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FFTF/LMFBR
METHODS FOR SODIUM LEAK
DETECTION, FIRE PREVENTION
AND FIRE CONTROL

AUGUST 1971

JOINT TASK FORCE
AI/ANL/ARD/BECHTEL/HEDL

HANFORD ENGINEERING DEVELOPMENT LABORATORY
UNITED STATES ATOMIC ENERGY COMMISSION

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I. INTRODUCTION

This report presents the results of a study on FFTF/LMFBR Sodium Leak Detection, Fire Prevention and Fire Control. The study was performed by an inter-contractor Task Force at the request of WADCO Engineering .

The Task Force study objective was to develop proposed leak detection and fire protection functional requirements for inclusion in System Design Descriptions for FFTF and HEDL Developmental Facilities. The Task Force reviewed and evaluated (a) the present state of the art in sodium leak detection and fire protection, (b) on-going research programs in these areas, and (c) sodium leak detection and fire protection provisions in existing and planned facilities employing liquid metal cooling.

Based on the reviews, the Task Force (a) established proposed functional requirements for sodium leak detection and fire protection in the FFTF systems and in related HEDL Facilities, and (b) defined necessary supporting development and test programs.

Conclusions and recommendations of the Task Force were largely based on technical considerations. Assessment of cost and scheduler impact of implementing the recommendations was not within the scope of the Task Force.

11. SUMMARY

RECOMMENDATIONSLeak Detection

The principal method of sodium leak detection of the FFTF and associated HEDL facilities should be the continuous monitoring of gas spaces around piping and components. The detection and location system should use plugging type and/or chemical sensing methods. The system should have an overall sensitivity to detect in the order of 1 gram of sodium. The system should be able to locate leaks at major components and in reasonable runs of connecting piping. This principal method should be backed up by single point detectors at selected locations (such as valves, guard vessels). Leak detectors in the DHX's should be of the smoke detector type.

Plant Design

Inside containment, all sodium and alkali metal systems should be located in inerted cells and pipeways. Beyond the containment boundary sodium piping and components should be located, wherever practicable, in pipeways and cells which can be made relatively airtight so as to cause extinguishment of sodium fire due to oxygen depletion or by addition of inert gas. Where such enclosure is not practicable, sloping guttering should be provided to direct the leaked sodium to confined spaces where extinguishment is relatively easier. The DHX's are to be equipped with louvers and doors on the air passages to effect confinement. Catch pans should be provided below the tube banks for collecting leaked sodium and to allow application of extinguishants by installed systems. Floors in spaces housing sodium equipment or where sodium is handled should have curbing and depressions to localize spilled sodium.

Fire Control

The facilities should have an adequate supply of dry fire extinguishing material available at the site for controlling and extinguishing sodium fires. The quantity and method of application should be determined by defining a design basis fire and by development results. Inert gas should be used to control sodium fires when they occur in relatively tight enclosures. The use of dry extinguishing material should be under administrative control; it should be applied only where it can be effective. There should be no automatic release provisions for the extinguishant. Maintenance procedures

for sodium filled equipment and enclosures housing sodium should include provisions for fire detection and control.

Smoke Control and Abatement

Provisions with fire control should be coupled with effective means for smoke abatement and control. Particular attention should be given to control and clearing of smoke from sodium fires. Capability should be provided for smoke clearing to restore visibility for fire control and to limit smoke discharged to the atmosphere from the design basis sodium fire to concentrations acceptable under pollution control standards defined for the Hanford Area. More effective alternatives to filtering should be developed and proof tested.

Design Requirements

It is recommended that the FFTF System Design Descriptions include the sodium leak and fire related requirements stated in Attachment I. System Design Descriptions of test facilities should also include these or equivalent requirements if tests with sodium or alkali metals are contemplated in the facility.

Development Program

a. Leak Detection

The present program at LMEC for evaluation and testing of commercially available sensors should be continued. The scope of the program should be expanded to include tests of prototypic leak to sensor configurations and to test sensors under conditions simulating the dump exchangers. (Attachment II)

b. Fire Control

The sodium fires program scope at HEDL should be expanded to determine the most effective means of extinguishing alkali metal fires, effective smoke control and abatement methods and control of sodium-air reaction products. (Attachment III)

CONCLUSIONS

The Task Force Recommendations are based on the Conclusions described below.

Leak Detection

1. Failures of the pressure boundary in sodium systems are generally initiated by small, **weeping** leaks. Over a period of time, **if** not detected and repaired, corrosive action of sodium reaction products is likely to damage the metal around the leak and cause large, potentially catastrophic, leaks and resulting fires. Early detection of weeping leaks by means of highly sensitive leak detection system therefore is believed to be the most effective means of preventing large leaks or sodium fires.
2. Results from development programs and tests at LMEC indicate that commercially available sensor equipment can be utilized to detect small "non-flowing" leaks by sensing the presence of sodium and reaction products in a continuous gas sample.
3. Leak detectors of the single point (e.g., spark plug) or parallel wire type are useful to detect flowing leaks which can be directed toward the sensors; however, such devices are not generally useful for early detection of weeping type leaks.
4. In the FFTF dump heat exchangers, detection of non-flowing leaks may not be possible during forced convection operation, because of dilution of the products of combustion or smoke by the high volume airflow. Nevertheless, leak detectors of the smoke detector type will **probably** give warning of acute hazards in the modules.

Plant Design

A number of facility design features tend to minimize the probability of sodium fires and/or limit damage and downtime. Such features include:

- Inerting the atmosphere in cells and spaces where sodium equipment is located. Inerting should be used inside containment and around primary sodium equipment.

- Outside containment, where possible, sodium piping and equipment should be placed in relatively tight pipeways and enclosures where, in the event of leaks, sodium fires would subside due to oxygen depletion or inert gas could be added.
- Where enclosed pipeways and spaces are not practical guttering or curbs can be used to direct the escaped sodium to locations where sodium fire can be effectively controlled or the fire can burn out without further damage to the facility.

Fire Control

1. Good operational practice requires early detection and location of leaks with subsequent shutdown and draining of the affected system. Repair and maintenance operations in the area of failure require careful planning and rigid procedural control.
2. Dry powder type fire extinguishing agents, presently on the market, have been tested on fires involving only limited quantities (~80 lbs.) of sodium and with pools of shallow configuration. The effectiveness of such extinguishing agents on large sodium fires has not been demonstrated. Halides contained in **some** extinguishants can cause corrosion when deposited on surfaces; thus meticulous cleaning must follow the application of these agents.

Smoke Control and Abatement

Smoke accompanying sodium fires makes fire location and extinguishing in closed spaces extremely difficult because of limited visibility. Effective manual fire fighting cannot begin until the smoke is exhausted or otherwise eliminated. Dissipation of sodium-air reaction products to the environment must fall within established clean air standards. **It** was concluded that High Efficiency Particulate filters (HEPA) will be clogged very rapidly; thus other, more effective methods are needed for prolonged use.

Development Programs

Development programs undertaken for leak detector sensors at LMEC and the sodium fire program at HEDL represent a significant start. The sensor development program should be expanded to test sensor capabilities in near prototypic system configuration. The sodium fires program should include tests to determine the most effective fire control and smoke control and abatement methods.

III. DISCUSSION

A. SODIUM LEAKS AND LEAK DETECTION

For purposes of this discussion, sodium and alkali metal leaks have been classified in three categories based on quantity and rate of leakage:

- Non-flowing leak,
- Intermediate leak, and
- Catastrophic leak.

In the following, each of the leaks is characterized, its consequences described, and the detection methods useable and/or available are identified.

1. Non-Flowing Leak

One speaks of a non-flowing leak where the rate of sodium discharge is small enough that complete chemical reaction with the atmosphere or insulation takes place before the sodium migrates from the leak site. In air, the leak rate is in the order of tenths of grams per minute. In oxygen depleted atmosphere sodium migration would probably set in at even lower leak rates. Usually there is no sodium fire associated with such leaks.

The recent sodium leak in CCTL (described in detail in Exhibit C) and the HNFP dump tank leak are typical of this class of leaks. While the leaks themselves have little immediate effect on the operation of the facility, corrosion of the pressure boundary caused by the products of chemical reactions with sodium occurs around the leak site. Such damaged metal is a prime site for failure and larger sodium leaks, should the leak remain undetected and unrepaired (see figures 1, 2, 3). Fortunately in the incidents cited, alert personnel or plant shutdown prevented development of a major catastrophe. It was concluded that detection of these leaks should be emphasized.

Leak detection systems presently deployed in sodium facilities, such as the spark plug or parallel wire type, cannot detect such leaks except for a chance coincidence of sensor and leak locations.

Sensors detecting airborne particles of Na vapor products of chemical reaction or radioactivity in the atmosphere offer the capability for detecting non-flow leaks. Table 1 lists the types of sensors used in sodium systems. Descriptions of the operating principles of these devices with comments on application and effectiveness are given in Exhibit A.

Tests conducted at LMEC show that plugging type and chemical sensors (pH meter) are able to indicate products of reaction concentrations in the parts per million range which is considered adequate for detecting non-flowing leaks. These tests should be expanded to verify capability in prototypic environment and with hardware configuration simulating FFTF and facility applications, such as inert, or oxygen depleted atmospheres, length and shape of suction tubes, modular insulation, etc.

Non-flowing leaks are possible through any part of the sodium boundary although mechanical joints and weldments are more probable sites. Detection by plugging indication or chemical methods is probably useable in most locations. A notable exception is the DHX. There is some concern that the high volume airflow will cause dilution of particle concentrations below the sensitivity of the methods. This would preclude detection of non-flowing leaks. Some facilities such as SEFOR use smoke detectors in the DHX. Tests should be conducted to determine the size of detectable leaks in DHX's.

Since one would not expect visible indication of non-flowing leaks on the outside surfaces of insulation, leak sensing take off points should be spotted to aid in locating the leak as well. In the primary HTS loop, for example, pickup points should be located at the major components (pump, IHX, valves) and one or two points on pipe segments connecting these components.

2. Intermediate Leaks

Intermediate leaks up to a few gallons a minute are typical for cases of ruptured bellows or improperly seated and tightened flange joints. These leaks are the most commonly observed ones. Sodium appears at the outside surface of insulation shortly after the failure occurs. Leakage of this level in air results in small fires that seldom cause major property damage.

Most existing installations are equipped to detect intermediate leaks. "Spark plug" or parallel wire systems are adequate detection schemes. Personnel observation of smell or visual inspection have detected such leaks.

Upon detection the facility can be shut down, depressurized and drained before large quantities of sodium can escape. For an inerted cell the leaked sodium is allowed to cool down, then cleanup, repair, and recommissioning work is executed. In air atmosphere, the fire is extinguished with

FIGURE 1. CCTL Sodium Valve With Insulation Removed
After Sodium Leak

FIGURE 2. CCTL Sodium Valve of Figure 1 After Water Washing

CLAMPING LIP
BEFORE INSTALLATION

CLAMPING LIP AFTER
SODIUM LEAK

FIGURE 3. CCTL Sodium Valve Bonnet Clamping Lip and Damage By Sodium Leak

TABLE 1

TYPES OF SODIUM LEAK DETECTORS

Type of Emission Detected	Type Detector	Sensitivity	Comments
Liquid Sodium	Pair of Electrodes (i.e. "Spark Plug")	LMEC Tests showed Sensitivity @160 g/hr	Widely used in USA and in Europe. Planned For FFTF Primary System
	Pair of wires serving as electrodes	Comparable to Sparkplug	Used by Dutch and French. Reliable design configuration not available for FFTF
Sodium Vapor (emitted from non-flowing leaks)	Absorption of Specific Frequencies of Light	$75 \times 10^{-6} \text{ g/m}^3$ under bench test conditions	LMEC Tests not successful - Unable to maintain sodium in vapor phase long enough for detection
	Flame Photometry	$\sim 1 \text{ ppb}$	Requires piping of samples to chemical analysis room.
	Chemical Method (color indication Phenolphthalein or Thymol blue)	$2.3 \times 10^{-4} \text{ g/m}^3$	Final analysis performed in laboratory
	pH Method	$\sim 1 \text{ ppb}$	Successful LMEC Tests: Commercial pH meters available - method suitable for on-line use
	Conductivity Method	$\sim 1 \text{ ppb}$	Commercial meters available - method suitable for on-line use
Sodium Vapor - Sodium Oxide Mixture	Plugging Type Flowmeter	"As responsive as any meter"	LMEC successfully tested. Sensitive to false alarms
	Filter Type Flowmeter	Probably better than plugging type $\sim 8 \times 10^{-10} \text{ } \mu\text{Ci/cc}$	No test data. Sensitive to False Alarms
Radiation From Airborne Particulates	Filter followed by gamma monitor		Commonly used for primary loop of nuclear reactors
Smoke Detection - Sodium Oxide	Various Methods	Variable - limit $1.5 \times 10^{-3} \text{ g/l}$	Methods have been applied in sodium systems
Hydrogen (from Na Reaction with H_2O)	Hydrogen Detector	Above 1.5 g/hr	LMEC tested successfully, but appears not suitable if tritium is present

manually applied Met-L-x or equivalent. It is noted that smoke evolution even from small fires is extensive and could hinder fire fighting in enclosed spaces to the point that personnel require self-contained breathing equipment. At least partial clearing of smoke is necessary to allow visibility.

3. Catastrophic Leaks

Leaks in excess of few gallons per minute are classified as catastrophic. They might result from poor design, overloading of equipment due to operating error or from maintenance procedural errors. Such incidents release relatively large quantities of sodium before the leakage can be stopped. A well documented leak of this type occurred in the EBR-II secondary system control room resulting in the release of approximately 30 gallons of sodium.

Leak detection systems indicated for intermediate fires would detect catastrophic leaks. In addition, effects of the leak could register on normal process instrumentation such as level indicators, or flow meters. A survey of the state-of-the-art for sodium fire protection is given in Exhibit D.

B. LEAK DETECTION DEVELOPMENT

The Task Force has concluded that sensors are available for detection of non-flowing leaks in all locations except possibly in the DHX, and that these should be tested extensively under FFTF and LMFBR conditions.

