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DESCRIPTION OF THE
SODIUM FIRES TEST INSTALLATION

AEC Research and Development Report

ATOMICS INTERNATIONAL

A DIVISION OF NORTH AMERICAN ROCKWELL CORPORATION

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SODIUM FIRES TEST INSTALLATION

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I. INTRODUCTION

The purpose of this document is to describe the Sodium Fires Test Installation and its use in achieving the test program objectives of the project on "Nuclear Safety, Gaseous Effluents, and Sodium Fires." The presentation of results of experiments conducted at this test facility will be detailed in forthcoming reports.

Atomics International is currently operating two experimental facilities in support of the overall Characterization of Sodium Fires and Fission Products program. The first facility, located at AI Headquarters, is utilized for laboratory studies of aerosol behavior and sodium spray burning, and includes the Laboratory Test Chamber (LTC) and the Spray Test Vessel (STV). The second facility, located in the Building 009 complex at Atomics International Nuclear Field Laboratory, is the Sodium Fires Test Installation (SFTI) and consists of two major test configurations: The Large Fires Apparatus (Phase I) and Large Test Vessel (LTV). Sodium pool fire tests in the LTV are referred to as Phase II of the test program.

II. DESCRIPTION OF SODIUM FIRES TEST INSTALLATION

A. PHYSICAL PLANT

The basic physical plant comprising the Sodium Fire Test Installation is shown schematically in Figure 1. The mechanical portion of the plant consists of four basic subsystems: the test vessel, gas mixture system, sodium storage and transfer, and the effluent control system.

1. Test Vessel

Either the Phase I vessel or the Large Test Vessel may be used to contain the sodium-oxygen reactions. Both test vessels are fitted in parallel to the gas mixture, sodium storage and transfer, and effluent control subsystems. The Phase I vessel is operated primarily in an equilibrium gas flow mode, with a constant bulk sodium temperature condition. The Large Test Vessel may be operated either as a closed or open system (with reference to gas mixture or effluent control subsystems). In each configuration, sodium is added only at the start of the test. These systems are discussed in more detail in Section II-B.

2. Gas Mixture Subsystem

The gas mixture subsystem supplies controlled atmospheres at predetermined rates and oxygen concentration to either the Phase I vessel or the Large Test Vessels. This system includes a 5000-gallon liquid nitrogen storage tank, a nitrogen vaporizer capable of delivering gaseous nitrogen at flow rates up to 600 CFM, a 30-HP blower capable of delivering filtered air at flow rates up to 200 CFM, a mixing manifold, and a 60-Kw gas heater. The nitrogen vaporizer and air blower are connected in parallel to the mixing manifold, where (with a full complement of flow meters, and pressure and temperature indicators) gas with controlled oxygen concentration (0-21 v/o O_2) may be delivered to each test vessel.

3. Sodium Storage and Transfer Subsystem

This subsystem comprises a 1250 gallon storage tank fitted with separate drain lines and control valves to each of the two test chambers. The main storage tank is charged with filtered sodium from a premelt-and-transfer station

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Figure 1. Schematic of SFTI Mechanics

handling bulk sodium in barrel quantities. The main storage tank, drain lines, and control valves are fitted with electrical heaters such that sodium temperatures to 1300°F may be provided to each test vessel.

Sodium pool burning tests in the LTV which require charges of sodium of less than 150 lb employ an auxiliary sodium storage-and-transfer system. This auxiliary system including transfer lines and control valves is fitted with electrical heaters to provide bulk sodium at test temperature conditions.

4. Effluent Control Subsystem

The effluent from the fire in either vessel is withdrawn from the respective test chamber via a 10-in. diameter pipe through a 140-gal. bubbler and 4-stage, 50-gal. commercial type scrubber. Constant effluent flow (and pressure) is maintained by use of a bypass valve around a positive displacement blower which exhausts to the atmosphere. For Phase I operation, the bubbler is fitted with a 3-in. diameter manometric type pressure relief valve.

