound on a form 1 in. in diameter and 1 in. long. The design of the coupling rod between the float and the core is such that the response of the indicator is linear for only 10 in. of the 18-in. level change for which it was designed. An endurance run of 1500 hr gave no trouble, nor was any change encountered in the operation of the indicator. Level can

be controlled with this indicator to 0.5% of the total indication by using limit switches on the indicating millivolt meter. In addition, by using two of these indicators together, a null-balance system can be obtained that will hold the level in one tank to within 0.1 in. of that in another tank. Calibration at the temperatures desired is necessary.

Resistance-Type Level Indicator

The resistance-type level indicator consists of a rod insulated from and mounted within a tube; both the rod and the tube are mounted partly submerged in the liquid whose level is to be measured. Electrical connections are made to the rod and to the tube, which is grounded. The resistance of the circuit depends on the height of the liquid which shorts the tube to the rod. Tests have been made in which such a resistance-type probe immersed in sodium was connected to a Brown potentiometer through a Wheatstone bridge. As the sodium level fluctuated, the resulting resistance change of the probe produced a signal which both indicated and controlled the level. This indicator is satisfactory except that the probe resistance will change as a result of sodium buildup.

Gas-Bubbler Level Indicator

The bubbler type of level indicator employs gas flowing through a tube which extends to the bottom of the tank in which the level is to be controlled. The gas bubbles through the liquid, and the pressure required to maintain a constant flow of gas through the liquid is directly related to the height of the liquid level above the end of the tube. The pressure is measured by a manometer connected between the gas tube and the gas space above the free surface of the liquid. Such an instrument has been used for indicating and controlling liquid levels.

The accuracy of this type of level indicator depends on the difference in specific gravity of the manometer fluid and the liquid, as well as on the susceptibility of the gas tube to plugging by condensed liquid-metal vapor. In one experiment the specific gravity ratio was 1:3, and the accuracy of the level measurement was determined to 0.04 inch. The experiment was operated for 140 hr under dynamic conditions, with over 1000 cycles of operation, and 742 hr under static conditions. As a result of tests with this model, it is concluded that the level in a fluid system operating at 1500°F can be remotely indicated and controlled by this technique. This method has the disadvantage of continuous gas bleed which can result in gas-line plugging.

Resonant-Cavity Level Controller

A liquid-level indicator that uses the principle of a resonant cavity was designed but not tested. The frequency in the S-band microwave region and all S-band microwave components were to be used. The control signal would be the energy absorbed by the cavity. This signal would then operate a servo system which would in turn control the frequency of the Klystron tube. Only simulated experiments have been made with this indicator, but from all indications it should be extremely accurate.

Flowmeters

Measurement of flow in liquid metal systems is usually effected with an electromagnetic flowmeter because it is accurate and dependable and can be mounted external to the liquid-metal-containing pipe. Flow measurement may also be effected by a conventional venturi or a Rotameter type of flowmeter with a variable inductance core, but these devices have no clear-cut advantages over the electromagnetic flowmeter. The Rotameter type of flowmeter is an

enclosed, accurate device, but it has the disadvantage that it cuts off at low flow velocities. The Venturi is simple and dependable, but it depends upon an associated pressure measurement.

Table 7 summarizes the relative merits of the various methods of flow measurement which have been considered. The methods are listed in order of suitability.

Table 7

Comparison of Various Methods of Flow Measurement

<u>Method</u>	<u>Advantages</u>	<u>Disadvantages</u>
Electromagnetic	External to fluid pipe, continuous, accurate	Can only be used with materials of low resistivity
Venturi	Simple, no moving parts in liquid	Depends on pressure measurement
Rotameter	Continuous, accurate, enclosed system	Cuts off at low flows, maximum temperature 1300°F
Rotating vane	Enclosed system	Signal small compared with background; maximum temperature limited, 750°F

Electromagnetic Flowmeter

The electromagnetic flowmeter has proved to be quite reliable for use with sodium and NaK. As described in the Liquid Metals Handbook, the principle of operation is simply that of a direct-current generator. A permanent magnet bolted to the pipe sets up a magnetic field across the pipe, and the flow in cutting the lines of force generates a voltage within the liquid metal. This voltage is picked up by a pair of electrodes fastened to the pipe in a plane which is at right angles both to that of the flow and to that of the magnetic field. The unit is externally mounted on the pipe, and thus can be replaced easily. There is negligible head loss associated with the use of the magnetic flowmeter because negligible power is drawn by it. Since

the variable measured is velocity, the indication varies linearly with flow. These flowmeters require at least 500 gauss in the center of the liquid, and therefore the size of the magnet depends on the size of the pipe. Satisfactory electromagnetic flowmeters are commercially available from the General Electric Company.