The non-flowing sodium leak detection program at LMEC should be continued and expanded. Tests to date have been conducted only in a nitrogen environment. Data are needed on capabilities in air atmosphere at various humidity levels.

The two plugging type detectors described in Exhibit A should be submitted to additional tests wherein diffusion, agglomerated aerosol deposition and transport time are evaluated with respect to gaseous volumes, surface areas, transmission line lengths and transmission line diameters. Three chemical type detectors, namely pH, specific ion, and flame photometry, should be subjected to similar tests as those described for the plugging types and in addition should be evaluated for maximum sensitivity in order to evaluate the potential for using multiple channels with one detector for the limiting leak criterion specified.

An environment test should be conducted on both the plugging and chemical type sensors to ascertain the effects of airborne particulates and contaminants on long term sensitivity and effectiveness. Each of the detector types selected should be evaluated for long term reliability.

The system developed by this program should be installed on the FFTF prior to startup (Table 2).

The Task Force is particularly concerned with detecting sodium leaks in the dump heat exchanger. Leaking sodium would tend to burn very rapidly and combustion products would become widely diffused as the result of the high velocity air coolant.

Detection of combustion products is expected to be difficult due to dilution. Candidate detectors meeting the criteria are limited to high sensitivity detectors (infra-red, ultraviolet, photoelectric) or extremely sensitive plugging or chemical type detectors. A test program is required for evaluation of these devices under simulated conditions. Candidate devices should be field tested at SCTI in the DHX test program.

C. FIRE PROTECTION DEVELOPMENT

Development is required for an improved sodium fire extinguishant, for an effective method of application of the extinguishant for evaluating and improving structural resistance to fires, for improved methods of post-fire cleanup and equipment recommissioning and for evaluation of smoke abatement methods.

1. Material for Sodium Fire Suppression

A satisfactory material must be available which can be depended upon for extinguishing sodium fires, either from hand extinguishers for small fires, or from fixed type extinguishing systems for large fires.

It is recommended that a development program be initiated to identify, develop, and proof test other materials until a suitable extinguishant is available. This is an urgent requirement as the knowledge must be available before January 1973 to permit incorporation of such systems into FFTF.

2. Structural Materials Evaluation

A test program is required to investigate the interrelationship between sodium fires, molten sodium and confining structures to develop criteria for design of structures capable of sustaining the action of sodium or sodium

TABLE 2
SPECIFICATION AND PROCUREMENT SCHEDULES
Specifications for Leak Detection Systems

<u>Item</u>	<u>Specification Completion Date</u>
Piping	October 29, 1971
Piping Supports - Nuclear Service	July 16, 1971
Seismic Snubbers	September 17, 1971
Insulation Heater Module	July 14, 1972
Leak Detectors	January 3, 1972

Leak detection concept will have to be coordinated with insulation and piping support design.

Procurement of Leak Detectors

<u>Item</u>	<u>Specification Completion Date</u>
Testing Program (Start 2nd Phase)	September 1, 1971
Start RDT Standard	January 3, 1972
RDT Standard Complete	March 1, 1972
Specification Complete	May 1, 1972
WADCO & RDT Approval	June 11, 1972
Request Bids	June 18, 1972
Receive Bids	August 13, 1972
Complete evaluation of Bids	August 27, 1972
WADCO Approval	October 22, 1972
Issue Purchase Order	November 5, 1973
Receive Vendor Drawings	January 23, 1973
Approve Vendor Drawings	February 13, 1973
Complete Fabrication	April 29, 1973
Delivery	May 15, 1973

fires sufficiently long to permit cooling of spilled sodium below the ignition temperature.

To provide adequate confidence in the plant design, the knowledge should be available by early 1972. The existing large sodium fires experiment at HEDL should be directed in such a manner that maximum benefit and confidence in proposed structural materials is obtained.

3. Cleanup and Requalifications

Given that a large sodium fire has occurred, a major problem is the cleanup and requalification of the equipment. Specifically: in a large sodium fire stainless steel and other materials can be damaged by the effects of heat and products of combustion. **It** is necessary to know how to determine the extent of this damage so that recovery operations can proceed without delay. There has been little study to determine non-destructive means of appraising the extent of metallurgical damage to equipment after a fire.

After a large fire and clean-up, **it** is necessary to assure that the remaining debris and cleaning agents have been removed to the extent that no further damage will ensue due to corrosion or for other reasons. Thus, there is a need for non-destructive testing to assure complete clean-up.

It is recommended that the work necessary to resolve these questions be incorporated in the large sodium fires study (Table 3) by installing typical equipment in the area of the fire, exposing **it** to damage, and appraising the available cleaning and testing procedures under actual service conditions.

4. Smoke Abatement

The sodium oxide ("smoke") formed in a sodium fire presents a real hazard. **It** is toxic, blinding, capable of entraining radioactive particles, and capable of severely damaging instrumentation and other delicate equipment.

The FFTF smoke abatement filter system should be tested under conditions of large sodium fires to assure that filter performance would be adequate under such emergency conditions.

The tests should involve measurement of the pressure drop history of the filter with respect to time, the pre-and post test weight of the filters and post-examination of the filter for possible internal damage. In addition, the rate of removing the smoke from the fire area should be measured to determine the effectiveness of the system. The potential for reentry of fire protection personnel to completely control the fire should also be evaluated.

TABLE 3
DESIRED INFORMATION FROM LARGE SODIUM FIRES EXPERIMENTS

1. Characterize Fire.
 - Analysis of products of combustion and agglomeration pattern.
2. Evaluation of fire fighting materials.
 - a. Dry powder candidates
 - b. Other candidates
 - c. Effect of materials on components
3. Study of distribution of reaction products to the environment.
Evaluation of effect of reaction products on environment.
4. Demonstration and evaluation of confinement techniques leading to O_2 depletion.
5. Evaluation of design for segregating and constraining spill area.
6. Evaluation of smoke retention capabilities of confinement structures.
7. Study of interaction of structural , piping, insulating and electrical materials in direct contact with fire.
 - a. Effect of fire on materials
 - b. Effect of materials on fire
8. Study of heat transfer into walls and structures with time.
 - a. Evaluate damage to fire retention structures.
 - b. Evaluate damage to load bearing structures.
 - c. Evaluate damage to components and piping.
9. Evaluation of smoke suppression techniques, i.e., scrubbers , electrostatic precipitators , filters , etc.
10. Evaluation of fire suppression techniques
 - a. Perforated deck plate
 - b. Spill area drain capability
 - c. Fire blankets
 - d. Chemical extinguishant application
 - e. Heat sink concept
 - f. Combinations of above.
11. Evaluation of post fire cleanup techniques.
12. Change of character of fire with environmental conditions.

ATTACHMENT ■

FFTF/LMFBR SODIUM FIRE PROTECTION REQUIREMENTS

Requirements for Containment System (SDD 27) and Reactor Support Building (SDD 21)

- Equipment normally containing primary sodium shall be housed in closed, inerted and steel lined cells.
- Floors of cells and pipeways housing sodium filled equipment are to be sloped to induce collection of leaked sodium to localize damage and cleanup.
- Curbs or similar configuration shall be installed in large horizontal surfaces to localize spilled sodium.
- Pipeways or other areas containing secondary sodium equipment at or below grade shall be concrete structures with sloping floors to direct spilled sodium toward appropriate catch basins. Such pipeways are to be covered to limit gas leakage and to exclude rain water. Provision to inject inert gas to such spaces shall be included.
- Ports and plugs shall be provided to allow visual survey of cells and pipeways without violating containment of inert atmosphere.
- Temporary covers shall be provided over access ports of cells for use when cells are opened to air atmosphere for maintenance operation.
- Safety requirement: Equipment in cells and enclosed spaces shall be laid out in a manner that will permit access for maintenance operations and will permit expeditious exit of personnel in case of emergency.
- Structural members **shall** be protected from the effects of high temperatures resulting from Na fires by suitable insulating provisions.
- Within containment all sodium or alkali metal containing equipment shall be housed in closed, inerted and lined cells or pipeways.

Requirements for Heating & Ventilation System (SDD 25)

- Cell cooling equipment shall be designed to allow isolation of containment spaces to limit spreading of products of combustion to otherwise unaffected areas.

- Filtering and other devices shall be included in the design to limit discharge of airborne particles to levels acceptable under pollution control standards applicable at the FFTF site.
- Provisions shall be made for clearing the atmosphere in enclosed spaces of smoke to allow effective fire control.
- Capability for local isolation and atmosphere control shall be provided for use in cells during maintenance operations.

Requirements for Plant Fire Protection System (SDD 26)

- Building spaces and cells containing primary Na shall be equipped with continuous gas sampling equipment to detect the presence of sodium outside of pressure boundary. Equipment should sense gram quantities of escaped sodium. Detection and alarm to be provided in SDD 93.
- Leak detection and location capabilities are to be provided on or near sodium containing components and piping. Such equipment should detect "weeping" leaks and should be able to establish leak location at individual major component and in reasonable pipe segments. A design basis sodium fire is to be established for each cell and space to establish extinguishment methods and the type and quantity of extinguishants to be provided. (Detection and alarm system to be provided by SDD 93.)
- The reference extinguishant for alkali metal fires is Met-L-X. Provisions shall be included to permit conversion to other extinguishant such as calcium carbonate.
- Equipment and procedures shall be provided for post fire cleanups and for establishing the extent of damage (visual inspection only).
- Protective clothing and self-contained breathing equipment shall be provided to permit trained personnel to approach the fire site with extinguishant.
- Provisions are to be made to remove and neutralize airborne products of combustion to enhance visibility for effective fire fighting effort. (Provided by SDD 25.)
- Fire retardant and/or extinguishants used in spaces housing alkali metals shall be of composition that do not cause harmful or toxic reaction on contact with alkali materials.

Requirements for SDD's 51, 61, 41, 81 and 32 (as applicable)

- Insulation and trace heating provisions shall permit and shall be compatible with leak detection system on sodium piping and other sodium carrying equipment (SDD 93).
- Sodium-to-air heat exchangers shall be designed to permit closing of inlet and outlet louvers or doors to limit access of air in the event of fire.
- Shut-off valves are to be provided at inlet and outlet sodium pipes of DHX's to isolate each unit or module and limit sodium available for leakage.
- Design of each DHX module or unit shall limit damage from or effects of sodium fires to the module or unit where the fire occurred.
- The design of the DHX modules or units shall be such that sodium leaked within the casing will not leak to the surroundings during pool burning fires.
- The dump heat exchanger housing shall be equipped with access ports for deployment of fire extinguishant or for introducing inert gas blanket in the event of sodium fire.
- Maintenance and other operational procedures involving breach of the sodium boundary shall be prepared in full consideration of sodium fire potential and shall define requirements to be met for preventing sodium leakage and for fire protection in the event of failure of precautions.

Requirements for Process Monitoring & Control System (SDD 93)

- Leak detection system shall be provided in spaces occupied by alkali metal containing equipment. Sampling shall include spacial samples and samples drawn from spaces between equipment and insulation.
- The leak detection methods shall provide means for locating leakage at major components and in reasonable segment of piping. As a goal the detection system shall have an overall sensitivity to detect gram quantities of leaked sodium in either air or N_2 atmosphere.
- To the extent feasible leak detection equipment is to be insensitive to the environment, e.g., temperature, inert atmosphere, radioactivity. Alternately, sensitive equipment shall be installed in protected locations.

- Leak detection system shall be capable of in-place testing (functional check and calibration).
- The reference leak detection system consists of ΔP indicators across orifices or filters and chemical sensors in tandem. This system shall be used for all cases except the dump heat exchangers. Spark plug type indicators shall be used as backup at selected locations.
- Smoke detectors shall be used for leak/fire detection in the dump heat exchangers.
- The leak detection system shall provide essentially continuous surveillance and alarm capability.
- Piping and gas handling equipment for leak detection system shall be provided. (SDD 85)

Requirements for Inert Gas Receiving & Processing System (SDD 82)

- A supply of N_2 shall be provided to blanket sodium fires as defined by (SDD 26).

Requirements for Impurity Monitoring and Analysis System (SDD 85)

- Equipment shall be provided to extract gas samples for leak.detection purposes from cell or confinement atmospheres and from gas spaces between equipment and insulation. Provisions shall include connections to sensors and, as necessary, conditioning of sample gases for disposal.

ATTACHMENT II

LEAK DETECTOR PROGRAM

Program Objectives

Objectives of the Leak Detector Development Program are to:

- Identify and select leak detection sensor devices of high enough sensitivity to detect weeping type and flowing leaks from sodium filled equipment in air or inert atmosphere
- Verify the capabilities of proposed sensing devices in prototypic detection systems and with configurations and conditions simulating application in the FFTF.

Justification

Detection of sodium leaks in the early, non-flowing stage is necessary to prevent extensive corrosive damage to and potentially larger leaks from equipment due to sodium reaction products. Sensing of leaks of gram quantities is required to give such early detection capability. Commercially available sensors have been found to have such capabilities in laboratory tests. Further screening tests are required to select the most promising candidates. Reliability and sensitivity of leak detection systems using such devices must be demonstrated under near prototypic conditions to obtain a satisfactory confidence level.

Scope and Relation to Other Projects

The program involves continued laboratory screening tests and the construction and testing of a complete sensor to readout and alarm module, the construction and testing of one or more prototypic sodium component configurations with insulation and heaters using prototypic source to sensor configuration.

Analysis of test results and reportings are included in the scope. This program is closely related to the Sodium Fires Program and to the Heater Insulation Development Program. Close relation will be maintained with other LMFBF sites to assure universal applicability of the test results.