With minor system changes, the Phase I effluent crossover pipe is removed and replaced with the LTV crossover pipe. Operation of the LTV with the effluent control system is required only to establish pretest atmospheric conditions for closed-cell or closed-cell secondary-containment tests, for atmosphere control on long duration tests, or for bypass of system overpressure.

B. TEST VESSEL DESCRIPTION

1. Phase I Test Vessel

The Phase I configuration is a modification of the previous Large Fires Apparatus.* It is basically a 45-ft³ conical head placed above a 5-1/2-ft O.D. annular ring. A 2-ft diameter, 1-ft deep burn pan is suspended from the center opening of the ring. The Phase I test vessel is shown in Figures 2 and 3. The cone is fabricated from 1/8-in. thick stainless steel and has several sealed penetrations for electrical and instrumentation leads, gas and sodium oxide aerosol sampling, a viewing port, and four symmetrically spaced gas inlet ports each of which is baffled to reduce "jetting."

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*G.N. Lauben, "Initial Experience with Large Sodium Fires Experiments (LF-1)," NAA-SR-12041

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Figure 2. Phase I Burn Chamber (Photo)

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Figure 3. Phase I Burn Chamber (Schematic)

A typical burn pan is 2-ft in diameter and is supported by a donut shaped annulus which in turn is supported at its outer edge by the chamber structure. Both the pan and the donut are fabricated from 1/2-in. thick carbon steel. The sodium fill-and-transfer line penetrates the donut and is routed to the edge of the burn pan.

Auxiliary electrical heating is provided (22.5 kw) at the bottom of the burn pan, but the pan and heaters are separated by a 1-in. thick circular stainless steel platen. This platen reduces the temperature fluctuation in the burn pot caused by the tubular heaters and provides a convenient means of monitoring the electrical heat input to the burn pot by measurement of its temperature gradient.

Thermal insulation of the system is provided as shown in Figure 3.

2. Large Test Vessel

The Large Test Vessel (LTV), Figure 4, is basically a 2200-ft³ cylindrical pressure vessel, 1/4-in. thick carbon steel, 10-ft diameter by 30-ft high, and rated at 40-psig. It is mounted vertically, entirely within the building, and rests on the bottom of a 10-ft deep pit. The vessel may be separated into 4 major flanged-components (a) the lower inverted vessel head which is welded to a 7-ft cylindrical support section (b) two 8-ft-6-in. cylindrical spools, and (c) the top vessel head. The assembly is designed such that either or both spools can be removed and the upper dome can be resecured to the lower section thus providing three major volume increments. A schematic of the vessel is shown in Figure 5.

The lower head and integral 7-ft section is referred to as the "cell" and any combination of the upper sections are referred to as the "secondary containment." Each vessel section is provided with 2-in. of high temperature insulation for personnel protection and to impede heat transfer to the room.

Communication of the gas atmospheres between cell and secondary volumes can be partially restricted to simulate a sodium pool fire occurring in an LMFBR equipment cell which is open to the secondary containment during system maintenance. This is accomplished by means of an annular structure which is secured between the vessel section flanges; see Figure 5. This annular structure is a 12-in. thick, hollow donut which has provisions for changing the size

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Figure 4. Large Test Vessel (Photo)

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Figure 5. Large Test Vessel (Schematic)

of the intervolum communications hole. Additionally, the 12-in. thick hollow section can be filled so that its thermal properties can be changed to simulate various construction materials.

