OVERVIEW OF LMFBR PROGRAM AT HANFORD

by

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Richland, Washington

Introduction

Good afternoon. It is a special pleasure to speak to you at the 11th AEC Air Cleaning Conference here in the Tri-Cities. At a time when so much effort and rhetoric is being spent on the quality of our environment, I think it is especially significant that we have been giving the subject our careful attention long before most of the people and other industries have done so.

Today I will present to you an overview of the Liquid Metal Fast Breeder Reactor Program. I am going to begin by briefly discussing the overall LMFBR program, then proceed to a more specific discussion regarding the role of the Hanford site in the LMFBR program, and conclude by discussing in as much detail as time permits the FFTF project, which is to be the focal point of the LMFBR program in the years ahead. Following the presentation, I will be happy to answer your questions.

Narrative

[Slide 1 - LMFBR Overview]

To view the LMFBR program in its proper perspective, let us begin by placing it in the larger framework of the Civilian Nuclear Power Program as stated in the Atomic Energy Act of 1954. These objectives are:

[Slide 2 - Objectives of Civilian Nuclear Power Program]

1. To foster and support the growing use of nuclear energy.
2. To explore the vast energy resources latent in fertile materials.

These goals are as vital and valid today as they were when established in the early 1950's.

LMFBR/FFTF AT HANFORD

Slide 1

OVERALL CIVILIAN NUCLEAR POWER PROGRAM

FOSTER AND SUPPORT THE GROWING USE OF NUCLEAR ENERGY

EXPLORE THE VAST RESOURCES LATENT IN FERTILE MATERIALS

The Commission intends to continue to exercise positive and vigorous leadership in assuring growing participation by the nuclear industry and ensure the effective use of the vast resources of fertile Uranium-238 and Thorium-232.

[Slide 3 - Objectives and Program Elements]

The specific LMFBR program objectives amplify these general civilian nuclear power program objectives and indicate the priority approach the AEC has selected to meet national energy demands. These objectives are as shown:

1. To achieve, through R&D, the technology necessary to design, construct, and safely, reliably and economically operate a fast breeder reactor power plant in the utility environment.

2. To assure maximum development and use of a competitive, self-sustaining industrial capability in the development program.

The specific program elements include: Plant Design, Components, Instrumentation and Control, Sodium Technology, Core Design, Fuels and Materials, Fuel Recycle, Physics, Safety, Necessary Research and Development Facilities.

[Slide 4 - Contributions of LMFBR to Society]

The benefits which will be accrued from early commercial introduction of the LMFBR are many. Some of the key ones are set forth on this chart:

First - Low Cost Electricity - Electric power growth in the U.S. continues to be greater than previously experienced or predicted. Less than 90 years ago there was no production of electricity. Today, 20% of our energy is in electric form. In the year 2000, it is estimated at 50%.

Second - Eliminate Air Pollution - LMFBR's have the potential for higher thermal efficiencies, and therefore can be designed to add less waste heat to the environment per unit of power produced than even the most modern fossil plants. As with other types of nuclear plants, LMFBR's will not add combustion products to the air.

Third - Efficient Ore Utilization - The fast reactor of the future will permit 60 to 80% utilization of the uranium processed from the ore, compared with 1 to 2% achievable in the commercial light water reactors.

Fourth - Plutonium Production - Breeder reactors produce more fissionable material than they consume. If we define the amount of fissionable material produced per unit of original fissionable material burned as the "conversion ratio", the breeder has a conversion ratio greater than 1, and theoretically can exceed 1.5.

LIQUID METAL COOLED FAST BREEDER REACTOR PROGRAM

—————————OBJECTIVE—————————

To Achieve, Through R&D, The Technology Necessary To Design, Construct, And Safely, Reliably, And Economically Operate A Fast Breeder Reactor Power Plant In The Utility Environment.

To Assure Maximum Development And Use Of A Competitive Self-Sustaining Industrial Capability In The Development Program.

—————PROGRAM ELEMENTS INCLUDE—————

Plant Design

Components

Instrumentation And Controls

Sodium Technology

Core Design

Fuels And Materials

Fuel Recycle

Physics

Safety

Necessary Research And Development Facilities

CONTRIBUTIONS OF LMFBR TO SOCIETY

─────── THE LMFBR WILL ───────

Provide Access To Virtually Limitless Sources Of Electricity At Low Cost

Virtually Eliminate Air Pollution From Electrical Power Plants

Assure Efficient Utilization Of Fissionable Ore Reserves

Produce Large Amounts Of Plutonium For Energy Production And Other Peaceful Uses

Assure Continued Preeminence Of The U. S. In Its World Leadership Role In Nuclear Power

Fifth - U.S. Pre-eminence - The pattern in the U.S. and the future industrialized world will be shaped by our ability to meet, on schedule, our present commitments to the LMFBR program.

[Slide 5 - Operating Costs]

The general distribution of funds between the industry and Laboratory, as contained in the FY 71 Congressional submission, is as shown here. The "laboratories" perform basic research, applied R&D, engineering development, and process and product improvement, while on the other hand, industries' prime role in the program is to develop demonstration and commercial reactor plants.

[Slide 6 - LMFBR Demonstration Plant Program]

Following an approach similar to the one it used for the development of light water reactors, the Commission's LMFBR Program Plan includes plans to participate with industry in the construction of a series of LMFBR demonstration plants. A two-phase approach to the first demonstration plant is in progress. The principal objective of the first phase is to define the project in sufficient detail to give all the major participants a firm assessment of both the efforts required and the technical and economic risks involved. Contracts have been executed between the AEC and Atomics International Division of North American Rockwell Corporation, the General Electric Company and Westinghouse Electric Corporation to participate in the Project Definition Phase. Cost sharing in this arrangement will be about 50-50. Westinghouse is concentrating its site study on the Hanford Reservation as a primary candidate for the demonstration plant.


[Slide 7 - FY 71 Fund Distribution]

Focusing in now from the larger civilian power and LMFBR picture to Hanford's role in the program, you see the amount of anticipated 1971 financial commitments to participating Hanford contractors which are being scheduled in each of the separate budget categories.

WADCO receives approximately 34.2 M civilian power program dollars. Battelle-Northwest receives $1.5M. The Fast Flux Test Facility, which is the most important test facility in the breeder program, will receive $20.5M of the civilian power reactor budget here at Hanford.

[Slide 8 - WADCO Organization]

WADCO - a wholly owned subsidiary of Westinghouse Electric Corporation - operates and manages the AEC's Hanford Engineering Development Laboratory and is the principal LMFBR/FFTF contractor here at Hanford. WADCO employs about 1,100 highly skilled personnel in such diverse disciplines as Engineering, Chemistry, Physics, Electronics, Radiology, and the administration and service fields. The corporate organizational alignment as shown here is under President Dr. Walter Esselman.

LMFBR PROGRAM--OPERATING COSTS
FY 1971 CONGRESSIONAL SUBMISSION
OVERVIEW OF INDUSTRY - LABORATORY
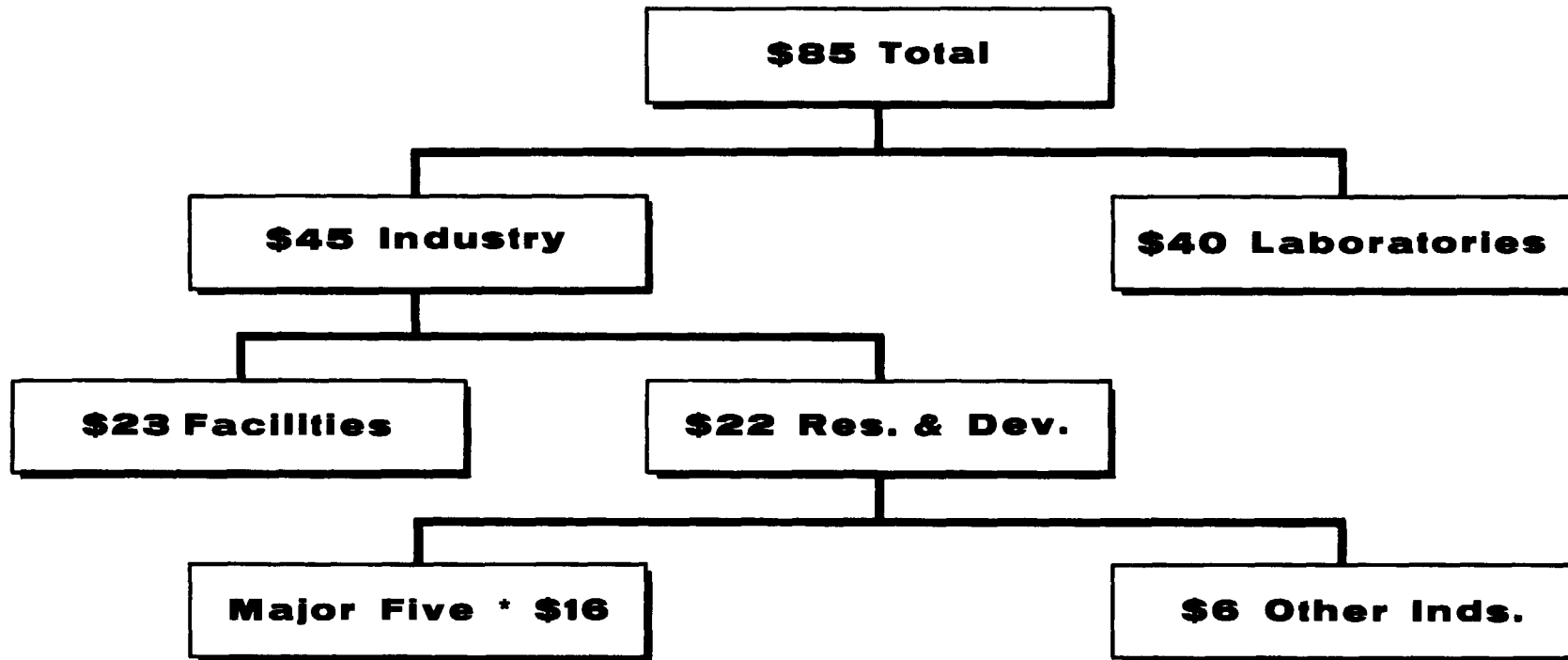
(In Millions Of Dollars)

(* AI, B&W, CE , GE, , W)

Slide 5

LMFBR DEMONSTRATION PLANT PROGRAM

PHASE I - PROJECT DEFINITION

Part 1. Engineering And Economics

Part 2. Management And Administration

PHASE II - DEFINITIVE COOPERATIVE ARRANGEMENT

Part 1. Design And Related Work.

Part 2. R&D Supporting Design

Part 3. Develop Codes And Standards.

Part 4. Engineer And Fabricate Components.

Part 5. Instrumentation And Component

Part 6. Construction

Part 7. Design Confirmation And Pre-Operational Testing.
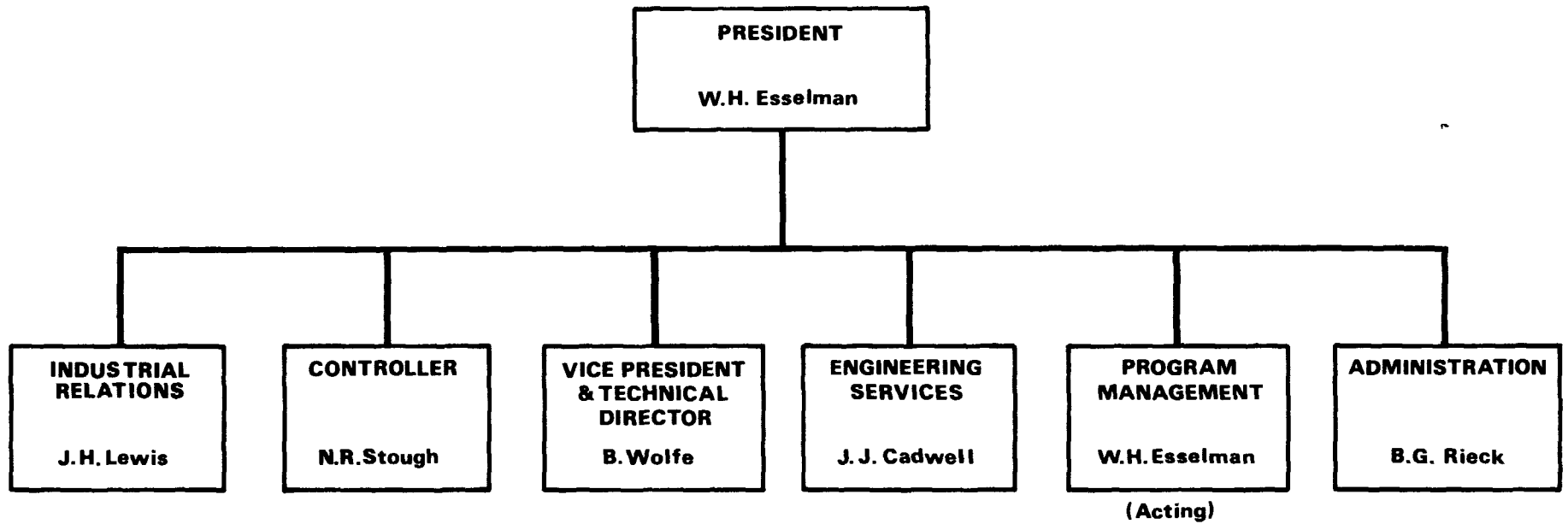
Part 8. Test-Operation.

Part 9. Post-Construction R&D.

Slide 6

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FY-71 04 PROGRAM/FUND DISTRIBUTION

	WADCO	BNW	Other
CIVILIAN POWER REACTOR			
Pu Utilization		1,000	
Canadian Coop		175	
LMFBR	12,855		
FFTF	20,500		
Gen R & D	675		
	34,030	1,175	
SPACE PROPULSION SYSTEM		100	
GENERAL REACTOR TECHNOLOGY	6,014	2,936	
NUCLEAR SAFETY	590	1,790	
OPERATIONAL SERVICES		50	
	40,634	6,051	100

GRAND 04 TOTAL $46,785

WADCO ORGANIZATION


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                          │    PRESIDENT     │
                          │                  │
                          │  W.H. Esselman   │
                          └──────────────────┘
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INDUSTRIAL RELATIONS	CONTROLLER	VICE PRESIDENT & TECHNICAL DIRECTOR	ENGINEERING SERVICES	PROGRAM MANAGEMENT	ADMINISTRATION
J.H. Lewis	N.R. Stough	B. Wolfe	J.J. Cadwell	W.H. Esselman (Acting)	B.G. Rieck

Slide 8

[Slide 9 - Fast Flux Test Facility]

As I mentioned earlier, the key test facility in the LMFBR program is the Fast Flux Test Facility. As the key facility it will serve as the focal point and the primary irradiation facility for the LMFBR program. The primary and additional objectives for the FFTF are as shown:

[Slide 10 - FFTF Objectives]

Primary Objectives

A. Provide fast flux testing needs of LMFBR Program
B. Provide fast flux testing for other AEC programs

Additional Objectives

A. Contribute to the development of competitive industrial capability necessary for ultimate industrial LMFBR

B. Contribute to the development of systematic methods of safe, economical plant design, construction and operation

C. Contribute to the development of standards and specifications for LMFBR

D. Contribute to the development of sodium systems and components for LMFBR such as purification systems, valves, IHX and pumps

[Slide 11 - Site Location Map]

The FFTF site is approximately 4 1/2 miles west of the Columbia River and 6 miles north of Richland. Site preparation is under way.

[Slide 12 - Site Photo]

This is the FFTF site as it looks today. This particular photo shows a drill rig engaged in core drilling for sub-soil investigation.

[Slide 13 - Plant Perspective]

This is an artist's view of how the FFTF will look upon completion in 1974. The design of the facility shown in this perspective is proceeding under the direction of WADCO, with Bechtel as the architect-engineer and Westinghouse Advanced Reactor Division as the reactor plant designer.

[Slide 14 - Parameters]

The basic FFTF design parameters are shown on this chart. The 900° outlet temperature has been put in parentheses as it is the initial operating temperature, with the targeted design temperature closer to 1100°. Other parameters of particular interest are the fast flux figures and closed loop capability.

FAST FLUX TEST FACILITY

FAST FLUX TEST FACILITY - OBJECTIVES

## —————— PRIMARY OBJECTIVES ——————

A. Provide Fast Flux Testing Needs Of LMFBR Program.

B. Provide Fast Flux Testing For Other AEC Programs.

—————— ADDITIONAL OBJECTIVES ——————

A. Contribute To The Development Of Competitive Industrial Capability Necessary For Ultimate Industrial LMFBR.

B. Contribute To The Development Of Systematic Methods Of Safe, Economical Plant Design, Construction And Operation.

C. Contribute To The Development Of Standards And Specifications For LMFBR.

D. Contribute To The Development Of Sodium Systems And Components For LMFBR Such As Purification Systems, Valves, I. H. X. And Pumps.

FFTF SITE
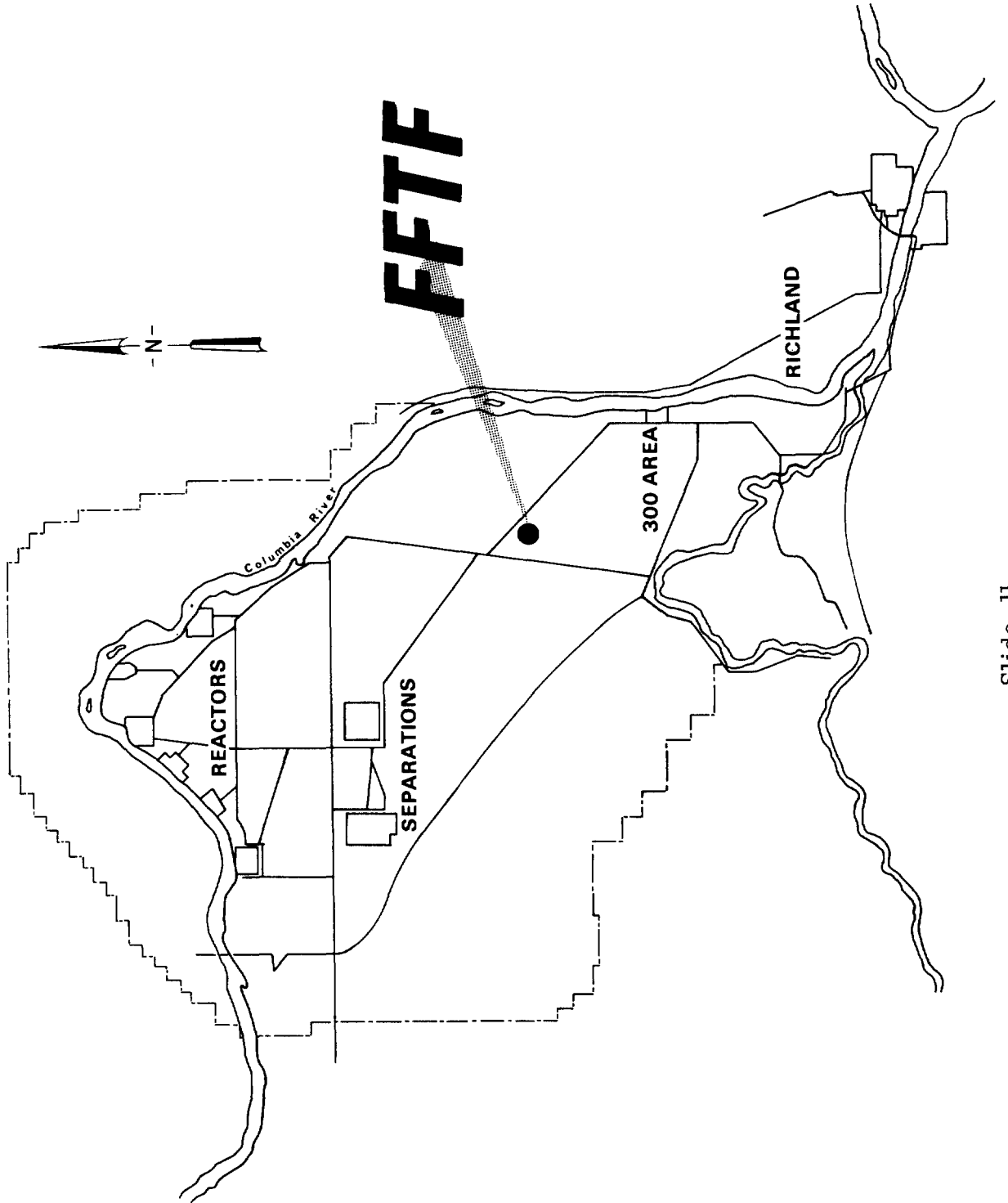
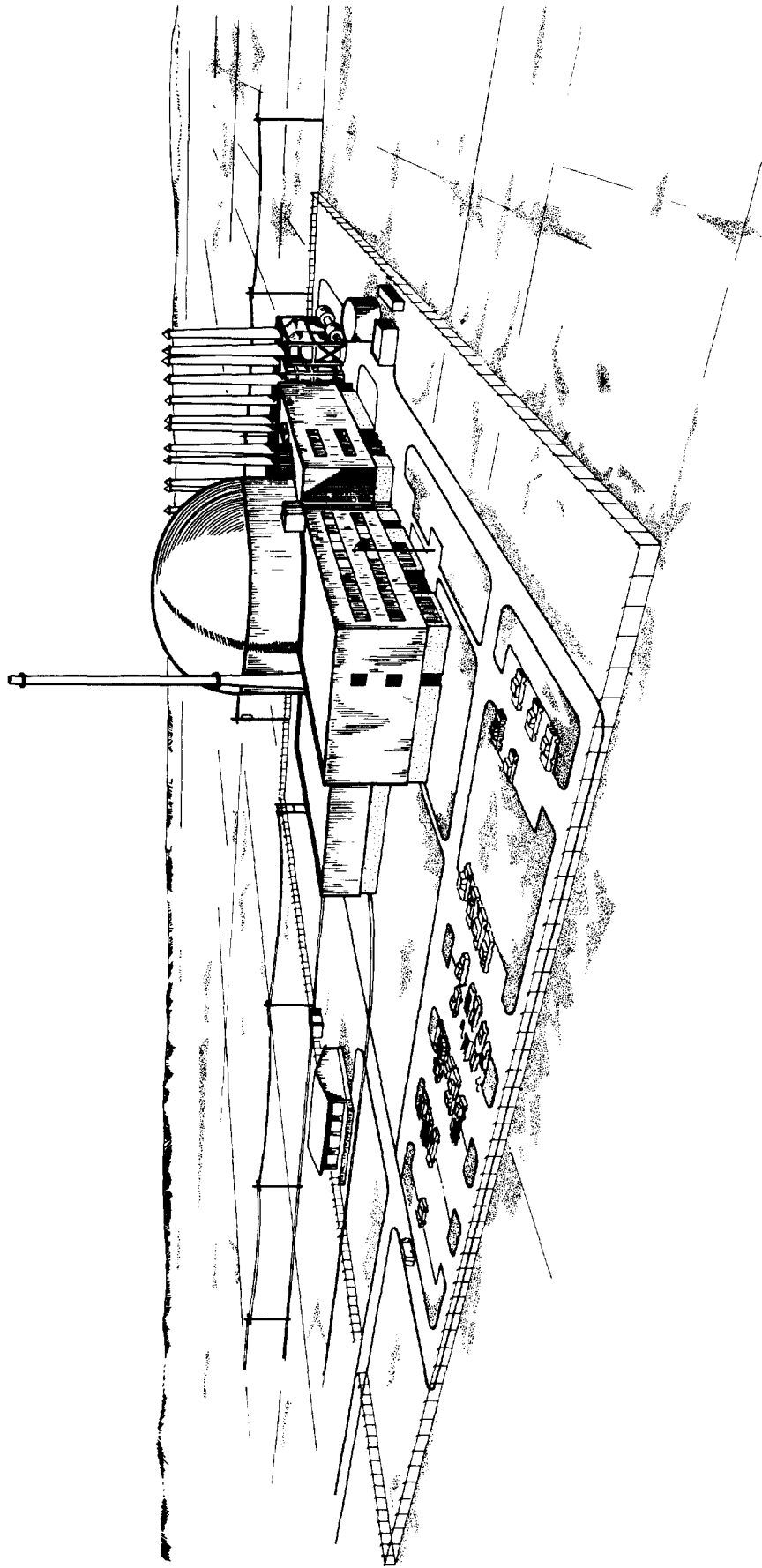Slide 11

Slide 12. Site photograph.

