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LMFBR ALTERNATE SHUTDOWN SYSTEM DEVELOPMENT AND TESTING

SECOND QUARTERLY REPORT
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LMFBR ALTERNATE SHUTDOWN SYSTEM DEVELOPMENT AND TESTING

Second Quarterly Report
April 1972—June 1972

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ABSTRACT

This work summarizes the initial screening of 27 various alternate shutdown system components. Six basic concepts are retained for further evaluation and consideration. The system design is discussed with respect to its classification, relationship to the primary shutdown system, and the logic design. A preliminary nuclear evaluation determined that the reactivity worth of the lithium manometer concept is sufficient to meet requirements.

1. INTRODUCTION

The objective of this program is to select an alternate safety system for LMFBR application and to prove the basic feasibility of the concept through testing in a sodium environment. The system selected for testing should be different in concept from the standard LMFBR control rod system which is driven by drive shafts through the reactor vessel head.

The concept selection phase is currently in progress. Draft system criteria, submitted⁷ prior to this quarter, provided a basis for evaluating the various concepts being considered.

2. SUMMARY

The initial screening process of 27 various alternate shutdown system concepts is summarized and six basic concepts are retained for further evaluation and consideration. These are the six basic concepts:

1. The hydraulic drive concept that uses the main sodium coolant, elevated in pressure by a control pump, to actuate the control element.
2. A latch release mechanism concept that uses the core coolant pressure as the scram assist.
3. A lithium absorber concept.
4. A concept that encapsulates a mechanism and absorber within a sealed container.
5. A concept that achieves control element actuation and position indication through the control assembly bottom.
6. A through-head integral valve concept that changes the primary coolant flow path through the control assembly to actuate the control element.

Also, further consideration will be directed toward more flexible, articulated control elements. Brief descriptions of each concept are included plus an evaluation table listing their response to the criteria and the reason for maintaining or rejecting the concept.

The system design is discussed with respect to its classification, relationship to the primary shutdown system, and the logic design. The alternate shutdown system is classified within the plant protection system. It is recommended that the two shutdown systems, the primary and alternate, be designed to collectively meet the plant protection system (PPS) criteria, and that each system be designed to function as independently from the other as is practical to achieve.

A preliminary nuclear evaluation of the lithium manometer concept indicates a 7.9\$ total system worth, which is sufficient to meet requirements.

3. TECHNICAL ACCOMPLISHMENTS

3.1 SCREENING OF CONCEPTS

3.1.1 Introduction

This work records the initial screening of alternate shutdown system concepts. The scope of PA-64 is to evaluate existing and new methods of providing an alternate shutdown system. Almost all of the existing reactor control systems use a drive mechanism that moves the control element through a drive shaft. Since the purpose of the alternate shutdown system is to be diverse from the primary system that has a drive shaft, and since binding of the drive shaft is a potential common mode failure, the various drives from the literature that have drive shafts were not included. Also since the purpose of the alternate shutdown system is to be diverse from the primary system, the head mounted and shaft coupled drives typically found in the literature were omitted.

The alternate shutdown system is a second shutdown system in the plant protection system and works in parallel with the primary shutdown system. The alternate system should provide diversity for the primary system in all areas, such as the sensors which measure selected plant variables, the protection system logic, the actuator mechanism, and the neutron absorber element. Only the actuator and absorber are considered here.

3.1.2 Summary and Conclusions

3.1.2.1 Summary

A brief description and diagram of each concept considered is presented. The general criteria, given in Reference 7, are given in brief form and the concepts are evaluated relative to the criteria and their design attributes. The concepts maintained through this screening for further design consideration and analysis are grouped into basic concept areas. A later evaluation will select the reference concept and the fall-back concept.

3.1.2.2 Conclusions and Recommendations

Most of the individual concepts classified as "maintained" in section 5 can be grouped into basic concept areas where the individual concept can be thought of as a variation to the basic concept. More detailed design consideration and analysis is recommended for the basic concept areas before incorporation of the best features of the individual concepts can be attained, and before selection of the reference concept and fall-back concept can be initiated. The following listing and grouping shows the basic concepts and their contributing concepts.