Connecting lines are provided from the vessel to the gas mixture manifold, sodium storage tank, and the bubbler-scrubber subsystems. A single 3-in. line extends from the gas mixing manifold to the cell section to provide gas mixtures with oxygen concentrations between 0 and 21 v/o O_2 at flow rates up to 200 CFM. Also, a 3-in. line is connected to the secondary containment section to provide 100% air at flow rates up to 200 CFM. A bypass line connects the cell section to the exhaust side of the effluent control crossover pipe to permit oxygen concentration reduction during pretest procedures. A single 2-in. transfer line is connected from the vessel to the sodium storage tank. Provisions are made to connect a 6-in. transfer line to the same vessel nozzle for high sodium transfer capability. Either sodium transfer line is extended from the inside nozzle connection to the sodium burn pan through flexible joint fittings. Each of these transfer lines is fitted with electrical heaters capable of heating the transfer pipe to the temperature of the bulk sodium in the storage tank. The exhaust line connecting the vessel with the effluent control subsystem is fitted with a 12-in. gate valve for system isolation. A 4-in. pressure relief line with 40-psig rupture disc bypasses the gate valve to relieve system overpressure.

Each spool section is fitted with instrumentation bulkheads to allow penetration of a variety of instrumentation and power leads. Other vessel penetrations include experimental nozzles for aerosol sampling; and 18-in. diameter manhole in the cell and lower secondary sections; and three viewing windows, two in the cell section and one in the lower secondary section. The viewing windows in the cell section allow personnel observation and continuous motion picture recording of the fire history.

The LTV can accommodate spill pans with surface areas from 6 to 60 ft².

C. INSTRUMENTATION

1. Process Instrumentation

The process instrumentation is primarily associated with the support equipment (primary and auxiliary sodium storage tank and transfer lines, bubbler-

scrubber, vaporizer, mixing manifold, etc). Process temperatures are sensed with both chromel-alumel thermocouples and dial thermometers. Thermocouples are readout on either multipoint indicators or recorders.

Pressure in the various gas lines and the storage tanks is monitored with bourdon tube gages. Pressure in the Phase I vessel is sensed with a differential bellows arrangement and is strip-chart recorded; range = -15 to +45 in. of water. The Phase I vessel pressure data are considered "process" since all tests are performed at a constant pressure of +2 to +4 in. H_2O . The pressure measurements in the LTV tests will be discussed in a later section.

2. Test Instrumentation

The primary data required for the characterization of sodium fires involves temperature and oxygen concentration measurements. Also measured, as required by the particular experiment, are inlet and outlet gas flow rates, inlet gas humidity, radiant heat flux within the test vessel, conductivity in the bubbler-scrubber water, and in the Phase II tests, test vessel pressure.

All data that are required for any interpretation or presentation are recorded on a data logger. The logger will automatically scan at preselected time increments, or continuously, up to 300 channels of millivolt data at a rate of 3 channels per second. The data in millivolts units together with the time, data, and channel identification are recorded on a perforated paper tape for subsequent digital computer analysis; see Section II-C-2-d. The logger is shown in Figure 6 and its block diagram logic scheme is shown in Figure 7. As many as 48 of the thermocouple channels that are recorded on the logger may be simultaneously recorded on multipoint recorders.

a. Temperature Instrumentation

Approximately 120 thermocouples are used to define the energy distribution and balance in the Phase I experiments. Measurements are made in the inlet and outlet gas streams; in the bulk sodium and gas space above it; on the walls of the burn pot; on the burn chamber cone metal and in the insulation adjacent to these locations, on the donut and in adjacent insulation, or both surfaces of the heater platen; on the edge of the donut; and in the air space surrounding the burn pot.

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Figure 6. Instrumentation Console

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Figure 7. Data Logger Operational Logic

In the LTV, the first Phase II tests were performed while using approximately 170 thermocouples. A radial and axial distribution within the gas space in both the cell and secondary sections allows the average closed cell atmosphere temperature to be determined. An axial array of thermocouples placed on the vessel wall (inside and outside) and in the adjacent wall insulation provide heat-transfer-and-retention data. Thermocouples are also provided on the burn pan and in the bulk sodium.

Careful attention is given to the fabrication and installation of all thermocouples. All metal surface junctions are formed by discharge welding of the separate thermocouple leads to adjacent positions on the metal (approximately 1/16-in. apart). Gas temperatures are made with bare junctions formed by welding 0.010-in. diameter thermocouple leads. Insulation temperatures are monitored by attaching the thermocouples to 0.020-in. stainless steel tabs and positioning these tabs between layers of insulation at the desired location.