FAST FLUX TEST FACILITY

Slide 13

FFTF PARAMETERS

THERMAL POWER	400MW
MAX. CORE OUTLET TEMP.	(900°F)
NOMINAL CORE ΔT	300° F
MAX. CORE ΔT CAPABILITY	400° F
PRIMARY SODIUM FLOW CAPABILITY	43,000 GPM
PRIMARY SODIUM DYNAMIC HEAD	500 FT
CORE DIAMETER	4 FT
CORE HEIGHT	3 FT
PEAK FAST FLUX INITIAL	7×10^{15} nv/cm^2/sec
PEAK FAST FLUX ULTIMATE	1.3×10^{16} nv/cm^2/sec
INSTRUMENTED CLOSED LOOP CAPABILITY	4 POSITIONS
TEST POWER	2-4 MW
OPEN TEST POSITIONS	5

[Slide 15 - General Building Arrangement]

The FFTF containment and structures, clockwise from 12:00, include: the Reactor Containment Building (which is 135 feet in diameter, 122 feet above grade and 72 feet below grade), the Engineering Operations and Control Building, Polar Bridge Crane, Clem Transporter, Auxiliary Equipment Building, Transfer Dolly and Shipping Cask, Radioactive Maintenance and Fuel Examination Operations Area, Radioactive Core Decay Storage, Reactor, Primary Sodium Pump, Intermediate Heat Exchanger, Dump Heat Exchanger, Reactor Service Building, Secondary Sodium Pump, and Closed Loop Cells.

One of the most important experimental portions of the FFTF is the closed loops. The current plan is to initially install four closed loops. Two of these will be experimental loops for conducting safety experiments such as fuel failure propagation, and the other two will be 2 MW general-purpose loops whose primary use will be in conducting high risk irradiations of fuels and materials. The cooling systems for these loops are independent of the main Heat Transport System for the FFTF.

[Slide 16 - Reactor Head Area Plan]

This is a plan view of the reactor head. The actual reactor head is outlined in green; the Fuel Handling Machines in orange; the core instrumentation assemblies in blue. The actual core is outlined by the center hexagonal section in which are the control drive motors, and in-reactor equipment assemblies.
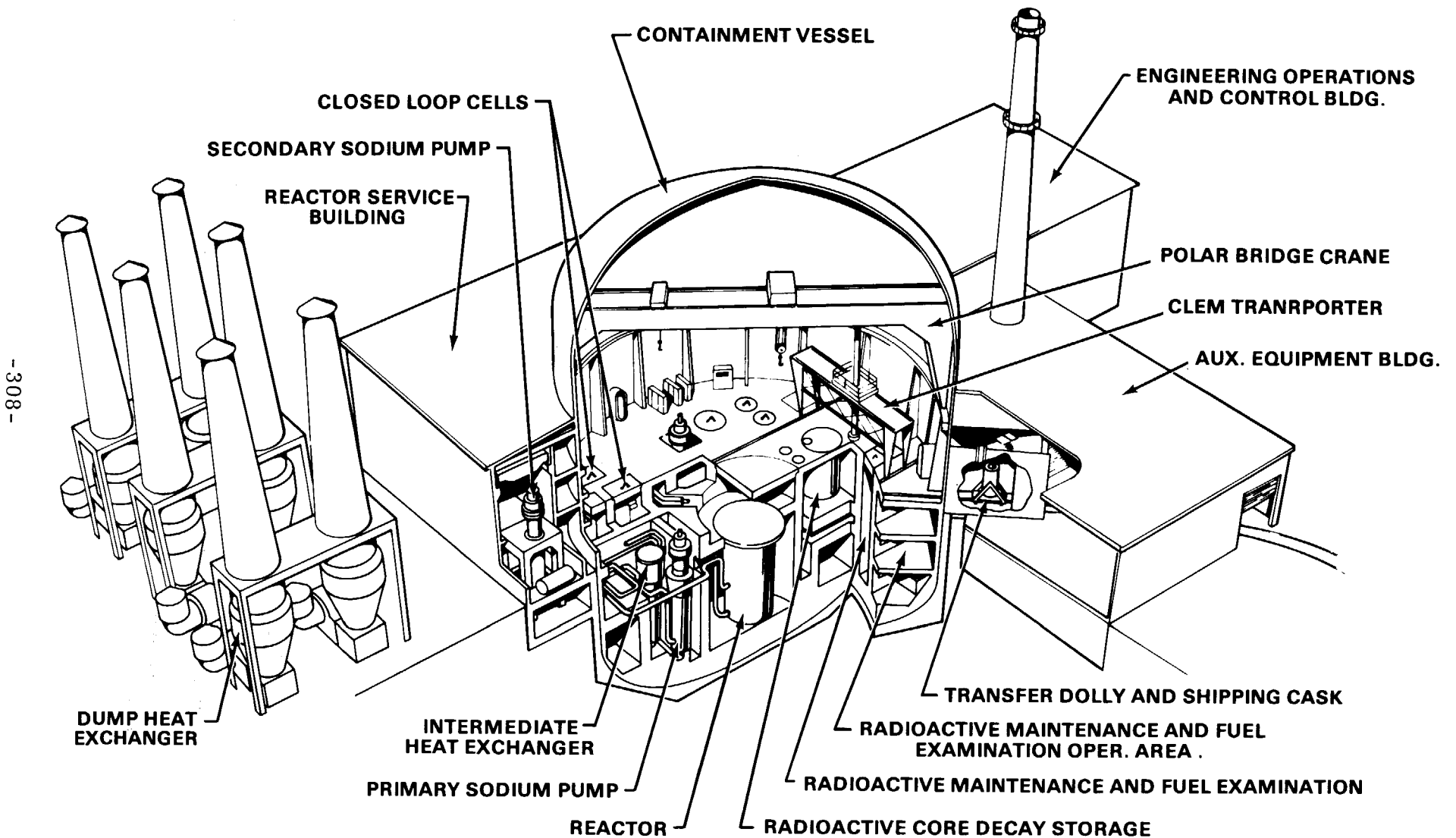

[Slide 17 - Heat Transport System]

Reactor cooling is performed by a piped system which consits of three independent heat transport circuits, each circulating about 14,000 gpm of sodium. Each circuit has a primary and secondary loop. Each primary loop includes a circulating pump, two isolation valves, a check valve and a shell side of an intermediate heat exchanger. The three associated secondary loops consist of the tube side of the intermediate heat exchanger, a circulating pump, expansion tank, valves, connecting piping, and forced draft air heat exchanger modules which dissipate the process heat to the atmosphere. The Reactor Coolant System dissipates 400 MW of reactor heat for all modes of reactor operation including emergency cooling and shutdown.
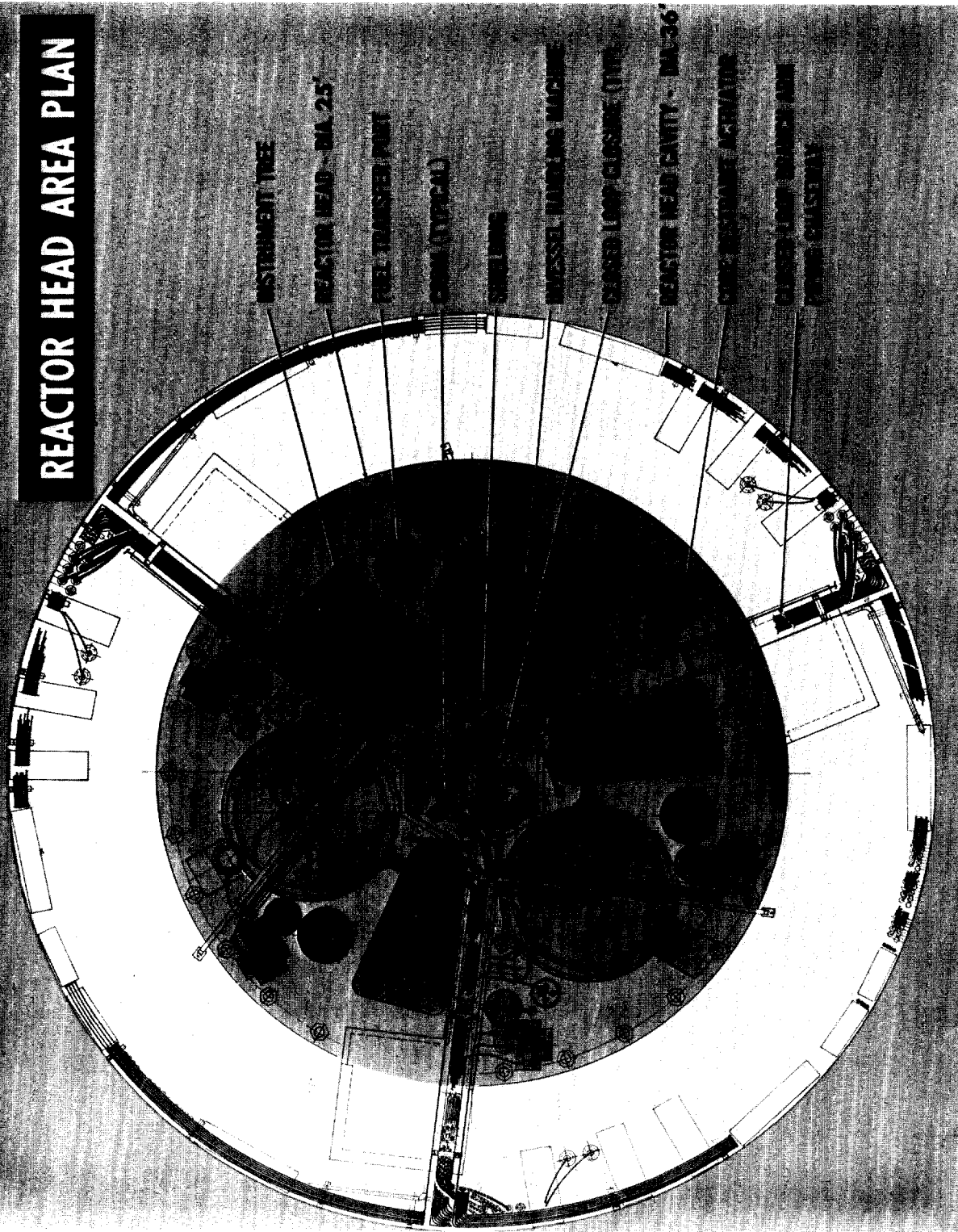

[Slide 18 - Fuel System]

The fuel assembly consists of the hexagonal flow duct containing a close-packed array of 217 fuel pins. The pins are clad in 316, 20% cold-worked, wire-wrapped, stainless steel tubing and are about 8 feet long. The active core itself is about 3 feet long. The core is comprised of 1/4 inch pellets .194 inch in diameter, containing 75% UO_2 and 25% PuO_2. The goal is to reach 80,000 MWD/T maximum. This is equivalent to 306 full power days.

FFTF GENERAL BUILDING ARRANGEMENT

CONTAINMENT VESSEL

CLOSED LOOP CELLS

SECONDARY SODIUM PUMP

REACTOR SERVICE BUILDING

ENGINEERING OPERATIONS AND CONTROL BLDG.

POLAR BRIDGE CRANE

CLEM TRANRPORTER

AUX. EQUIPMENT BLDG.

DUMP HEAT EXCHANGER

INTERMEDIATE HEAT EXCHANGER

PRIMARY SODIUM PUMP

REACTOR

TRANSFER DOLLY AND SHIPPING CASK

RADIOACTIVE MAINTENANCE AND FUEL EXAMINATION OPER. AREA .

RADIOACTIVE MAINTENANCE AND FUEL EXAMINATION

RADIOACTIVE CORE DECAY STORAGE

Slide 15

REACTOR HEAD AREA PLAN

Slide 16

FFTF REACTOR HEAT TRANSPORT SYSTEM

ONE OF THREE PARALLEL COOLANT CIRCUITS

SECONDARY PUMP
ARGON PRESSURE
EXPANSION TANK
260 FT HEAD 14,500 GPM
CONTAINMENT BOUNDARY
FLOW METER
8"
16"
8"
4-DHX MODULES
33 MWt EACH
16"
REACTOR CONTAINMENT FLOOR & GRADE LEVEL
51' -6" (20' -0" MIN)
22' -6"   17' -6"
4" GAS LINE
ARGON INLET
25' -1"
Na MAKE-UP
Na OVERFLOW
FLOW METER
FROM IHX
16"O.D.
16"O. D.
TO REACTOR
GUARD VESSEL
28" O. D.   40' -1"
40' -2"
16" O. D.
CORE
PRIMARY PUMP
IHX
GEOMETRIC CENTERS
500 FT HEAD 14,500 GPM
REACTOR

REACTOR DATA

POWER	400 MWt
INITIAL PEAK FLUX	7.0×10^{15}
CORE OUTLET, INITIAL	900°F
MAX DESIGN	1100°F
CORE INLET, INITIAL	600°F
MAX DESIGN	830 °F

HEAT EXCHANGER DATA

HEAT REMOVAL/CIRCUIT	133 MWt @ 85°F LMTD
HOT LEG PRIMARY SODIUM,	
INITIAL	858°F
MAX DESIGN	1050°F
DHX AIR INLET, DESIGN	90°F
DHX AIR OUTLET	~ 600°F

FFTF FUEL SYSTEM

DRIVER FUEL PIN labels:
- UPPER END CAP
- CLADDING
- PLENUM SLEEVE
- PLENUM SPRING
- UPPER REFLECTOR
- INSULATOR PELLET
- FUEL PELLET
- WIRE WRAP SPACER
- INSULATOR PELLET
- LOWER REFLECTOR
- LOWER END CAP

DRIVER FUEL PIN

DRIVER FUEL SUBASSEMBLY labels:
- UPPER FUEL SUPPORT GRID
- FUEL COLUMN
- LOWER FUEL SUPPORT GRID

DRIVER FUEL SUBASSEMBLY

SECTION A-A
(Includes Upper and Lower Fuel Support Grid but not Duct)

FUEL COLUMN

SECTION B-B
LOWER FUEL SUPPORT GRID

FUEL COLUMN

FTR CORE

NOSE PIECE

COOLANT INLET PORTS

FAST TEST REACTOR labels:
- CLOSED LOOP
- DRIVER FUEL ASSEMBLY
- CONTROL ROD
- FTR CORE

FAST TEST REACTOR

[Slide 19 - Cost Estimate]

The current cost estimate is the result of an intensive design activity at HEDL, W-ARD and Bechtel, the product of which was a definitive conceptual design and a detailed estimate of the schedule and cost for this concept. As you see, the current estimate for the project is $102,847,000.

[Slide 20 - FFTF Project Basic Schedule]

As noted earlier, site preparation is under way. An access road and railroad are currently being constructed as well as installation of a 13.8 kv electrical line from the nearby Hanford 300 Area. The current schedule shows FFTF completion in mid-1974.

[Slide 21 - FFTF Total Manpower]

Total manpower involved in actual construction of the project is projected to peak at about 1300 in 1973. During the operational phase after construction there will be a continuing operational staffing level of about 425 personnel.

[Slide 13 - Plant Perspective]

In addition to the FFTF project, WADCO is responsible for conducting related development and testing work in special test or mockup facilities either already built or scheduled for construction in the near future. These test areas include: reactor equipment development; core coolant dynamics; fuels development; fuel handling; instrument development; materials technology; and sodium technology.

Some of the key test facilities which are being constructed for this development work include:

1. The High Temperature Sodium Facility, a multi-purpose facility, providing both office and development space, to support high temperature sodium systems testing.

   For example, the Composite Reactor Component Test Activity, which provides a static high temperature sodium environment to test full-scale reactor core components, is located in this facility.

2. The Fast Reactor Thermal Engineering Facility, a high temperature, flowing sodium loop for heated fuel pin development test programs associated with thermo-hydraulic requirements and safety analyses.

3. The Core Segment Development Facility, a general-purpose facility for testing reactor control rods, driver ducts, closed loops, and their inter-action in high temperature sodium environment.