Description of the Work

Sodium Component Leak Detection

A testing facility will be provided in which gram quantities of sodium at 300 - 1200°F temperature can be injected into controlled atmospheres of

air, nitrogen, and argon. Temperature and humidity of the gas will be measured and controlled so as to simulate FFTF environment. Heatable tubes up to 50 ft length will connect the test chamber to the sensor test point. Detectors such as pH meters, conductivity meters, plugging indicators, and others will be connected at the sampling point. The sensitivity of each sensor will be determined from threshold indications. Sensitivity to line losses will be determined from comparison between the indicated concentration and the concentration in the atmosphere chamber. Further tests will be conducted using prototypic pipe and insulation configuration in place of or within the controlled atmosphere chamber to determine "actual" sensitivity of the system and to indicate between joint tightness requirements of insulation modules. Again gram quantities of sodium leaks will be simulated and observations as indicated above will be made. Finally test reports and appropriate RDT Standards will be prepared.

DHX Leak Detection System Test

A testing facility will be provided in which small quantities (in the order of grams) of sodium can be injected into high volume air streams of 20 - 100 ft/sec velocity. Temperature and humidity of the air stream will be measured and controlled to simulate DHX outlet conditions. Sensing devices with prototypic pick up tube length such as those indicated for component leak detection will be used to sample effluent air contamination with sodium reaction products. Sensitivity will be related to the quantity of sodium leaked into the system. In addition sensor detectors, photo-electric, infrared and ultraviolet detectors will be tested for sensitivity. The sensors will also be checked for propensity to errors due to smoke channeling and to false alarms.

Detectors for Flowing Leaks

Configurations of certain FFTF sodium components will be mocked up and prototype leak sensors such as parallel wire or spark plug type will be installed and tested using simulated flowing leaks in air and in nitrogen atmosphere. Adequacy of sensor positioning to detect leaks originating at different locations and freedom from false alarms will be observed.

Expected Results

The above test program will provide data to select the most suitable leak detection systems for all sodium containing parts of the FFTF. It will provide data for selection and design of such systems for future LMFBR plants. Sensitivity and reliability of the leak detection system will be demonstrated.

Schedule

See attached schedule sheet.

		LEAK DETECTION PROGRAM MILESTONE SCHEDULE																			
ACTIVITY DESCRIPTION	FY 1971												FY 1972				FY 1973	FY 1974	FY 1975	FY 1976	FY 1977
	J	A	S	O	N	D	J	F	M	A	M	J									
Modify existing facility so that gram amounts of sodium can be leaked into air, nitrogen, and argon atmospheres.																					
Test detection systems for piping and heat exchangers.																					
Fabricate facility so that gram amounts of sodium can be leaked in a high velocity air stream.							6														
Test leak detection systems for air dump heat exchangers.							7														
Prepare RDT to meet leak detection systems																					
MILESTONES																					
1. Complete modification of existing facility																					
2. Complete assembly of leak detection systems for testing																					
3. Complete testing of leak detection systems																					
4. Issue interim report																					
5. Issue final report																					
6. Complete fabrication of facility for evaluating leak detection systems for Air Dump Heat Exchangers.																					
7. Complete assembly of leak detection systems for Air Dump Heat Exchangers																					
8. Complete testing of leak detection systems for Air Dump Heat Exchangers																					
9. Issue interim report																					
10. Issue final report																					
11. Complete preparation of RDT Standard																					
12. RDT Standard approval																					

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ATTACHMENT III
SODIUM FIRE PROGRAM

Program Objectives

Objectives of the program are

- a. To screen and select suitable extinguishants for sodium fires
- b. To test designs of sodium fire extinguishing systems under controlled conditions to establish their effectiveness and to determine best methods of extinguisher application
- c. To test methods of smoke control and abatement in sodium fires to aid fire extinguishing and to limit discharge to the environment.
- d. To characterize damage to structural materials and equipment caused by sodium fires and to develop clean up and recommissioning requirements.

Justification

There is a paucity of experimental information in regard to fire extinguishing materials and their application for alkali metal fires. Sodium and NaK fire control is complicated by:

- Extremely high chemical activity of these metals with air and with conventional fire extinguishing materials.
- Dense noxious smoke obscures visibility and requires life support for locating and controlling fires.
- There is no known tried reliable extinguishing agent for large sodium fires.
- The effect of sodium fires on materials of construction is not fully known and understood.

Scope and Relation to Other Projects

The program involves engineering evaluations, tests, and studies for fire protection system performance. The program is closely related to the leak detection program. Close relationship will be maintained with other AEC-LMFBR sites to collect information on incidents and fire protection methods proposed or used.

Description of Work

Several large (nominal 4000# each) and a number of small sodium fires will be established, controlled, and the fire area subsequently cleaned up. During the course of fires the following observations will be made and/or data will be taken:

Small fire tests

Small fire tests will be used to identify and characterize suitable fire extinguishants. Desirable and/or mandatory characteristics of extinguishants which will be observed include:

- Ability to form gas tight and tenacious barrier to exclude oxygen from above the hot sodium surface
- **Ability** to contain pool and/or spray type fires
ease of application by manually controlled or fixed means, or automatic delivery
- Absence of chemical reaction with sodium that would aggravate the fire problem
- Absence of tendency to disperse and form aerosol which aggravates smoke and visibility or contribute to clean up problems
- Absence of corrosive behavior with materials of construction such as steel, stainless steel, concrete, and other materials commonly used around liquid metal systems
- High extinguishing efficiency in terms of weight of extinguishant required per unit fire area.

Other desirable attributes of extinguishants include good shelf life, nonhygroscopic, ready commercial availability, and low cost.

Large Fire Tests

Extinguishants selected on the basis of performance in the small fire tests and prototypic application systems will be tested on large fires to observe, measure, and define the following:

- Effectiveness for control of large fires in air
- Reliability of application systems
- Quantity required to control fires
- precautions or modifications needed to assure effective control of pool and spray fires

Materials Impact Evaluation

In conjunction with the fire test, materials which are used in the FFTF will be placed in or near the fire area. Materials of the following type of construction will be mocked up:

- Reinforced concrete to simulate fire walls and shield walls
- Fire doors in typical wall configuration
- Steel lined concrete walls
- Steel catch basins and diverting channels
- Concrete with insulating plaster for protection of structural steel
- Piping with insulation
- Roof structure such as used in secondary HTS buildings.

Such materials will be exposed to sodium fires as follows:

- 1000°F sodium, weeping type leak, approximately 48 hours
- 1000°F sodium, spray fire, approximately 30 minutes
- Pool fire, large surface area, 12 hours

Upon completion of exposure the specimens will be examined by visual, non-destructive, and destructive methods for evidence of damage by the fires.

Cleanup and recommissioning

After the test, the test cell and equipment will be cleaned up and the test facility will be restored to functioning status using methods and equipment proposed for the FFTF to verify adequacy.

Smoke Cleanup and Dispersal

The smoke abatement and cleanup system proposed for the FFTF will be installed in the existing filter train of the test facility and will be used during the fires. During the fires, optical density measurements will be made. The filters will be weighed before and after the tests and continuous pressure drop measurements will be made across the filter during the tests. These tests will be used to establish the effectiveness of the filter system to determine susceptibility to clogging and to give indication of the opaque character of the sodium smoke.

Expected Results

1. Identification and characterization of sodium fire extinguishant best suited for FFTF and LMFBR applications.
2. Definition of requirements and of general design parameters for fire extinguishant application systems (e.g. fixed nozzle dispensers).

3. A verification of application procedures and equipment.
4. Provide bases and input to operating and maintenance manuals with respect to sodium fires.
5. Provide data base for quantity of extinguishant required and for storage methods.
6. Data on effects *of* sodium fire on structural materials will be provided and damage mechanisms will be understood, thus aiding in determining adequacy of existing designs and guiding future plan designs.
7. Information will be obtained on effects of extinguishants on plant components and on the extent of cleanup required.
8. Usefulness of smoke cleanup system designs will be demonstrated and data will be provided for future designs of such systems.
9. Data will be obtained on requalification requirements and methods for fire protection equipment, process equipment (to the extent simulated) and exposed structures.

Schedule

See attached schedule sheet.

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EXHIBIT A*

DESCRIPTION OF EXISTING TYPES OF DETECTORS

The following is a review of presently available types of sodium leak detectors.

a. Liquid sodium detectors

1. Single Point Detector

i. Description

This type of detector consists essentially of a pair of electrodes which are placed in the expected path of the leaking liquid sodium. The leaking sodium bridges the gap between the two electrodes and completes an electric circuit which in turn can be used to light a lamp, energize a relay, etc., as shown in the attached sketch, Figure A-1.

The electrodes are usually contained in an insulated metal fitting. Such detectors are not commercially available as sodium leak detectors, but it is common practice to use either of two commercial items for this purpose (1) spark plug or similar device (2) thermocouple without a junction.

ii. Application

This type of detector could be used under the main equipment components such as valves, pumps, IHX, tanks, etc. The present reference design for FFTF depicts a spark plug type detector applied to each major component as described above and also at the low end of each piping insulation module (approx. 4 feet). In this concept, the inside surface of the insulation consists of a thin layer of stainless steel. A small trough is built into the bottom of the modular insulation to direct the leaking sodium to the spark plug type detector located at the lower end of the module.

In the case of spark plug type detectors used on the main equipment components the detectors are installed in a tube so that they can be retracted for inspection.

FIGURE A-1. Sodium Leak Detector System (Reference Concept)

* Prepared by Bechtel Corporation

Each spark plug type detector is provided with a means (pushbutton switch) to check the integrity of the electrical circuit.

- iii. This type of detector is being used quite extensively for sodium leak detection on major equipment components and on piping by both US and European sodium plant designers (refer to Table #1.)

iv. Effectiveness

Despite its simplicity, a number of factors limit the success of this method:

1. Electrode wetting. Good electrical contact requires wetting of the electrodes by the sodium. Clean surface and high temperature facilitate wetting. Surface conditions and environment which inhibit wetting may prevent satisfactory electrical contact. By "rule of thumb," the reliability of sodium wetting and making good electrical contact with the materials commonly used is uncertain at temperatures below about 300°C. Above this temperature, there is ordinarily little uncertainty or delay in wetting. To operate electrical alarm circuits, such as those in a leak detector, complete wetting or high-quality electrical contact is not necessarily required. The problem is in the uncertainty of contact and possible erratic contact under conditions of poor wetting.
2. Electrode spacing. The electrode spacing determines the amount of sodium needed to bridge the gap and close the electrical circuit. For best threshold the minimum spacing is limited by the possibility of an inadvertent short circuit caused by mechanical shifting of one or both electrodes. A well-designed mechanical support with a close spacing provides a fair solution to the problem. Consideration of thermal-expansion-induced shifting as well as the other mechanical forces is required.
3. Detoured leak. Several conditions can occur to cause a leak to follow a path other than the one leading to the sensor. For example, sodium from a small leak anywhere on a pipe may be expected to flow along the circumference to the lower surface and drip onto a sensor. However, several factors may cause the sodium to squirt away and never follow a path to the sensor.

4. Leak rate and total quantity of sodium leaked

A substantial quantity of sodium is "consumed" in several ways before any is available to actuate the sensor. The leaking sodium may be consumed by reaction with oxygen, hydrogen and water, by filling crevices and basins, and by wetting the surfaces it contacts.

5. Geometry and dimensions.

The amount of leaking sodium consumed as described above depends on the geometry and dimensions of the surfaces involved. This includes the position of the leak on the vessel, the slope of the trough, and interference from possible heaters attached to the insulation.

6. False Actuation

Some users find this method of detecting leaks to be satisfactory, but more report it to be unsatisfactory. The most specific complaints relate to accidental shorting with the consequent false alarms. The accidental shorting could occur from dirt, moisture accumulation, or other foreign substances bridging the electrode gap.

7. Overall Appraisal

It appears that the single point liquid sodium type detector is quite effective in detecting sodium leaks when the leak is of sufficient size to cause the sodium to flow to the vicinity of the detector. Major factors affecting the success of this method of detection appear to be the temperature of the sodium, the geometry of the flow path, and the environmental conditions such as the amount of oxygen and water vapor in the atmosphere in the vicinity of the leak.

V. Sensitivity

Sensitivity tests were performed on this type of detector at LMEC during the period April to June, 1971. These sensitivity tests were performed with a detector mounted on a fitting screwed into the receptacle provided in the test apparatus through so only the electrodes protruded into the trough.

The receptacle was placed 60 inches downstream from the leak hole. The trough mounted below a slot in the thermal insulation sheath was parallel to the test pipe and had a slope of 1/32 inch per foot. The trough was insulated thermally so that its temperature was nearly as high as the test pipe temperature.

The amount of sodium consumed enroute to the detector was found to be of the order of 100 grams. At a low leak rate of 1.5 grams per hour, 67 hours would have been reached in order for the sodium to reach the detector. At a rate of 160 grams per hour, the sensor was activated within 37 minutes. During another test with a spurt of leakage, the response time was 54 minutes.

In several cases when tests were conducted in an atmosphere of high moisture content, +45°F dew point, and high oxygen content, 2%, the atmosphere penetrated the leak hole and the reaction with sodium caused plugging. This made initiation and control of the leak rather difficult. However, at 160 grams per hour leak rate, the effect of the environmental factors was less.

VI. Other Factors of Interest

None.

2. Eddy Current Detector

i. Description

The Single Point Eddy current sodium detector consists of a high-frequency energized inductor placed in the expected path of leaking sodium. Sodium, entering the electromagnetic field about the inductor, absorbs electrical energy (by eddy-currents). The electrical circuits are designed to respond to the energy change.

ii. Application

The Eddy current type detector could be used for the same applications as the single point contact detector. This detector seems to have the advantage of not being as susceptible to the false alarms characteristic of the two conductor contact type detectors. However, no specific tests to evaluate this aspect have been made.

iii. Usage

No reported use of this method in existing sodium facilities being designed could be found. Eddy current type sensors, available commercially as proximity sensors, may be able to function as sodium leak detectors if they can withstand the high temperatures involved. Models, custom designed and fabricated by LMEC, have been tested.

iv. Effectiveness

Physical contact of the leaking sodium with the sensor is not required. However, the factors expected to affect its leak detection capability are essentially the same as those listed for the single joint electrical contact type. The eddy current type seems to be less susceptible to malfunction than the contact type.

v. Sensitivity

Two tests were performed by LMEC on this type of detector. One test was made at temperature of 1050°F, the other was at 800°F. The response times were 12 and 30 minutes respectively.

