CONCEPTUAL SYSTEM DESIGN DESCRIPTION
OF THE SYSTEM FOR
EMERGENCY REMOVAL OF
EBR-II INSTRUMENTED SUBASSEMBLIES (INSERT)

by

P. Elias, E. Hutter and O. Seim

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ABSTRACT

An instrumented subassembly is operated in the EBR-II reactor in place of control-rod-drive No. 6. After its irradiation in the reactor is completed, the instrumented subassembly is separated into two pieces by a cutting device. The upper part (extension tube) is removed by lifting it upward through the reactor-vessel cover and through the rotating shield plug into a receiver tube. The lower part (subassembly) is removed from the reactor and primary tank by the existing fuel-handling system. If the separation fails, the subassembly will be removed from the reactor by an emergency system. This system is composed of the following major components: (1) sealed container and shielding; (2) lower adapter tube; (3) storage tube; and (4) support structure. The lower adapter tube is attached to the control-rod-drive nozzle at the bellows-flange level (50 in. above the top of the small rotating plug) and extends to the top of the control-rod-drive support column (about 100-in. level), where it is coupled to the sealed and shielded container -- about 100 in. long. On the top of the container is secured the storage tube with a cutting machine at the lower end and a lifting device at the top. The assembly is attached to the support structure and the building crane. The instrumented subassembly is lifted in one piece into this assembly, cut into two parts (extension tube and subassembly) and then removed for storage or examination.

I. INTRODUCTION

A system for removing an instrumented subassembly from the EBR-II reactor when the normal method of removal does not succeed has been developed. It was chosen after several methods were considered. This report defines the requirements of such a system and describes its conceptual design.

A. Instrumented Subassembly System and its Normal Operation

The instrumented subassembly¹ (Figs. 1 and 2) is an addition to the EBR-II systems that serves various experimental purposes.

An instrumented subassembly resembles in its dimensions an EBR-II control rod and incorporates a variety of instrument sensors. Sheathed leads from the sensors extend through the upper adapter of the subassembly into a dry well of the extension tube (Fig. 3). The lower end of the extension tube fits over the hexagonal upper end and adapter of the subassembly. A four-jaw coupling, suspended from the top flange of the extension tube, is engaged to the subassembly's upper adapter. The coupled components are about 35-1/2 ft long, with a 2-7/8-in. maximum diameter at the top. When the subassembly is installed, a 46-in.-long upper part of the extension tube remains above the small rotating plug and is surrounded by a bellows. The lower end of the bellows is sealed to the control-rod-drive nozzle No. 6 and the upper end to the upper flange of the extension tube. On the top of this flange is mounted a terminal box containing the lead connections.

An extension of the central support column for control-rod drives supports the drive mechanism for the instrumented subassembly. This mechanism provides for 96-in. vertical movement necessary for fuel handling.

Normal removal of an instrumented subassembly from the reactor requires three major operations: (1) uncoupling of the instrumented subassembly from its extension tube by moving the locking sleeve of the coupling jaws upward to allow them to be spread and thus release the upper adapter of the subassembly; (2) removal of the coupling tool from the extension tube and insertion of a cutting tool that is revolved around the upper adapter of the subassembly to sever the leads from the sensors flush with the hexagonal jacket of the subassembly; and

Fig. 1. Installation of Instrumented Subassembly

Fig. 2. Drive System for Instrumented Subassembly
(All dimensions in inches)

Fig. 3. Extension Tube of Instrumented Subassembly
(All dimensions in inches)

(3) removal of the extension tube by lifting it up into a receiver tube. The instrumented subassembly left in the reactor is subsequently removed by the fuel-handling mechanisms.

In the unlikely event that normal separation of the extension tube fails, the emergency removal method (INSER) is available to insure removal of the subassembly and to maintain the reactor in operating condition.