FFTF COST ESTIMATE

Engineering, Design And Inspection Costs		**$ 16,976,000**
Construction Costs:		**65,304,000**
(1) Reactor System	30,306,000	
(2) Closed Test Loops	3,355,000	
(3) Fuel Handling AndStorage	2,206,000	
(4) Buildings, Structures, Cranes, Electric		
And Miscellaneous Services	15,401,000	
(5) Interim Fuel Examination Facility	3,881,000	
(6) Containment	8,340,000	
(7) Nuclear Proof Test Facility	Deferred	
(8) Maintenance Facility	1,815,000	
Subtotal		**82,280,000**
Contingency		**20,567,000**
Total Project Cost		**$ 102,847,000**

FFTF PROJECT BASIC SCHEDULE
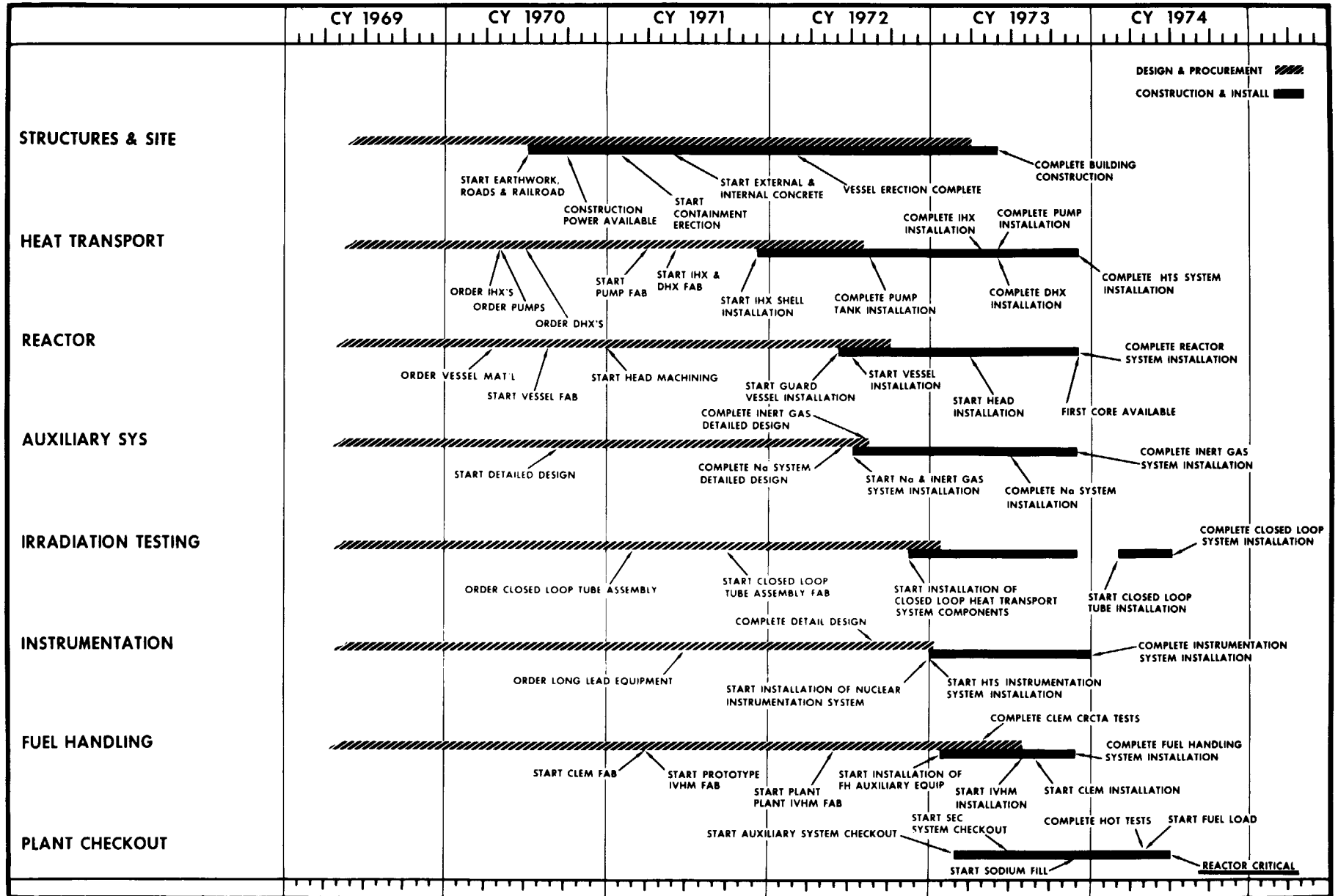
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FFTF PROJECT TOTAL MANPOWER

INCLUDING OFF SITE WESTINGHOUSE AND BECHTEL DESIGN

| CY | PROJ. MGMT WADCO | DESIGN OFF SITE | | CONSTRUCTION | | OPERATIONS | | TOTAL |
		Westinghouse	Bechtel	Manual Non-Manual	Field Engineering	Plant Operations	Technical Support	
1969	330	70	50	0	10	10	0	470
1970	330	190	100	50	20	15	0	705
1971	250	220	100	250	75	25	0	920
1972	200	175	90	525	100	70	0	1160
1973	175	110	70	675	100	150	20	1300
1974	140	50	30	275	100	250	50	895
1975	80	20	0	0	40	300	65	505
1976	0	0	0	0	0	350	75	425

MANPOWER NUMBERS ARE AVERAGE FOR YEAR SHOWN

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Conclusion

In concluding, I would like to stress the role of the Fast Flux Test Facility as the central test facility for the LMFBR program. Further, the critical role of the Fast Breeder Reactor in the total national energy picture will become increasingly obvious as development of the system proceeds during the 1970's.

Meetings among specialists such as yourselves are integral parts of the program.

The potential of satisfying mankind's energy needs and preserving our environment lies with you technical contributors who are involved in this exciting challenge.

The information which you will be exchanging during this conference will put many of the basic LMFBR problem areas in the field of air cleaning on the table for discussion, and in doing so will move the program forward.

If there are any questions, I will be happy to entertain them at this time.

VENTILATION SYSTEMS FOR THE FFTF

B. O. Shaver

WADCO Corporation
Richland, Washington

ABSTRACT

The Fast Flux Test Facility (FFTF) is a coordinated facility for investigation into the behavior of fuels and structural materials subjected to high, fast neutron flux prototypic of fast reactor environments. Heat is removed from the reactor by circulation of liquid sodium coolant through the reactor and associated heat exchanger systems. The heat energy is rejected to the atmosphere without power recovery.

Since the primary mission of the reactor is to provide reliable fast flux testing, closely controlled and instrumented environmental conditions is a primary objective. The heating and ventilation system provides the required environmental conditions within FFTF for all air and nitrogen spaces and, by filtration of the exhaust air, controls the release of contaminants discharged to the environment.

Features of the FFTF ventilation systems include:

- A central ventilation supply and filtered exhaust system serves the containment vessel as well as the potentially contaminated areas outside of containment. The exhaust air is discharged through a 200-foot high stack.

- Recirculating atmosphere coolers are provided for all spaces and cells within containment to maintain required temperature conditions in nitrogen and air atmosphere spaces during normal and accident conditions.

- Redundant cooling equipment and coolant piping are provided for spaces where cooling is required to assure reactor operating continuity and for post-accident cooling.

- Local exhaust ducts with filters are provided for air purging of nitrogen spaces. These filters, and exhaust filters in all locations, are specifically selected to handle sodium smoke as required, including post-accident conditions.

- Ventilation containment valves are provided at containment barrier penetrations which respond to above-normal radiation levels inside containment and to off-normal conditions in the containment exhaust.

- Building pressure levels are selected and controlled to maintain control of airborne contamination during normal reactor operation in all spaces where there is a potential for contamination release. Relative pressure levels between nitrogen and air atmosphere spaces are controlled to maintain required atmospheric purity in the cells.

INTRODUCTION

The Fast Flux Test Facility, as proposed, is a 400 megawatt, mixed plutonium-uranium oxide fueled nuclear reactor to provide a fast neutron environment for Liquid Metal Fast Breeder Reactor testing purposes. The primary sodium coolant system consists of three piped loops which transport heat from the reactor to intermediate heat exchangers and then via secondary sodium loops to dump heat exchangers that dissipate the heat to the atmosphere.

Each of the three primary sodium loops and its components is located in separate inert atmosphere cells within the containment structure.

Secondary sodium pumps located outside of containment in an air atmosphere structure deliver the secondary sodium to the air blast heat exchangers. The dump heat exchangers are of a modular type, four modules per exchanger, with each module having sodium-to-air finned coils and an air blower arranged to permit operation independently of the other modules. Each module is equipped with dampers that are used to control air flow during operation and to protect blower equipment and minimize heat loss during shutdown. Auxiliary oil-fired heaters are provided to initially heat up the sodium to flowing temperature conditions in the heat dump system and electrical resistance heaters are used in the piping systems elsewhere for the same purpose.

SITE

The FFTF site has been selected at a location on the Hanford Reservation approximately 5-1/2 miles north of the southern boundary of the reservation and 4-1/2 miles west of the Columbia River (approximately 14 miles NW of Richland). Site preparation was initiated during calendar year 1969 and the beginning of physical construction is scheduled for late 1970. Major contractors engaged in the design of the facility are the Bechtel Corporation, who is the Architect-Engineer for the plant, and the Westinghouse Electric Corporation, who is the Reactor Plant Designer.

FACILITY DESCRIPTION

The Fast Flux Test Facility plant is composed of the Reactor Containment Building, the Reactor Service Building,

the Auxiliary Equipment Building and the Engineering, Operations and Control Building. Surrounding the Containment Building, the major portion of the facilities are contained under one roof and are isolated from each other by partitions and/or shielding walls. The overall plant perspective is shown in Figure 1 and the general building arrangement is shown in Figure 2. A brief discussion of each facility or area follows.

Reactor Containment System

The Reactor Containment System consists of two barriers to control the release of radioactive materials. It is designed to protect the public and environs from the consequences of accidents which might release radioactive material from the reactor core, the primary coolant system or the closed loops.

The first barrier consists of steel-lined concrete vaults, housing the reactor and primary systems. These vaults are designed to prevent the leakage of inert atmosphere under normal operating conditions. Limited leakage is anticipated under accident pressure and temperature conditions. The final containment barrier is a steel pressure containment vessel which houses interior concrete vaults containing the reactor and process equipment and is used as a personnel work area during normal reactor operation. Major cells and facilities within containment include:

Reactor Cavity Vault

The reactor cavity is a steel-lined vault which houses and supports the reactor vessel. The reactor vessel is suspended by its top flange from the top of the vault structure to permit thermal expansion in the radial and longitudinal directions.

The reactor cavity vault structure is designed to withstand accident-generated pressures and temperatures. A nitrogen atmosphere is planned for this space with cooling capability provided by the Heating and Ventilation System.

Reactor Head Access

An enclosure is provided between the reactor vessel cover and the operating area floor above to house appurtenances which penetrate the reactor cover and to confine a potential sodium release resulting from component failure or a reactor accident. A nitrogen atmosphere is planned for this space with capability of changing to air to permit personnel entry during reactor shutdown conditions. Cooling is provided by this system.
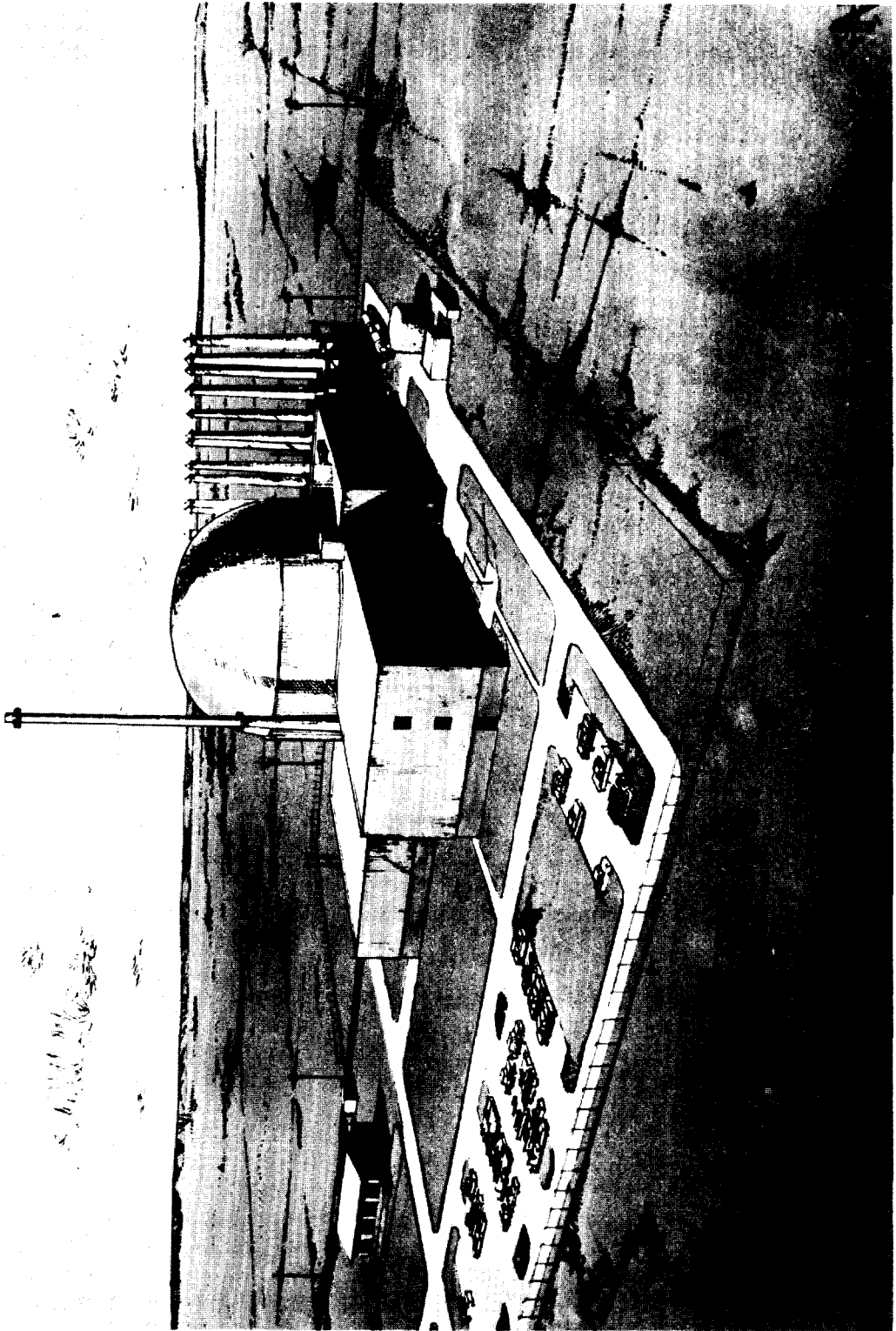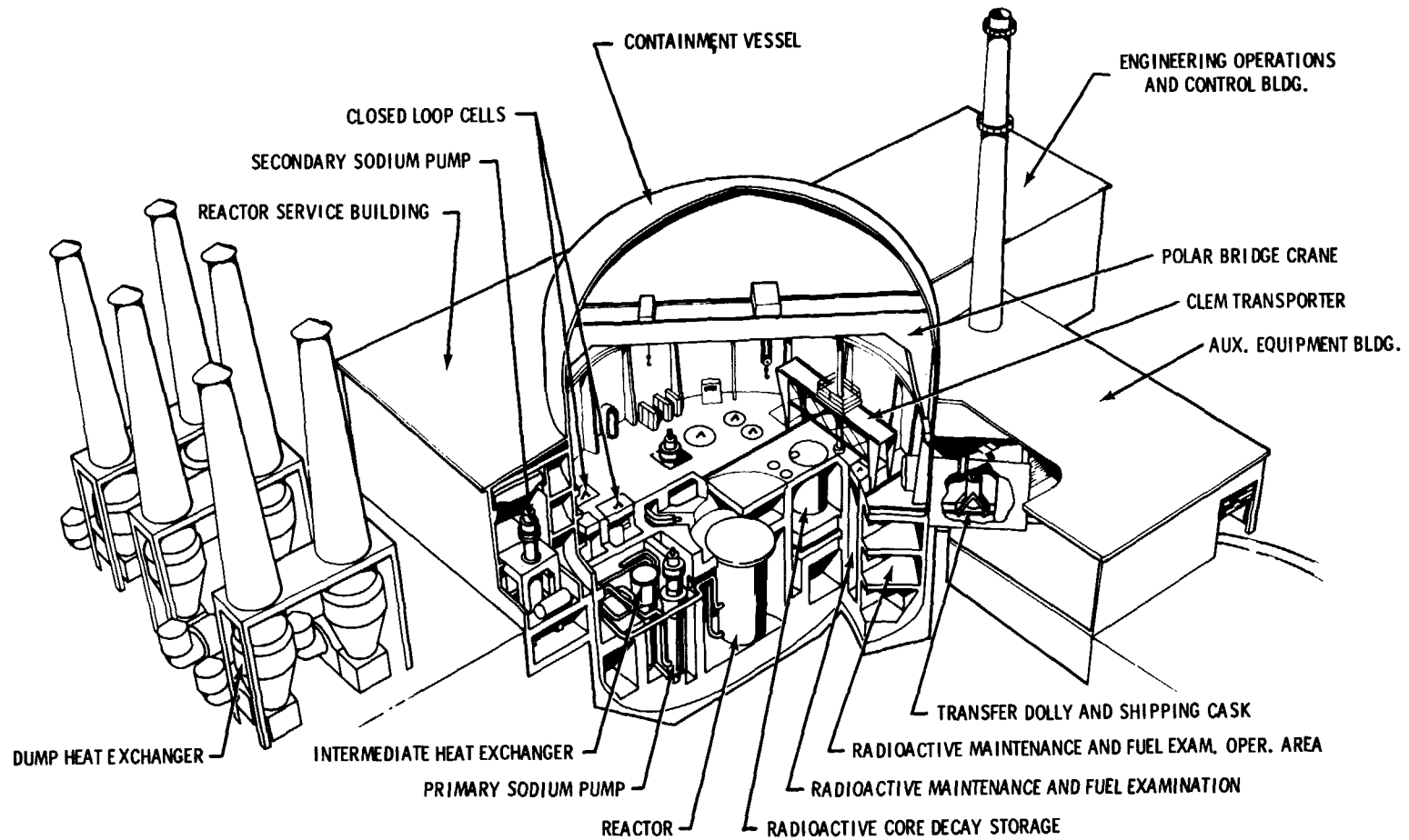
FIGURE 1. FFTF Plant Perspective

CONTAINMENT VESSEL

ENGINEERING OPERATIONS
AND CONTROL BLDG.

CLOSED LOOP CELLS

SECONDARY SODIUM PUMP

REACTOR SERVICE BUILDING

POLAR BRIDGE CRANE

CLEM TRANSPORTER

AUX. EQUIPMENT BLDG.

DUMP HEAT EXCHANGER

INTERMEDIATE HEAT EXCHANGER

PRIMARY SODIUM PUMP

REACTOR

TRANSFER DOLLY AND SHIPPING CASK

RADIOACTIVE MAINTENANCE AND FUEL EXAM. OPER. AREA

RADIOACTIVE MAINTENANCE AND FUEL EXAMINATION

RADIOACTIVE CORE DECAY STORAGE

FIGURE 2. FFTF General Building Arrangement

Primary Heat Transport (HTS) Cells

The primary heat transport cells house and support the primary sodium system equipment components for the primary sodium loops. Each of the three shielded and steel-lined cells are designed to withstand internal pressures resulting from accident conditions and constitute a barrier to leakage resulting from accident conditions originating within the cell. A nitrogen atmosphere which can be changed to air to permit entry during reactor shutdown is provided in each cell. Cooling is provided by the Heating and Ventilation System.

Closed Loop Cells

Two closed loop cells are provided initially which are constructed similar to the HTS cells and contain the primary sodium components of individual reactor channel piped test loops. Space and structural facilities are included in the Containment Building for two future closed loop cells. Cooling is provided by the Heating and Ventilation System.

Reactor Support Buildings

The reference design for the Reactor Support Buildings includes three buildings under one roof which are wrapped around the Reactor Containment Building. The three buildings are identified as:

- The Auxiliary Equipment Building

- The Reactor Service Building

- The Engineering, Operations and Control Building.

The Auxiliary Equipment Building

Constructed of concrete and structural steel framing with insulated metal siding, this building is about 130 feet by 124 feet in plan and 60 feet in overall height. It joins the northwest quarter of the cylindrical reactor containment vessel. Portions of the building are designed for confinement control to minimize potential radioactivity leakage to the environs during the handling of fuel casks and radioactive wastes. Major functional areas and equipment housed in this building include:

- Fuel Handling

- Test Assembly Transfer

- Reactor Core and Small Component Transfer

- Radioactive Waste Collection and Transfer

- Radioactive Gas Decay Storage and Circulation

- Maintenance and Operations Materials Handling

- Central Exhaust Ventilation Equipment.

The Reactor Service Building

Constructed of concrete and structural steel framing with insulated metal siding, this building is about 180 feet by 100 feet in plan and 60 feet in overall height. The building joins the east half of the cylindrical reactor containment vessel. Major functional areas and equipment housed in this building include:

- Sodium Receiving and Processing Equipment
- Inert Gas Receiving and Processing Equipment
- Auxiliary Cooling and Heating Equipment
- Heating and Ventilation Supply Equipment
- Heat Transport System secondary sodium pumps, expansion tanks, and associated equipment
- Closed Loop System secondary sodium pumps, expansion tanks, and associated equipment.

Engineering, Operations and Control Building

Constructed of concrete and structural steel framing with insulated metal siding, this building is about 84 feet by 140 feet in plan and 45 feet in overall height and joins the southwest quarter of the reactor containment vessel. Functional areas and equipment housed in this building include:

- Central Control and Data Handling
- Instrument and Electrical Equipment
- Personnel Access Control
- Office Area.

PLANT PARAMETERS

The basic plant parameters are indicated in Figure 3.

FUNCTIONAL REQUIREMENTS

The reference design discussed herein is based upon the FFTF Scope Document reference concept of April 27, 1970, together with some modifications made since that time. Major functions and design requirements imposed upon the Heating and Ventilation System consider all modes of plant operation including accident conditions and are outlined below.

Functions

The Heating and Ventilation System performs the following functions during normal plant operations:

- Controls the temperature, humidity and cleanliness of the air and nitrogen atmosphere spaces within FFTF

REACTOR CONTAINMENT BUILDING

CYLINDRICAL VESSEL	135 FT DIAM
OVERALL HEIGHT	193 FT - 4 1/2 IN.
DEPTH BELOW GRADE	69 FT - 9 IN.
VOLUME (GROSS INCLUDING STEEL STRUCTURE)	2,365,000 CU FT
REACTOR HALL - FLOOR AREA @ EL 0:0'	14,300 SQ FT
(~GROUND ELEVATION)	
INTERNAL DESIGN PRESSURE	10 PSIG
EXTERNAL DESIGN PRESSURE	(-) 0.20 PSIG
DESIGN TEMPERATURE	
MAXIMUM	250 °F
MINIMUM	(-) 10 °F
LEAKAGE RATE	0.5% VOL @ 10 PSIG/24 HR

REACTOR SUPPORT BUILDINGS

FLOOR AREA	113,000 SQ FT
VOLUME	2,500,000 CU FT
CONSTRUCTION MATERIAL	CONCRETE AND STEEL

FIGURE 3. FFTF Buildings Parameters

- Controls the spread of airborne contamination within FFTF under normal conditions by maintaining proper building pressure levels and airflow direction

- Provides the capability for air purging of the spaces which are normally maintained in a nitrogen atmosphere

- Controls the release of airborne contaminants to the environs by filtration of exhaust air.

In addition, the Heating and Ventilation System performs required atmosphere cooling functions following a hypothetical reactor core disruptive accident.

Design Requirements

Pertinent requirements applicable to the design of the Heating and Ventilation System to satisfy all modes of plant operation include:

- The system must be capable of providing required ventilation and cooling at all times, including periods of electrical power failure.

- The system must provide required filtration of exhaust air to meet AEC requirements.