The eddy current detector performance was entirely satisfactory. However, they appear to have the same sodium flow limitations under low temperature, high oxygen and moisture conditions as the electrical contact type.

vi. Other factors of interest

None

3. Two wire method

i Description

This type of detector consists essentially of two parallel wires positioned on an insulating material and shaped to assure exposure of the wire surface over a considerable length. The wires are part of an open electrical circuit and are placed along the bottom of the piping or containment vessel in the path of potentially leaking sodium. Shorting of the wires by the leaking sodium will actuate the alarm circuit. The choice of wires used for this purpose is limited to those which retain satisfactory wetting surfaces in the operating environment. Stranded constantan wire has been suggested for this purpose. The wires are positioned where they are most likely to be contacted by leaking sodium (generally, on the lower surface of the containment vessel). However, sometimes the wires are wrapped around to cover a substantial area.

ii Application

This type of detector would have its greatest potential application in detecting sodium leaks on horizontal sections of piping.

iii Usage

This type of detector is being used by the Dutch and French. Refer to Table #1.

IV Effectiveness

The factors which were expected to affect the performance of this detector are essentially the same as those identified for the single joint contact type. One significant difference is the much shorter path over which the leaking sodium must travel in order to activate the sensor, therefore the response time is correspondingly lower and the threshold sensitivity is correspondingly higher. On the other hand because of the much greater exposure surface this type detector is expected to be more subject to false alarms than the spark plug type.

V Sensitivity

Since the leak path is much shorter with this type detector relative to the spark plug type, this type will be much more sensitive to sodium leaks.

VI Other factors of interest

None

b. Vapor Type Detectors

Sodium leakage into a gas ~~or~~ gas-solid environment produces sodium vapor as well as liquid sodium and solid reaction products. The sodium vapor is pervasive; this assures its reaching the sensor in the gas line unless specific impediments in the line are imposed.

Vapor type detectors, in general, require a continuous annular space over the length of sodium equipment or piping which is to be monitored for leaks if leak location is to be performed.

The types of instruments which function by response to sodium vapor are based on the methods of: 1) light absorption; 2) light emission; 3) plugging type; 4) filter type (moving and fixed; 5) chemical methods.

1. Atomic absorption and light absorption methods

i. Description

In the Atomic Absorption Method, the substance, in an unexcited ~~or~~ ground state, absorbs radiation of specific wavelengths characteristic of itself. The wavelengths are those which are produced when the substance is excited. In general analysis, a wide range of wavelengths is required. However, for a specific substance, as in the case of sodium vapor, a sodium lamp provides the required wavelengths.

In this method of detection light from a sodium lamp traverses the region containing the vapor and passes to a light sensor, typically a photoelectric cell. The amount of light absorbed is a function of the vapor concentration and the path length through the vapor. Generally, some form of zeroing or checking circuits are added.

In the Light Absorption Method, the photoelectric cell measures a reduction of light intensity. The

reduction of light intensity is caused by the dispersion effect of the collimated light beam in the sodium smoke formed by chemical interaction of the sodium with the environment.

The absorption method of detection was tested by LMEC with a detector described as follows:

The light source was a hollow-cathode sodium lamp mounted in a supporting enclosure. The power was supplied by a Jarrel-Ash Power Supply, Model 82-385. The gas sample cell consisted of a stainless steel block having three passages for gas and the traversing light beam, heaters to prevent condensation of vapor, and thermocouples to measure the cell temperature. The light sensor was a photomultiplier tube mounted in a housing which was a part of the power supply and amplifier. The power supply amplifier unit contained a meter which indicated the intensity of the light reaching the cell.

Light source and sensor were mounted on a sliding frame to permit surveillance of each cell. By this means, "zeroing" to eliminate possible errors due to any of the possible degrading factors could be eliminated and two samples could be sequentially examined or one of these could be a standard gas for calibration purposes.

ii. Application

The absorption method of sodium detection has a limited application. The test data showed that sodium vapor cannot be generated and maintained under any of the test conditions long enough to activate a detector. The vapor reacted with the environmental gas reactants, oxygen or moisture, forming sodium oxides and hydroxides.

The application of the light absorption method is discussed in section (e) on smoke detection.

iii. Usage

The atomic absorption method has been described in several reports investigating the feasibility of leak-detection methods. Bench tests have been performed in an atmosphere containing less than 20 ppm oxygen but no evidence of the use of this method in operating systems has been found.

iv. Effectiveness

The factors which were expected to affect the performance of the vapor detector were:

- a) Temperature of the leaking sodium, the environment, and the gas transmission line to the detector. The formation of a vapor depends on the temperature of the leaking sodium, the higher the temperature, the greater the quantity of sodium vapor which can be generated and maintained. The presence of reactants in the environmental gas diminishes the amount of vapor by the formation of surface films and reaction products.
- b) Leak rate and total quantity of sodium leaked. The amount of sodium vapor formed is limited by the available sodium surface. Since the vapor oxidizes readily, the leak rate must be great enough to provide vapor at a rate greater than its oxidation rate. The amount of vapor produced must exceed that consumed by oxidation or condensation by an amount sufficient to activate the detector.

- c) Oxygen, hydrogen, and moisture content. The presence of these reactants diminishes the amount of vapor which can be generated and maintained as discussed in item (a).
- d) Vapor transport driving force. The environmental flow, serving as a carrier, is the main source of vapor transportation; diffusion is a relatively small contributor.
- e) Vapor Detector Threshold sensitivity. This value limits the minimum detectable leak capability.
- f) Sodium Vapor Detector selectivity. Response to some stimuli other than sodium vapor could cause a false alarm.
- g) Length of vapor transmission line. Condensation of vapor within the line reduces the amount available to actuate the sensor.
- h) Ambient Gas Disturbances. Vapor paths and the concentration at the sensor are very susceptible to gas currents such as caused by ventilation or convection. However, this can be an advantage if the sensors are placed in the ventilating ducts since the vapor concentration there will be increased. In an outdoor installation, vapor detection is practical only if the vapor path is protected. Unless some protection is provided, vapor issuing into the atmosphere soon oxidizes and becomes smoke which readily blows away in slight atmospheric disturbances or wind.
- i) Diffusion. The concentration of a vapor at a sensor may be a function of its distance from the source, in the absence of directive devices

such as ducts. In the case of steady flow, the relation is the consequence of geometrical factors. In the case of a point source, the usual situation for a small leak, the concentration varies inversely with the distance for distances substantially less than the line length. For a surface source, the concentration is independent of distance for distances substantially less than the surface dimensions.

V. Sensitivity

In one design using the atomic absorption method, a light beam from low-pressure sodium traverses the very low (20 ppm/oxygen inert gas) region under surveillance to an optical detector cell (CdS). The threshold limit of sensitivity is $75 \times 10^{-6} \text{ g/m}^3$. This instrument is reported to perform well when the leak is in the vicinity of the light beam. Another technique uses sampling tubes to convey the vapor from the region under surveillance to the optical instrument. This technique is capable of detecting concentrations as low as about $35 \times 10^{-6} \text{ g/m}^3$.

The sensitivity of the light absorption method has been quoted as having a limit of $1.6 \times 10^{-3} \text{ g/liter}$, (reference, United Kingdom Atomic Energy Authority "An Appreciation of Fast Reactor Safety (1970)") However quoted experiences in open air under actual operating conditions indicate less sensitivity is obtained.

2. Light Emission Method

i. Description

In the light-emission method of analysis, the substance is excited to produce radiation characteristic of itself. The radiation wavelengths are indicative of the identity of the atoms producing the radiation, and the intensity is indicative of the concentration. In general, the sensor, typically a photoelectric cell, has a relatively broad wavelength response, so the wavelength is determined by passing the light through a monochromator to resolve the wavelengths. The sensor output signal amplitude indicates the radiation intensity. The possible means of excitation include: flame, radio frequency, arc, spark, x-ray fluorescence, and neutron activation. The most common form of excitation, and the only form used for sodium leak detection, is the flame. This technique is commonly known as flame photometry. Sodium is easily ionized in a flame, emitting a characteristic yellow light, the principal radiation being at 5.89×10^{-7} m. The wavelength resolution requirements for leak detection generally are not rigorous; therefore, an instrument of considerable simplicity compared to the typical analytical instrument is satisfactory. The flame will decompose sodium compounds; hence, the flame method will be effective in detecting smoke which is essentially particles of sodium oxide.

- ii. An open flame is generally regarded as undesirable in an operating area and its use as a means of excitation may be particularly undesirable for sodium leak detection. Possible undesirable problems associated with combustion products may be a disadvantage of this method. However, it has a potential for on-line use if sufficient products can be conducted to a stationary chemical laboratory.

iii. Usage

No reports on a method using flame photometry directly for on-line sodium leak detection were found. Other techniques using other means of excitation are not sufficiently developed for immediate use. Flame photometry was used to analyze phenolphthalein and water solutions through which gas was bubbled in the LMEC tests.

iv. Effectiveness

The method is very effective for absolute analyses of gas-borne sodium components.

v. Sensitivity

Instruments for detecting sodium vapor are proven and commercially available. They are very sensitive, having a threshold limit of 5×10^{-3} g of Na per cubic meter of air. However these instruments are not recommended for sodium leak detection since an open flame is undesirable in operational process areas.

3. Plugging Type Detector

i. Description

This type of detector consists of a tapped gas line running from the annular space surrounding pipe or equipment (i.e. between the component and the insulation), to which a device with a restricting gas passage is attached. The gas line runs to a flowmeter measuring the continuous flow of gas. When a sodium leak occurs sodium oxides tend to plug the restricting gas passage and cut the flow of gas. The flowmeters senses the gas flow reduction and thereby indicate a sodium leak.

LMEC made and tested for this purpose several specific models. One model consisted of a 1/4 inch stainless steel tube, flattened along 5/8-inch of its length and installed on one of the environmental gas exit stubs. The size and shape of the gas passage was simply that which formed after the flattening pressure was relieved. The gap formed was of the order of a few thousandths of an inch. Two other models were made; one used a 1/4-inch tube flattened over a length of 4-7/16 inches; the other a 1/8-inch tube flattened over a 1-1/4-inch length. In addition, another configuration was made of a tee fitting in which a restriction in the tee was formed by a rod mounted in one leg protruding into the flow passage through the other two legs. This is shown in Figure A-2. This device was tested with two different sizes of clearance passages (adjusted by the rod position), 0.005 and 0.009 inches.

ii. Application

This detector was found during a laboratory test to be as responsive to sodium leaks as any other detector. However it may require additional operational testing

FIGURE A-2 Plugging Type Detector

in simulated process systems to define the required characteristics of detection in order to prove the success of its application as an operational sodium leak detector.

iii. Usage

No record of the use of this method in operational systems could be found.

iv. Effectiveness

The factors which were expected to affect the performance of these detectors were:

- a) Temperature of the leaking sodium and the leak environment. The formation of vapor and the reaction of sodium with oxygen, hydrogen, and moisture in the environmental gas increases with temperature, hence the higher the temperature, the greater the production of plugging material.
- b) Supply of gas reagents. A sufficient quantity of gases which can react with the leaking sodium must be available to produce an adequate quantity of plugging material. The moisture content of the environmental gas should be the main factor since the moisture produces plugging material and enables the reaction of oxygen and hydrogen with sodium.
- c) Reaction product driving force. Only those products which are suspended in the environmental gas and are carried to the sensor can contribute to the plugging.
- d) Plugging detector threshold sensitivity. The geometric factors which affect the sensitivity have been only partially investigated.
- e) Length of transmission line. Deposition of sodium

and its compounds within the transmission line reduces the amount of material which can be available to contribute to plugging unless the plugging orifice is located at the input to the line.

- f) Plugging detector selectivity. Material other than the sodium leak generated products may deposit in the orifice and cause plugging, causing a false leak indication. This type of false alarm might be found to be prevalent with the plugging detector in process systems. However, corn starch did not plug the detector in the tests. Potential for foreign particulate material in the actual operating environment must be made in order to assess the applicability of this detection method, particularly if it is to be used to identify locations of leaks.

v. Sensitivity

The behavior of the four models made and tested by LMEC differed somewhat in their plugging characteristics. However, within this limited range of testing, no clearly discernible feature which would indicate the "best configuration or dimensions" was evident. The effectiveness of all forms of the device in detecting leaks was nearly the same. That is, plugging to 90% of flow immediately following visual indication of a sodium leak. The plugging devices responded satisfactorily except in three of the 400°F and one in the 500°F tests. They responded satisfactorily in one of the 400°F tests. From these results it appears that the sensitivity of this type of detector is limited to operation in systems of temperatures above 500°F if in a relatively inert atmosphere.

vi. Other factors of interest

A cursory experiment was performed by LMEC to determine the susceptibility to plugging by particles other than sodium leak products. When a dust of cornstarch was used no plugging occurred. In several tests performed to unplug a sodium oxide plug, unplugging was readily accomplished in all cases but one. This was a plug formed under high moisture conditions and was the only case of complete orifice plugging.

The plugging detectors were not tested at the end of the SO-foot line since the most efficient position is at the inlet to the line. Other test data had shown that a substantial amount of the plugging material deposits in the line. In one test the amount of material reaching the detector through a SO-foot line was 40% of that which reached the detector through a 9-foot line.