Rotameter Flowmeter

The Rotameter type of flowmeter consists of a Rotameter "float" within a tapered barrel. The float position, which is a function of the flow, is indicated by a tapered iron core attached to the float. The iron core is chrome plated to resist corrosion. This core operates in the cylinder of static liquid that extends downward from the flowmeter. An inductance coil that is capable of being operated at any constant temperature up to 1300°F (the curie temperature of the core) is placed around the core in the vicinity of the tapered barrel. As the core moves in the field of the inductance coil, the movement is sensed by suitable instrumentation which may be calibrated to accurately indicate the flow rate of the fluid through the Rotameter barrel. The flowmeter shown in Fig. 12 has now operated for 600 hr, and has measured flows of up to 17 gpm to an accuracy of within 10%. This accuracy can be maintained over the temperature range of the liquid around the tapered barrel. The temperature is usually 1100°F in comparison with the 1300°F of the stream. This flowmeter measures the flow directly and does not depend upon an associated pressure measurement; however, it does have the disadvantage that it cuts off at low flow velocities.

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Fig. 12—Rotameter type of flowmeter with variable inductance level indicator.

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Venturi Flowmeter

A Venturi section with its associated pressure-sensing instrumentation is an entirely adequate device for measuring flows in high-temperature sodium systems, although it substitutes the problem of pressure measurement for one of flow measurement. However, its simplicity and reliability recommend its use if adequate pressure-measuring devices are available.

Rotating-Vane Flowmeter

A rotating-vane type of flowmeter, manufactured by the Potter Instrument Company and modified for high-temperature application, was tested. The instrument consists of a permanent magnet rotated in the fluid stream by a small turbine. A pick-up coil is placed outside the flowmeter in close proximity to the rotating magnet. This coil, when connected to a Hewlett-Packard electrical tachometer through a preamplifier that furnishes 60 db of amplification, should very accurately sense the rate of rotation of the permanent magnet. At room temperature, this arrangement was calibrated in terms of accurate flow measurement with a pick-up coil located as much as 3 in. from the magnet. However, when the instrument was installed in a thermal convection loop operating at 1300°F, no signal that could be calibrated in terms of flow was obtained from the flowmeter. One difficulty experienced was that the loop heater circuits caused induced voltages in the pick-up coil that were greater than the signal expected from the flowmeter. In addition, however, it is quite probable that the device is limited to temperatures of around 750°F not only by the weakening of the magnet (which is of limited size) but also by the greater friction on the bearings on which the magnet rotates.

In view of the successful applications of the electromagnetic flowmeter and the variable-inductance Rotameter type of flowmeter, further development of a rotating-vane instrument was suspended.

Pressure Devices

The pressure in liquid metal systems may be measured by a diaphragm device, a bellows device, or by the more conventional Bourdon gages or manometers. The Bourdon gages measure the pressure of gas trapped in a volume provided for that purpose above the surface of the sodium. Although these gages must be removed and insulated from the high temperatures of the liquid metal systems, their relative simplicity recommends their use. Manometers, on the other hand, require a transparent fluid container, and the fluid and the container must be compatible with the liquid metal in the system. The principle of operation of both the diaphragm and the bellows devices is that of balancing the liquid pressure with the gas pressure through a thin intervening wall. The bellows device is used in preference to the diaphragm device because it is commercially available.

Table 8 summarizes the relative merits of the various methods of pressure measurement which have been considered. The methods are listed in order of suitability.