- The system must be protected against the adverse effects of filter plugging.

- The system must have required redundancy to protect against failure of vital ventilation equipment.

- The system must be provided with a cooling media for use in the cooling coils which will not create deleterious effects in the event of a leak, or cause hazardous conditions, or accentuate the adverse consequences of an accident.

- The system components, whose proper operation is necessary for the safety of the plant, must be capable of assuming the proper position during periods of loss of instrument control power.

- The system must provide required cooling of the reactor cavity and the three heat transport cells following a hypothetical reactor core disruptive accident. Specific requirements include:

  - Each cell cooling system shall be designed to continue operating throughout and following a hypothetical reactor core disruptive accident.

  - Each cell shall be provided with a redundant cooling unit isolated from the cell during normal operation. The isolating mechanisms shall insure that no accident will impair the capability of placing the standby unit in service. The isolation mechanisms shall be remotely operable from the control room.

- Each cell cooling unit shall be equipped with filters which will accommodate airborne sodium smoke (without plugging) resulting from the reaction of the oxygen in the cell.

- Each cell cooling unit shall be designed to tolerate sodium vapor condensation without degradation of the cooling capacity more than 20 percent.

BUILDING ZONES

The building is zoned to meet process and facility needs using partitions and isolation barriers to provide the required zoning. The air atmosphere spaces are pressure controlled to provide airflow from zones of lesser-to-greater contamination potential.

Inert atmosphere spaces are maintained at a positive pressure relative to the adjacent air spaces to provide required inert gas purity. The building zones and tentative zone pressures are set in the following range.

Zone	Space (Typical)	Zone Pressure
I	Containment Vessel (air spaces)	Minus 0.50 inches water
IA	Inert Atmosphere (nitrogen)	Minus 0.25 inches water (inside containment)
II	Auxiliary Equipment Building (Fuel & Radioactive Waste Handling Areas)	Minus 0.15 inches water
III	Reactor Service Building (Equipment Spaces, Secondary Sodium Areas)	Atmospheric
IV	Engineering Operations Building Central Control Room	Slightly above Atmospheric

VENTILATION SYSTEMS

Several ventilation systems serve the FFTF building complex. The various requirements of the facility impose varying needs for ventilation and air treatment. While some of the needs are typical of an industrial plant, some are special and have an overriding effect in dictating the philosophy used in establishing the system design. The ventilation systems are portrayed diagrammatically in Figure 4 and are described below.

Supply Systems

Separate central supply systems serve each of the following areas:

- Reactor Containment Building and Reactor Service Areas

- Control Center and Computer Room

- Engineering, Operations and Control Building.

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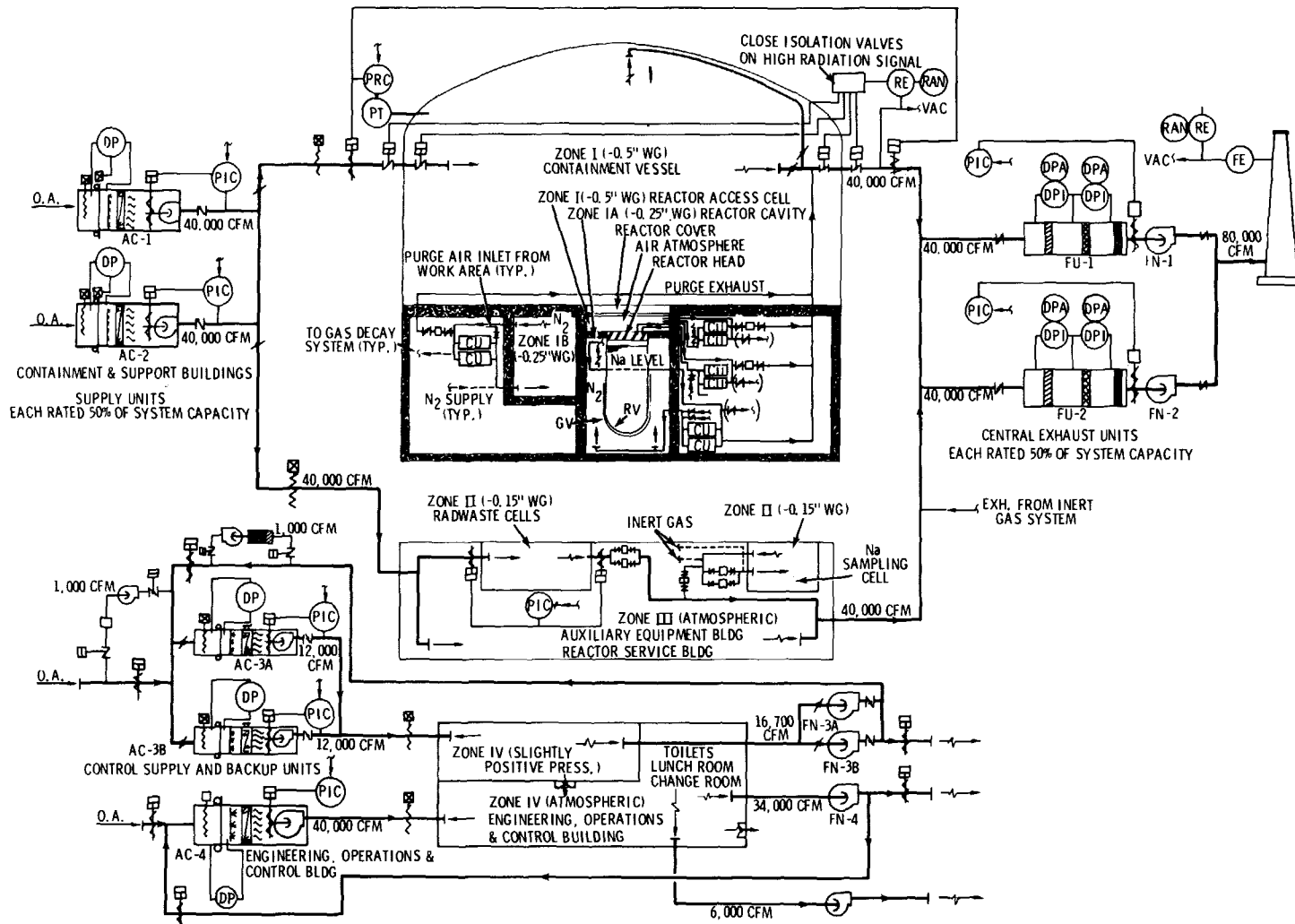FIGURE 4. Heating and Ventilation System Diagram

Reactor Containment Building Supply

For the Reactor Containment Building and Reactor Service areas, two 50 percent capacity units are provided. Each unit is made up of inlet filters approximately 50 percent NBS efficiency, electric heating coils, sprayed cooling coils and electrically driven fans. The fans are each equipped with individual control and isolation dampers and are connected in parallel to a common ductwork system. Two 50 percent capacity matching exhaust fans are used for exhausting the spaces served by the Reactor Containment Supply System. Thus, a failure of any fan or component can be compensated for and the system operated at reduced capacity.

Control Center Supply

The Control Center Supply System is made up of components similar to the Reactor Building Supply System, except the capacity of each unit is rated for 100 percent instead of 50 percent. Thus, failure of a component would still permit cooling of the Control Center at the normal rate. The 100 percent redundancy is provided because of the important electronic gear contained in the Center.

Engineering Operations Supply

The Engineering Operations spaces are served by one 100 percent capacity system similar to the above. During component failure or periods of BPA power outage this system is shut down.

Cell Coolers

Two recirculating atmosphere coolers, each rated for 100 percent of the system requirements, are provided for each of the inert atmosphere cells with one unit normally in operation and one unit in standby condition. These systems are portrayed diagrammatically in Figure 5 and pictorially in Figure 6. Major cells served by these systems include:

1. Reactor Cavity

2. Reactor Access Cell

3. Heat Transport Cells (three)

4. Closed Loop Cells (two provided-two future)

5. Pipeways (two)

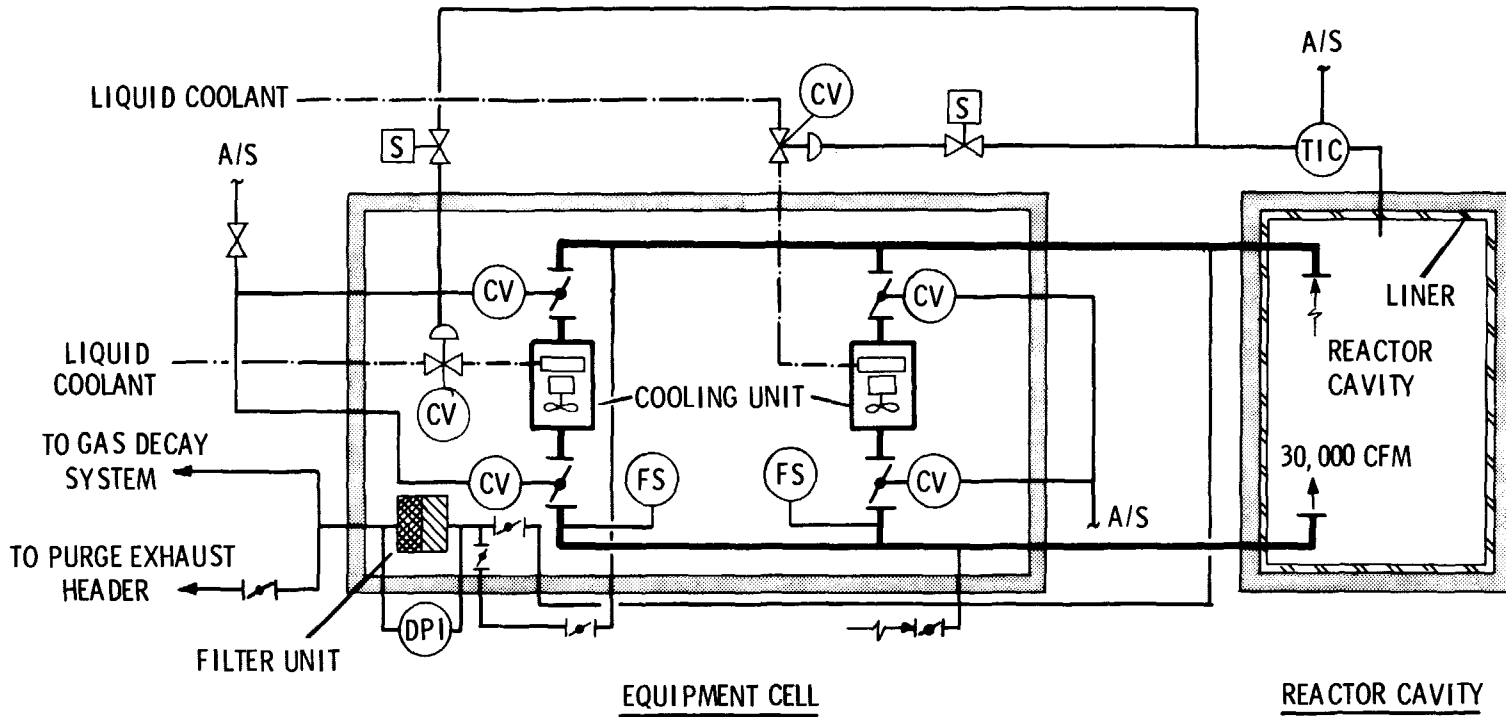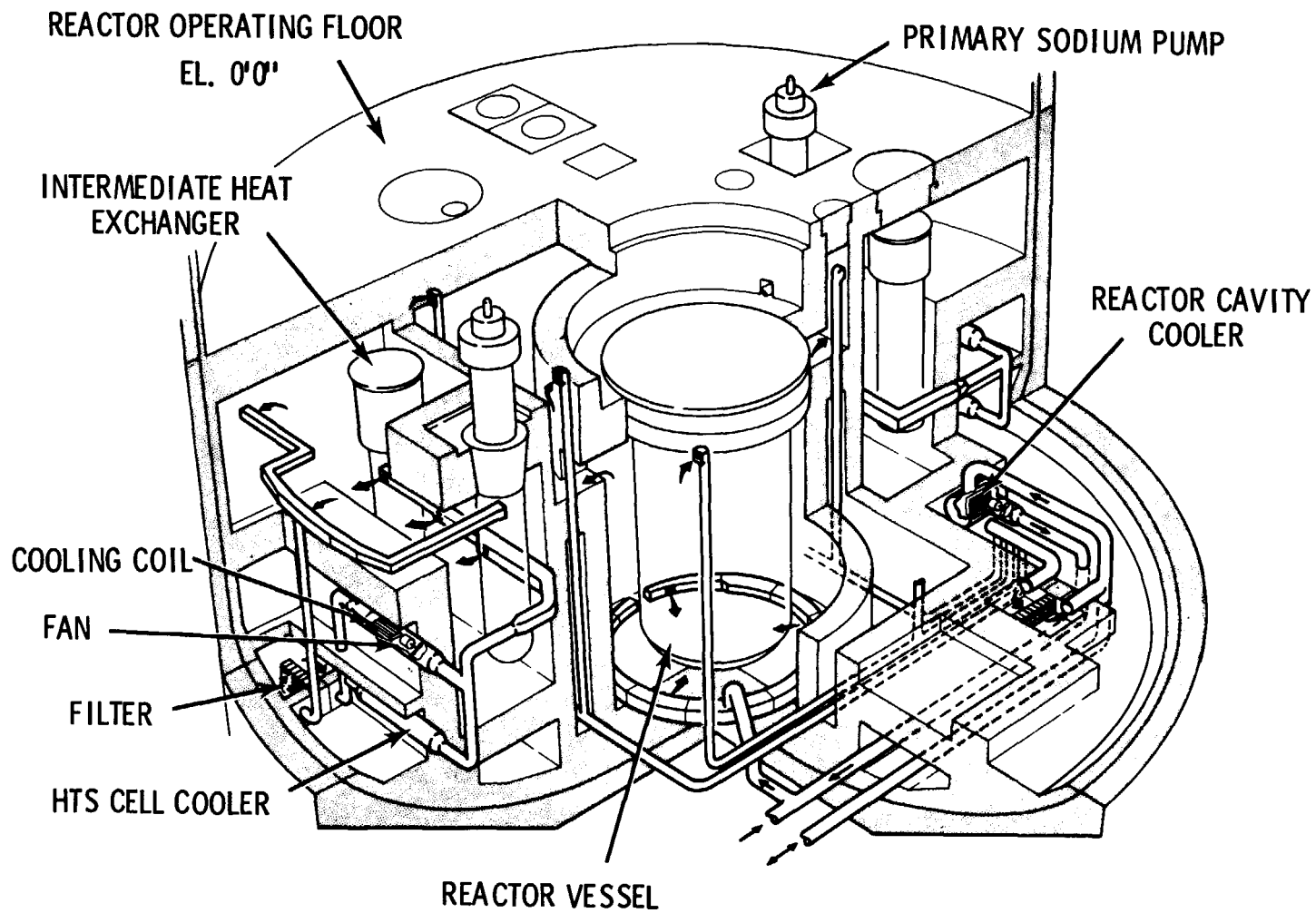6. Cold Trap Cells (two)

7. Miscellaneous Cells (three).

FIGURE 5. Heating & Ventilation Process Equipment Cell Cooling Diagram

REACTOR OPERATING FLOOR
EL. 0'0"

PRIMARY SODIUM PUMP

INTERMEDIATE HEAT
EXCHANGER

REACTOR CAVITY
COOLER

COOLING COIL

FAN

FILTER

HTS CELL COOLER

REACTOR VESSEL

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FIGURE 6. Reactor Cavity and Process Equipment Cells Cooling

The coolers are located outside of the cell served and the entire system consisting of the fans, coils, filters and ductwork is capable of withstanding the design pressure of the connected cell. Isolation valves are provided which permit the operation of either unit.

Similar cooling systems are provided to directly cool components vital to reactor operation. These systems are high pressure and serve the following components.

1. Low Level Flux Monitors (LLFM)

2. Control Rod Drive Mechanism (CRDM)

3. Reactor Vessel Support Ring

4. Reactor Top Head

Each of these systems is also backed up by a 100 percent capacity redundant unit.

Exhaust Systems

Central Exhaust System

A central filtered-exhaust system is provided to handle the exhaust air from the Containment Building and the reactor support facilities outside of containment. The system is made up of two 50 percent capacity filter and fan units which utilize a common ductwork system. The exhaust fans are each equipped with individual control and isolation dampers and the exhaust air is discharged through a 200-foot high stack.

Central Exhaust Filters

The exhaust air is treated by zones on the basis of contamination potential as indicated below:

Zone	Space (Typical)	Exhaust Treatment
I	Containment Vessel	Containment Zone Filtered Exhaust
IA	Inerted Spaces*	Filtered Exhaust
II	Auxiliary Equipment Building (Fuel & Radioactive Waste Handling Areas)	Filtered Exhaust
III	Reactor Service Building (Equipment Spaces, Secondary Sodium Areas)	Unfiltered Exhaust
IV	Engineering Operations Building Central Control Room	Unfiltered Exhaust

* Containment or confinement depending upon location.

The two 50 percent capacity central filter units are located in the Auxiliary Equipment Building. Each filter

unit contains two filter banks in series with space for a
third bank if required. Airtight, pneumatically-operated
closures are provided at the inlet and outlet ends to permit
isolation of the unit.

The filter system, in conjunction with the Radiation
Monitoring System, provides the necessary control over
plant radioactive gaseous effluents such that the total
activity released to the atmosphere does not exceed that
permitted by the AEC. The initial filter bank is made up of
roughing filters followed by standard HEPA filters in the
second bank. The space for the third filter bank is
provided for halogen filters. The roughing filters have been
tentatively selected having a 60 percent NBS efficiency
rating. The choice was based upon review of typical filter life
factors and included the possibility of a sodium fire within
the facility. For this eventuality, the greatest possibility
of a serious fire is within containment which would be
isolated during a fire. Outside of containment, the
possibility of a fire in a portion of the facility which is
exhausted through these filters would be comparatively small,
and dilution of the smoke with other air affords the necessary
plugging protection of the filters. Thus, the medium efficiency
roughing filters are considered adequate for both the life
factor and the sodium fire conditions.

Local Filtered-Exhaust

Inert atmosphere cells (or hoods) which require personnel
access during maintenance operations are provided with local
exhaust filters in series with the central exhaust filters.
These filter units contain roughing filters followed by
HEPA filters. The choice of the roughing filter is being
reviewed based upon individual needs for handling of sodium
smoke.

Also, for the Containment Work Area, the use of a
similar filter arrangement in the recirculating coolers is
proposed to facilitate cleanup of airborne material follow-
ing a fire. The use of portable filtered-exhaust units is
also being considered for this service.

Instruments and Controls

Instruments and controls are provided in support of the
Heating and Ventilation System to monitor and control the
atmospheric condition in FFTF within the limits set by the
system. Parameters include:

- Zone pressure within the buildings

- Differential pressures between designated building zones

- Temperatures within the buildings

- Humidity in specified locations

- Pressure drops across the central exhaust filters
- Airflows to the major zones
- Local control panels.

The radiation levels at key locations in the ventilation system are indicated and out-of-limits alarmed in the Control Room. Monitors are provided as follows:

- Downstream of the HEPA filters at the central exhaust filters
- Background compensated activity monitors at shielded filter locations
- Activity monitor in the stack.

Ventilation System Parameters

The major ventilation system parameters are indicated in Figure 7.

SYSTEM OPERATION

Normal System Operation

During normal operating conditions, all of the central supply and exhaust ventilation equipment is in operation together with the cell recirculating coolers and the reactor component cooling systems. Cooling fluid is supplied from a central system supplied by four large refrigeration chillers, circulating pumps and associated cooling towers. By modulating the cooling fluid to the individual cooling coils, required space temperatures are maintained. Generally, personnel occupied areas are maintained at 80 °F and unoccupied cells are maintained at 100 °F. Variations from these conditions are determined by the individual space requirements.

Humidity levels are controlled by the use of sprayed cooling coils in the central supply systems. Personnel occupied areas are maintained at approximately 50 percent relative humidity by control of the dew point of the supply air.

Spaces provided with redundant cooling equipment are the nitrogen atmosphere cells and the Central Control Room. Continuous operation of these cooling systems is required because of the vital functions performed by those systems. Redundant coolant piping loops are also provided to these systems.

Building Pressure Control

The central supply and exhaust fan radial inlet dampers are modulated to maintain the supply and exhaust system header pressures respectively. From these headers, system mains

A. SUPPLY SYSTEMS

Reactor Containment & Support Buildings   80, 000 cfm (2 Units @ 50%--120 tons each)

Control Center   12, 000 cfm (2 Units @ 100%--25 tons each)

Engineering Operations   40, 000 cfm (1 Unit @ 100%--80 tons each)

Buildings Refrigeration   1000 Tons (4 Units @ 25%)

B. CENTRAL EXHAUST SYSTEM

Central Exhaust System   80, 000 cfm (2 Units @ 50%)

Central Exhaust Filter   80, 000 cfm (2 Units @ 50%)

Unfiltered Exhaust   Misc. Size Units

C. CELL COOLERS (CONTAINMENT)

1. Reactor Cavity   120 Tons* (1 Unit)

2. Heat Transport System Cells (three)   90 Tons (3 Units @ 30 Tons)

3. Closed Loop Cells (two)   60 Tons (2 Units @ 30 Tons)

4. Cold Trap Cells (two)   20 Tons (2 Units @ 10 Tons)

5. Reactor Access Cell   20 Tons (1 Unit)

6. Pipeway (two)   35 Tons (1 Unit @ 10 Tons)
     (1 Unit @ 25 Tons)

7. Fuel and Gas Decay and Sodium Tank Cells   45 Tons (1 Unit @ 25 Tons)
     (2 Units @ 10 Tons)

8. Containment Work Area   125 Tons (5 Units @ 25 Tons)

D. SPACE COOLERS (OUTSIDE CONTAINMENT)

Support Bldg.   45 Tons (3 Units @ 15 Tons)

General Area

E. COMPONENT COOLERS

Control Rod Drive Mechanism   8 1/2 Tons* (1 Unit)

Reactor Top Head   10 Tons (1 Unit)

Reactor Vessel Support Ring   23 Tons (1 Unit)

Flux Monitors   6 Tons (1 Unit)

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* Does not include redundant units.