4) Filter Type Detector (moving and fixed)i. Description

This method of detection utilizes an arrangement using a moving or a fixed filter together with a flow indicator. This arrangement is connected to the gas line coming from the annular space between the sodium piping and the insulation. During a sodium leakage the sodium vapor- and sodium oxide become suspended in the gas and are carried to the filter. The filter removes the particulate constituents from the gas stream and retains them. This continuous build up of particulates of sodium and sodium oxide on the filter restricts the gas flow. An indication of this restriction in the flow is monitored by the flow indicator.

ii. Application

This detector seems to be responsive to sodium leaks. It has possibilities for use in sodium leak detection by either monitoring the annular space surrounding piping and components or as a **gross** check on a cell where the filter type detector would be placed in the cell exhaust line. However, operational tests should be made to define its characteristics for sodium leak detection when connected to a process line.

iii. Usage

No reported use of this method in existing sodium facilities could be found.

iv. Effectiveness

The factors which seem to affect the performance of this detector are essentially the same as those identified

for the plugging type detector. However, this method will tend to plug more rapidly than the orifice type due to foreign particles. Thus the filler must be placed at the outlet of the transmission line located at 100 ft, 90% line desposition losses or more are predicted to occur. On the other hand accessibility to the filler for replacement and chemical analysis may be a distinct advantage. Since no tests have been conducted there is no basis for factual evaluation of this concept.

v. Sensitivity

No recorded sensitivity value is available; however, previous experience with air filters indicates that this method of detection would probably be more sensitive than the plugging type method. The filter method is subject to false alarms from dirt accumulation in the same manner as the plugging type.

C. Chemical Methods

1. Chemical Analysis Method

i. Description

In this method, a tube carries the vapor from the region under surveillance to a detector consisting of a solution of a reagent which responds to sodium. LMCC made and tested a detector using a phenolphthalein solution. The sample of the environmental gas was bubbled through this solution to detect either sodium vapor or airborne sodium oxide particles. Although phenolphthalein will discolor, it varies with the concentration of the solution. This depended upon chemical analysis for evaluation of sodium content. Gas volume flow-through was measured very carefully to determine the average sodium concentration in the gas during the duration of the test. Good response led to continued use of the phenolphthalein solution during the remainder of the testing program. After completion of each test, the phenolphthalein solution was analyzed in the laboratory by flame photometry for quantitative data on the amount of sodium in the environmental gas. The laboratory analysis greatly increased the sensitivity of this method and eliminated the uncertainties involved in detecting the appearance of a pale color. The same type of detector can utilize a solution of Thymol blue in place of phenolphthalein.

ii. Application

The phenolphthalein solution indicated a sodium leak in each test conducted. It is difficult to discuss the response time of this instrument since the color change is slight and is very gradual. Also, in some cases, no color change was discernible but the detection was verified only upon laboratory analysis. Another factor is that the effect is cumulative, i.e., the longer the gas is bubbled

through the solution the more sodium is collected for detection. This detector cannot be utilized as an on-line leak detector since the solution has to be taken to the laboratory for analysis.

iii. Usage

No published data is available on the performance of this method in operating systems.

IV. Effectiveness

The factors which were expected to affect the performance of this method were:

- (a) Temperature of the leaking sodium, as discussed previously for formation of vapor and reactants.
- (b) A supply of reactants such as oxygen, hydrogen, and moisture in the environmental gas must be available to produce an adequate quantity of air-borne material. The moisture content of the environmental gas should be the main factor since the moisture produces sodium compounds and enables the reaction of oxygen and hydrogen with sodium.
- (c) Reaction product driving force. Only those products which are suspended in the environmental gas are carried to the sensor.
- (d) Chemical indicator selectivity. Material other than the sodium leak generated products may activate the sensor unless a chemically selected sensor is used.
- (e) Chemical indicator sensitivity. The responses of the chemical indicators are cumulative, i.e., the longer the gas is passed through the indicator the greater the indication.
- (f) Transmission line length as previously discussed in Section b3 on Plugging Type Detectors.

V. Sensitivity

With a phenolphthalein solution a successful operation at the end of a 50-foot transmission line was demonstrated. In one test with a gas flow rate of 3.0 cc/minute and a flow duration of 57 minutes the sodium concentrations in the cells were 1860 ppm(w) at the end of a 9-foot line and 736 ppm(w) at the end of a 50-foot line. It is evident that a substantial amount of material was deposited enroute. However, the amount, 736 ppm. which was available for detection is well above the detection threshold limit. With a Thymol Blue solution, a concentration as low as 2.3×10^{-4} grams of Na per cubic meter of nitrogen carrier gas could be detected. This method is not considered practical for temperatures below 250°C.

However, when the absorbing solution was analyzed by flame photometry, detection was effective over all temperature environments tested at LMEC. (i.e. as low as 400°F).

2. pH Method

i. Description

Defined as the negative logarithm of the activity of the hydrogen ion, pH is the measurement of acidity or alkalinity of an aqueous solution.

The pH scale runs from 0 to 14, with pH 7, the neutral point, being the pH of pure water at 77°F. A pH value of less than 7.0 indicates acidity, and above 7.0 alkalinity.

Instrumental measurement of pH is made by immersing a special glass electrode and reference electrode into the solution. The glass electrode produces an electrical potential dependent on the activity of the hydrogen ion. The reference electrode completes the circuit and furnishes a stable reference potential for comparison against the glass electrode potential. The difference in potential between the glass and reference electrode is directly proportional to the solution pH.

A thermocompensator is usually immersed in the solution to automatically compensate for the glass electrode's millivolt-temperature relationship.

For industrial process pH measurement, the glass electrode, reference electrode, and thermocompensator are usually placed in an electrode chamber which is installed in a sample line, or submerged in a tank or trough.

The voltage developed at the electrodes is measured by a stable precision amplifier and read out as pH. Outputs from the pH analyzer may be connected to recorders and/or controllers to achieve continuous pH control of a process.

LMEC tested this method of sodium leak detection using a Beckman Research pH meter with a non-selective ion electrode. This instrument provided a continuous indication of the sodium in the environmental gas when collected in a distilled water solution.

ii. Application

The pH indicator is a commercially available instrument. It can be used for on-line operation. When a sodium electrode is added to the instrument, the pH detector becomes responsive to sodium. Consequently, leak detection by gas sampling and sensed by a sodium ion electrode pH indicator is a suitable method, when slow time response and extensive sampling is acceptable or where leaks in low temperature systems must be detected.

iii. Usage

No published data are available on the performance of the instrument in operating systems for sodium leak detection.

iv. Effectiveness

The factors affecting the operation of this detector are substantially the same as those affecting the operation of the chemical analysis method. Hence it is safe to assume that it will detect leaks over the same range shown for the phenolphthalein solution. This detector needs water supply and some careful attention. It has slow response and it is difficult to automate.

v. Sensitivity

The concentration of sodium in the cell is a function of the sodium concentration in the sampled gas, and of the length of time the mixture is bubbled through the water bath of the pH instrument. Consequently, the threshold sensitivity increases with bubbling time. As an example, in one test by LMEC, the pH at the time the leak was initiated was 6.78 and 28 minutes later was 9.30. The Beckman Research pH Meter was found able to indicate changes as small as ± 0.0005 pH. However, such a small change could not be regarded as the indication of a leak. Additional investigation is required to establish the change which could be regarded as a true indication of a leak.

With a pH meter having a sodium ion electrode, measurement of the sodium ion activities could be made over at least four decades of concentration; however, this electrode responds also to silver and lithium ions. This electrode is used for general laboratory applications where sodium ion activities are of interest. A commercially available industrial type sodium ion electron pH meter can measure in the range of 1 ppb up to 1000 ppb.

3. Conductivity Method (Specific ion)

i. Description

In this method, the sample of gas is drawn from the region under surveillance and the gas is bubbled through pure water. Any sodium in the gas sample will react with the water and produce several reaction products, which result in an increase in the ionic conductivity. To minimize the possible effects of environmental variations causing conductivity changes, a pair of identical cells are exposed to the same environment but with sample air bubbled through only one cell. The two cells are connected to the electrical circuit so that an imbalance created by a change in conductivity of one produces a signal.

ii. Application

The analytical technique described above is applicable to detection of sodium smoke or sodium oxide as well as vapor, since sodium smoke will produce an easily detected reaction in a conductivity cell.

This method can be utilized for on-line leak detection.

iii. Usage

No published data are available on the performance of this method in operating sodium systems. However, extensive data are available on the performance of detecting sodium in fossil fuel plant cooling water as a result of condenser leakage of sea water.

iv. Effectiveness

The factors which are expected to affect the performance of this detector are the same as those which affect the performance of the chemical analysis method. This detector needs water supply and some careful attention. It has slow response and it is difficult to automate.

v. Sensitivity

The concentration of sodium in the cell is a function of the sodium concentration in the air and the length of time the mixture is bubbled through the water. Consequently, the threshold sensitivity increases with bubbling time.

A commercial conductivity detector has a sensitivity of measurement of 1 ppb of Na or 10 Mho of conductivity.

d. Radiation Detectors

i. Description

When natural sodium ^{23}Na has been activated, forming ^{24}Na , the strong gamma radiation from the sodium provides an additional means of detection: the use of gamma radiation sensors. The common situation in which ^{24}Na is formed is in sodium used to transfer heat from a nuclear reactor core. The radioactive sensing method of leak detection is commonly used for the primary loop of a nuclear reactor. Any leak results in at least a trace amount of vapor or smoke released to the atmosphere. Since a loop carrying radioactive sodium (or the primary system of a reactor) normally is enclosed, and controlled forced ventilation is provided, the common method of sampling is to monitor the exhaust atmosphere with a gamma sensor, typically placed in the exhaust ducts. In this method of detection, tubes can also be connected to carry the sodium vapor to the monitor outside the sodium cell from the region surrounding the sodium equipment and piping (annular space).

The detection system utilized for this purpose is an airborne particulate monitor attached to a vacuum system. This monitor has the task of collecting the particulates from a large volume of gas and concentrating them onto a small collecting area, or an air filter, where a detector measures the amount of radioactivity in the particulates built up on the air filter. The air filters applicable to sampling airborne radioactive particulates have an efficiency of about 99% for particle sizes of less than a micron. More efficient filters are available. The air filters are of two types: 1) a fixed air filter; 2) a moving air filter. The detector responds to the activity of the accumulated radioactive particulates on

the filter and sends signals to the attached electronics which trigger the alarm unit indicating a radioactive sodium leak in a particular area.

ii. Application

Particulate monitors have been utilized in nuclear power plants. They are used to monitor the radioactive particulate concentrations in the effluents of the process systems and in the effluents released into the environs. They will be utilized in the FFTF to monitor the air-borne radioactive particulate concentrations in the breathing air inside the nuclear facility for personnel protection.

iii. Usage

There are numerous reports which describe favorably the usefulness of the particulate monitor in operational application for radioactive particulate monitoring in nuclear power plants.

iv. Effectiveness

The factors which seem to affect the performance of the particulate monitor for sodium leak detection are limited by some of the factors pertinent to detection of sodium vapor mentioned in section (b). These factors are:

- (1) temperature of the leaking sodium, the environment and the gas transmission line to the detector;
- (2) leak rate and total quantity of sodium leaked;
- (3) vapor transport driving force;
- (4) detector threshold sensitivity;
- (5) length of the transmission line;
- (6) ambient gas disturbances;
- (7) diffusion and activity of the sodium.

This method of radioactive particulate monitoring is applicable only for detection of radioactive sodium.

e. Smoke Detectioni. Description

Sodium smoke or sodium oxide may form as the consequence of sodium burning as it leaks, or in the conversion of sodium vapor to smoke as discussed in previous sections.

A number of smoke detection methods can be applied. One method of detection, Light Emission Method, described in a previous section to detect sodium vapor, can be utilized for sodium smoke detection. The operating principle is somewhat different in that the light traversing the smoke is scattered rather than absorbed. The wavelengths in the light are not significant.

One technique used is based on the change in current in an ionization chamber as the result of smoke particles. Two identical ion chambers are used. They are connected in a balanced electrical circuit, and placed so that both are in a similar environment; but one is exposed to the sampling region and the other is protected from smoke. A voltage is maintained across the electrodes and an ion current is maintained by an alpha emitter (a minute amount of radium). The presence of smoke particles in the exposed chamber reduces the current flow and this actuates the electronic circuit which operates a relay to ring an alarm.

An improved type of photoelectric fire detector (one design is interchangeable with the ionization type) is now commercially available, and this instrument does not appear to have some of the disadvantages of the ionization type detector as described in section e. iv. In the photoelectric detector, smoke particles entering the chamber are illuminated, and the scattered light from these particles reaches the photocell causing an alarm.

ii. Application

A number of smoke detection methods are possible and some methods have been applied for leak detection in several operating sodium systems. Also, some of the vapor detection instruments can respond to smoke.

The photoelectric detector may be used for applications in which it is not practical to use ionization detectors due to high ambient concentrations of combustion products and in which the material expected to burn produces a dense visible smoke. This method of detection has a possible application in secondary sodium systems which are located in air environment.

iii. Usage

Commercial smoke detectors are used in a number of sodium installations. Their rather widespread usage probably is due to their commercial status, availability, and ease of installation, rather than demonstrated performance as sodium leak detectors. No substantial body of performance data on the smoke detectors has been published, but oral reports indicate disappointing performance in some cases.

iv. Effectiveness

Smoke detection is limited by some of the factors pertinent to vapor; these are: (1) the need for the conditions for smoke formation, i.e., moisture and oxygen in the atmosphere, (2) ambient atmosphere disturbances; and (3) diffusion. The discussion of disturbances and diffusion in previous sections on vapor is applicable to smoke.

Ionization chamber type detector may produce false alarms caused by changes in ambient conditions and by detection of dust or other particles not related to a leak.

Therefore, this method requires a back up system using another method of detection in order that monitoring could be done during the reactor startup or when the sodium activity is below normal due to reactor shut down.

v. Sensitivity

Because of the ability of the particulate monitor to concentrate the activity from a large volume of gas, this monitor can provide very good sensitivity. A commercially available particulate monitor using a scintillation detector has a sensitivity of $8 \times 10^{-10} \mu\text{C/cc}$ of ^{137}Cs in a background of 2 mR/hr. The radiation shielding used for this monitor is 4 inches of lead.