Table 8

Comparison of Various Methods of Pressure Measurement

<u>Method</u>	<u>Advantages</u>	<u>Disadvantages</u>
Bellows	Null-balance, direct measurements, high temperature	Continuous gas flow
Diaphragm	Null-balance, direct measurements, high temperature	Continuous gas flow, less sensitive than bellows
Bourdon	Inexpensive	Temperature limited, requires gas lines and a trapped-gas volume
Manometer	Accurate	Temperature limited, fragile, requires a trapped-gas volume

Bellows-Type Pressure Transmitter

The bellows pressure-measuring device, Fig. 13, depends upon the compression of a bellows as the pressure outside the bellows is increased. An instrument of this type developed by Moore Products Company incorporates this bellows with a gas valve whose regulator is attached to the bellows so that any tendency of the bellows to compress is counteracted by an increase in the gas pressure within the bellows. The gas pressure required to balance the pressure of the liquid on the bellows may be measured in a conventional manner. This device has been used extensively and has proved entirely satisfactory.

The temperatures used with this pressure transmitter have ranged as high as 1400°F, and pressures of up to 70 psi have been measured. A slight zero shift occurs, as expected, at high temperatures. Accurate temperature control of the instrument should eliminate this source of inaccuracy.

Diaphragm-Type Pressure Transmitter

The diaphragm pressure-measuring device depends upon the deflection of a thin (may be as thin as 0.010 in.) metal diaphragm. The deflection of the diaphragm may be measured and calibrated against pressure, or inert gas pressure on the opposite side of the diaphragm may be employed to balance the liquid pressure. A device, Fig. 14, in which the diaphragm deflection was measured by a linear differential transformer has operated for more than 100 hr at temperatures of up to 1040°F. Operation is reliable up to this temperature in the pressure range 0 to 40 psi. The only observable effects of increased temperature are a shift in the zero point and an increase in the slope of the pressure calibration curves which, up to 40 psi, are essentially linear.

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Fig. 13 — Moore nullmatic pressure transmitter.

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Fig. 14—Diaphragm pressure-measuring device.

Bourdon Gage

The Bourdon gage measures the pressure of gas trapped in a volume provided for that purpose above the surface of the liquid. These gages are satisfactory but they must be removed and insulated from the high-temperature liquid system and they require unrestricted gas flow from the pressure chamber. In using the Bourdon gage it is desirable to employ a chamber with a maintained-level, liquid-gas interface and to heat the gas line to the gage to prevent vapor condensation. Although heating the gas line can introduce a small temperature error, the major objection to the use of this pressure gage is that additional instrumentation and equipment are required for maintaining the liquid-gas interfaces, unless, of course, this interface already exists, as in a surge tank.

Manometer

Manometers have also been used to measure differential pressure in liquid metal systems. Although they provide a reasonably accurate measurement of the differential pressure, these devices require the use of transparent indicating tubes which are usually quite fragile. In addition, the gas line (or lines) to the manometer should come from a trapped-gas volume, such as that required for the Bourdon gage.

OPERATIONS

The successful operation of any sodium (or NaK) system depends, to a large extent, on careful control of the amount of oxygen in the sodium. The singular importance of this contaminant is emphasized over and over again in each of the various manipulations which constitute the operation of a liquid metal system. For example, cleaning of metals to remove oxide scale; purification of sodium and helium to remove oxygen; special welding techniques to negate the formation of weld scale; and special handling, transferring, and sampling techniques are required to minimize or prevent oxygen contamination of the system. Aside from this one all-important requirement, there is nothing unique in the operation of liquid metal systems.

The methods and techniques described below are those now in effect at ORNL. It is obvious, as in some cases where alternate methods are given, that there may be several equally effective ways of accomplishing a given end. The techniques described here are not necessarily the best, but they are employed as a consequence of the experience and equipment available and are entirely adequate for the purpose.

Cleaning Before Assembly

The corrosion experienced in a liquid metal system is directly related to the contamination therein; the only important contaminant usually encountered is oxygen (or oxides). This contaminant enters the system from (1) the walls of the equipment, (2) the liquid metal, and (3) the inert gas maintained above the liquid or used to load the system. Consequently, every precaution must be taken to reduce contamination from these three sources to a minimum. The precautions established include careful cleaning of the container walls and purification of the inert blanketing gas and the liquid metal.

(In addition, all large-scale liquid metal systems are equipped with a purification system which continuously removes oxides from the liquid metal by low temperature filtration and/or by the use of cold traps as described under "Normal Operations.")