FIGURE 7. Heating & Ventilation Parameters

serve the various building zones which are provided with individual zone control dampers. The zone pressures are maintained by modulation of these dampers. As indicated on page 10, the containment building is maintained at (-)0.50 inches water gage pressure.

To assure that the entire facility is operated from a common pressure base, an atmospheric reference system is provided for the Heating and Ventilation System which is also used by the Inert Gas System for control of the nitrogen atmosphere cell pressures. These cells are maintained slightly positive relative to the adjacent air spaces to prevent infiltration of oxygen into the cells. Positive pressures are in the range of 0.12 to 0.25 inches water gage.

The exhaust fans have sufficient capacity to allow for pressure buildup of the central exhaust filters to approximately 5 inches water gage and still maintain control of building pressures.

Abnormal Operating Conditions

The ventilation systems must accommodate various modes of failure and accident conditions and still perform required ventilation and cooling functions. Except for potential accident conditions which are discussed in the next section, failure and special conditions to which the system must respond are:

a.   Electrical power failure

b.   Component failure

c.   Air purge.

a.   Electrical Power Failure

Ventilation cooling must be performed in some areas even during periods of electrical power failure. An investigation was made of spaces considered to be vital to the reactor safety and plant protection to establish the electrical loads applicable to the emergency diesel generator system.

A detailed analysis of transient cooling loads for an earlier building arrangement indicated that there are very few areas which require cooling during this period and these areas are noted to be ones in which large amounts of process heat are stored. During this period, there is a major step reduction in lighting and other electrical loads, and the major cooling loads result from the decay energy of this stored heat.

The cooling concept for the reactor cavity, the HTS cells and the other inert spaces and cells is that provided by recirculating coolers with no other type of cooling provided. In order to check the conditions in the cells during an electrical power failure, an analysis of the transient cooling loads in a selected cell was made.

For this analysis, it should be noted that the emergency electrical system is supplied from two emergency-diesel generators and vital ventilation equipment loads are split between the two generators. One chiller is connected to each generator. Since a remote possibility exists that only one of the two generators may start, an analysis was made to determine if sufficient cooling could be provided by only one chiller to maintain safe cell temperature conditions. This analysis was recently completed by Bechtel. The electrical ventilation equipment loads applicable to this case were:

System	Operating Condition
1. Central Containment Supply	Both units off
2. Central Filtered Exhaust	One exhaust fan off One at 3/4 speed
3. Containment Work Area Coolers	Off
4. Inert Cell Coolers	All at 3/4 speed
5. All other supply and exhaust systems	Off
6. Central Chillers	One operating Three off

The analysis for the HTS Cell for the above conditions indicated that the rate of rise in cell temperature was not significant, so a case was run with no cooling provided. For this case, which is considered to be the most severe case, the calculated cell temperature after 3 hours was approximately 200 °F. Since the maximum allowable limiting temperature of 250 °F was not exceeded, it was concluded that the planned emergency electrical system was adequate.

b. Component Failure

Since all of the central supply and exhaust ventilation equipment will normally be in use, a component failure, such as a major supply fan, requires that a matching exhaust fan be shut down. The system design provides this capability without upsetting the system balance, but it may require curtailment of operations in the affected areas until repairs can be made. Redundant cooling units are provided for vital cooling loads and thus operations will not be affected by a component failure in these locations.

c. Air Purge

A special operation which is required during periods of personnel access into normally inert cells is air purging of the cell. This capability is provided in the ventilation system through the use of valved cell air inlet and exhaust connections. The exhaust is routed via local filters through the central filtered exhaust system to the stack.

Accident Conditions

The ventilation system must accommodate certain potential accidents and still perform required ventilation and cooling functions. Accident conditions to which the system must respond are:

a. Ventilation Containment

b. Sodium Fires

c. Design Basis Accident.

a. Ventilation Containment

The passive design features of the containment system in conjunction with the control exercised over the ventilation exhaust, prevent the release of unacceptable quantities of radionuclides to the environment. Signals provided to the containment system perform two functions as follows:

- Isolate the outer containment barrier in the event of high radioactivity in containment exhaust coincident with pressure

- Isolate the ventilation system for the outer containment area in the event of high radioactivity in the containment exhaust.

The main exhaust stack is monitored for alpha and beta-gamma airborne particulates and radioactive gases. Alarm signals from these stack monitors are provided to actuate control valves to divert the radioactive gases from the inert gas system into decay storage tanks.

Three airborne particulate monitors and three gas monitors continuously sample the effluent from the containment zone. Alarm signals from these monitors are routed to the Plant Protection System to actuate the containment valves which results in ventilation containment. During this period, all ventilation supply and exhaust systems continue to operate to maintain normal building zone pressures outside of containment. All recirculating coolers both inside and outside of containment continue to operate to maintain normal cell conditions.

b. Sodium Fires

Sodium fires are a potential threat to the operation
of the FFTF. To minimize this potential, all of the spaces
containing primary sodium are maintained in an inert atmos-
phere and are located inside containment. These systems are
radioactive and the oxygen levels in the spaces are controlled
to approximately one percent. Thus, if a fire should occur,
the extent of damage is limited and the effects can be
contained. Recirculating atmosphere cooling systems are
provided for these spaces which contain filters; thus filter
plugging is a potential problem.

Secondary sodium containing areas are located outside
of containment in an air atmosphere. These systems are
nonradioactive and there are no filters in the exhaust;
filter plugging is therefore not a problem.

1. Small Sodium Spills. Small sodium spills in inert
spaces result in pool surface reactions and there is
comparatively little heat generated from the sodium
reaction. Also the amount of sodium oxide produced is
limited by the one percent oxygen present. For example,
a large primary Heat Transport Cell contains approximately
20,000 cubic feet and the one percent oxygen condition
at 100 °F results in approximately 40 lb of sodium
oxide.

The atmosphere cooling system capacity for this cell
is 10,000 cfm and contains 10 filters. Also, it has
been observed from A-I test work and that of others,
that approximately 50 percent of the oxide can be
considered to plate out on walls and other surfaces.
This leaves approximately 20 lb of sodium oxide to which
the filters are exposed and a net loading of approximately
two pounds per filter. This particulate loading can be
readily accommodated by conventional filters and filter
plugging is therefore not considered to be a serious
problem as a result of small sodium fires.

2. Major Sodium Spill. A major sodium spill in a cell
is a potential accident from which recovery must be
made. One of the calculated spills in an HTS cell
involves the release of approximately 75 tons of sodium
on the floor of the cell. The conditions following the
spill result in pool surface reactions and the conversion
of the oxygen to sodium oxide and the atmosphere
saturated with sodium vapor. It should be noted that
the amount of sodium oxide generated in a large spill
is the same as that generated in a small spill.
However, during a major spill, the cell pressure and
temperature conditions slowly build up and the atmosphere
becomes saturated with sodium vapor.

For the HTS cell spill, the temperature builds up from 100 °F to a peak of 340 °F in approximately 2 1/2 hours at a corresponding pressure of 6.10 psig. By operation of the coolers during this period, the peak temperature can be reduced to 300 °F at a pressure of 5.10 psig. The considerations necessary to permit operation of the coolers during this period are being reviewed and the requirements are discussed in the following paragraph.

c. Design Basis Accident (May 1970)

The design basis accident (DBA) is a 350 MW - second reactor core disassembly accident under postulated conditions. Details of the accident pertinent to the Heating and Ventilation System are to note that the accident results in the spill of approximately 18,000 lb of sodium into the reactor cavity and 82,500 lb of sodium into each of two of the three HTS cells. (The third HTS loop remains intact.)

The reactor cavity pressure and temperature conditions following a DBA are shown in Figures 8 and 9. As can be observed the cell pressure and temperature conditions build up very rapidly and the transient maximum pressure is approximately 25 psig and the instantaneous temperature is over 1000 °F. Following the accident, the atmosphere cools very quickly by heat loss to the walls and other surfaces. As noted from the curves after 3 minutes, the cell conditions are fairly well stabilized at approximately 300 °F and 5 psig pressure, following the high pressure and temperature transient conditions.

The cell cooling system must be able to withstand the above conditions and the requirements necessary for them to continue to operate and provide cooling are discussed below.

1. From a design standpoint, a transient design pressure of 35 psig must be accommodated by the cooling system. Pressure containing ductwork and enclosed components are planned in conjunction with tight closures for isolation of the redundant system.

2. The high transient temperatures last only a few minutes and then stabilize at approximately 300 °F. This temperature is not significantly above nominally attainable component ratings and should not present a serious problem.

3. As discussed under small sodium spills, the filters in the system can accommodate the amount of sodium oxide particulate loading without plugging, but the filters and the rest of the system will also be exposed to the saturated sodium vapor conditions at the coincidental pressure and temperatures indicated in the figures.
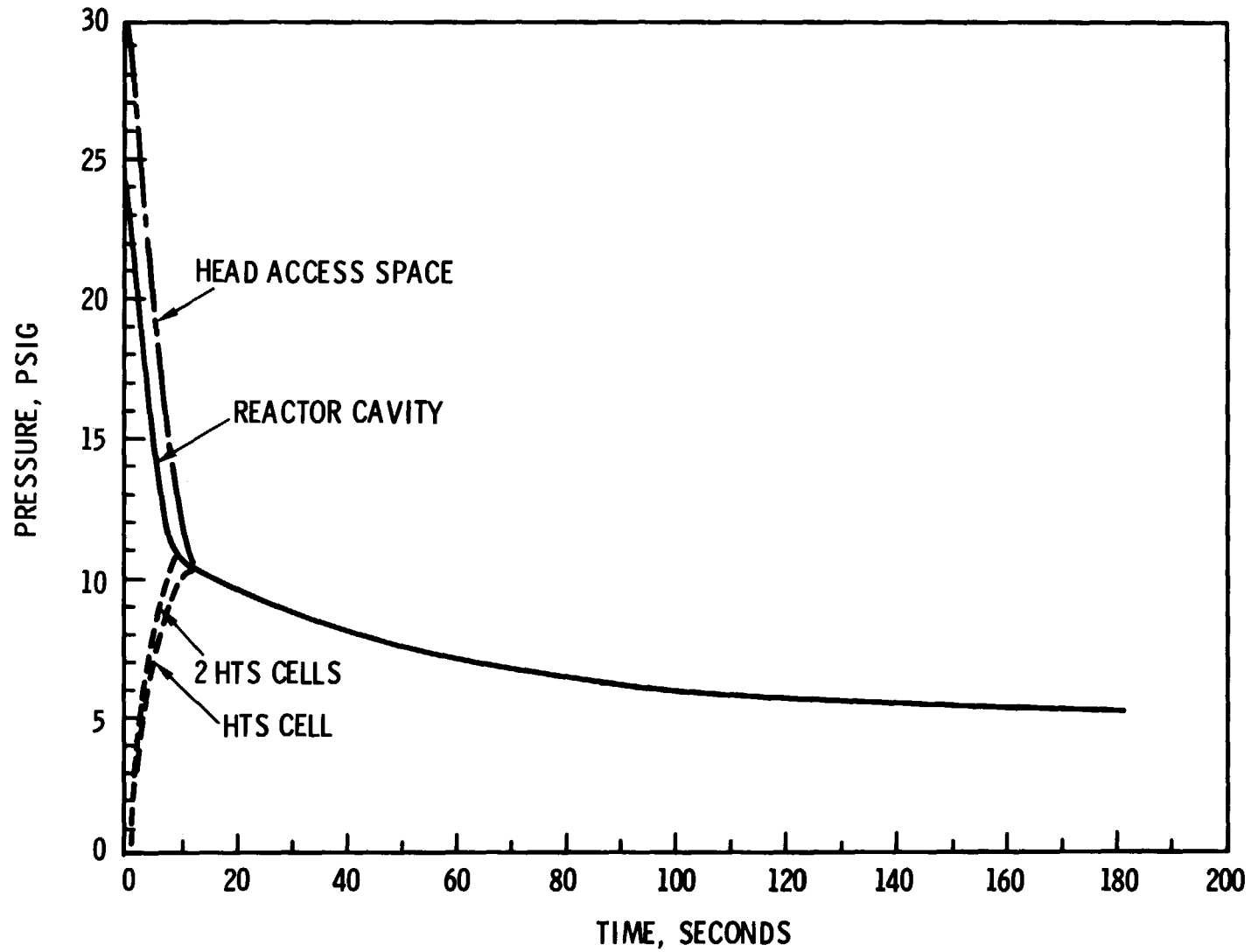
-339-

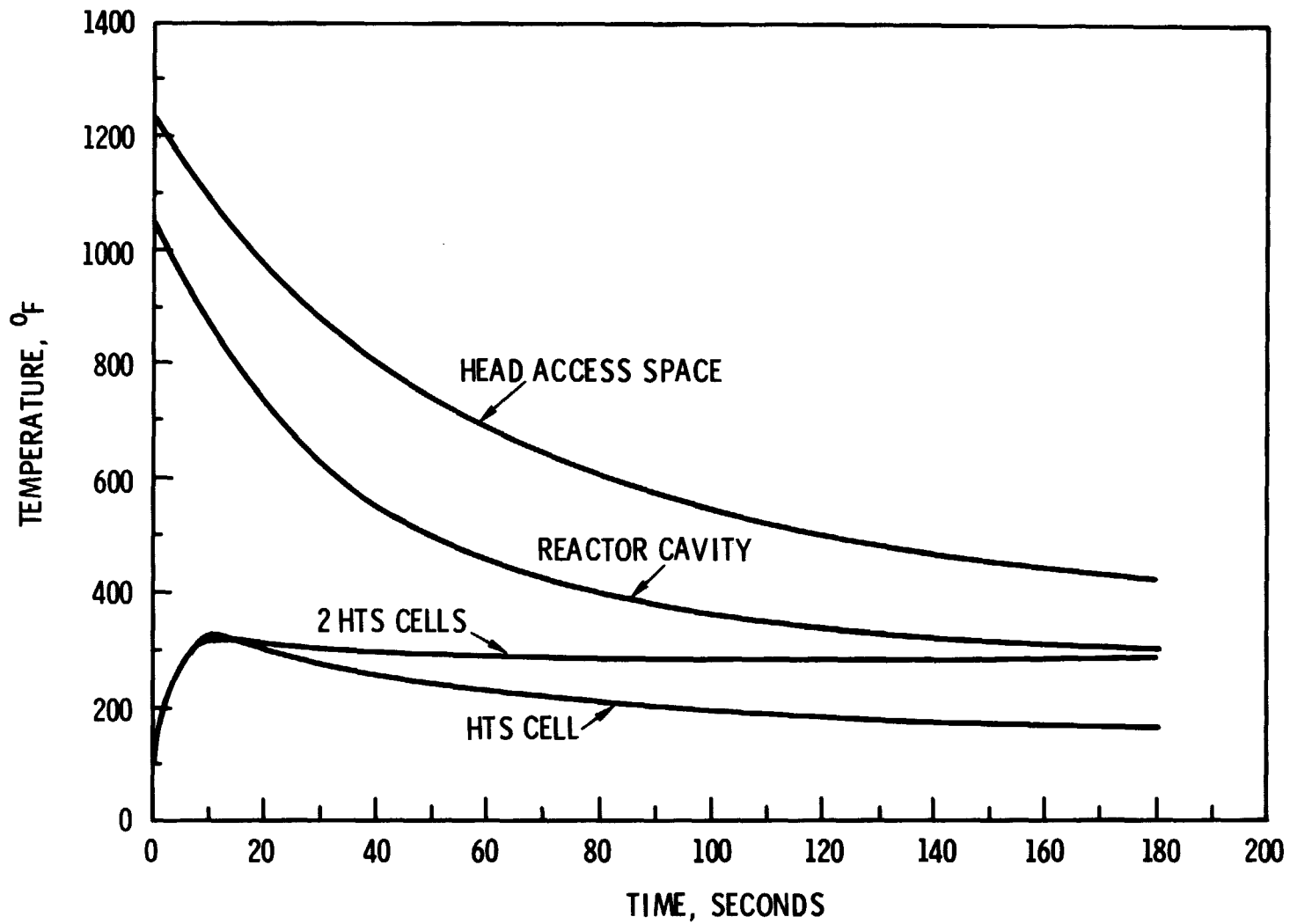FIGURE 8. Pressure Transient (Inerted Equipment Spaces)

FIGURE 9. Temperature Transient (Inerted Equipment Spaces)

4. The cooling function of the system is performed by means of a conventional finned coil which utilizes a cooling fluid circulating at a nominal 60 °F to maintain a normal cell atmosphere temperature of 100 °F. During the accident condition when saturated sodium vapor is present in the atmosphere, the sodium vapor will condense on the cooling coil and other cold surfaces and may present a plugging problem. Analysis of this vapor condition and its impact on the system requirements is beyond present design capability to predict.

For the current containment concept, the HTS cells and reactor cavity cooling systems are considered as reactor safeguard items. The system capability must therefore be verified to the required degree of reliability by proto-typical testing or other means. Bechtel is currently preparing the required development program for this effort, and based upon the results of this investigation, the feasibility of using the cell coolers in support of the containment system will be established.

DISCUSSION

DYMENT: Could you say please Mr. Shaver what type roughing filters are you intending to install on the main exhaust system?

SHAVER: Well we, for the central exhaust, are thinking in terms of 60% NBS efficiency roughing testing filter. The point there being that we have a high dilution factor. In other words, where we have a local fire that ratio to ventilation exhaust, in terms of full capacity, represents a minimal plugging potential. In this application we are thinking in terms of approximately 60% efficiency ruffing filters.

ALVAREZ: I have a statement related to the environment of the components. You didn't mention what would be the temperature and relative humidity of the system operating during normal full power operation.

SHAVER: Yes. I have glossed over this. Specifically, personnel occupied areas are maintained at 80° at approximately 50% relative humidity. All of the nitrogen atmosphere cells, the reactor cavity, and the HTS cells and closed loop cells are maintained at 100°F. And this of course being nitrogen, 1% oxygen.

ALVAREZ: My question is related to the accessability of the cooling equipment. Are you planning to have accessability to this equipment at full power, or do you have to bring the plant to a shutdown?

SHAVER: As I indicated all of the equipment is located outside of the specific cells served. From the standpoint of the radiation levels in the cells any cell equipment won't be accessable. Potentially, in a few cases, there might be radiation levels outside the cells that will restrict the working time of people, but the fact that we do have a 100% redundant system allows the capability of equipment shutdown and then to go in and change filters.

ALVAREZ: Finally, you mentioned that fact that you are maintaining the containment at a negative pressure at all times. Does this mean that you are operating the purge system constantly or does it mean that by sub-cooling you are maintaining a negative pressure?

SHAVER: Under normal conditions we are maintaining the containment vessel at slightly negative pressure, approximately a half inch water. And of course under accident conditions, this is a different story. But it is maintained by control of the dampers on the ventilation system.

ALVAREZ: In other words you are purging at full power,
constantly.

SHAVER: Well, what I was speaking of was an air atmosphere
space, such as the work area.

ALVAREZ: And that's the area you are purging constantly.

SHAVER: Right.

ALVAREZ: And you do not expect any leakage from the other
compartments into the area at full power?

SHAVER: This will be a controlled situation. First of all,
the design of the cell with the liner allows us to maintain atmospheric
security in those cells and because of that design, would limit any leakage.
So we expect essentially no leakage of those cells into the air atmosphere,
which is maintained negative to the outside air.

HIRSCH: Can you tell me, sir, regarding those areas where
you intend to have a nitrogen atmosphere how do you intend to control the
humidity?

SHAVER: It's a feed and bleed system. It is strictly on an
input-output.

BEATTIE: As I understand it, your containment system is
vented during normal operation. You keep the pressure negative. Pre-
sumably when you have an accident you have to shut the venting system off
quick. Can you tell me what your figure of reliability is for shutting off
the venting system in this accident situation.

SHAVER: 100%.

BEATTIE: Could I reply, that I don't believe that this is
possible in practice.

SHAVER: Speaking probably in this sense, I don't know
whether the question time for tripping of the containment is your direct
question. In the exhaust stream in the containment vessel, we have three
separate particulates and activity monitors which in the event of anything
being released from the containment, the ventilation system is automatically
closed off, and the containment system isolated. The timing, of course,
depends entirely upon sensitivity and settings of those instruments.

BEATTIE: Briefly in reply, in former times it was the popular pastime to twist the lion's tail so I'm really tweaking the giant eagle's tail just a little bit. You don't mind? I agree that your shut off system will have a high reliability, I'm sure. I'm making the point that it cannot be 100%, it might be 99.9%, but there is still a chance that it might be even lower.