B. Functions of INSER

The INSER system is to: (1) retrieve the coupled instrumented subassembly and extension tube safely from the reactor via the control-rod-drive nozzle into a sealed container, in an argon atmosphere to avoid reaction of sodium with air at high temperatures; (2) separate the subassembly from its extension tube; (3) disconnect the subassembly container from the extension-tube container; (4) transfer the subassembly from the reactor building into an examination cell or storage facility for further processing; and (5) transfer the extension tube into a storage area inside the reactor building.

II. FACTORS AFFECTING DESIGN

The main difference between installation and removal of an instrumented subassembly is that the subassembly is highly radioactive after irradiation in the reactor. The magnitude of radioactivity depends on the subassembly's total power generation during its residence in the reactor and its subsequent cooling time after reactor shutdown. The nuclear characteristics of a subassembly will vary from test to test, but the maximum radioactivity of an irradiated instrumented subassembly may be assumed to equal that of a subassembly of driver fuel. Thus heavy shielding is required. (See Requirements for Shielding and Cooling) Installation of such shielding requires considerable space and is a primary design consideration for INSER.

The control-rod drives are positioned around the center support column for the drives, which extends 101-1/8 in. above the top of the small rotating plug (see Fig. 1). The center of the nozzle of control-rod drive No. 6 is 8 in. from the center of the support column. Existing drive mechanisms are designed to fit into a segment of a 30° angle,

which has its vertex in the center of the support column. To the top of the original support column is bolted an extension column, 69-1/8 in. high, to support: the drive for the instrumented subassembly; and the air cylinders for control-rod drives. Access to the nozzle of control-rod drive nozzle No. 6 is limited further by the lifting mechanism for the reactor-vessel cover. The mechanism includes columns, 224-3/4 in. high, which are designed to carry the 15-ton weight of the cover.

The 20-ton-capacity building crane, capable of raising its hook 44 ft, 4 in. above the operating floor (46 ft, 4-1/2 in. from the top of the small rotating plug), can be used to transport the components of INSER.

Access to the INSAT location can be improved by disassembly of certain mechanisms around the support column for the control-rod drives, such as adjacent drive motors, air cylinders, extension column, lifting motor for the reactor-vessel cover, and related components.

III. CRITERIA

The equipment and operations for emergency removal of an instrumented subassembly from the reactor must satisfy several requirements for safety and effectiveness:

1. INSER must consist of separable sealed gas-tight transfer containers for the instrumented subassembly and its extension tube.
2. INSER must incorporate a lifting device that couples to the upper end of the extension tube of the instrumented subassembly and can lift the subassembly (about 350 lb) into the sealed transfer container.
3. Shielding during lifting and storing operations for the subassembly must be comparable to that required for handling a regular driver-fuel subassembly that has been cooled in sodium for two weeks after reactor shutdown. (Calculated maximum radiation levels must not exceed 100 mr/hr 3 ft from the centerline.)
4. Separating the instrumented subassembly from its extension tube while these components are inside sealed transfer containers must be possible.

5. The transfer container for the subassembly must have enough cooling capacity to remove 1.5 kW of fission-product heat and keep the cladding temperature well below 1000°F.

6. The sealed and shielded transfer container must pass through the equipment air lock of the reactor building and through the passageway, on the cask-transfer carts. The size of the assembly is limited by the space above the nozzle of control-rod drive No. 6, by the internal space of the equipment air lock, and by the space available below the floor hatch of the FEF air cell.

7. The sealed transfer container must be separable from the shielding at the floor hatch of the FEF air cell by the existing air-cell manipulators and must be able to pass through the large transfer lock between the air and argon cells.

8. The equipment must be attached to and disconnected from the nozzle of the control-rod drive without endangering the primary sodium-coolant system.

9. Disassembly of existing mechanisms to accommodate the INSER installation must be minimized, although safety considerations and simplicity of the design shall have priority.