Liquid Metals

The method of purification now employed with sodium or NaK involves low-temperature filtration. The solubility of Na_2O , the chief contaminant in sodium, decreases with temperature, as shown by Fig. 15. Accordingly, the sodium (or NaK) is held under an inert-gas blanket at approximately 250°F for at least 24 hr to give the suspended oxide particles time to agglomerate. The agglomerated oxides will appear on the walls and at the surface of the sodium, and the main body of liquid will be substantially clean. The sodium is then filtered from above the tank bottom through a $5\text{-}\mu$, sintered, stainless steel filter into an inert-gas-blanketed system. Analytical results indicate that this filtration step consistently reduces the oxide content to below 100 ppm. The results also indicate that no appreciable reduction in oxide content is achieved with further filtration. Recent developments indicate that tightly packed stainless steel (or Inconel, nickel, etc) wool filters are structurally more reliable than sintered-metal filters, and they do an entirely adequate job of oxide removal.

The analytical determination of the oxygen contamination, once a problem, is now effected by a method¹⁰ which depends upon the reaction between sodium and γ -butyl bromide hexane solution. The Na_2O contaminant does not react

10. J. C. White, W. J. Ross, and R. Rowan, Jr., The Determination of Oxygen in Sodium, ORNL-1286 (Apr. 30, 1952).

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Fig. 15—Solubility of Na_2O and K_2O in sodium and NaK.

with the reagent and can be determined, after the addition of water, by titration. This analytical method is believed to be accurate for determining oxygen concentrations down to 0.001%, with a standard deviation of 0.003 to 0.005%; it is comparatively rapid and requires only the simplest of equipment. There is also the advantage that with this method impurities other than oxygen can be determined on the same sample.

The oxygen contamination may also be determined by a method developed at KAPL by Pepkowitz and Judd which involves the titration of a mercury-sodium amalgam. When sodium containing oxygen is mixed with mercury, the sodium and mercury amalgamate, while the oxide impurity floats on the surface. These phases are separated and then analyzed for sodium and oxygen, respectively, by titration with HCl.

Inert Gas

Inert gases used for blanketing liquid metals in operating systems must be purified to minimize oxygen content. The argon cylinders tested have, generally, contained on the order of 20 to 50 ppm oxygen, and helium cylinders have shown as high as several thousand ppm. A purification apparatus has been put into operation which removes oxygen from blanketing gases by bubbling them through a column of NaK. The tests made thus far indicate that use of this system consistently reduces the oxygen content of the gases used in operating systems to below 15 ppm, which is considered a safe level.

To obviate the necessity of inert-gas purification, sufficiently pure gas may be purchased from the Bureau of Mines. The oxygen content of inert gases (principally helium) is determined by a colorimetric method¹¹ which gives excellent precision below 25 ppm; however, at higher concentrations, the precision drops off sharply.

11. L. J. Brady, "Determination of Oxygen in Inert Gases," Anal. Chem. 20, 1033 (1948).

Container

When the parts which comprise the container are shaped to the final dimensions before welding, they should be cleaned of all dirt, except scale, and thoroughly degreased, externally and internally. Internal cleaning should be inspected carefully because it is likely to be less thorough than external cleaning. Just before welding, the scale should be removed (with file, emery cloth, etc.) at the place to be welded, and the parts should be given a final rinse in a good, quick-drying solvent, such as pure alcohol or acetone.

Preparation of System for Liquid Metals

The cleaned components of the liquid metal system are assembled into an integral system, and the entire system is leak tested and cleaned before being heated to receive the liquid metal. The details of each of these steps, together with alternate methods for some, are discussed. ●

Assembly

Every precaution should be taken to assure sound welds.¹² Heliarc welding is preferred, with pure inert backup gas on the back side of the weld. It was found that 25 parts of oxygen per million parts of gas, by volume, was the maximum oxygen content needed for preventing scaling (discoloration).

Welded joints are preferred when not too inconvenient. Other joints successfully used are (1) metal ring gaskets in flanged joints, (2) flared tubing joints, and (3) compression-type joints; the joint used depends on size and pressure. There are, of course, other joint designs which would probably be quite satisfactory.

¹². See more detailed discussion of welding on p. 16.

Leak Tests

Leak tests should be made after the system is assembled, and special attention should be given to all joints. Leak testing involves the following steps:

1. The system is filled with inert gas at operating or higher pressures, and the entire system is checked by brushing soap solution on the outside. A leak would cause bubbles to form in the soap solution.