All leadwires are brought to a constant-temperature junction box and copper leads then transmit the signals to the logger. The temperature of the junction box is monitored by using a thermocouple and an electronic reference junction, and by recording it on the logger.

A schematic representation of thermocouple locations in both the Phase I and Large Test Vessels is shown in Figures 8 and 9.

b. Oxygen Concentration

Oxygen concentration measurements are made with an accuracy of $\pm 1\%$ of full scale by means of analyzers which utilize the paramagnetic properties of oxygen. These analyzers require clean, dry gas furnished at a flow rate of 150 to 200 cc/min, but with flow fluctuation held to less than ± 10 cc/min.

All components of the oxygen sampling system are maintained at a pressure slightly in excess of the reference atmospheric or system pressure to eliminate any interference from air-inleakage. The volume of the sampling system is kept small in order to minimize the response time of the system. To fulfill these

Figure 8. Phase I Thermocouple Installations

Figure 9. LTV Thermocouple Installations

sampling objectives, relatively high capacity tubing or diaphragm pumps (~ 1500 cc/min) are installed close to the sampling point. This high flow rate is used to flush the large volume components (filters and drying towers). The excess flow above that of the analyzer requirements is bypassed and returned to the test effluent system for Phase I tests and to the test vessel for the Phase II tests. Although the sodium oxide particulate filters are placed upstream of the gas pumps, the high concentration of oxide tends to plug the inlet sampling lines. This portion of the sampling system is provided with an inert gas purge to clear the inlet lines as required. The sampling systems for the Phase I and II tests are shown respectively in Figures 10 and 11.

In the Phase I tests, sodium burning rates are calculated from a knowledge of the heat of combustion of the reaction of concern, the inlet gas flow rates, and the oxygen consumption rate. However, in the Phase II tests, sodium burning rate determination requires a volumetric integration of the oxygen concentration within the cell and secondary volumes or over the entire system. This is accomplished by using four analyzers scanning various sampling stations; see Figure 11.

c. Miscellaneous Instrumentation

The inlet gas mixture flow rate determination for either experimental system is made by summing the nitrogen and air flow components as indicated by variable area glass tube flowmeters. The same flow (less the oxygen consumption) can be measured downstream of the bubbler-scrubber subsystem by use of an orifice type meter.

A standard, commercially available conductivity meter with automatic temperature compensation is used to monitor the sodium hydroxide concentrations in the scrubber-bubbler water. These data, plus a titration analysis, provide the input for a determination of the release rate of sodium from the burn chamber.

The humidity of the input gas mixtures is recorded by an instrument in which the hygroscopic film of the sensor changes its resistance with small changes in relative humidity. Three sensors are manually changed in order to cover a range from 5 to 95% relative humidity.

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Figure 10. Phase I Gas Sampling and Oxygen Analysis System

Figure 11. LTV Gas Sampling and Oxygen Analysis System

A complete understanding of the heat transfer characteristics of a sodium fire requires knowledge of the radiant heat flux arriving at the surface of the test vessel or absorbed in the gas phase. This heat flux is measured in both test vessels at the wall surface with sensitive radiant flux detectors having a restricted view angle. The radiometers have provisions for purging the sensor window (the bypass flow from the oxygen analyzer system) in order to reduce the possibility of sodium oxide plating. More recent radiometer models include cooling provisions to allow closer placement of the detector to the reaction zone.

d. Data Processing

The first step in each scan by the data logger is to punch a BCD identification of the equipment, the date, and the clock time. Subsequent to this, three digits of channel identification, polarity indication and four digits of the millivolt data on that channel are recorded. The decimal point is not punched, but depending on the amplifier gain, the last digit usually corresponds to 10 microvolts.