10. INSER components must be lifted by the existing building crane.

IV. DESCRIPTION OF SYSTEM

Several INSER systems have been studied. One with a fully shielded container appears to be the most feasible. In this system a three-piece gastight container is surrounded by shielding. The lower section of the container extends the nozzle of the control-rod drive from the upper flange of the bellows of the instrumented-subassembly extension tube to the top of the support column for control-rod drives. On top of this section is attached a sealable storage container (for the instrumented subassembly) and on top of that a cutting machine and storage container (for the extension tube). These sections are separable for handling purposes. See Appendix A for a description and evaluation of other systems studied.

A. Components

The INSER system consists of the following major components:

(1) sealed container and shielding; (2) lower adapter tube; (3) storage tube; and (4) support structure.

1. Sealed Container and Shielding

The sealed container (Fig. 4) is a tube, 100 in. long and 4 in. square, that has a 3-in.-dia cylindrical central cavity. The container is surrounded by lead shielding that is cast within a 1/2-in.-thick steel shell. The shielding has a cylindrical middle section, 24-in. OD and 24-in. long, with tapered ends reduced to 16-in. OD.

The end closures of the container are 4-in.-thick metal block valves sealed by "O" rings (Fig. 5). The valves can be operated remotely with a special wrench. To open the valve, the valve block is retracted into a sealed housing attached to the shielding shell. For closing, the block is pushed into a seat at the container end. A cam arrangement actuated by turning a handle presses the "O"-ring face section of the valve block against the sealing surface of the container end. When the handle is retracted, the valve block remains locked between a frame and the sealing surface. This seal arrangement allows the container to be withdrawn from the shielding and handled or stored conveniently while it remains sealed.

INSER includes a closed-loop, gas-cooling system, which consists of the following major components: (1) a variable-speed electric motor that adjusts the gas flow to meet the cooling demand; (2) a blower; (3) a filter; and (4) electric interlocks that prevent the motor blower from operating unless the lower valve of the sealed container is closed.

Coolant gas is forced into the container from the top by a closed-loop blower through flexible hoses. Use of these hoses prevents the motor-blower assembly from obstructing the storage tube and shielding. Coolant flow through the subassembly is effected by a gate valve that obstructs flow passage outside of the subassembly. Coolant leaves the subassembly via the lower adapter and returns to the blower by heat-exchanger tubes in the container walls. Heat from the coolant is dissipated through the container walls into the surrounding lead

Fig. 4. Sealed Container and Shielding Assembly of INSER
(All dimensions in inches)

Fig. 5. Lower Valve of Sealed Container
 (All dimensions in inches)

shielding. After the container is removed from its location above the reactor, it could be filled with liquid metal (e.g., Cerrotru* or sodium), for more convenient cooling. Electric heaters are embedded into the container walls for heating the container and subassembly if necessary.

The upper end of the container has lifting lugs and release mechanisms to facilitate separating the container from the surrounding shielding for storage or examination.

2. Lower Adapter Tube

The lower adapter tube, (Fig. 6), is about 50 in. long, with a 3-in. ID and a 3-1/2-in. OD. It is used to connect the sealed container and the bellows-flange valve of the extension tube of the subassembly. The upper end of the adapter is connected to the lower valve of the sealed container just above the top of the support column for control-rod drives. The lower end of the adapter is sealed to the bellows-flange valve by a sliding sleeve. This connection is made after a piston is lowered over the coupling of the instrumented-subassembly extension tube and fastened to it by a pin. Because of the close tolerance between the mating components, the necessary alignment is achieved by the adjustable pads of the support structure.

About 30 sec is required to pull the subassembly through the lower adapter tube. Sectionalized lead shielding, 8 in. thick, is installed in front of the adapter to attenuate gamma radiation. The rear area is partially shielded by the support column for control-rod drives and other metal equipment. Personnel might have to be excluded from the rear area while the piston is being pulled up.

3. Storage Tube

The storage tube (Fig. 7) is used to store the extension tube of the instrumented subassembly. It is 29-1/2 ft long, with a 3-in.-ID central hole. A block valve, similar to that used for the sealed container, is attached to the lower end. The under side of the valve has a pilot section that aligns the tube with the sealed container. Four cam locks keep the rubber-gasket connection gastight.