Commercial ionization detectors require routine maintenance and calibration. They are relatively insensitive to sodium oxide smoke (smoke densities that are readily detected visually may not actuate the ionization detector). The detectors should be located very near the potential fire site and must be in the ventilation airflow in order that the time delay in detecting the fire be a minimum. This may create a problem in large spaces where there is no specific pattern of airflow, and actual location of fire in a complicated or modified system may not coincide with the fire location predicted when the detector was installed. Furthermore, the ionization detector is quite sensitive to normal smoke and combustion gases (for example, from a welding torch), and this sensitivity often results in false alarms. Because of this problem, these detectors are frequently installed in a compromise location, or the sensitivity of the detector is reduced to a point that its value as a sodium fire detector is severely limited.

v. Sensitivity

The smoke detection by means of optical methods was discussed under the section describing the light absorption method.

The detection by means of an ionization chamber has a threshold sensitivity of about 0.1 g/m^3 but this sensitivity is limited by the onset of false alarms caused by fluctuation of the ambient conditions or entrance of other particles.

Preliminary tests by the ANL Fire Protection Department indicate that the photoelectric detector has much greater sensitivity to sodium oxide smoke than the ionization detector and is recommended for installations where sodium or other smoke-producing metals might be the prevalent type of fire. However, the location of the photoelectric detector must also be selected with care.

f. Hydrogen Detectori. Description

The use of a hydrogen sensor as a sodium leak detector is based on the generation of hydrogen as the result of the reaction of water (moisture) in the environmental gas with the leaking sodium.

The general operating principle is as follows: an evacuated tube, closed at one end by a palladium or other suitable membrane, is placed in the carrier gas stream. The tube contains an electron emitter and anode. Palladium, being permeable to hydrogen, permits the passage of hydrogen into the electrode region. The hydrogen passed is ionized in the electrode region and the resulting ion current change indicates the presence of hydrogen.

LMEC tested this method of sodium leak detection using a hydrogen detector connected to the test apparatus through an unheated, 12-foot long, 1/4-inch x 0.035 inch wall stainless steel tube. The sample point was 9 inches downstream from the leak hole.

ii. Application

LMEC, on the basis of their test program concluded that the hydrogen detector could be expected to provide satisfactory performance as a leak detector except under the following conditions:

- a) High hydrogen concentration background. In these tests the required test range was 0-2% hydrogen. A specific effort to provide the hydrogen background was not made. However, the important results relative to this factor were obtained. In most tests, the amount of hydrogen generated caused sensor satu-

ration at least temporarily. In some tests, the recovery time was substantial--hours and sometimes days. A hydrogen concentration of 2% was found to saturate the instrument. It was found that the instrument could not function as a sodium leak detector at hydrogen concentrations even approaching 2% (20,000 ppm(v)). All tests were conducted at concentrations of only a few ppm. The concentration at which operation becomes impractical was not determined.

- b) Low temperature. In these tests, a temperature range of 400 to 1050°F was required. This range was covered. At 400°F and at 1.5 gram/hour leak rate, no response was obtained under any of the environmental gas conditions.

iii. Usage

No published data are available on the performance of this method in operating systems for sodium leak detection.

iv. Effectiveness

The factors which seem to affect the performance of the hydrogen leak detector are the following:

- a) Temperature of leaking sodium and leak environment. The chemical reaction rates increase with temperature.
- b) Leak rate and total quantity of sodium leaked. The amount of hydrogen generated is limited by the available sodium surface.
- c) Moisture content of the environmental gas. The moisture, H₂O, reacting with the sodium is a source of hydrogen.

- d) Oxygen content of the environmental gas. The oxygen reacting with the leaking sodium and sodium vapor will form sodium oxide and this will interfere with the hydrogen generation.
- e) Hydrogen content of the environmental gas. A hydrogen detector sensitive enough to detect hydrogen from small sodium leaks would be saturated if a high hydrogen background exists. Also a detector which could accommodate a high hydrogen background may not be capable of a hydrogen concentration increment of the size caused by a small sodium leak.
- f) Hydrogen transport driving force. Hydrogen diffuses readily; however, the transport is assisted by the environmental gas flow to the detector.
- g) Conditions which permit preservation of hydrogen during its transport from the leak region to the detector. The sodium-hydrogen reaction is reversible. Hence, under some conditions the hydrogen could react with sodium and thereby reduce the amount of hydrogen available to actuate the detector.
- h) Hydrogen detector threshold sensitivity. This value limits the minimum detectable leak capability.
- i) Hydrogen detector selectivity. Response to some stimuli other than hydrogen could cause a false alarm.

v. Sensitivity

The test performed at LMEC showed that this detector was found to respond rapidly, usually within a few minutes after the leak was initiated. However, the signal was affected by the environmental gas flow rate. During each test, a constant flow rate was maintained. The rate was 200cc/min for 10 tests and 100cc/min for 4 tests. No recorded value is found on the sensitivity of this hydrogen leak detector.

h. Other Methods for Sodium Leak Detection

There are available few other methods which have been reported for sodium leak detection. The following description gives a brief sketch of each of these methods.

1. Tape type sensor

This form uses two wires positioned by weaving them into a fabric tape. The required wire characteristics described for the ceramic bead-spaced type are applicable. The fabric tape must be capable of withstanding the environment without disintegration or causing false short circuits. The disintegration of some fabrics at high temperature apparently is acceptable if the thermal insulation or other material provides wire support. The tape usually is made of a ceramic fiber material. While the use of the fabric tape may offer some advantages in the mechanical positioning function, the tape fabric inhibits sodium penetration to the wires, resulting in a delay or failure to indicate a leak. A loose weave should permit better penetration.

Reports on the performance of the tape-type sensor in operational systems are lacking. It was described in early literature but no evidence of present day usage has been found.

2. Sodium impairment of electrical insulation

The detector is made of a two-electrode assembly designed so that the electrodes make contact directly if the separating material or insulation is dissolved by the action of the leaking sodium. Satisfactory operation depends on the integrity of the insulation in the absence of sodium, the speed and effectiveness of the insulation removal by sodium, and the quality of the electrical contact.

No record of the use of this method could be found; however, an examination of the feasibility and preliminary tests of one design has been reported. Its operation is based on the destruction of the insulating film on anodized aluminum. In one form, a grid of anodized aluminum wire is used. The resistance between the intersecting wires is measured; a significant decrease is indicative of the failure of the insulating film at the intersections. Tests on a model having 2.54 mm spacing of the wires readily detected 20 to 50 mg of hot sodium falling onto the grid.

3. Sodium providing electrical capacitance

The detection techniques described above can operate only when electrical conduction is achieved. Another method of operation is possible based on the change in electrical capacitance of the electrode circuit caused by the presence of the sodium. Sodium contact, or at least electrical conduction, is not involved; therefore, such problems as the lack of wetting, or conversion of the leakage material to a poorly conductive reaction product are avoided. This method is applicable to the electrode systems described, but requires an alternating current. In general the capacitance increase due to the presence of leaking sodium is small; therefore, the alternating current frequency must be rather high. The frequency required depends on the capacitance change which is a function of the leakage mass and electrode geometries, the relative positions, and the permittivity of the dielectric materials involved.

No reported application of this method was found. The concept is sound, and a model can be postulated in which satisfactory operation appears certain. However, the practical problems involved with the high frequencies

required make it doubtful that this technique would be feasible for sensors using long wires to "cover" a substantial area. However, for point sensors, the problems are fewer and the method appears attractive to the extent that electrical contact is not required.

4. Sodium breaking electric circuit by dissolving wire conductor

Sodium leakage can be detected by its action in opening an electric circuit. The feasibility of this method is postulated on the highly reactive nature of sodium and reaction compounds which have the ability to dissolve or corrode several metals. The sensor consists of a wire of such a metal placed so that the leaking sodium contacts it and the reaction destroys the wire continuity. Since the wire is part of an electric circuit, the loss of continuity stops the current flow thereby signalling a leak. Many of the factors discussed in the circuit-closing type are involved in the circuit-opening type. Hence, the usefulness is not significantly different. The response of the wire to the sodium may be improved by passing enough current through it to raise its temperature. This is particularly applicable to wires of the noble metals which, in general, are soluble in sodium. Other metals, such as copper, may be sufficiently soluble in sodium, but the high temperature may cause the formation of surface films which have an adverse effect.

No reported use of this method could be found. Conditions can be postulated in which a detector based on this technique may be satisfactory. However, the general applicability is doubtful. In addition response time may be poor.

5. Thermal methods

Thermal contact of leaking sodium with a thermal sensor can be used as the basis for a leakage indicator. Good thermal contact is advantageous but the contact requirements are less stringent than those for the electrical contact method. The disadvantage of the thermal method is that the useful property, heat transferred from the sodium in indicating its presence at the sensor, is negligible for very small leak rates and may be negligible in other circumstances. This is because operation of the thermal detector requires the leaking sodium to transfer enough heat to the sensor to raise its temperature a significant amount above the sensor ambient temperature. In typical circumstances, leaking sodium may lose so much heat to its surroundings in its travel to the sensor that the sodium-to-sensor temperature difference will be small, hence the signal will be small. This method may be feasible in circumstances in which the required thermal conditions can be met. The sensors may be used in the manner described for electrical circuits, i.e., point sensors mounted in drip pans or other sodium receptacles, or may be distributed as indicated for wire sensors. A conventional thermocouple is an example of a thermal sensor for point detection service. For monitoring a line or an area, a special form of thermocouple can be used. This consists of a cable containing a pair of thermocouple wires insulated by an insulator having a negative resistivity temperature coefficient. A high temperature at any point or region along the length decreases the resistance of the insulation at the point to a low enough value that the point becomes a thermocouple junction.

The use of thermal sensors for leak detection appears negligible, and possibly is nonexistent. This method

is probably restricted to special circumstances; it does not appear to have general applicability.

6. Specific chemical reagents

This method requires a reagent which can be suitably dispersed in the region under surveillance so that any leaking sodium will contact it. The contact between the sodium and the reagent should produce a readily detectable reaction product.

The reaction of methyl alcohol with sodium to produce hydrogen is an example of this technique which was developed to detect leaks at temperatures below the range of successful operation of vapor detectors. Although developed for a NaK system, it is applicable to sodium systems. The ambient atmosphere consists of an inert gas that contains some methyl alcohol vapor. The alcohol vapor reaction with leaking sodium produces hydrogen, a product easily detected by means of proven commercial sensors. The method was reported to be satisfactory in bench tests, but the lack of leaks during use on a system prevented a complete evaluation.

The reaction of ammonium compounds with sodium releases free ammonia which can be detected in several ways. This method uses an ammonium sulfate compound at the probable leak areas. However the ammonia released by thermal decomposition of the ammonium sulfate due to the high temperatures of the examined areas produces high ammonia concentration in the environment without the presence of alkaline compounds. This high background ammonia level makes the detection of small increases due to the presence of Na_2O impossible, and the method has not been explored further. Other methods based on adding a specific reagent to form a reaction product have not been developed or even considered to any significant extent.

7. Infra-red and ultra-violet methods

These methods utilize light sensors which are triggered by the hot sodium leak. Infra-red photography has been used to determine temperature distribution in arrays of piping. This method could be adapted to sodium leak detection. The number of situations in which such a technique would be possible is very limited.

8. Solid state device

This is a solid electrolyte. This device is in the very early stages of development and no satisfactory evaluation of it can be made. It is intended that the detector when placed in the gas annulus ~~or~~ in sample lines, responds to sodium liquid or sodium vapor as its electrical conductivity is affected by the sodium.

9. Visual and olfactory detection

Visual and olfactory identification of the dense oxide smoke formed when alkali metals burn are sensitive and common methods used for fire detection. Because the commercially available automatic detectors are much less sensitive, the operators of even large, expensive alkali-metal systems rely heavily upon the visual detection of a fire.

Visual fire detection demands that personnel are within view of the sodium fire. The complexity of a reactor plant and the inaccessibility of totally enclosed experiments precludes the possibility that all sodium fires will be visually detected in time to prevent significant plant damage. For this reason, automatic detectors must be relied upon.

10. Television monitors

A modification of visual fire detection is the use of closed-circuit television. At the ANL Illinois Site, such a system is used by a two-man off-shift crew to monitor sodium operation between Buildings 206 and 308. In this application, the two-man shift is required at only one building. The TV monitor can be used by men at either site to monitor unattended sodium operation at the other site. The use of a TV monitor to view one or more remote locations does not demand that an operator watch the monitor continuously, as electronic circuits have been developed to give alarm signal when the scene changes. Thus the appearance of smoke or fire would constitute a change and sound an alarm.

ANL has experienced practical problems in the maintenance of the TV monitor. For example, a TV monitor, in itself, can give more operational problems than the sodium system that the monitor is supposed to view. In addition, a single TV monitor has a limited field of view. A monitor focused to observe one small area in great detail cannot view a large area at the same time. Conversely, a monitor focused to give a very wide field of view may not detect a small fire until the small fire has become large.

TABLE 1
SODIUM DETECTOR APPLICATIONS

<u>Detector</u>	<u>Applications</u>
Spark plug	<p>British - On piping and equipment in the reactor rooms.</p> <p><u>Inter Atom</u> - No leak detection systems used or being developed.</p> <p>Dutch - Spark plugs were to be installed in low sections of tanks. Special pockets were provided for these detectors.</p> <p><u>French</u> - Installed at low points in secondary piping, and on sections of the Phenix vessel wall.</p>
Smoke detector	<p><u>British</u> - All exhaust ventilation ducts.</p> <p><u>Dutch</u> - These detectors were to be installed in the vicinity of the major piping. However, they were installed in DHX.</p> <p>French - Located in each room and in ventilation ducts.</p>
Two wire detector	<p><u>Dutch</u> - Two wires separated by bead insulators installed on the system.</p> <p><u>French</u> - Installed on secondary piping and on auxiliary Na circuits. These detectors are separated by ceramic 0.1 inch apart and strapped to the pipe. This is also standard for all installations and is imbedded in insulation.</p>
Inductive coil detector	<p>French - For large leaks in tanks and compartments, these are troughs provided in the floors (about 2 inches wide) around which inductive devices are provided to trigger alarms when major leaks occur. Inductive coil level probes are also installed in guard tanks which should trigger alarm on breaks in piping.</p>
Thermal method	<p><u>French</u> - This method is to trace failure of heater systems by scanning these areas at a rate of 20 thermocouples per second.</p>

EXHIBIT B

STATUS OF ON-GOING DEVELOPMENT PROGRAMS

1.0 ORGANIZATION NAME

Liquid Metal Engineering Center

1.1 DETECTOR TYPE

Plugging and chemical

1.2 APPLICATION (FACILITY)

FFTF

1.3 STATUS

Preliminary tests on "proof of principle" models were completed and the results were sufficiently promising that more engineering and testing are justified. A letter to WULCO presenting recommendations for continued work on these detectors is in preparation. This letter recommends a brief study of the design factors, fabrication of a model of each type, and performance testing over a set of conditions which includes the expected secondary system environment.