2. The system is evacuated to a few microns pressure and the rate of pressure rise is checked. After sufficient time has been allowed for outgassing, the rate of pressure rise is again checked. If two successive tests give the same rate of pressure rise, it is evident that there is a leak. Obviously, a zero rate of pressure rise is the ideal, but a rate of rise of $1 \mu/\text{min}$ with a base pressure of about 20μ is indicative of an acceptably tight system.

3. The helium (or freon) leak detection method, which is very sensitive, is used next. This method will not be described because it is too lengthy. It consists, essentially, of the detection, with special detectors (for example, those manufactured by the General Electric Company or the Westinghouse Corporation), of helium (or freon) leakage into a highly evacuated system.

4. Step 2 is then repeated at or above operating temperatures.

5. If the material to be contained is likely to attack scale or weld inclusions, additional leak tests should be made at operating temperatures and appropriate pressures with the system filled with the material to be contained.

Cleaning

Any surface that will be exposed to an alkali metal should be descaled. This may be done by several methods, some of which are suggested below:

1. Chemical Pickling. After chemical pickling, the system must be thoroughly rinsed with distilled or demineralized water and evacuated to absolute pressures of the order of 10 to 100 microns.
2. Alkali Metal Cleaning. This is done by introducing pure alkali metal into the system, heating the system to the appropriate temperature (not less than 1450°F for 2 hr), circulating the metal through the system and through a partial bypass which contains an oxide filter that is maintained at a low temperature, draining the system, distilling off the remaining traces of alkali metal, and removing or blocking out the bypass. All these steps must be accomplished under a very pure inert gas blanket.
3. Molten Salt Cleaning. The various methods for molten salt cleaning are too numerous to be described here. In all methods, a pure inert gas blanket is required. Virgo salts, for example, may be used as the cleaning material.
4. Hydrogen Firing. The hydrogen-firing method of cleaning involves evacuating the system, purging with pure dry hydrogen, heating to the required temperature while passing pure dry hydrogen through the system, purging with inert gas, and closing the system.

Preheating

The clean, inert-gas-blanketed system to be filled may be preheated by any desired method (with gas, steam, electric radiant heat, direct-resistance heat, etc.) to temperatures above the melting point of sodium (208°F); the

evenness of the temperature within the system and within the molten sodium must be consistent with the allowable thermal strains to be induced on filling.

The sodium storage tank, the oxide filter, and the transfer line (tubing) to the vessel to be filled should also be brought to a temperature consistent with that of the system, but it should be remembered that the colder the filtering temperature, the less oxide there will be in the delivered sodium.

Normal Operations

Included under normal operations of the liquid metal system are filling and draining of the system, operation of the continuous purification system (cold trap), and sampling.

Filling

Filling is accomplished by pressurizing the molten sodium from the storage tank through the filter and transfer line into the system to be filled. Filling is stopped by releasing the gas pressure in the storage tank. A schematic sketch of the storage and receiver tanks, including the associated equipment, is shown in Fig. 16, together with a list of the steps required to effect a normal transfer.

Draining

The system may be drained by gravity or pressure transfer into a tank blanketed with inert gas or, if the sodium is cool enough, into a receiver partially filled with a hydrocarbon or an oil that is lighter than sodium.

If it is desired to completely remove the sodium from a vessel, several methods are available, for example:

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Fig. 16—The filling operation.

1. Evacuate receiver and fill with helium.
2. Purge transfer line through V_4 .
3. With helium flowing from both, attach transfer line to receiver.
4. Close V_4 , leaving V_5 open and P_2 at least equal P_1 .
5. Preheat transfer line and receiver.
6. Close V_5 , bleed through V_6 until receiver is filled to desired level, as measured by probe.
7. Close V_6 , close V_1 , open V_2 , open V_5 .
8. When gas bubbles back through stored sodium, close V_3 , close V_2 , open V_4 .
9. Disconnect transfer line from receiver and plug both open ends.
10. Operate filled system.

1. Drip water into the sodium until the reaction is completed, and then rinse out the NaOH; the H_2 must be vented. This method involves violent reactions.

2. Heat the vessel to above saturated steam temperature and admit superheated steam; then rinse as in method 1. One volume of steam will give one volume of H_2 .

3. Drip alcohol, instead of water, into the sodium as in method 1. The reactions will be less violent than those of method 1.

4. Distill off the remaining sodium and condense it under an inert gas. A small flow of inert gas should be maintained in the system during the distilling process.