*An alloy of bismuth and tin

Fig. 6. Lower Adapter Tube of INSER (Piston shown in down position; all dimensions in inches)

Fig. 7. Storage-tube Assembly of INSR
(All dimensions in inches)

A cutting machine (Fig. 8) is attached to the lower section of the storage tube. Cutting with an abrasive wheel is preferable to other methods because of the lower feed pressure required. The wheel, which is powered by an electric motor, is moved into the material by a feed screw attached to the motor housing. Destructive overfeeding is prevented by protective circuitry that shuts the motor off if an overload occurs. The wheel, which is one of the types specified for stainless steel, is about 1/8-in. thick and 9-10 in. in diameter. After the cutting operation, the machine is retracted and locked in its starting position to avoid blocking the storage tube. The lower 48-in. section of the storage tube is shielded by 4-in.-thick lead, which allows safe operation of the cutting machine at the base of the storage tube and attenuates radiation from deposits of cutting dust.

Three screws hold the extension tube steady while it is being cut off from the subassembly.

A Teleflex lifting mechanism and cable with the pull-up piston is attached to the upper end of the storage tube. The cable can lift 500 lb and can push the unloaded piston down through the storage tube, sealed container, and lower adapter tube to the connecting level above the bellows-valve flange. The piston speed is about 6 in./sec. When moving upward, the excess cable is stored on a takeup drum, which is powered by a negator spring arrangement (an arrangement that gives a constant force). A slip clutch protects the motor and the pull-up system if any abnormal obstruction develops during removal. At the top of the storage tube the cable passes through a seal.

4. Support Structure

The shielding, the sealed container, and the associated parts are supported by a structure that is attached to the support columns of the lifting mechanism for the reactor-vessel cover. The support structure (Fig. 9) is a welded combination of I-beams and channels. The I-beams form a support accessible from an open side. The weight of the shielding is carried by a shield-support ring that rests on adjustable support pads. The pads, which have Teflon surfaces, are adjusted by screws.

Fig. 8. INSR Cutting Machine

Fig. 9. Support Structure for INSR
(All dimensions in inches)

B. Operation of the System

The emergency removal operation consists of the following general activities: (1) disassembly of the existing mechanisms to make space available for the INSER components; (2) installation of the INSER components; (3) transfer of the instrumented subassembly and its extension tube into the sealed container and storage tube; (4) separation of the subassembly from its extension tube; (5) handling of the separated subassembly and extension tube and removal of the subassembly from the sealed container; and (6) removal of the INSER components and reassembly of original mechanisms.

1. Disassembly of Existing Mechanisms

Limited space around the nozzle for control-rod drive No. 6 requires removal of some of the existing reactor components. Normal removal of the extension tube of the instrumented subassembly requires removal of the subassembly terminal box, portions of the drive mechanisms, and the motor and mechanisms for lifting the reactor-vessel cover. The following additional mechanisms must be disassembled (Fig. 10 shows the locations of the existing mechanisms with respect to the components for the proposed emergency removal system):

(a) Four air cylinders for the control-rod drive near the No. 6 nozzle (Nos. 4, 5, 7, 8); and

(b) Extension of the center column for the control-rod drives (installed for the instrumented-subassembly drive).

These mechanisms have been removed in the past.

2. Component Installation

The components of the system are installed in the following sequence:

(a) The shielding support structure is mounted on top of the support columns for the lifting mechanism of the reactor-vessel cover (Fig. 9).

Fig. 10. Necessary Disassembly of Reactor Components in Removal of Instrumented Subassembly (Components shown within dashed and dotted circles; typical components marked with maximum elevation in small circles; all dimensions in inches)

(b) The sealed container and related components are inserted in the shielding, and the end valves of the center cavity and the coolant gate are fully opened. Then the assembly is lifted by the building crane and placed on the pads of the support structure.