CHARACTERIZATION OF ENERGY RELEASE AND AEROSOL BEHAVIOR FROM SODIUM SPRAY FIRES*

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ABSTRACT

In liquid metal cooled reactors, there remains the remote possibility of sodium leakage into environments containing oxygen. In the case of a spray discharge, a significant energy release can result. Concurrent with these "fires" is the formation of an aerosol which contains radio-active substances. A knowledge of the aerosol characteristics, the energy release, and the resultant leaked mass is required for effective safe-guards analysis and design. Previous work in the area of spray fire has neglected the chemical nature of the reaction products, and the geometry and dispersion of the spray.

An experimental setup is described for measuring the rate of sodium injected from different sized jets into variable oxygen environments. As the sodium is injected, measurements of oxygen consumption, pressure rise, and gas and wall temperature changes are made, all as a function of time. Measurements of the aerosol concentration, chemical form, fallout rate, and particle size distributions are made after the injected sodium has burned.

Experimental results verify that pressure pulses resulting from a spray fire may be significant, but are probably much lower than presently assumed.

Agglomeration of the sodium oxide was found to be rapid, and an aerosol distribution of large particles forms within seconds of formation. The factors controlling the rapid agglomeration of the oxide are discussed.

I. INTRODUCTION

A knowledge of potential contaminant release to the environment is an essential part of reactor siting and hazard evaluations for a Liquid Metal Fast Breeder Reactor (LMFBR). The energy release from a sodium-oxygen fire, and the attendant containment pressure rise, be-comes the driving force for leakage of sodium oxide and other aerosols to the environment. This paper describes experimental work being per-formed at Atomics International to further define the parameters and limits of sodium spray fires, and resultant oxide aerosol behavior.

II. SODIUM OXIDATION CONSIDERATIONS

The oxidation of sodium metal appears to be limited mainly by mass transfer of reactants and products, since the reaction occurs at room temperature as rapidly as clean sodium surfaces are exposed (i.e., no large activation energy). Both solid and low-temperature-liquid sodium - oxygen reactions are impeded by an oxide layer which rapidly forms to shield the reaction interface. The large free energy of formation of the oxide strongly favors rapid reactions, also. As the temperature of the sodium surface increases, the vapor pressure of sodium also increases, creating a corresponding metallic vapor region, which is capable of instantaneous reaction and of creating a hot surface. It is this hot vapor-oxygen interface which emits the characteristics light or flame of a sodium fire.

In the case of a spray fire, the liquid surface is a droplet surface preceded by a metallic vapor film. Reaction occurs as rapidly as oxygen can be brought to the film, or as rapidly as evaporated sodium can find free oxygen. If the reaction does not occur very close to the droplet surface, the droplet cools by evaporation, convection, and radiation until its vapor pressure is negligible, with a corresponding decrease in reaction rate. The droplet, and its contribution to the fire, is then quenched. Since evaporation and convection are both surface-controlled phenomena, one would expect droplet size to have a pronounced effect on the burning rate.

There are two potential limits to the sodium burning rate, one being the rate at which forced convection and film diffusion for the sphere can provide oxygen within the spray volume, and the other being the rate at which free convection can bring oxygen to the area bounded by the spray volume. For fires involving large amounts of sodium, the latter rate will probably control, unless the spray impinges on a nearby surface and disperses extensively. The tests presently discussed in this paper more nearly simulate the former case, however, so that an upper limit to the burning rate can be established.

III. EXPERIMENTAL APPARATUS AND PROCEDURE

The experimental apparatus used for the spray fire investigations is composed of a spray chamber, spray pot, spray injection systems, oxygen analysis system, recording system, and programmer.

The spray chamber is a 2-ft diameter by 10-ft high vessel,[*] with penetrations for sampling and instrumentation at five different heights. Measurements are obtained for pressure, oxygen, and temperature as a function of time.

A spray pot is rack mounted outside the vessel, and is remotely filled to the desired level with molten sodium (up to 200 gm, 1/4 gm accuracy), prior to pressurizing and spraying. During the spray, the gas in the spray pot is held at a constant pressure above the vessel atmosphere, such that the spray velocity is sustained throughout the injection period.

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*Referred to as the Spray Test Vessel (STV)

The spray injection system is composed of four insulated, resistance-heated injection lines which enter the spray chamber through the base plate, four nozzles, a remotely operated pneumatic valve, and a manual valve. Molten sodium is injected into the chamber through one line only. In this manner, four experiments can be performed, prior to opening the chamber and changing nozzles.

The oxygen analysis system is composed of a filter, cooling line for constant temperature, constant pressure device, analyzer, and recorder.

An F. M. tape system is used to record the drive pressure, vessel pressure, spray zone air temperautre, chamber wall surface temperature (internal and external) with 0.1 °F resolution, and oxygen concentration, all as a function of time. The data are later plotted on an X-Y recorder.

A programming module, using punched tape, controls the initiation and termination of the spray fire and all actuation functions.

The various steps in the test procedure include adjustment of each signal amplifier to an expected signal, calibration of all sensing devices, adjustment of oxygen/nitrogen ratio in chamber, transfer of the desired quantity of sodium to the spray pot, purging of sodium injection lines, adjustment of controller to the desired initial pressure and temperature, and starting the programmer.

IV. EXPERIMENTAL RESULTS AND DISCUSSION

Spray Burning

One of the important observations made during these tests is that, in all cases, the major reaction product of the spray fire was sodium peroxide (Na_2O_2), which is contrary to the assumptions employed in most accident analyses currently being performed. Two assumptions may be made from this, and the knowledge that sodium peroxide is unstable at temperatures >1600 to 1700°F. One assumption is that the temperature of reaction is very low; but this is hardly likely, since the burning droplet does emit a flame characteristic of high temperatures. The other assumption is that sodium monoxide is formed close to the droplet, but then is converted to peroxide in the cooler region surrounding the burning zone.

The pressure history trace (Figure 1) shows the nonadiabatic nature of the test vessel, which has a thermal time constant of ~10 sec for these conditions. This thermal loss is indicative of free or mildly forced convection, caused by an overall heat transfer coefficient of ~2.8 Btu/hr-ft^2-°F. The data in Table 1 include a computation of the potential pressure for an adiabatic system.

One also notices, from Figure 1, that the pressure rise ceases at the termination of the spray injection period. The massive, upper vessel head freezes and binds all of the sodium which reaches it.
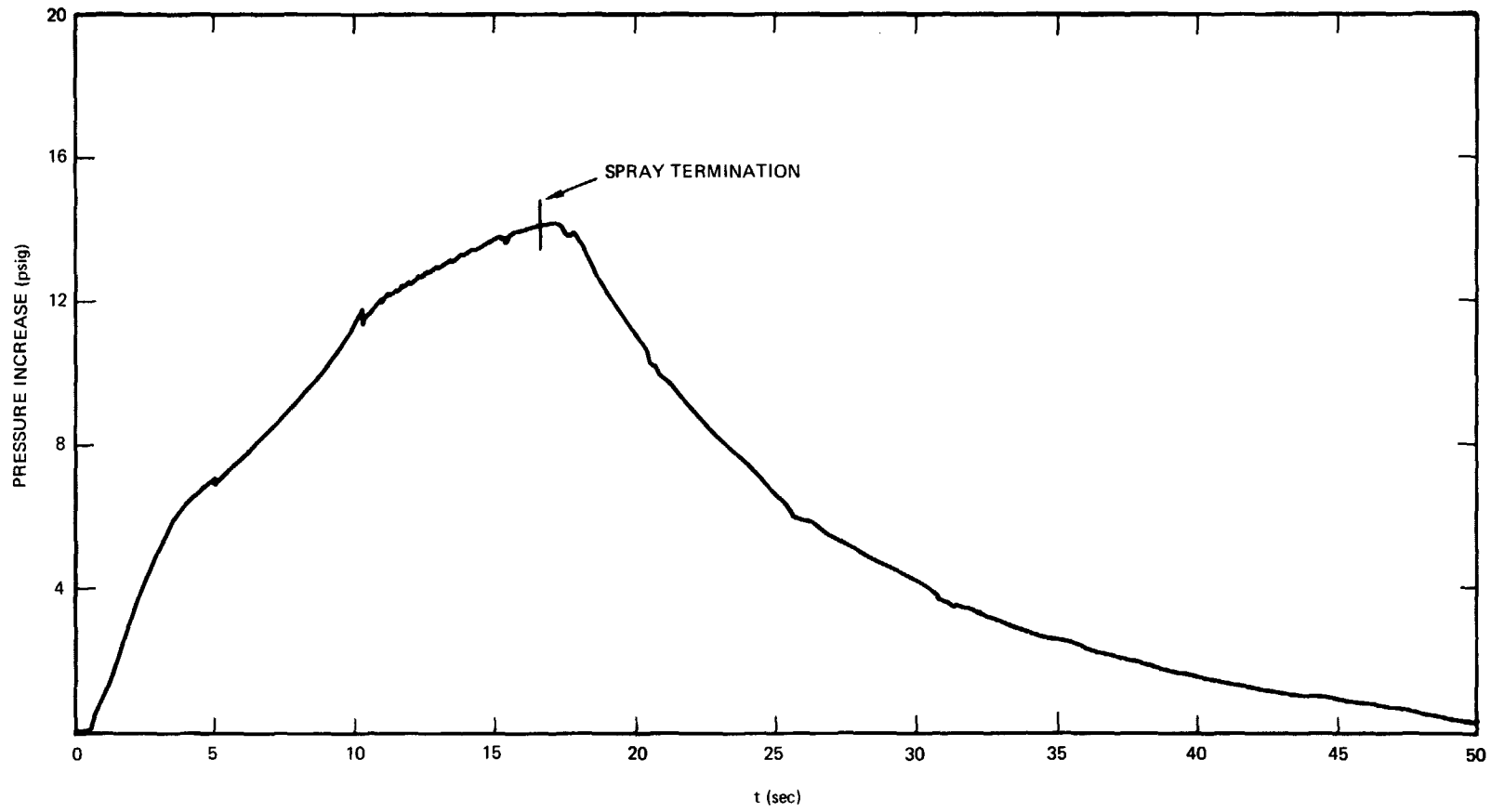
Figure 1.   Pressure History of Spray Fire

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TABLE 1

SPRAY TEST VESSEL – SPRAY FIRE SUMMARY

Spray Test No.*	Oxygen in Vessel (%)	Sodium Sprayed During Fire (gm)	Sodium Consumed During Fire (gm)	Sodium (Consumed/ Sprayed)	Moles of Sodium Ejected/ Moles O_2	Sodium Reacted as Monoxide (%)	Observed $\Delta P/\%$ O_2, (psig)	Oxygen Used During Spray (%)	Spray Temperature in Flame Zone (°F)	Spray Period (sec)	Initial Dew Point (°F)	Nozzle Type (mils)	Sodium Spray (gm/sec)	Sodium Consumed (gm/sec)	Initial Vessel Pressure, P_i (psia)	Measured Maximum Pressure ΔP (psig)	Computed Adiabatic Pressure, P_{ad} (psig)
7	21	78.0	31.3	0.407	0.438	30	13.6	1.17	1300	7.0	~23	Swirl Full Cone (65)	11	4.5	17.7	15.9	25.7
9	2	100.8	36.3	0.360	5.95	0	11.3	2.03	952	4.6	~45	Swirl (65)	21.6	7.9	16.2	22.9	34.0
10	2	68	22	0.350	9.95	-	10.9	1.18	827	4.5	High	Swirl (65)	15.0	4.9	17.7	17.0	27.5
11	2	166	2	0.012	6.31	-	68.5	0.090	454	10.2	8	Swirl Full Cone (65)	16.3	0.2	17.6	6.17	~8
Series 1																	
AH	21	130	55	0.421	0.542	25	6.45	~2.2	950	16.5	43	28-mil jet	7.9	3.35	19.7	14.2	34.4
AL	21	181	52	0.290	0.756	0	4.30	2.7	760	27.5	-28	28-mil jet	6.9	1.91	19.7	11.6	39.5

*In all tests the initial temperature of the sodium was 1000°F and the spray pressure was ~50 psig.

Six sodium spray fires are described in this paper. Four were performed with the original instrumentation, using a full cone spray in 21 and 2% oxygen environments. The remaining two were straight jet sprays, in 21% oxygen atmospheres and controlled humidities. Table 1 allows a parameter intercomparison of the fires conducted this year. Some direct observations are that humidity has a pronounced, perhaps catalytic, effect on the burning rate of sodium. Fires in 2% O_2 appear most affected (compare Tests 10 and 11) by humidity.

Figure 2 shows air temperature - time data, characteristic of a spray fire in which the rapid increase of temperature near the end of spray time is caused by atomization of the sodium, caused when excess N_2 was allowed to exist in the spray chamber (solenoid failure).

A spray droplet size distribution was obtained from Test 11, and is shown in Figure 3, the mean size being 240 μ in diameter. A calculation, using this distribution for Tests 9 and 10, provides a burning rate similar to that which forced convection of oxygen to a sphere would predict.

Aerosol Behavior

High gas temperatures, which result from the high burning rates in a relatively small volume, cause rapid aerosol growth during spray fires. Turbulence and Brownian motion causes the particle to reach nearly a maximum size within seconds after its production in the chamber (Figure 4). By the time the particles are sampled (<5 sec after the spray ceases), the aerodynamic diameter has grown to a size of 5 μ.

Figure 4 shows both the aerosol concentration and the aerodynamic diameter of the sodium oxide, as a function of time, for the last series of tests. Test B is unique, because a blocked nozzle released only 2.4 gm of sodium, which oxidized and settled in a somewhat tranquil environment. One immediately notices the small initial particle size, which is not characteristic of previous spray fires. Brownian agglomeration, and a high concentration in a relatively small volume, is the probable mechanism creating the characteristically large particles observed in Test 1 AL; and, as such, must be modeled by the agglomeration studies.

The initial fallout half-time ($T_{1/2}$) of Test 1 AL is <1-1/2 min, and is typical for the latter series of STV fires. As mentioned previously, the aerosol composition is primarily sodium peroxide, but with a density considerably reduced from ideal; however, the rapid fallout does indicate a high aerosol growth rate.

The large initial droplet size (340 μ), compared to the mean aerosol particle size ($\sim 2\ \mu$), allows one to infer also that the reaction of sodium and oxygen at the droplet surface releases small particles, near molecular size, which then must grow to the initial sizes which are observed.
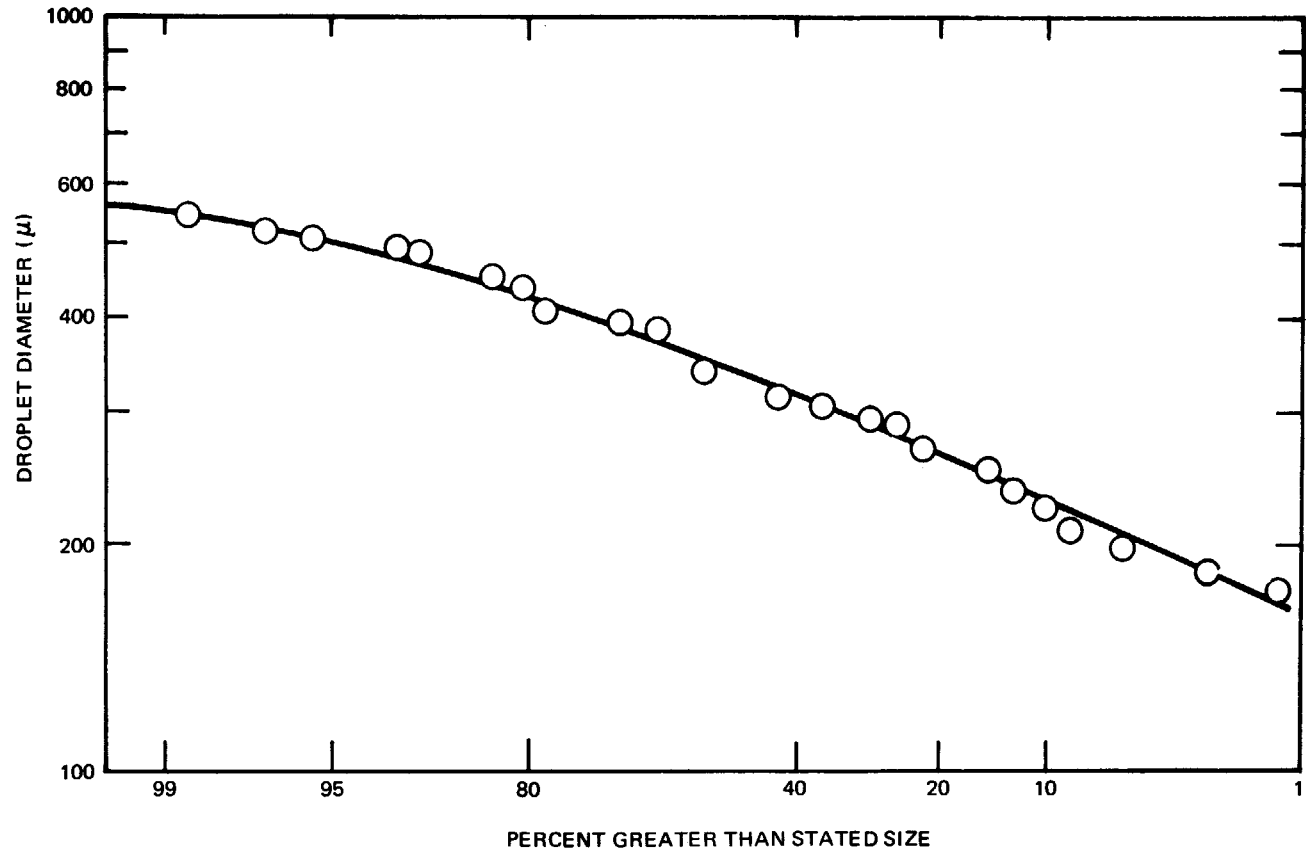
V. CONCLUSIONS

The results of the spray burning experiments conducted thus far indicate that limiting assumptions previously employed in predictions of pressure rise from a spray fire can probably be modified. In the case
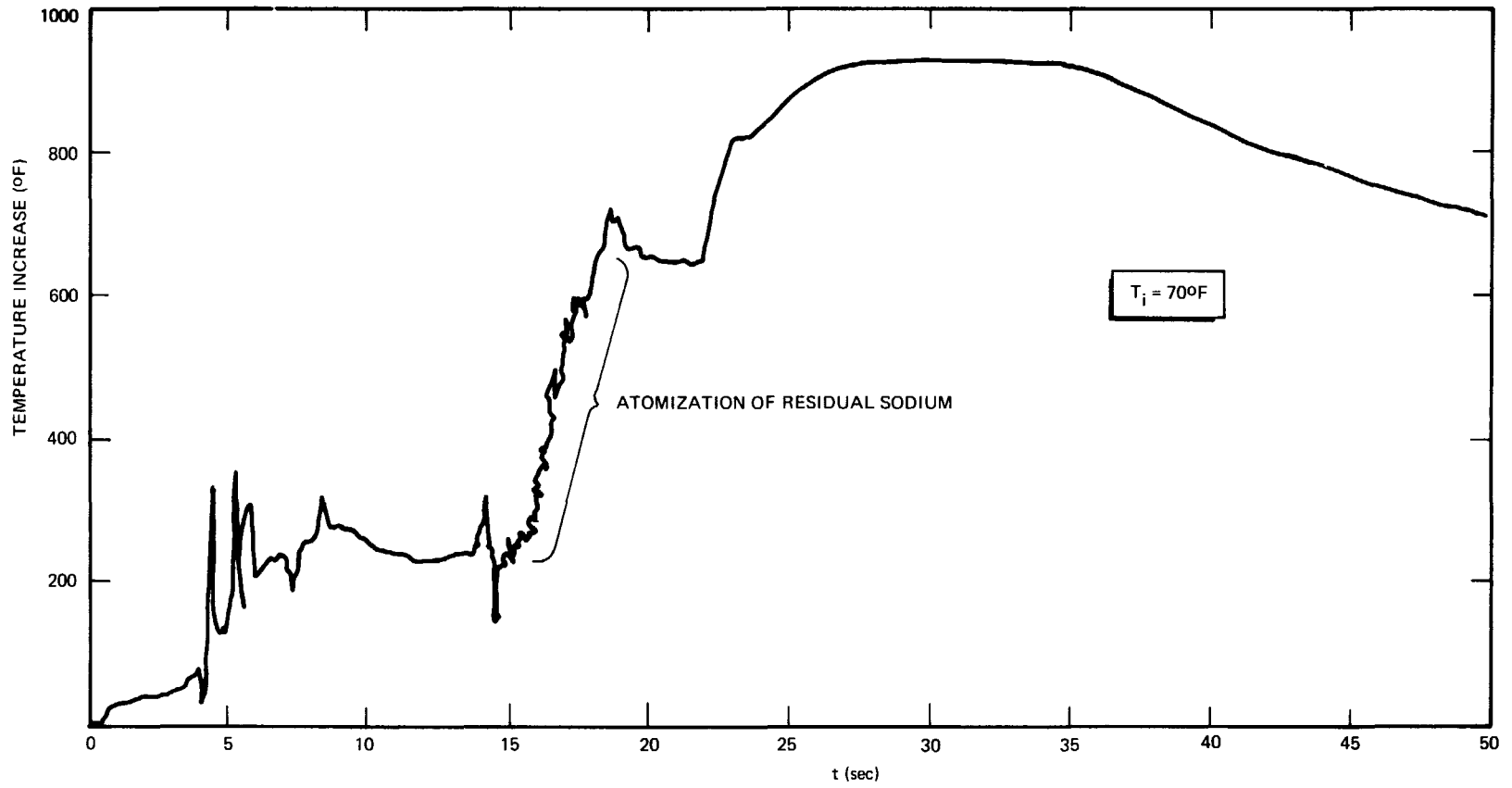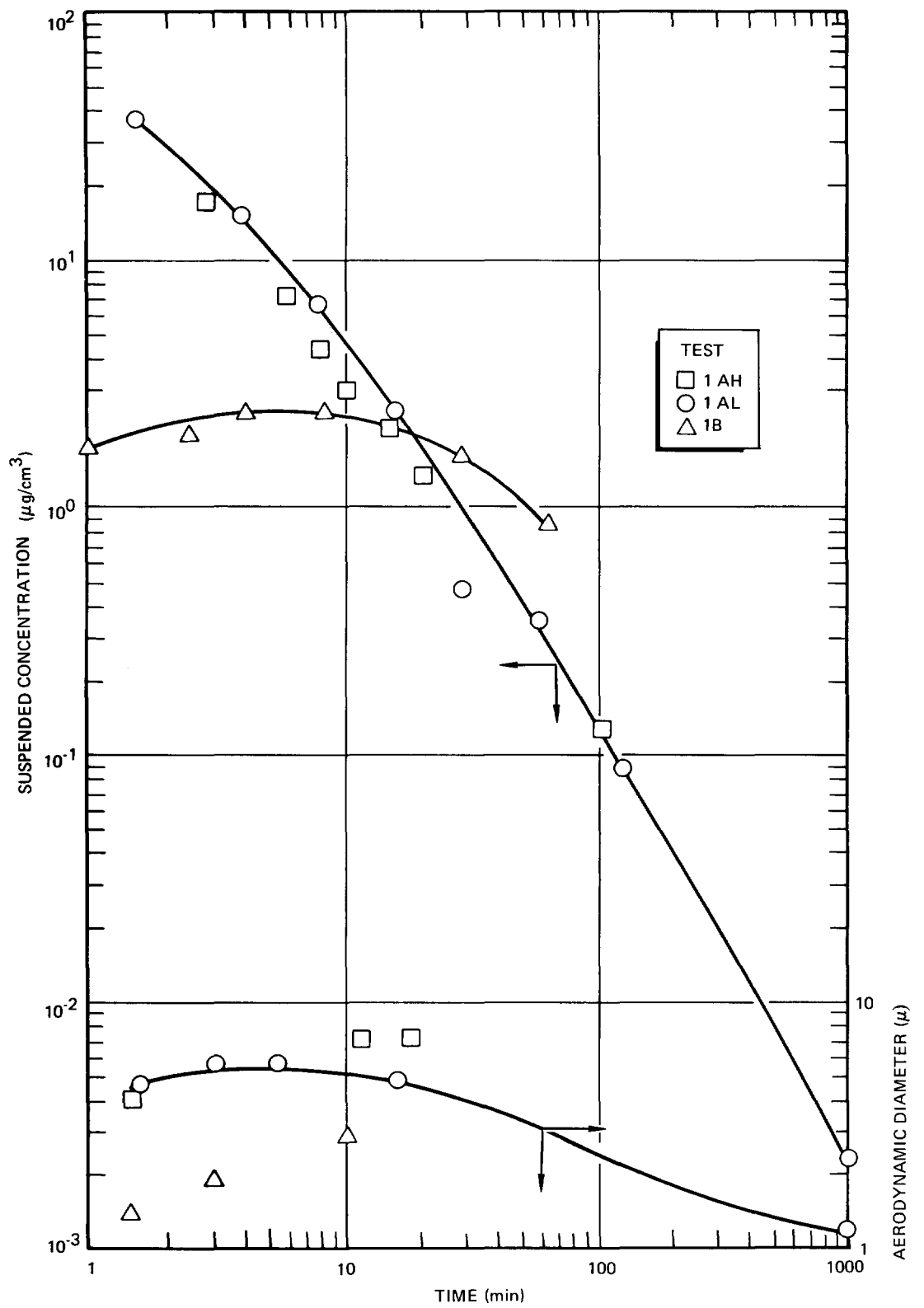
Figure 2. Air Temperature Following Spray