1. Hydraulic Drive
 - A. Hydraulic Control Drive (Concept C)
 - B. Hydraulic Control Drive with Upstop (Concept D)
 - C. Closure Mounted Pump (Concept U)
2. Latch Release
 - A. Electromagnetic Control Drive (Concept B)
 - B. Magnetic Latch Drive (Concept S)
 - C. Cable Release Latch/Spring Actuate (Concept V)
3. Lithium Absorber
 - A. Pressurized Manometer (Concept K)
 - B. Buoyant Control Element (Concept X)
4. Encapsulated Mechanism
 - A. Screw Drive (Concept L)
 - B. Rolamite with Constant Torque Spring Motor (Concept M)

5. Modified Compression Cable (Concept N)

This basic concept is attractive if the position indication and control element actuation occurs through control assembly bottom. The scram assist would be developed from the high pressure plenum similar to concept B. The significant incentive for this arrangement is that during refueling the control element could be actuated (with position indication) without requiring any structure above the core, thus keeping the area free for the refueling grapple operation. Various methods for achieving this goal will be considered.

6. Thru — Head Integral Value (Concept R)

7. Articulated Element (Concepts 26 and 27)

Concepts 26 and 27 identify the general area of very flexible control elements. Further consideration will be given to achieving this through various methods. These concepts would be applicable generally to the basic concepts listed above except the lithium absorber.

3.1.3 Concept Description

3.1.3.1 Valve Actuated Hydraulic Control Drive (Concept A)

The control channel assembly has the same outer shape as the reactor core fuel assemblies and fits in the core array among the fuel assemblies at selected positions. The control assembly is cooled from the same source of reactor coolant as the fuel assemblies. See Figure 1.

The control element slides inside a circular guidetube mounted concentrically on the control assembly axis. The control element includes a low clearance drive piston which slides freely in the guidetube but yet has a small enough annular gap to develop a pressure drop large enough to lift the control element. Orifice flow passages, located in the guidetube at elevations above and below the control element stroke range, provide a pressure reduction of the high pressure plenum to values which permit controlling the control element position. The position control is achieved by a valve or a valve like assembly which communicates with the lower guide tube region. When the valve is closed, the lower guidetube pressure will be higher than when the valve is open. However, the upper guidetube region above the control element piston remains comparatively uniform. By properly sizing the flow passages, sufficient pressure change in the lower guidetube region by the valve operation will cause the control element to move up or down. The valve assembly does not have to seat tightly, but needs only to change the flow rate adequately.

The upper end of the guidetube is partially sealed off. Several methods could achieve this; however, the method illustrated uses an ultrasonic position indication probe which extends to the top of the reactor closure.

A scram is triggered by releasing (opening) the valve which drops the pressure on the lower side of the control element. The higher pressure remaining above the control element will tend to assist the scram motion.

The energy source for this hydraulic control drive's operation is the high-pressure plenum pressure. Since this pressure varies with reactor power, the lifting force and scram times will vary with reactor power level. This drive principle is feasible for plants that have 1/3-full power flow rates at startup and zero power.

ADVANTAGES

1. The high pressure plenum pressure is always available during reactor power operation to provide the scram assist.
2. More flexibility is possible in locating the reactor control valve in the reactor design than an electromagnetic sodium pump used for another hydraulic drive concept.
3. Loss of primary coolant flow would result in a gravity-effected scram of control element.

Figure 1. Valve Actuated Hydraulic Control Drive

DISADVANTAGES

1. Maintenance and repair of control line would be very difficult.
2. Speed of control element withdrawal from core is relatively fast and not directly controllable.
3. Operation would be marginal at low primary flow rates.
4. Ultrasonic position indication is not yet developed into a reliable system.

3.1.3.2 Electromagnetic Control Drive (Concept B)

The electromagnetic control rod drive is shown in Figure 2. The drive motor and lead screw (1) raise and lower the magnet (2) to raise and lower the control rod (3). The slip-fit seal (4) allows pressure to be built up on the top side of the piston (5), thus providing the driving force for scram. A dash ram (6) on the end of the control rod drops into a hydraulic dash pot (7) to gently slow the rod down and stop it at the end of the scram stroke. The main reactor flow is directed to the top side of the piston and flows down past it into the lower pressure plenum.

This concept shows simplicity of design and operation as well as an inherent failsafe feature. The coupling, which may be a direct magnet-to-armature connection or a magnetic latch, will require development tests to prove its reliability under the severe environmental conditions of high temperature liquid sodium. Some analysis has been done; a literature search made on magnets in high temperature environments, and feasibility has been indicated. There have been instances in electromagnet tests wherein the insulated wire windings failed after long periods of high temperature exposure. These problems associated with the magnet do not seem unsolvable but will require developmental work.