(c) A coupling is attached to the top of the instrumented-subassembly extension tube.

(d) The lower adapter tube is placed on top of the bellows-flange coupling and secured by toggle clamps. With the floating sleeve of the adapter tube (at the lower end) used as checking tool, the shielding support pads are adjusted until the sleeve slides freely over the upper section of the bellows-flange valve.

(e) The storage tube and attached components are lifted by the crane above the shield assembly. The pilots are aligned with the respective holes in the lower valve of the storage tube and the whole assembly is lowered into its seat. The connection is secured by four toggle clamps. The position of the crane is adjusted so that the connection undergoes no bending strain. The upper end of the storage tube is left connected with the crane and is moved upward until slack is taken out of the crane cable. The valve of the storage tube is checked to assure that it is open, and the holding screws are retracted. Then the motor of the Teleflex cable is actuated and the piston is moved down. The arrival of the piston at the bellows-coupling level is observed while the floating sleeve is held at its upper position. A swivel joint between the piston and the Teleflex cable allows for alignment of the coupling-bolt hole.

After the coupling bolt is secured, the floating sleeve is moved down over the valve-coupling section and secured by a machine screw. The sealed system is now purged of air and filled with argon just above atmospheric pressure. This pressure is maintained by bleeding in argon from a gas cylinder. This arrangement keeps the instrumented subassembly in a controlled inert atmosphere, and the travel of the lifting piston through the valve sections (where the piston seal is ineffective) does not affect purity of argon gas in the system.

(f) The lower sectional shielding is placed around the lower adapter tube and the bellows.

(g) The coolant hoses are connected to their respective adapters.

3. Transfer of the Instrumented Subassembly and its Extension into the Sealed Container and Storage Tube

The holding screw for the bellows-flange valve is retracted. The drive motor for the Teleflex cable is started, to move the cable upward. The subassembly is raised from its seat in the reactor and lifted until the lower end is about 5 in. above the lower valve of the sealed container. The lift length is controlled by limit switches. The lower valve is closed and sealed. The coolant-flow gate in the sealed container is closed and the cooling system is started. The lower adapter tube may now be separated from the lower valve of the sealed container by opening the toggle clamps. Travel of the instrumented subassembly from the reactor into the sealed container requires a 40-1/2-ft lift. At a motor speed of 26 rpm, total travel takes approximately 1-1/2 min.

4. Separation of the Instrumented Subassembly from its Extension

The instrumented-subassembly extension is separated from the subassembly by cutting crosswise through the subassembly with the abrasive wheel about 1/2 in. below the top edge of the hexagonal top end fixture. Before the operation is started, the holding screws in the storage tube are tightened to keep the extension tube steady during the cutting.

After the cutting, the subassembly drops 5 in. to rest on top of the lower valve. The holding screws are retracted and the separated extension tube is raised above the storage-tube valve so that the upper valve of the sealed container and the lower valve of the storage tube can be closed. The instrumented subassembly is thus contained in the cooled sealed container and the extension tube is in the storage tube.

5. Handling of Separated Subassembly and Extension Tube

After the cutting operation the subassembly and its extension tube are handled separately. Opening the toggle clamps permits the storage tube to be transferred to a storage area by the building crane.

The sealed container within the shielding is moved from the reactor area by the building crane. Four attachable legs support the shielded container in an upright position. On the operating floor the gas cooling can be shut off and the sealed container filled with liquid metal -- Cerrotru or sodium -- for an extended cooling period. The container is filled as follows: The gate inside the sealed container is opened, the gas cooling is shut off, and the Cerrotru inlet valve (an auxiliary to the gas-inlet valve) is opened to drain the Cerrotru from a nearby heated container. The inlet valve is shut off when the electric probe signals that the sealed container is filled.