2.0 ORGANIZATION NAME

Atomics International

2.1 DETECTOR TYPE

Not selected yet

2.2 APPLICATION (FACILITY)

FBR

2.3 STATUS

AI has a project for evaluation of the corrosion effects of sodium leaks. This is in support of the FFTF project and is a continuation of the work on this matter formerly done at ORNL. The objective is to evaluate the nature and extent of corrosion resulting from a sodium leak under the conditions specified for FFTF containment system operation. A work plan has been prepared and submitted to HEDL for concurrence. This work is related to leak detection to the extent that the results will have a significant effect on the leak detection requirements.

Under the FBR program, AI is to design a sodium-to-air leak detection system and submit it to LMEC for test.

3.0 ORGANIZATION NAME

Varian Vacuum Division, Varian Associates

3.1 DETECTOR TYPE

Hydrogen Detector

3.2 APPLICATION (FACILITY)

No specific facility. Company funded development.

3.3 STATUS

A commercial model of a hydrogen detector using a vac-ion pump having a palladium membrane as the hydrogen "window" was tested in the LMEC sodium leak detector test program. This detector was found to be very sensitive and selective (specific to hydrogen). It is tentatively regarded as not satisfactory for use on systems carrying radioactive sodium due to the high hydrogen background. However, it may be satisfactory on systems containing non-radioactive sodium.

No further effort on the sodium leak detector is in progress at Varian.

4.0 ORGANIZATION NAME

Oak Ridge National Laboratory

4.1 DETECTOR TYPE

None. The work is related to leak detection to the extent that leak detection requirements are affected significantly by the results of the type of work (corrosion studies) done.

4.2 APPLICATION (FACILITY)

FFTF

4.3 STATUS

The work on corrosion effects of sodium leaks or spills has been discontinued. The results had been published in the periodic reports and there were plans to issue a topical report.

A work program having substantially the same objectives as that in the ORNL program has been initiated at AI.

5.0 ORGANIZATION NAME

Idaho Nuclear Corporation

5.1 DETECTOR TYPE

Eddy-Current Sodium Leak Detector

5.2 APPLICATION (FACILITY)

Argonne National Laboratory, FEFFL

5.3 STATUS

This detector was designed to operate in a liquid sodium environment at temperatures up to 1300°F. Tests at 1300°F for 1170 hours have not impaired the coil operation. The detector performance was evaluated in the LMEC tests where its performance was satisfactory. The sensor temperature was as high as 850°F for several hours (about 6) and performed satisfactorily. Work on this type detector at Idaho Nuclear has been suspended. Other types of leak detectors are being considered for the application.

6.0 ORGANIZATION NAME

Westinghouse

6.1 DETECTOR TYPE

Solid State Sensor

6.2 APPLICATION (FACILITY)

No specific facility, company funded development so far.

6.3 STATUS

Westinghouse-supported research has shown that a significant change in electrical resistance of beta alumina occurs when the alumina is contacted by sodium vapor. This suggests possible application as a sodium leak detector. However, no tests have been conducted to determine its selectivity i.e. the factors beside sodium vapor which could produce the same effect. This type detector is in the "conceptual" stage so far as practical application as a sodium leak detector is concerned.

Westinghouse hopes that there will be support for development of a model which can be sent to LMEC for test.

EXHIBIT C*

CHARACTERIZATION OF SMALL (NON-FLOWING) SODIUM LEAKS
BASED ON CCTL EXPERIENCEI. Introduction

The consequences of very small sodium leaks have received little attention. This is due to several reasons: (1) the belief that very small leaks would always enlarge slowly and be detected before significant damage results, (2) the inability to detect these leaks, and (3) the lack of information on the leak rate of non-flowing leaks. A recent sodium leak in the Core Component Test Loop (CCTL) at ANL provides evidence that small, non-flowing leaks can be potentially hazardous and could progress rapidly into catastrophic leaks. The CCTL leak was detected while still in a non-flowing state. A rough estimate of the leak rate was made.

A good summary of the behavior of sodium at a leak is presented in Ref. (1) pp. 49-50. In this study reference is made to the accumulation of reaction products at the leak area which could "induce corrosion on the container surface thereby engendering a substantially larger leak." This statement is no doubt based on years of observation of the effects of sodium leaks at LMEC and AI. Details on leaks where corrosion of the surrounding metal occurs are minimum. Known instances of this phenomena occurring are the following:

1. G. E. Mass Transfer Loop No. 5 (1960). Statement by R. Lockhart, Ref. (2) pp. 196 and 211.
2. Statement by Mr. Holt of DuPont, Ref. (2) pp. 196.
3. HNPF No. 3 Expansion Tank (1964), Ref. (3).

Added to this list is the incident on the CCTL at ANL on April 17, 1969. Ref. (4).

Of these, the HNPF and the CCTL incidents, Ref. (3) and (5), both conclusively show that a secondary leak was caused directly by the corrosive action on stainless steel of reaction products of a primary sodium leak nearby. This cause of large sodium leaks is a serious problem which indicates the need for use of special sodium leak detection systems.

II. CCTL Non-Flowing Leak Incident

This leak is unusual in that it was discovered by operating personnel who smelled the smoke of a carbonaceous fire, not sodium. The fire was actually

the burning canvas pipe insulation covering, in an area around a 2-inch control valve which at the time was operating at 1060°F - 45 psig. The appearance of the insulated pipe immediately after dumping the CCTL and allowing the fire to self-extinguish, is shown in ANL Photos 113-1966 through 113-1968. Smoldering of the fire continued for about 1-1/2 hours after shutting down and dumping the sodium from the system. No attempt was made to extinguish the fire. At no time did any sodium drip from the fire area. Allowing the fire to smolder out was considered far safer than attempting to remove insulation to fight the fire while the system was still very hot. Actually burning during the 1-1/2 hour period was an accumulation of sodium oxide and reaction products of sodium and pipe insulation. It was estimated that the fire was the equivalent of 10 cc of sodium burning in free air. The incident up to this time gave the appearance of a typical small leak at a valve.

After the piping at the leak area had cooled to room temperature the damaged insulation was removed. A series of five photos, ANL No.'s 113-1971, 113-1970, 113-1969, 113-1974, and 113-1972, show the appearance of the insulation and valve as the sodium-reacted insulation was removed. The insulation on the valve and adjoining 2 inch pipe consisted of a 0.004" thick foil of 304 stainless steel over the pipe and valve followed by 2 inches of Kaylo 20, followed by 2 inches of Kaylo 10 (hydrous calcium silicate).

Based on the judgement of experienced sodium operators and the consideration of density change in the affected insulation, it has been estimated that 2 to 5 lbs. of sodium had leaked into the area.

III. Examination of CCTL Leak

The valve was a conventional air operated, bellows-sealed flow control valve. Its appearance after water cleaning is shown in ANL Photo # 113-2107 (Fig. 1 in Ref. 5). It was observed that: (a) the 316SS gaskets between the valve body and the bonnet and the bottom plug had corroded severely (see ANL Photo No.'s 113-2125 and 113-2128, Fig. 2 and 3 in Ref. 5), and the 316SS flange of the valve bonnet had almost completely disintegrated (see ANL Photo No. 113-2124, Fig. 4 in Ref. 5), (b) the 316SS body of the valve, particularly the shoulder support for the slipon flange, had been attacked severely, producing a "pie crust" scale, rather than evidence of intergranular attack, and (c) the horizontal inlet pipe (304SS) to the valve had ruptured approximately 6 in. upstream

* Submitted by ANL.

from the valve body (See ANL Photo No. 113-2130, Fig. 6 in Ref. 5). The pipe outer surface adjacent to the rupture suffered severe intergranular attack. The pipe inner surface adjacent to the rupture exhibited mild intergranular attack but no evidence of pitting or accelerated intergranular attack. Thus the pipe rupture resulted from the air-contaminated leakage sodium corrosively attacking the outside surface of the pipe, rather than from the sodium within the pipe attacking the inner surface of the pipe.

The precise cause of the valve-gasket failure is not known and cannot be determined. As to the subsequent mechanisms of failure, it is postulated that sodium had leaked through the upper gasket of the valve and picked up oxygen from the atmosphere, causing the severe intergranular attack of the 316SS gasket. Catastrophic oxidation of 316SS by MoO_3 (molybdic oxide) has been reported by Leslie and Fontana (Ref. 6). The failed gasket material and the adjacent valve body shoulder have been analyzed to contain 1.42w/o and 2.37w/o Molybdenum, respectively.

The high temperature of operation of CCTL (1060°F) could combine with the higher temperature of sodium oxidation (~1600°F) due to the leaking gasket to permit the rapid thermal dissociation of MoO_3 reported by Fontana.⁶

The reaction products from the leaking valve gasket are also believed to have caused intergranular attack of the outside surface of the adjacent 304SS pipe. The pipe rupture, then might have resulted from either (a) wall collapse assisted by torsional strain in the region of the rupture or (b) the combined effects of exterior-surface pipe corrosion followed by steam cleaning.

IV. Evaluation of the Potential Consequences of the CCTL Leak

The design of the leaking valve was such that the entire valve bonnet and bellows-seal was clamped to the valve body by a bolted flange. This flange was gasketed at the location of the original leak. (See ANL Photo # 113-2128 and 113-2124). The clamping lip was about 80% consumed (~1 cu. in. of 316SS completely missing). The force on the clamping lip at the time of the incident was ~550 lbs. Any significant additional loss could have caused an abrupt rupture of the clamped lip and the quick release of 45 psig sodium supplied by a centrifugal pump then operating at 400 gpm.

Admittedly, the circumstances of this leak were unusual in that a highly vulnerable structural member (valve bonnet flange) was very closed to a leak (flange gasket).

V. Leak Detection Requirements

At the time of the CCTL small leak incident the leaking valve had been in service for 5100 hours; the last 3500 hours were continuous service at 1060°F. The type of leak (at a bolted flange) would suggest that the flange had been improperly tightened initially and that the leak had been in existence throughout the entire 5100 hours. This assumption allows us to place the lower limit on an estimate of the average sodium leak rate.

$$2 \text{ lb. of sodium} = 3.92 \times 10^{-4} \text{ lbs/hr} = 4.3 \text{ g/day}$$

The capability of detecting 1 g of sodium as reaction products is desired. A leak at this low rate cannot exist as sodium, even in an atmosphere of <10 ppm oxygen. Therefore, the requirement should be stated in terms of the reaction products, usually sodium oxide.

VI. Conclusions

1. On systems insulated with tight fitting, conventional, fibrous insulation, consideration should be given to providing each critical structural member (flange bolts, valve bodies, etc.) with an electrical continuity detection system. The system could consist of high temperature insulated (asbestos or fiberglass) wire wound in a long continuous circuit around valves, flanges or even pipe on about 1 inch spacing. The wire would be quickly corroded by sodium oxide and alarm on loss of continuity.

2. On systems where a gas annulus exists around all sodium vessels, a leak detection system as described above could be used in conjunction with a gas surveillance system sensitive to about 1 g/day of sodium in sodium oxide.

3. A program should be initiated to test wire and electrical insulation types in sodium oxide at high temperature. The requirements of this wire system would be severe. It must retain its integrity for many years at 1200°F in air or nitrogen yet disintegrate quickly in sodium oxide.

REFERENCES

- (1) "Sodium Leakage Detection State-of-the-Art Study," by K. A. Davis, LMEC-Memo-69-35.
- (2) "History of the AEC Sodium Components Development Program," by H. W. Savage, ORNL-3955, Vol. 1.
- (3) "Evaluation of Non-Fuel Material Behavior in HNPF," in Proceedings of Sodium Components Development Program, Chicago, June 16-17, 1965, CONF-650620, R. X. Wagner and J. D. Stearns.
- (4) "CCTL # 1 Incident Report," ANL, Oct. 16, 1969, F. A. Smith.
- (5) "Evaluation of CCTL Operating Experience," by S. Greenberg, C. F. Cheng, and L. Burris, ANL, Sept. 25, 1969. No Number.
- (6) "Mechanism of the Rapid Oxidation of High Temperature, High Strength Alloys Containing Molybdenum," W. C. Leslie and M. G. Fontana, Trans. ASM 41, pp. 1213-1247 (1949).

EXHIBIT D
STATE OF THE ART, FIRE PROTECTION

An excellent summary of the State of the Art in Sodium Fire Protection was presented in Reference (1), and is extracted below for the information of the reader.

Highly effective firefighting agents are not available for many sodium fire situations. Conventional firefighting agents are normally useless. In general, fluids cannot be used for fighting fires, because most fluids are either flammable or they react with sodium with explosive violence. Inorganic powders, almost alone, are the agents used for extinguishing sodium fires. The theoretical densities of these powders, however, are greater than the density of liquid sodium. This limitation upon firefighting fluids, and the fact that the inorganic powders, to prevent their sinking below the surface of the sodium, must be applied gently, severely limits the distance from which firefighting can be done. Sodium fires, particularly large or radioactive fires, can be very difficult to extinguish by manual firefighting methods; therefore, the use of sodium dump tanks, inerted enclosures, automatic fire-extinguishing systems, and conservative engineering design criteria are used as fire-control methods. Firefighting experience to date has been limited to relatively small sodium fires, and very large sodium fires, under some conditions, may be essentially impossible to extinguish.