5. Dissolve the remaining sodium with liquid ammonia at low temperatures.

Continuous Purification (Cold Trap)

Every large-scale liquid metal system should be equipped with a continuous purification system consisting of a low-temperature filter and/or cold trap for a bypass stream of the circulating fluid. Adequately sized cold traps packed with stainless steel wool will completely remove sodium and potassium insoluble oxides and will pass only those oxides that are soluble at the cold-trap temperature. (An adequately sized trap is one in which the metal can be kept below a specified temperature ($< 350^\circ F$) for at least 5 minutes.) The recommended cold-trap packing material is York stainless steel wool; ordinary steel wool tends to break up. As an added precaution, it is desirable to employ a 5- μ micrometallic filter at the cold-trap outlet. To minimize heat losses, an economizer type of heat exchanger may be employed. Also, additional cooling may be provided around the cold trap.

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SAFETY PRECAUTIONS

Safety precautions for the use of sodium and NaK are described in considerable detail in the Area Safety Guide.¹³ Since the "Guide" treats all alkali metals alike, the discussion which follows points out some considerations which are applicable to sodium alone. As a consequence of the considerable experience in handling sodium at KAPL and MSA, as well as the three years of experience at ORNL, it has become apparent that the safety regulations given in the "Guide" for the handling of sodium are somewhat more stringent than is necessary.

The following precautions, which should be strictly adhered to, summarize the present attitude on the safe handling of sodium.

1. All people who are working in an area in which there is sodium should wear safety glasses (or a mask) to protect their eyes.

2. All people who are working near enough to a sodium-containing system to be within reach of spray from a sodium leak should wear protective clothing with long sleeves, gloves, a head cover (hat, cap, etc.), and a mask.

3. If it is reasonably possible that a large, sprayed leak will occur, the protective clothing prescribed in the "Guide" should be worn.

4. The protective clothing listed in item 2 should be worn when putting out a small sodium fire.

5. The protective clothing prescribed in the "Guide" should be worn when fighting a large sodium fire.

13. P. Hill, Alkali Metals Area Safety Guide, ORNL Y-811 (Aug. 13, 1951).

6. In all places where sodium will be used often (including sodium transfer tank storage areas), there should be adequate exhaust ventilation to remove air laden with Na_2O particles.

7. Quick-opening safety showers (water) should be installed as near as practical to any sodium operation. It is believed that the safest and best way to remove sodium from the clothing or skin is to flood it with water. (Of course, the shower should be sufficiently removed from the sodium-containing apparatus that, in the event of a sodium leak, the water cannot reach the sodium.)

8. Powdered graphite, which is believed to be the best all-around fire-extinguishing material for use with sodium, should be readily available in open containers for shoveling onto a leak or onto any open puddles of sodium. Met-L-X will extinguish sodium fires somewhat more quickly and permanently than will graphite, but it is corrosive to metal parts.

9. Used sodium that is to be disposed of should be placed in inexpensive, expendable cans in quantities of up to 50 pounds. After the sodium has solidified, holes may be punched in the container and the can and sodium catapulted into a pond or river where pollution can be tolerated. The explosions will be violent, and all observers should remain at a distance of greater than 100 feet.

CONCLUSIONS

Although the technology of the use of sodium as a circulating heat-transfer fluid is in its infancy, it has already developed to the point where such systems have been successfully operated for several thousands of hours. Whether or not - in any given application - the use of sodium would effect the most economical process, can only be determined from thorough analysis of the process using sodium compared with alternate means. It is a fact, however, that many of the components required for any sodium system have been developed; most of them perform satisfactorily and give every indication of having sufficient life to be useful in industrial applications. Subsequent improvements, which may reasonably be anticipated in so youthful a technology, can only serve to enhance the use of sodium. The sodium system may, even now, be fabricated from any one of a number of commercially available structural metals, the choice being dependent upon strength and fabricability, since corrosion of most structural metals in sodium is negligible. In addition, many commercially available items, such as valves and instruments, are suitable for use with sodium. The unique developments upon which this successful use of liquid sodium has depended include (1) adaptation of a pump to liquid metals, (2) fabrication methods, and (3) operating techniques. Of these, the last two involve the most important single aspect in the successful use of sodium, that is minimizing oxygen contamination. While the use of sodium involves certain hazards, they are not of such consequence as to deter its application.

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