After the components of the gas-cooling system are removed, the shielded and sealed container assembly can be handled by the transport equipment of the interbuilding coffin by use of a special adapter. Under the air-cell hatch of the Fuels and Examination Facility (FEF), the sealed-container is separated from the shielding and lifted into the FEF. In an examination cell, the sealed container is set in a drain basin. If the coolant has solidified, the container's built-in electric heaters are used for remelting the coolant.

6. Removal of INSER-system Components and Reassembly of Original Mechanisms

Removal of the storage tube and of the shielded and sealed-container assembly from the support structure concludes emergency removal. The support structure is removed and the extension of the center support column for the control-rod-drives and the air cylinders are reassembled. A new instrumented subassembly is installed according to the prescribed procedure, including the reassembly of the cover-lifting drive.

C. Requirements for Shielding and Cooling

In the conceptual design of the INSER system special attention has been given to the shielding and cooling required for the irradiated instrumented subassembly.

1. Shielding

Shielding is required to protect operating personnel from radiation from the irradiated instrumented subassembly and its extension tube. Because the fuel section of the subassembly varies from test to test and the irradiation time or burnup also varies, the radiation level has a wide range. In shielding calculations for transfer coffins for fuel subassemblies, the subassemblies are assumed to have been operated at 33% above the rated power of 62.5 MWt and have been cooled 14 days in sodium. These assumptions represent an average operating power of 1.25 MWt per subassembly.² If the subassembly is surrounded with 11 in. of lead at the core section, 9 in. at the blanket sections, and 7 in. at the ends, the calculated radiation dose at any point 3 ft from the subassembly center does not exceed 100 mr/hr. These requirements are satisfied by the configuration of the sealed-container shielding. The total weight of the shielding is about 13,000 lbs and the height is 100 in.

The subassembly passes through the bellows section and the lower adapter tube on its way into the sealed container. The path is partially shadow-shielded by the support column and drive mechanisms for control-rod drives. Moreover, this section is temporarily shielded by lead bricks or special shielding. The time required for the subassembly to pass through this section is estimated to be about 25 sec. Remote operation of the Teleflex cable mechanisms allows operating personnel to be in a protected area while the irradiated subassembly is passing.

The lower end of the storage tube is shielded radially by 4 in. of lead for 4 ft. This shielding provides protection against radioactivity from the lower section of the extension tube of the instrumented subassembly that has been in the primary tank below the reactor cover and has about 100-200 R/hr of gamma activity.

The shielding provisions restrict other activities in the reactor plant for only a short time.

2. Cooling

The instrumented subassembly houses experiments containing fuel and related components. The analysis assumes that the maximum fuel content is less than that of an ordinary subassembly of driver fuel,

because the instrumented subassembly is smaller. The fission-product energy of a driver-fuel subassembly, after 14 days of cooling, is calculated to be 1.4 kWt. In the same manner, calculations for the instrumented subassembly XX01 predicted 276 W after two weeks of cooling in the reactor. Thus, the cooling requirements for an instrumented subassembly in the emergency removal system may vary widely. If the fission-product decay heat is less than 250 W, no special cooling is necessary in the sealed container; heat transfer by natural convection and conduction into the mass of the shielding is sufficient.⁴

If the fission-product decay heat is above 250 W, forced cooling is required. For a description of the closed-loop gas-cooling system to transfer heat from the subassembly into the sealed container and lead shielding, see Sealed Container and Shielding.

Calculations⁵⁻⁷ show that at an assumed maximum heat generation of 1500 W, the required argon flow rate is 2.86 lb/min. The equilibrium temperatures are expected to be: inlet argon, 213°F; fuel-subassembly cladding, 546°F; and the shielding (outside), less than 213°F. Such equilibrium will not be reached for several hours.

When the sealed container is filled with Cerrotru, the temperature of the cladding is only about 250°F and the radial temperature drop through the shielding is 35°F.

After the sealed container, filled with Cerrotru, is separated from the shielding, the heat-transfer surface is about 11 ft². The higher temperature gradient between the sealed container and the surroundings increases the heat-transfer coefficient to about 4 Bth/hr-ft²-°F; thus the cladding temperature is 200-300°F.