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Figure 3.   Droplet Size Distribution of Spray

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Figure 4. Suspended Mass Concentration vs Time

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of low-oxygen environments, preferential formation of sodium peroxide, instead of the assumed monoxide, will contribute to a lower pressure rise. In any oxygen environment, the rate or degree of burning appears to be controlled by gaseous reactant transport, which is slow, compared to the typical airborne time of realistic sprays. Appropriate utilization of this information, in conjunction with geometry considerations, will result in lower pressures, by modifying the assumption that the entire sodium spray burns to completion. Preliminary results, requiring further substantiation, on the possible importance of humidity can also contribute to reduced spray fire consequences.

The data obtained on aerosol behavior following a spray fire have shown that agglomeration, growth, and hence fallout of the airborne combustion products, is more rapid, when compared with aerosols generated during pool fires.

Utilization of such data in LMFBR safeguards evaluations will result in a significant reduction in the leakage of contaminants released during postulated accidents involving spray burning.

DISCUSSION

CLOUGH: I was interested to see your picture of the sodium aerosol which you have collected and then exposed to the atmosphere. I think that sodium carbonate should be formed eventually and if that happens then the liquid mass which is formed should dry out I think at relative humidity less than about 90%. I wonder if you noticed whether in fact this happens?

GRANGER: This happens after two or three days, in our case, at room atmosphere.

BEHAVIOR OF IODINE IN SODIUM SYSTEMS

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ABSTRACT

Knowledge of the behavior of fission product iodine in a sodium or sodium compound environment is important in evaluating the potential hazards from both normal operations and accident conditions in a sodium-cooled breeder reactor system.

The evolution of radioiodine ^{131}I from a sodium peroxide system as a function of time, temperature, and carrier gas (nitrogen) flow rate was studied. Virtually no iodine was volatilized at 250°C, and a very small amount, of the order of 10^{-3}% per hour, at 630°C. Substantially greater amounts of iodine were volatilized at 725°C and 830°C. The data are consistent with the hypothesis that the mechanism of transfer is distillation of sodium iodide, and that elemental iodine is not produced in this system.

The detection method was gamma counting of radioiodine absorbed in bubblers containing sodium hydroxide-sodium thiosulfate solutions. The collection efficiency of a single bubbler was found to be about 98%, and 0.003 µCi could be detected easily in a one-minute count. When 30 µCi was used in a run, therefore, a transfer of 0.01% could be measured.

Preliminary investigations of the uptake of iodine in nitrogen from molten sodium were made. These studies are needed to predict the movement of fission product iodine from cladding breaks or from vented fuel elements.

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INTRODUCTION

Knowledge of the behavior of fission product iodine in a sodium or sodium compound environment is important in evaluating the potential hazards associated with liquid metal fast breeder reactor (LMFBR) operations under both normal and accident conditions. Consideration of the chemistry of iodine leads to the expectations that (1) sodium iodide in the coolant will remain nonvolatile even under conditions of a sodium fire, and that (2) any iodine leakage from fuel elements, presumably as molecular iodine will, be converted to sodium iodide.

The possible oxidation of iodide to volatile forms is of concern in reactor safety. Iodide is readily oxidized to I_2 by oxygen or by peroxide. In alkaline systems such as are commonly present in an LMFBR environment, however, I_2 disproportionates to iodide and iodate according to the following reaction:

$$3\ I_2 + 6\ OH^- \rightarrow 5\ I^- + IO_3^- + 3\ H_2O.$$
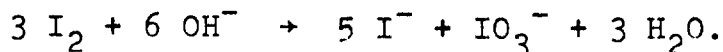
For these reasons, an investigation was undertaken of the volatility of iodine, originally present as iodide, in oxidizing systems.

Investigations of the release of iodine from sodium iodide when heated under alkaline oxidizing conditions included these parameters:

   a. temperature;
   b. mass of iodide in the mixture;
   c. gas flow rate over the heated NaI;
   d. duration of heating.

Another problem in LMFBR safety is the behavior of radio-iodine leakage from fuel elements into the coolant. Accordingly, another investigation concerned the uptake of molecular iodine by molten sodium. A nitrogen stream was used to carry the iodine. Among the parameters to be studied are:

   a. temperature;
   b. carrier gas flow rate;
   c. iodine concentration;
   d. height of sodium column;
   e. bubble size.

GENERATION OF IODINE STREAM, SAMPLING, AND ANALYSIS

Certain experimental techniques were common to both the

investigation of iodine evolution and iodine uptake. Accordingly, they are presented here, while procedures pertinent to either investigation are presented later.

a. Generation of Iodine Stream

A nitrogen stream containing a low concentration of iodine was required for testing the samplers and in the investigation of the uptake of molecular iodine by molten sodium. It was prepared by passing nitrogen through a bed of elemental iodine. The saturated vapor pressure of iodine at 0°C corresponds to about 40 ppm (by volume); at 25°C it corresponds to about 430 ppm. At a nitrogen flow rate of 120 ml/min for 4 hours, a total of 12 mg of I_2 would be evaporated for saturation at 0°C, and a total of 130 mg for saturation at 25°C.

The iodine was prepared by oxidation of sodium iodide with nitrous acid. To minimize transfer problems of the radio-active iodine, the reaction was carried out in the funnel of a filter apparatus consisting of a fritted support disk with a 20-ml chimney. It was supported in a 125-ml filter flask. A fine (0.45 μm) glass fiber filter disc was placed on the support and a few ml of water placed in the chimney. The required amounts of stable NaI and of radioactive $Na^{131}I$ were then added to the chimney with a little water and mixed by blowing air into the filter flask so that it bubbled up through the filter. After mixing, an excess of $NaNO_2$ solution was added and finally HCl was added dropwise. The addition of HCl initiated the oxidation. After two minutes, suction was applied to the flask, drawing the excess reagents and soluble reaction products through the filter and leaving the I_2 precipitate on the filter. The precipitate was washed with a small amount of water.

b. Sampling

The iodine samplers were bubblers about one inch in diameter with a total available volume of 30 ml. They were fitted with extra-coarse (170-220 μm) fritted glass tubes. Two bubblers were used in series, each containing twenty ml of 0.1 $\underline{M}$ NaOH-0.1 $\underline{M}$ $Na_2S_2O_3$ solution. The efficiencies of the bubblers were measured by determining the ratio of the counting rates in each bubbler after passage of $^{131}I_2$ (about 400 ppm in N_2) through two bubblers in series. This was done twice, with the order of the bubblers reversed the second time. The results are given below.

	Activity (cpm)	
Run Number	Bubbler A	Bubbler B
1 (A → B)	76,600	2,153
2 (B → A)	54	43,000

From these results, the efficiency of Bubbler A can be calculated as 0.973 and that of Bubbler B as 0.999. It is clear that the two bubblers in series absorbed I_2 quantitatively.

c. Analytical

The analytical method chosen was gamma counting of iodine-131 tracer. To permit measurement of iodine-131 in the sampler in the presence of much larger quantities of iodine-131 in the system, single-channel counting in the iodine peak region was selected. This enabled the counting system to reject scattered gamma radiation, which would be reduced in photon energy. The counting configuration chosen was 20 ml of aqueous sample, which was dictated by the sampling system. The energy region selected was 335-385 keV, approximately centered on the 364 keV ^{131}I gamma radiation. The spectrometer system consisted of a 1-3/4" x 2" NaI(Tl) well crystal connected to a linear amplifier and a single-channel analyzer. The sampling tubes were too large to be inserted in the well, and, therefore, were centered on top of the crystal. Under these conditions, the counting efficiency would vary with volume.

These bubblers were calibrated by counting various volumes of radioactive sodium iodide solution. Since all measurements in the experiment could be relative, the supplier's value for the activity of the radioiodine was used. Table 1 gives the results of these measurements.

TABLE 1

Calibration of ^{131}I Counting System

Vol. (ml)	^{131}I Activity (µCi)	Counting Rate (net cpm)	Counting Yield (cpm/µCi)
5	0.0835	6569	7.87×10^4
10	0.167	9771	5.85×10^4
15	0.2505	11040	4.41×10^4
20	0.334	11709	3.50×10^4
25	0.4175	12597	3.02×10^4

The data of Table 1 show that, in the vicinity of 20 ml, there is an increase in counting yield of about 5.2% per ml decrease in volume, and a decrease in counting yield of about 2.7% per ml increase in volume. As the volume could easily be maintained within $\pm$ 0.5 ml, no corrections for volume were needed.

EXPERIMENTAL AND RESULTS

a. Evolution of Iodine from Sodium Iodide-Sodium Peroxide

The system investigated were NaI -Na_2O_2. Varied quantities of NaI in 2 grams of Na_2O_2 were heated in a stream of nitrogen, and the stream was then passed through NaOH - $Na_2S_2O_3$ absorbers to detect any volatilized iodine. A diagram of the apparatus used is shown in Figure 1. The reaction mixtures were prepared by gently drying appropriate volumes of NaI and $Na^{131}I$ solutions in a nickel boat under an infra-red lamp, and adding 2 grams of Na_2O_2. The two chemicals were thoroughly mixed with a spatula. Tests showed that more than 90% of the radioactivity accompanied the Na_2O_2 when this was removed from the boat.

A total of 13 runs were made at varying temperatures, flow rates, and ratios of NaI to Na_2O_2. These are summarized in Table 2. In the early runs, a Vycor tube was used. However, it soon became apparent that this tube was badly attacked and eventually (run 5) the tube failed completely. The point of attack was almost exactly above the boat, and the corrosion is attributed to alkali distilled out of the boat. Tests with a protable survey meter (Picker G-M, Model 600081) showed that this visible alkali deposit did not contain much radioiodine. Most of the volatilized iodine was in the tube as a white deposit just beyond the downstream end of the furnace. This was clearly volatilized material depositing on a cooler surface. From its ready solubility in water, both from Vycor and from stainless steel, this was believed to be sodium iodide, rather than iodine. Other oxidized forms such as sodium iodate and periodate would be expected to decompose at the elevated temperature. Even if they did not decompose, they would be expected to react with the stainless steel in a manner such that the iodine would be rather firmly attached to the metal. Inspection of the remainder of the system with the survey meter showed that there was no large deposition of radioiodine except in this zone just beyond the furnace.

To test the variation of iodine release with temperature, several experiments were made in which the NaI-Na_2O_2 mixture was maintained at 250°, 630°, 735°, and 800°C (482, 1166, 1355, and 1472°F respectively). There is a marked influence of temperature. Very little iodine is volatile at 250°C (Run 3V).
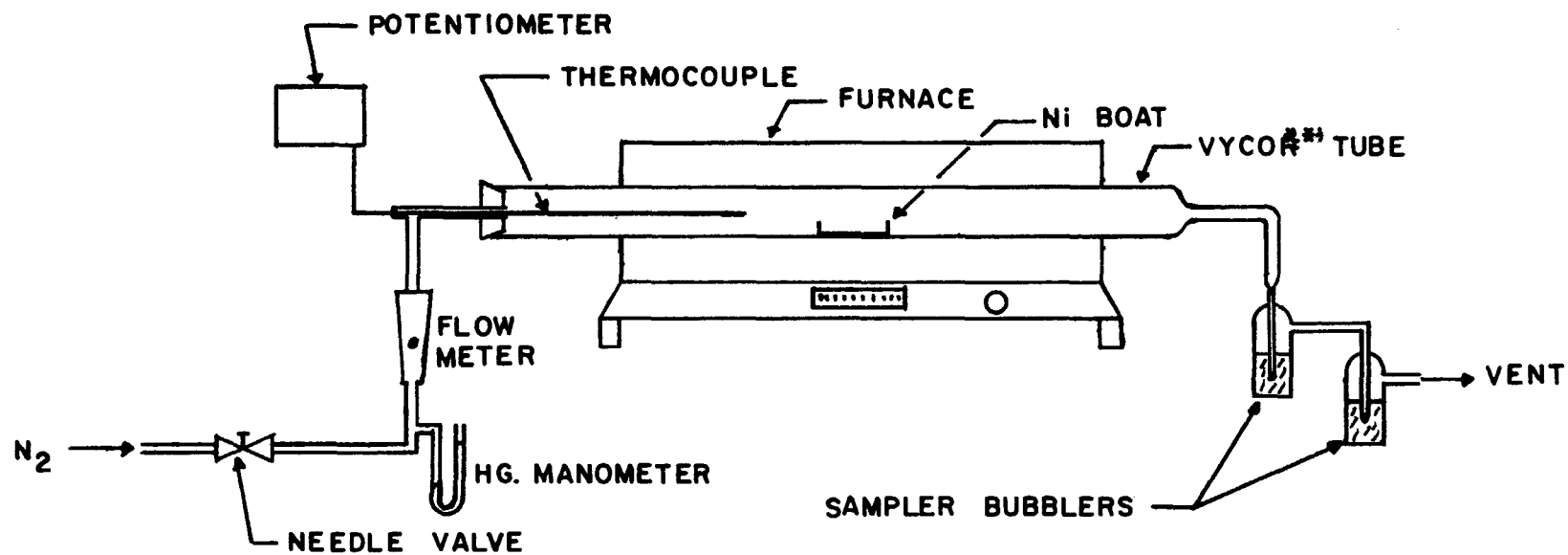
Figure 9.   Apparatus for Volatilization
of Iodine from NaI - Na_2O_2.

*The Vycor tube failed after several runs and was replaced by an oxidized stainless
steel tube

TABLE 2

Volatilization of ^{131}I from NaI-Na$_2$O$_2$ Mixtures--Summary

Run No	Flow Rate ml/min	Duration hrs	Av Temp °C	Iodide mg	^{131}I volatilized		
					In bubbler %	In tube %	Total %
1V[a]	66	4.25	630	2.0	0.009	0.023	0.032
2V	120	5.25	630	2.0	0.006	0.059	0.065
3V	66	5.0	250	2.0	0.002	0.004 (est)	0.006 (est)
4V	120	2.67	630[e]	0.2	0.037	6.12	6.15
5V[b]	120	3.3	632	0.2	0.041	--	--
6SS[a]	120	5.0	632	0.2	0.058	--	--
7V[c]	120	1.5	628	2.0	7.09	8.04	15.13
8V	120	1.0	800[d]	2.0	4.21	9.69	13.90
9V	120	1.8	735[d]	2.0	1.76	6.37	8.13
10SS	120	4.0	735	0.2	0.62	7.06	7.68
11SS	120	4.0	737[e]	2.0	1.12	7.91	9.03
12SS	120	4.0	736[e]	0.02	1.30	6.9 (est)	8.2 (est)
13SS[f]	120	1.25	740	2.0	0.05	2.52	2.57

[a]V Vycor tube; SS Stainless steel tube

[b]The Vycor tube cracked during run 5

[c]No Na$_2$O$_2$ was used in run 7; 2 grams were used in all other runs

[d]Thermocouple difficulties were encountered in runs 8 and 9. The temperature may have gone higher than indicated

[e]Higher temperatures were reached early in these runs--800 in run 4, 773 in run 11, 747 in run 12

[f]Carrier gas was N$_2$ until temperature reached, then air (start of air flow is time zero)

The·amount in the tube is indicated as being estimated in Table 2 because approximately half of the tube washings were spilled. Even if the amount spilled was as much as 3/4, which is most unlikely, the total amount volatilized would be only 0.01%. At 635°C at the same flow rate (Run 1V), the amount of iodine volatilized is greater, but still quite small--0.032%. The volatilization at 735°C may be best compared to that at 630°C in Run 10SS vs Run 6SS, in each of which smaller quantities of iodide were used. The amount of iodine reaching the bubbler at 735° is approximately ten times as much as at 630°. The tube washings were not counted in Run 6SS, but external readings of the tube with the survey meter were also in the 10:1 ratio, 24,400 counts per minute vs 2400. In the other runs at 735°C (9V, 11SS, and 12SS), somewhat larger quantities of iodine were volatilized. The early overheating apparently evaporated the iodide before the temperature was reduced to 735°C. This is confirmed by the single experiment at 800°C, in which almost 14% of the iodine became volatile in only one hour. This experiment cannot be taken as conclusive of conditions at 800°C, since there was some question as to the validity of the temperature reading. It may have been somewhat higher than 800°C.

In several experiments, the ratio of NaI to Na_2O_2 was changed. The highest ratio was 2 milligrams of NaI to 2 grams of Na_2O_2. In other experiments, 9.2 and 0.02 milligrams of NaI were used, again with 2 grams of Na_2O_2. The best test of the effect of the iodide:peroxide ratio is given by Runs 12, 11, and 10, which were operated under essentially the same conditions except for the amount of iodide used, which was 0.02, 0.2 and 2.0 milligrams in the three runs. The total amount of iodine evaporated was 8.2, 7.7, and 9.0% in the three cases. Obviously there is no marked dependence on the amount of iodide used, and the higher values in runs 11 and 12 are probably attributable to the early overheating.

In run 7V, no sodium peroxide was used. This run may be compared with Run 2V, in which all other conditions were the same. The amount of iodine volatilized in Run 7V was 233 times the amount in Run 2V, and the duration of the run was less by a foctor of 3.5. The rate of evaporation was then about 820 times as great in the absence of Na_2O_2.

Only two of the experiments, 1V and 2V, give any measure of the effect of flow rate. The amount volatilized at the high flow rate, corrected for the duration of the experiment, is 1.6 times the amount volatilized at the low flow rate. The ratio of the flow rates is 1.8. This strongly suggests that the amount of evaporation is proportional to the flow rate,

although, of course, a single pair of experiments cannot be considered definite.