Molten sodium is extremely reactive with water or with materials containing adsorbed or loosely bound water. This extreme reactivity results in explosive spread of the fire when sodium contacts such conventional material as concrete floors. Molten sodium can also reignite without external reignition sources. This feature requires the continuing attention of firefighting personnel for a period long after the fire has apparently been extinguished. This attention must also be continued during the final cleanup process after the fire.

Burning sodium produces a particularly obnoxious aerosol. It is an inhalation hazard to fire fighters and necessitates self-contained breathing apparatus. Its most obnoxious characteristic, however, is that it forms a dense cloud in the enclosure and severely limits or prohibits visibility of the fire. The limited visibility and the limited range of the available extinguishing agents severely inhibit firefighting activities.

(1) "Guidelines For Sodium Fire Prevention Detection, and Control", Report of the Ad Hoc Committee on Sodium Fires, Cissel, D. W. Coleman, L. F., et al, Argonne National Laboratory, ANL 7691, 1970.

The interrelationship of the extinguishment complications and the design of an alkali-metal facility offers almost unlimited variations, but many of the salient features of the interrelationship can be discussed while considering eight situations. The situations are arranged in decreasing order of ease of extinguishment of the alkali-metal fire.

1. Inert-atmosphere Enclosure

Alkali metals require oxygen (or other reactants) to start and maintain combustion; therefore a dependable enclosure containing an inert atmosphere is the ideal means to prevent alkali-metal fires. Unfortunately, this means is also expensive and presents a significant risk to personnel that have to enter the enclosure and therefore is probably restricted to cases in which the probability of metal leakage is high or the consequences of an alkali-metal fire are very serious.

When such protection is warranted, care must be taken to ascertain that the integrity of the enclosure will be maintained under accident conditions and that the atmosphere is sufficiently inert (a monitoring device should be provided); otherwise, the application will provide false security. In this regard, it is important to coordinate enclosure strength with pressure relief means to accommodate the pressure surge that may result if molten alkali metal is rapidly ejected into the enclosure.

2. Reasonably Gas-tight Enclosure. Air Filled

Enclosures can be designed that are only relatively gas-tight, and normal air atmospheres can be maintained in such enclosures to prevent the cost of continuous inerting. If an alkali-metal leak occurs in such an enclosure, or if fire may be self-extinguished by oxygen depletion within the enclosure, or it may be smothered by flooding with an inert gas such as argon, helium, or nitrogen.

The degree of oxygen depletion necessary to extinguish the fire will depend upon the type of leak. During a sodium spray leak, the oxygen concentration in the enclosure would have to be reduced below 4 vol % to prevent burning, and formation of airborne oxide would continue for oxygen concentrations down to 0.5 vol% and possibly to 0.1 vol%. If release of dispersed sodium ceased and the sodium burned in a pool, oxygen depletion to about 10 vol% might stop "burning" and start a slow cooldown of the pool. In either case, the reignition characteristics of the molten metal require that the low oxygen concentrations be maintained for a significant period of time to permit cooling of the metal (and stopping the spray).

Unfortunately, the design criteria for the construction of a "relatively" tight enclosure must be based upon engineering judgment with a minimum of sound technological input. Obviously, we are considering the case in which extreme leak tightness of the enclosure is not required because, if it were completely tight, an inert atmosphere would be justified. During the early stages of a sodium fire in the enclosure, the sodium oxide aerosol will deposit fairly uniformly over the inside surfaces of the enclosure and will often seal the seams of the enclosure and prevent or reduce the ingress of oxygen necessary to support combustion of the sodium. One advantage of this type of enclosure is retention of most of the generated alkali-metal oxides within the enclosure. Because smoke damage to surrounding equipment is often extensive in unenclosed fires, this advantage is significant.

Although this type of enclosure closely resembles the inert enclosure, it has one significant difference: with an initial air atmosphere, releases of high-temperature alkali metal will always result in a fire. For this reason, the enclosure must be sufficiently substantial to withstand the heat from the fire and, with pressure relief mechanisms, the pressure surge that will occur.

Sodium fire suppression by oxygen depletion offers an opportunity for engineering research which might prove of substantial value to future LMFR facilities; existing data are not sufficient for a reliable evaluation of this method of sodium fire control.

3. Air-Filled Semi-Enclosure That Can Be Converted to Complete Enclosure

Due to ventilation (heat removal) requirement or the requirement for frequent access, some facilities may not permit complete enclosure. Often, such a semienclosure can be converted to a complete enclosure by automatic (fire damper) or operator action. Because of the marked similarity to the relatively gas-tight enclosure, special comment is not warranted.

4. Semi-Enclosures That Confine Spilled Sodium or NaK to a Specific Area

One of the more prevalent types of situation in ANL experimental work involves semi-enclosures or splash shields which direct leaking alkali metal into a pan or tray beneath the experimental equipment. In the event of a liquid metal fire, this situation will result in the release of some alkali-metal oxides into the room, but should pose no significant problems in extinguishment since the fire should be easy and safe to approach to permit the application of an inert dry powder extinguishment. The complexity of extinguishment

and the amount of powder required will vary depending upon the specific alkali metal, the depth of the spilled-metal pool, the physical arrangement of the equipment, and the use or nonuse of a perforated plate within the tray or pan.

Extinguishment of an alkali-metal fire essentially consists of preventing oxygen from diffusing to the molten or gaseous metal and maintaining this state until the metal has cooled below the ignition temperature. At ANL, current firefighting practices for sodium and NaK fires involve the use of dry silica sand or MET-L-X (fine, treated NaCl) to provide the oxygen barrier. Dry soda ash is also referred to in the literature as an extinguishant, but care must be exercised to ensure that it is moisture free. The value of any of these extinguishants is apparently enhanced if the molten metal is confined in a pan and if the pan is provided with a perforated plate located at an intermediate depth in the pan. In some cases, it is reported that the perforated plate alone acts as an oxygen barrier and extinguishes the metal fire; additional studies on the use of perforated plates are, however, warranted.

In the design of collections pans (particularly for potentially large sodium spills), consideration must be given to thermal effects on the supporting floor. For example, a large pressure of steam could be generated under the pan due to trapped moisture or thermal decomposition of concrete. Therefore, the space between the floor and the metal liner may need to be vented to prevent excessive pressures from steam.

The ideal powder extinguishant for sodium or NaK fires would have a particle density less than the bulk density of the molten metal so that all the extinguishant would remain at the top of the molten metal. Neither silica sand, soda ash, nor MET-L-X have this advantage. Each has a theoretical particle density at least twice that of molten sodium or NaK, and therefore each must be gently dusted onto the surface of the molten metal to take advantage of surface effects (perhaps nonwetting, or possibly due to a sodium oxide scum or a reaction product between the sodium oxide and the extinguishant). When gently dusted, both the sand and the MET-L-X in contact with burning sodium, and less so with NaK, form a crust which permits the gradual buildup of a sufficiently thick layer of extinguishant to stop the fire.

In contrast, rapid application of these powder extinguishants results in the particles sinking into the molten metal and becoming ineffective as a blanketing agent.

5. Sodium or NaK Spills in Open Areas

Some sodium facilities have been built in open areas so that the leaking metal has no confinement either in the form of splash shields or drip pans. Such installations offer more problems in firefighting than those previously discussed. The floor surface is often steel, but in some cases it is concrete or even earth. With concrete or earth floors, firefighting is particularly difficult because the dripping or running molten metal frequently reacts violently with the floor, thus endangering the firemen and widely scattering the burning metal.

The main effort in extinguishing a sodium or NaK pool fire in an open area consists of restricting its spread. Because the rate of liquid-metal oxidation in a pool is directly proportional to the surface area, limiting the surface area can minimize both the direct fire damage and the quantity of sodium oxide smoke formed. Experience has shown that even rather large volumes of sodium can be contained by perimeter diking using dry sand, lead bricks, lengths of pipe, or practically anything else that can make a firm contact with the floor over an appropriate length. Once a sodium spill is diked, sand or MET-L-X can be used to extinguish the fire.

6. Sodium or NaK Drillage or Sprays from Elevated Leaks.

No Enclosure

Because sodium facilities are constructed, in general, above floor levels, leaks would, of necessity, be in elevated locations with the sodium dripping or spraying from the leak site, depending upon the system pressure and configuration. The spray is usually burning. To control a flowing or dripping fire, some method must be available to drain the system, to isolate the section that is leaking, or to close off the leak with a heat-resistant enclosure which can be put into place under adverse conditions. Such an enclosure, usually made of metal, would have to be custom-made to fit over potential sources of leaks such as expansion bellows, valve bonnets, and test sections. In the sense of these methods of control, the only alternative is to build up a dry powder hill to cover and possibly plug the leak. MET-L-X will frequently adhere to molten metal on vertical surfaces and extinguish the fire on such surfaces if the molten metal is relative stagnant.

Spray fires cannot be put out unless the oxygen in the gas phase can be reduced in the spray region to low levels and maintained at these levels for the duration of the spray. To achieve this, the facility design should tend to isolate and minimize the volume of the probable spray region, minimize the

oxygen in (or the ingress of oxygen into) the region, and minimize the time that the spray can exist. Minimizing the volume of the probable spray region can be simple for small pieces of apparatus. These can be completely enclosed, with the enclosure envelope filled with nonhygroscopic packing materials such as vermiculite. Such installations also tend to extinguish the fire by limiting the access of oxygen. Particular attention should be paid to flanges and other removable joints. Design provisions to limit the duration of a spray should include dump tanks and associated dump valves and means for depressurizing the system either by venting pressurizing gases or by deenergizing circulating pumps. (Dump tanks are regarded as a very important method for controlling or preventing a sodium fire). In essence, a spray fire in air cannot be fought--it must be prevented, or the spray must be stopped.

7. Combined Sodium and Ordinary Combustible Fires

Burning sodium or NaK has a small flame height, because of the limited vapor-phase burning of the metal. However, if conventional combustibles are ignited in the region of the fire, the fire can readily spread. This is a very serious problem and is compounded by the fact that the extinguishants normally used on conventional combustibles are dangerous to use near alkali-metal fires, and such fires will probably result in serious risks for the firefighters and in extensive property damage. The extinguishing agents normally used on sodium fires (sand or salt) are usually completely inadequate for extinguishing fires of flammable liquids and ordinary combustibles.

The ANL Fire Department recommends the use of dry silica sand (or MET-L-X) in conjunction with a multipurpose dry chemical agent (mono- or diammonium phosphate) for combined sodium and ordinary combustible (or flammable) fires.

Combustible materials (also any extraneous materials) in alkali-metal areas should be limited to an absolute minimum.

This problem was studied in some preliminary experiments with sodium and tetralin fires at Atomics International. In these experiments, it was concluded that the best method for handling a combination fire is the sequential use of a dry, inert powder to suppress the sodium fire, followed by carbon dioxide. Other workers have recommended the use of carbon dioxide first, followed by a powder extinguishant for the sodium fire. This combination of firefighting agents would probably be effective only for relatively small, organic-sodium fires.

8. Sodium or NaK Fires in Regions with High Radiation Backgrounds

In a few ANL facilities, all at Idaho, sodium or NaK systems are operated

in regions in which the **gamma-radiation** background prohibits direct access. Usually the gamma source is the alkali metal itself. Firefighting in this case is exceedingly difficult. Normally, the facility is provided with a fixed, remotely actuated MET-L-X system. The efficiency, and even the adequacy, of this fixed system, however, is severely limited by the inability to determine the extent of metal leakage and if the leakage has terminated. Such systems should be provided with means to determine the extent and duration of leakage. If practical, the systems should also be provided with inert-atmosphere enclosures, or means should be provided to apply such an atmosphere if a fire develops.

In addition to the extinguishment problems discussed under the above eight situations, the serious effects of the alkali-metal oxide which is produced in the fire must also be considered. This oxide aerosol will severely hamper fire-fighting activities. If the smoke is allowed to spread, it can seriously damage equipment in adjacent regions and present a health hazard to unprotected personnel

Self-contained air-breathing equipment is standard emergency equipment in sodium facilities and is used with full protective clothing to protect fire-fighting personnel from the smoke and from possible oxygen depletion of the atmosphere in the immediate vicinity of the fire. However, the problem of seeing through the dense oxide smoke has not been resolved and seems worthy of research effort.

Smoke within a building containing a sodium fire can be reduced by using proper ventilation equipment. Such reduction improves firefighting capability and minimizes caustic damage to equipment within the building. To prevent damage to personnel and equipment outside the building, the exhausted air should be scrubbed to remove the aerosol. Provision of an air scrubber should be considered for all buildings using significant quantities of sodium. This can be achieved by a venturi or cyclone scrubber, a water-film scrubber, or an electrostatic precipitator. Filters can also be used; however, they must be large enough to prevent "plugging" by the sodium oxide.

After each sodium or NaK fire, two stages of cleanup will be required. The mass of metal, oxide, and extinguishant will have to be safely disposed of. This mass will doubtlessly contain significant quantities of unreacted metal, which will reignite if carelessly handled. In addition, alkali metals can form peroxides and higher oxides. The lower oxide (M_2O) is formed if the oxide is in equilibrium with excess alkali metal; in the absence of excess metal at

equilibrium, the higher oxides can be formed (depending upon temperature and partial pressure of oxygen). These higher oxides are strong oxidizing agents and can react explosively with alkali metals and organic materials. Thus the residue from an alkali-metal fire (particularly potassium, rubidium, and cesium) should not be stored in contact with organic materials and the residue should be transported (as soon as practical) to a site where it can be safely reacted to completion and then disposed of.

The second stage of cleanup consists of cleaning the surrounding area and equipment. The damage to exposed wire, general equipment, and painted surfaces can be extensive. Unpainted surfaces are sometimes used to avoid the need to repaint areas susceptible to sodium fires. The smoke damage to some equipment could be extensive enough to make salvage questionable.

In summary, sodium and NaK firefighting is complicated by the high reactivity of the metal, problems in visibility, configurations of equipment, heat levels, and limitations of extinguishing agents. These complications require great emphasis on better design criteria leading to fire prevention and on fire-control methods in the design stage of each facility.