These analyses show that the temperatures of fuel-subassembly cladding are kept well below 1000°F.

CONCLUSION

The INSER system, designed for installation in control-rod drive position No. 6, appears to meet all requirements for emergency removal of instrumented subassemblies. Installation of the system in other rod-drive locations will be evaluated.

APPENDIX A

ALTERNATIVES TO INSER

Several other coolants and systems, which are described and evaluated in this Appendix, have been studied.

A. Alternative Coolants: Discussion and Evaluation

Liquid-coolant systems are very efficient for heat transfer into the massive shielding. Limitations are imposed by safety requirements, especially during work above the reactor. The system must be absolutely reliable. Reactions between liquids and traces of sodium on the subassembly must be minimized. In place of the closed-loop, gas-cooling system, a liquid-metal cooling system could be used. Cerrotru appears to be acceptable. For safety reasons the change of coolant should be made after the shielding assembly is moved from the reactor to the operating floor. Liquid sodium could be used, but it has some disadvantages because of its affinity with oxygen.

NaK, frequently used with sodium systems, reacts in air and thus imposes restrictions for removing the subassembly from the sealed container. Mercury vapor is poisonous, which would cause hazards of a spill occurred.

Sodium is acceptable as a coolant, and it may replace the argon at a later stage in the operation. During the early stages of emergency removal, including the cutting operation, however, sodium is not desirable.

Liquid nitrogen, when vaporized at 1 atm, absorbs about 87 Btu/lb and an additional 250 Btu/lb when expanded and heated to 700°F. Thus, both liquid and gaseous nitrogen could be used to remove fission-product heat. Outgoing gas could be passed into the building exhaust stack through flexible metal hose, which also would serve as a heat exchanger between room air and hot nitrogen from the sealed container. The temperature of the exit nitrogen could be used to control the nitrogen level in the container. However, thermal stresses would cause difficulties, and thus the use of liquid nitrogen is not recommended.

An open-loop air-cooling system was considered. It would take air from the pressurized air system of the reactor building. After the air passes through the hot subassembly it would be dumped into the radioactive-waste stack. No special equipment would be required except high-temperature hoses and valves. Serious limitations are imposed by reactions between oxygen and sodium; therefore, this system is not recommended.

Bottled inert gas or the building argon supply could be used for a short period but would be too expensive for extensive use.

B. Segmented-coffin System

1. Description

The segmented-coffin system, like INSER, is a one-piece emergency-removal system. The main difference between the two systems is that in the segmented-coffin system the coffin is lowered to the lowest possible level -- the bellows-flange level (about 50 in. above the top of the small rotating plug). Space is limited at this low elevation because of the center column for the control-rod drives. About a fourth of the coffin shielding is portable and is installed after the instrumented subassembly is transferred into the sealed container and the coffin is backed off from the transfer position about 8 in. to make space required for the portable section of shielding. Figure 11 shows the following main components of the segmented-coffin system: (a) shielded bellows section; (b) lower seal valves; (c) sealed container surrounded partially by shielding; (d) upper seal valves; (e) cutting machine and upper storage tube; (f) shield-lifting mechanisms and shield sections; and (g) pull-up mechanisms.

An abrasive-wheel cutting machine is attached to the lower section of the storage tube. Guideways for the portable shield are mounted along the side of the storage tube to about 310 in. from the top of the small rotating plug. Two shielding sections are attached to the guideways. The lower section fits the coffin and the upper one covers the lower end of the storage tube, when lowered. Both shields, which weigh about a ton, are operated by mechanisms attached to a platform at the 326-in. elevation. A segmented-coffin diameter of 16 in. was chosen because this size would allow the coffin to be used at all

Fig. 11. Segmented-coffin System for Removal of Instrumented Subassembly

control-rod nozzles. Despite this limited shielding, installation of the system requires removal of the following mechanism parts: (a) one control-rod-drive motor from each side of the instrumented-subassembly nozzle, (b) four control-rod-drive air cylinders and (c) the lifting motor for the reactor-vessel cover.