It proved impossible to follow the course of evolution of iodine with time, since only the iodine in the bubblers could be counted periodically during the experiments and this was usually much less than the amount which collected on the tube wall. In run 1, the activity in the bubbler increased sharply in the first hour (Figure 2), but in most of the other runs below 735°C, there was a slow increase in the first 1 to 2 hours, then a sharp increase, and finally a levelling off after 3 to 4 hours (Figure 3). At higher temperatures, more iodine was released early. This is particularly evident in those runs where early overheating occurred. As an example, Run 11 may be compared with Run 10.

In one investigation (number 13) an attempt was made to simulate more closely the situation in an LMFBR accident by passing oxygen over the NaI-Na$_2$O$_2$ mixture rather than nitrogen. In effect, atmospheric oxygen, which would be the major oxidizing material in the LMFBR, was added to supplement the oxidizing power of the sodium peroxide. In this experiment, nitrogen was passed through the tube until the operating temperature of 735°C was reached and then oxygen was passed through. This was done to avoid the possibility that oxygen might attack unmixed NaI before the entire mixture was properly heated. This experiment should be compared with the others carried out at 735°C. A very small amount of radioiodine, 0.05 percent, reached the bubblers, and the amount recovered from tube washings, 2.52 per cent, was also smaller than that found in the other 735°C runs. This experiment was somewhat marred by the fact that a considerable quantity of moisture from the atmosphere had entered the combustion tube before heating was started and some of the Na$_2$O$_2$ had reacted to form NaOH. Even with this fact taken into account, it is clear that the atmospheric oxygen did not produce significantly more volatile iodine than the peroxide alone.

b. Uptake of Elemental Iodine by Molten Sodium

Conceptually, this is a very simple investigation. A slow stream of nitrogen will be passed through iodine on a filter support at a specified temperature. The nitrogen and iodine will then be introduced into a reactor vessel containing molten sodium at a specified temperature, and the gas stream emerging from the sodium will pass through bubblers for analysis.

An apparatus for conducting the experiments has been designed and constructed. A schematic of the equipment is shown as Figure 4. The reactor is an 18-inch length of 2-inch #316 stainless steel pipe. The ends are stainless steel pipe caps.
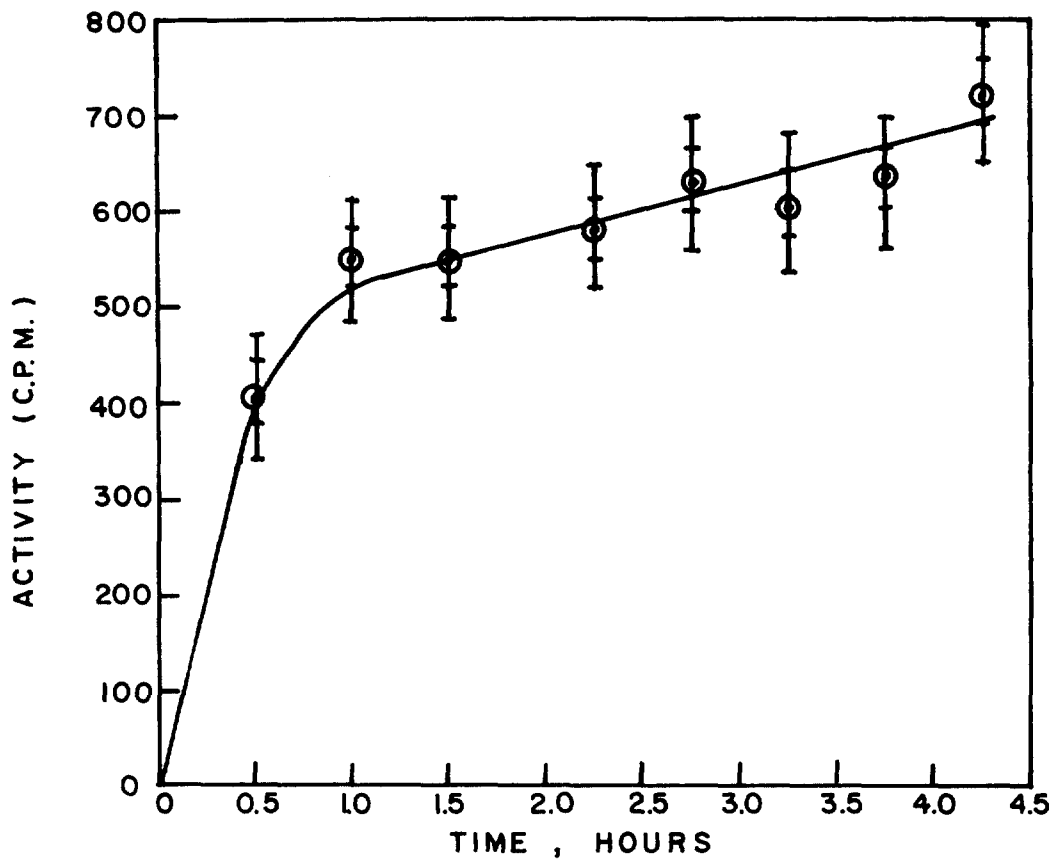
FIGURE 2. TIME COURSE OF RADIOACTIVITY IN BUBBLER, RUN NO. 1.
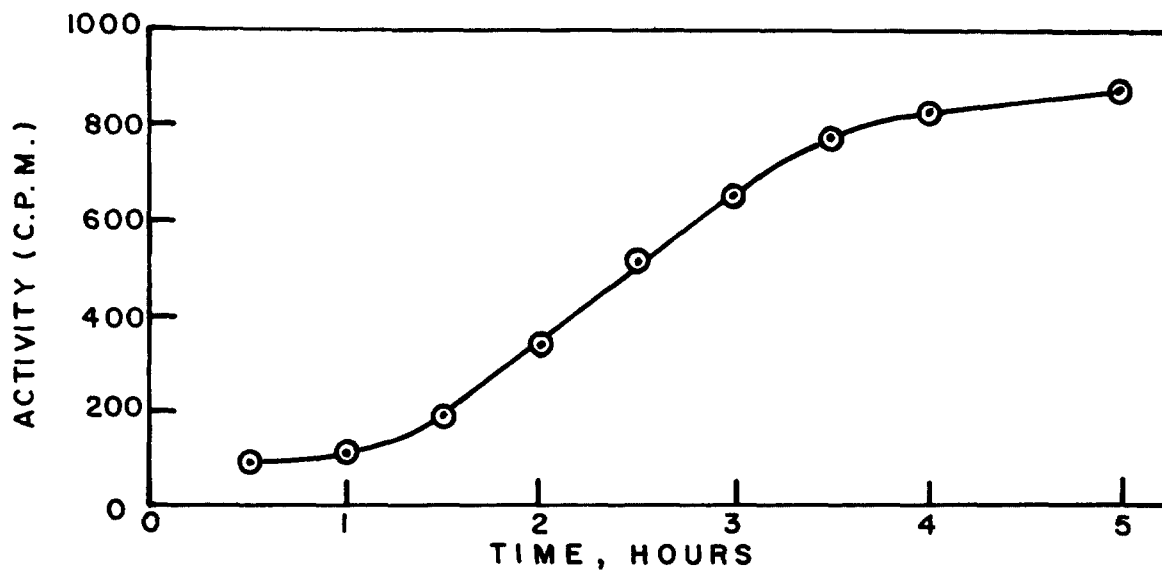

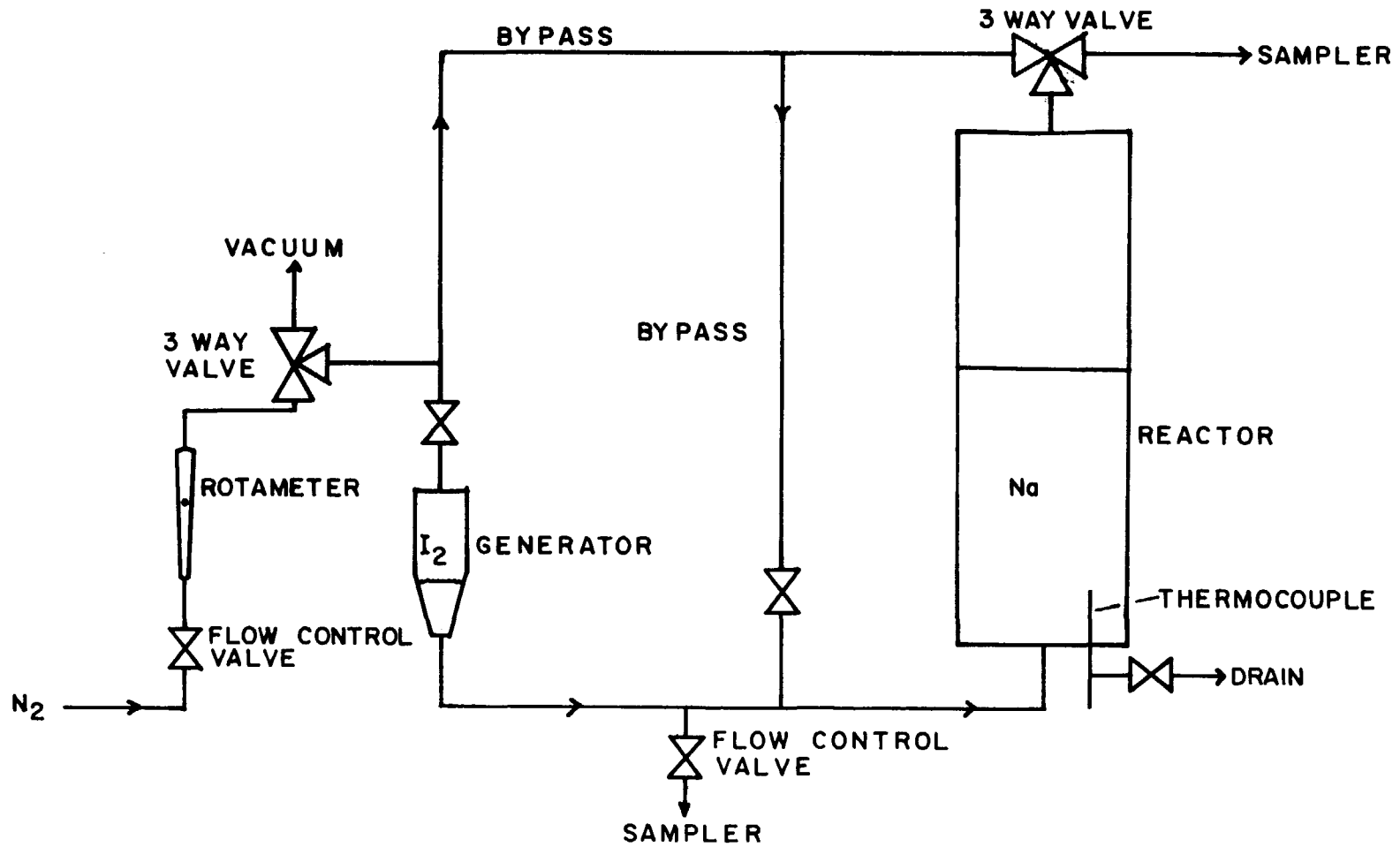FIGURE 3. TIME COURSE OF RADIOACTIVITY IN BUBBLER, RUN NO. 6.

FIGURE 4. SCHEMATIC OF IODINE UPTAKE APPARATUS.

A stainless steel pipe nipple is welded into the upper cap, connecting to a three-way Teflon and stainless steel ball valve. A stainless steel pipe tee carrying a thermocouple well and a Teflon and stainless steel drain valve is welded into the lower cap. The gas stream inlet, also welded in, is a 1/4" stainless steel tube ending in a male Luer lock which permits use of syringe needles at the actual point of introduction of the gas stream into the sodium. Thermostatically-controlled heating elements surrounding the reactor vessel permit operation at temperatures up to 600°C. The bypass lines permit evacuation of the system and also make it possible to pass nitrogen not containing iodine through the syringe needle and the sodium. This is essential when closing down the system to prevent solidification of sodium in the inlet lines. Originally, the entire system, from the iodine generator on, was of stainless steel. It was found that practically all the iodine was absorbed on this stainless steel before reaching the sodium vessel, even when the stainless steel was pre-oxidized by heating it while passing air through the system. Accordingly, the iodine generator has been replaced by the glass funnel previously described and the tubing and fittings between the generator and the sodium reactor vessel are being replaced by Teflon and polypropylene, except for a very short inlet section to the vessel, which is affected by the heat.

Bubble size is important in the absorption of iodine by sodium since it affects both contact time and diffusion path. Bubble size was investigated by passing nitrogen gas through syringe needles into water. At room temperature, the viscosity and surface tension of water approximate those of sodium at elevated temperatures. The size of bubbles from a given orifice can be calculated. The expected sizes from the various needles used are given below:

Needle No.	20	22	24	27
Orifice D, cm	0.048	0.041	0.030	0.020
Bubble D_b, cm	0.28	0.26	0.24	0.21

The bubbles formed did not conform to these diameters, but were all approximately the same size, 4 to 5 mm diameter. Photographs showed that succeeding bubbles, at all the flow rates used, formed so quickly that the first bubble was still at the needle tip, and therefore, the observed bubbles were actually composites of several bubbles.

Because of the difficulties with respect to the adsorption of iodine on the inlet lines, only a very few preliminary experiments have been performed. In one experiment, one pound of

sodium was placed in the reactor, which was maintained at a
temperature of 200°C. The iodine generator was at room tem-
perature (82°F = 27.7°C), corresponding to an iodine content
of about 550 ppm, if saturated. The gas flow was started at
30 ml/min, increased to 50 ml/min after 30 minutes, and to
80 ml/min after an hour. No iodine was detected in the outlet
sampler over a three-hour period, although the iodine content
of the gas stream immediately after the generator started at
420,000 counts per minute and increased to 530,000 cpm. Another
experiment was carried out without sodium after the reactor
vessel had been thoroughly cleaned. In this case, simultaneous
sampling was carried out upstream and downstream of the reactor
vessel. The respective sampling flow rates were 8 ml/min and
80 ml/min. No iodine reached the upstream sampler in a four-
hour period, indicating that this clean stainless steel had a
very great adsorptive capacity for iodine. The inlet counting
rates took an hour to increase from 7,000 to 320,000 cpm,
probably corresponding to saturation of the inlet tubing. There
was then a slow decrease, which may indicate a less saturated
stream as the quantity of iodine available for evaporation
decreased. The experiment was continued on the next day, and
eventually counting rates in the downstream sample of about
25,000 cpm were attained, still substantially less than the
inlet counting rates of about 120,000 cpm. On the next day,
the iodine was removed from the generator, and the desorption
of iodine from the system was observed. Counting rates of
about 25,000 cpm were observed in the downstream sampler, and
these increased to about 100,000 when the reactor temperature
was increased from 200°C to 340°C, showing desorption from the
walls of the reactor vessel.

DISCUSSION

A. Evolution of Iodine from Sodium Iodide-Sodium Peroxide

The system used in these investigations fails to duplicate
in some respects the conditions existing in an LMFBR cleanup
system after a sodium spill or fire. In the reactor system,
the sodium iodide in the aerosol will be intimately mixed with
a great excess of sodium oxide (Na_2O), sodium peroxide (Na_2O_2),
sodium hydroxide (NaOH) and sodium carbonate (Na_2CO_3). The
relative proportions of these four compounds will depend on
the circumstances of the release and the nature of the atmosphere
into which the sodium is released. Heating with Na_2O_2 was
selected as the most severe oxidizing condition possible for a
sodium aerosol. It is somewhat more severe, in addition, because
the sodium iodide is not in the same crystal as the sodium peroxide.
This less intimate mixing makes possible, or at least conceivable,
the oxidation of sodium iodide not in contact with the strongly

alkaline sodium peroxide. Intimate mixing, as from solution, would have been desirable, but was not possible because of the reaction of sodium peroxide with water.

It has been suggested[2] that the volatilization of radio-iodine from sodium iodide-sodium peroxide mixtures is due to the evaporation of sodium iodide, rather than to its oxidation to some more volatile compound. The nature of the radioactive deposit in the combustion tube has already been cited in support of this. The vapor pressure of NaI is described[3], over the temperature range 1063-1307°C, by the expression:

$$\log_{10} p(mm) = \frac{- (52.23) \ (165.1)}{T(°K)} + 8.371.$$

If extrapolated to 903°K (630°C), the equation gives a calculated vapor pressure of 0.067 mm Hg. A 66-ml/min stream, if saturated, would evaporate 2.1 mg/hr. In Run 1, only 0.032% of 2 mg was evaporated in 4.25 hours. The observed evaporation was less than the calculated by a factor of 1.4×10^4. If the 2 mg of NaI dissolved in the 2 g of Na_2O_2, its mole fraction was 6.1×10^{-4}, and if its vapor pressure was depressed proportionately, following Henry's Law, this would account for a factor of about 2×10^3. The remaining factor of 7 can be readily accounted for by the non-applicability of the vapor pressure equation at this temperature, and to possible non-saturation of the gas stream. If the equation is extrapolated to the other tempera-tures, it predicts that the vapor pressure at 735°C should be 10 times that at 630 and at 800°C about 5 times that at 735. The observed results are in rough agreement with these predic-tions. The amount of radioiodine volatilized at 250°C is far greater than would be predicted, but is so low that it may be attributed to dust carryover. The effect of varying the ratio of sodium iodide to sodium peroxide is further confirmation of the hypothesis that sodium iodide is being evaporated. The highest ratio of sodium iodide to sodium peroxide was 2 milli-grams to 2 grams, corresponding to a mole fraction of 0.00061. The other ratios used were 1/10 and 1/100 of this value. At these low concentrations, Henry's law can be expected to apply, and the vapor pressure of sodium iodide should be proportional to its mole fraction. The <u>percentage</u> of iodine evaporated should, therefore, be the same in all cases. The close agree-ment between Runs 12, 11, and 10 has already been noted. The much higher rate of volatilization of iodine from sodium iodide in the absence of sodium peroxide, about a factor of 820, is about half of what would be predicted from Henry's Law alone.

This is close enough, considering the approximations involved, to be a rough verification.

b. Uptake of Elemental Iodine from Molten Sodium

Obviously the amount of experimental work reported here does not warrant extended discussion. It is quite apparent that adsorption is a major problem in conducting the experiments. At low flow rates and low concentrations of iodine, there are so few iodine atoms present that a major fraction can be adsorbed by metal surfaces. When radioactive iodine is used, this adsorption can be observed. When stable iodine is used, it may not be observed and false conclusions may be drawn. It is necessary to bring the surfaces into equilibrium with iodine of a given specific activity, by prolonged passage of the gas stream, and then conduct the experiments with the same iodine.

Perry[4] indicates that bubbles remain spherical up to a diameter of about 2 mm, after which they become ellipsoidal and finally helmet-shaped. The 2-mm bubble may be a critical case, since it is the largest bubble which is diffusive. For all smaller bubbles, the mean diffusive distance is smaller and, therefore, loss of iodine to the sodium is greater. In larger bubbles, the diffusion distance is somewhat larger, although the flattening of the bubbles partially overcomes this increase. More important, the motion may be turbulent so that mass transfer of iodine to the bubble surface may be much greater. Production of 2-mm bubbles requires operation at a very low flow rate, probably as small as 10 ml/min with a #27 (0.2 mm diameter) needle. Such a small flow rate will further aggravate the adsorption problem.

SUMMARY

The evolution of iodine from mixtures of sodium iodide-sodium peroxide has been studied. The rate of evolution at 250°C and 635°C is not greater than 0.03% over several hours. The mechanism appears to be evaporation of sodium iodide, rather than oxidation to a more volatile form. The evaporated sodium iodide deposits rapidly on cooler surfaces.

Some preliminary experiments on the uptake of elemental iodine by molten sodium have been performed. No conclusions can be drawn as yet.

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3. Lange, N.A., Handbook of Chemistry (10th ed), p. 1449, McGraw-Hill, New York, (1967).

4. Perry, op. cit. p. 18-72.

DISCUSSION

BURCHSTED: This question is quite apart from the subject of your talk Mel, but you're quite familiar with the stress corrosion cracking of stainless by chlorides and fluorides; I wonder if there is any evidence at all of Iodide-induced stress corrosion cracking in the stainless steel tube that you substituted for the bypass?

FIRST: Not yet. Perhaps we haven't done the experiment long enough.

BURCHSTED: We have been told that Iodide will not do it, but it is in the same chemical family so I just wonder about that.

FIRST: There were approximately 5 runs made with the Vycor before it collapsed and 8 runs have been made with the stainless steel. To all outward appearances it's still intact.

BURCHSTED: Is the stainless under any stress?

FIRST: No, none whatsoever, except, of course, the heating. The pressure is atmospheric.

CLOUGH: You've described the behavior of sodium iodide in the presence of peroxide. Perhaps I could add something to that, which you probably won't find very exciting because it's what you would expect if you did the thermodynamic calculations anyway. Let me just say that in the presence of Na_2O, the sodium iodide remains as sodium iodide even in distillation at temperatures up to 750°C. When I measured the volitility of sodium iodide in sodium a couple of years ago, I did experiments in which I used oxygen concentrations of up to about 10,000 parts per million. I found that even after all the sodium had distilled and the materials remaining were Na_2O and NaI, then the iodine was still evolved with a vapor pressure which could be ascribed to NaI. In fact, Na_2O appears to have no effect on the behavior of NaI -- which is just what one would expect. But if I could just ask a question. Did you measure the water vapor content of the nitrogen that you passed over your specimen?

FIRST: It's commercial dry nitrogen. That was all the control we exercised; just took it out of the bottle. To comment on your statement (which I certainly do appreciate and agree with), we did select the peroxide for study first because we anticipated that this would be the more reactive compound and if we found no substantial volitization with the peroxide we probably would be safe with the monoxide. But, as you see, we did not come up with this result.