All processing of these data is done with the IBM System 360/50 computer. The first step is to convert the paper tapes to data cards. This process also checks for out-of-sequence punching (dropped digits, etc.) and tabulates the data as punched on the cards. This tabulation is then manually reviewed and any dropped digit is arbitrarily replaced so only that channel is lost, but none of the subsequent data. These manually edited cards are then used as input to the data reduction program.

The data reduction program, DATARED, is used to convert a millivolt test data from either system into engineering units. All channels for each scan interval (10-minute scanning interval in Phase I, and 22-minute intervals for short duration pool fire tests) in the LTV are tabulated in their corresponding engineering units together with the millivolt data. This program also plots the time behavior of all channels with as many as four arbitrary channels on a single chart. Manual editing of these plots quickly determines erroneous data points which can be screened from further processing. Additionally, at any specified time or time increment, temperature profiles (radial and axial) across any area may be plotted.

Further processing of the test data from pool fires is performed with the respective heat balance code, HTBALI or HTBALII. Within the HTBAL code, volumetric and area weighted temperature averages are calculated. These averages are then used to calculate the heat loss components of the respective system. The heat input components of the system include the electrical heat required to establish or maintain the required burn-pan temperatures and the combustion heat which is calculated from oxygen consumption per unit time. A simplified schematic of the HTBAL terms for Phase I and II tests are respectively shown in Figures 12 and 13. The heat loss and input component terms are described in the appendix. Balances are then made around the system boundaries and in an arbitrary region where combustion is assumed to take place. All of these calculations for each time point and a final subroutine call for result tabulation and plotting.

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Figure 12. Phase I HTBAL

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Figure 13. LTV HTBAL

APPENDIX

A. HTBAL I NOMENCLATURE

HC	Enthalpy change of cone wall
HCI	Enthalpy change of cone insulation
HD	Enthalpy change of cone donut
HDI	Enthalpy change of cone donut insulation
HDWN	Heat transferred from combustion zone to sodium pool
HIN	Electrical heat input
HKFI	Heat transferred through system flanges
HNA	Enthalpy change of sodium pool
HOXP	Enthalpy change of sodium oxide
HPI	Enthalpy change of pan insulation
HPL	Enthalpy change of pan flange
HPW	Enthalpy change of pan wall
HQGAS	Enthalpy of system atmosphere
HUP	Heat transferred from combustion region
QC	Heat transferred through cone wall to system atmosphere
QDI	Heat transferred through cone insulation
QD	Heat transferred through cone donut
QDI	Heat transferred through cone donut insulation
QPI	Heat transferred through cone pan insulation
QPW	Heat transferred through cone pan wall

B. HTBAL II NOMENCLATURE

HBP	Enthalpy change of burn pan
HD	Enthalpy change of donut
HDWN	Heat transferred from combustion region to sodium pool
HIN	Electrical heat input
HINC	Enthalpy change of cell wall insulation
HINS	Enthalpy change of secondary wall insulation
HNA	Enthalpy change of sodium wall insulation
HOXP	Enthalpy change of sodium oxide
HPRNC	Enthalpy change of protrusions in cell section

HPRNS	Enthalpy change of protrusions in secondary section
HQGASC	Enthalpy change of gas in cell section
HQGASS	Enthalpy change of gas in secondary section
HRB	Heat transferred from vessel bottom to fit floor
HSP	Enthalpy change of spider assembly
HUP	Heat transferred from combustion region to system atmosphere
HWC	Enthalpy change of cell wall
HWS	Enthalpy change of secondary wall
QBP	Heat transferred through burn pan wall
QDPR	Heat transferred through donut protrusion
QIN	Heat transferred through burn pan insulation
QINSC	Heat transferred through cell insulation
QINSS	Heat transferred through secondary insulation
QPRNC	Heat transferred through cell protrusions
QPRNS	Heat transferred through secondary protrusions
QWC	Heat transferred through cell wall
QWS	Heat transferred through secondary wall