The segmented coffin is suspended from the support structure at the 224-in. level, possibly by adjustable chains or cables. It also must be supported by the building crane because of its length and possibly unbalanced weights of the mechanisms.

2. Evaluation

Sectionalizing and reducing the size of shielding require less space and minimize disassembly of the components. The cut-out section of the shielding allows the sealed container to be installed at the bellows-flange level with shielding at the front side. The shielding covers three-quarters of the circumference. This arrangement shortens the distance the instrumented subassembly must be lifted above the floor into the removal container by about 50 in. Because the rear side is inadequately shielded, a special booth for the operator is required.

Disadvantages of the segmented-coffin system are mainly due to complexity of the required mechanisms: (a) Thickness of the segmented shielding is limited by the configuration of the mechanisms of the control-rod drives; and an optimal size required by the presence of the support column for the drives and attached mechanisms provides only limited protection against high-level radiation. (b) Design, assembly, and operation of the components, especially the storage tube with a multitude of attached mechanisms, create many complicated technical problems. Because of space limitations, the coffin and storage tube must be installed separately. After the instrumented subassembly and its extension tube are pulled into the sealed container and storage tube, the whole assembly must be raised and retracted laterally about 8 in. from the support column to provide space for installing the shielded segment. These movements require difficult synchronized movements of the support structure and the crane. Lowering and guiding the shield pieces, each weighing about a ton, into their seats require well-developed and tested, trouble-free, systems with adequate backups for safety.

In conclusion, the segmented-coffin system has excess mechanical complexity and during certain operational stages has inadequate shielding. These factors create many more problems than the recommended sealed-container system, even though the latter requires the additional disassembly of the extension of the support column for control-rod drives.

C. Mechanized-box System

1. Description

The system (Figs. 12, 13) consists of a shielded and sealed box, a pull-up pipe, and a gripper device, sealed to the box. The box contains electrically powered cutting tools of an endmill type and a manipulator capable of lifting the separated pieces of extension tube away from the instrumented subassembly. The pull-up pipe could be the same that is used for normal removal of the instrumented-subassembly extension tube. The front of the mechanized box is a shielding window capable of attenuating about 200 R/hr radiation to a tolerable level (under 100 mr/hr).

The system is installed at the bellows-flange level. The subassembly and extension tube are raised far enough that the upper adapter can be exposed in the box. The radioactive part of the subassembly is shielded by lead in front of the bellows and is partially left in the nozzle. The extension tube is cut off above the subassembly upper adapter, pulled into the pull-up pipe, and removed. After the jaws have cleared the upper adapter of the subassembly, the subassembly is lowered back into the reactor by a gripper device. The freed subassembly, replaced in its guide thimble, can be handled by normal fuel handling.

2. Evaluation

Basically the mechanized-box system seems very desirable. It eliminates the need for a special transfer coffin, a storage tube, support structures, etc. However, the space restrictions are difficult to overcome. Study shows that the box could be installed on top of the

Fig. 12. Vertical Section of Mechanized-box System for Removal of Instrumented Subassembly

Fig. 13. Horizontal Section of Mechanized-box System

bellows-flange valve. Shielding must be provided for the bellows section. Because separation of the subassembly from its extension tube could take hours, a substantial shielding thickness would be required for full protection.

Internal mechanisms of the mechanized box are of great concern. Cutting mechanisms must be capable of separating first the extension tube and then its lower end from the upper adapter of the instrumented subassembly. The endmill type of cutting tool is expected to be of a complicated design. A manipulator is needed to clear the adapter from the cut-off pieces. Because space available to house the mechanisms is small, specially designed components are required and many of the existing mechanisms have to be disassembled.

The mechanized-box system has significant merits, but the design and development of the system components would be prohibitively expensive.

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