ADVANTAGES

1. Positive control over poison element withdrawal rate is possible.
2. The concept is simple and straightforward.

DISADVANTAGES

1. Crud buildup on electromagnet or armature could impair the coupling holding ability.
2. Position of the poison element is not indicated throughout the scram stroke.

3.1.3.3 Hydraulic Control Drive (Concept C)

The alternate shutdown drive shown in Figure 3 is hydraulically operated, using primary sodium coolant as the hydraulic fluid. The control rod is moved to the up position by the developed flow of its electromagnetic control pump. The control pump generates a pressure greater than that of the high pressure plenum to create the lifting pressure across the control rod piston. To scram the control rod, the electromagnetic control pump is turned off. Then, the combined action of gravity and plenum pressure above the piston moves the control rod to the down position.

A position indication system extends from the refueling cell floor region through the reactor closure in a drive-guide tube and inserts into the top end of the alternate shutdown control assembly. The main purpose of the position indicator is to determine if the control rod is in the "up" or "down" position, or in the case of a malfunction, if it has stopped somewhere midway. The hydraulically damped spring assembly is located above the control element while provisions for core clamping are incorporated within the control assembly. Neutron shielding that is necessary to protect the core structure from neutron radiation damage is located between the core and core support structure.

ADVANTAGES

1. Simple principle of operation.
2. The control element is the only moving part.

DISADVANTAGES

1. Positive control of element withdrawal rate is not provided.
2. Undesirable penetrations of control piping through the reactor vessel are evident.
3. Maintenance and repair of control piping would be difficult.
4. An auxiliary pump is required which calls for a separate cell for containment.
5. Ultrasonic position indication is not yet developed into a reliable system.

Figure 2. Electromagnetic Control Drive

Figure 3. Hydraulic Control Drive

3.1.3.4 Hydraulic Drive with Withdrawal Control (Concept D)

A variation of the hydraulic drive described in Section 3.1.3.3 is shown in Figure 4. The configuration is similar and the actuation for scram is identical to that for the previous hydraulic drive. The concept here also incorporates the spring damper assembly and the neutron shielding.

The major additional feature is the closure - (6) mounted drive mechanism (4), which includes a motor (1) that drives a lead screw (3) to position the up-stop shaft (7). This shaft provides a precise upper stop for the control element (10) within the control assembly (9) but does not restrict scram motion of the control element. Withdrawal of the control element from the core region (12) is accomplished in a manner similar to that for the hydraulic drive. However, with the up-stop shaft (7) in the down position, the pressure from the control pump (5) is applied to the bottom of the piston (11) and forces the control element up against the stop. The screw can then be slowly retracted to allow precise element withdrawal. An appropriate position indicator (2) and proximity sensor (8) serve to report the position of the control element.

ADVANTAGES

1. Positive control of poison element withdrawal is provided.

DISADVANTAGES

1. Concept has undesirable penetrations of control piping through the reactor vessel.
2. Maintenance and repair of control piping would be difficult.
3. An auxiliary pump is required which calls for a separate cell for containment.
4. Position of the poison element is not indicated throughout the scram stroke.

3.1.3.5 Linear Induction Motor Drive (Concept E)

This concept (see Figure 5) employs a linear induction motor (3) to accelerate the shaft (7) and absorber rod (5) downward into the core region (6). The shaft and absorber rod are held in the ready position by a retaining and release mechanism, such as a holding coil (1) or a solenoid-operated latch (2). Upon receipt of a scram signal, the retaining mechanism releases and the linear induction motor is powered to assist the downward motion of the scrammed parts. Appropriate energy-absorbing devices provide a gentle stop of the moving parts when they reach the end of the stroke. Reversal of the current in the motor will provide an alternate means of slowing the moving parts near the end of the stroke.

After full insertion the absorber section may be disconnected from the main shaft to permit disassembly of the drive and its housing from the closure (9). The coupling (4) is shown only schematically, and the coupling-actuating mechanism is not shown.

Withdrawal of the shaft and absorber rod is accomplished through actuation of the linear induction motor. To ensure a slow, controlled withdrawal rate, the current to the motor will be carefully regulated. Precise control of the location of the shaft during withdrawal can be achieved through a motor-driven up-stop positioner (8).

Operating requirements may mean that the motor be sealed in a container and the scram motion transmitted through a bellows. Alternatively the entire unit might be encapsulated. This would mean that the unit could be removed from the head, the closure removed, and the unit replaced to provide a control drive for refueling.

ADVANTAGES

1. Positive control of poison element withdrawal is provided.

DISADVANTAGES

1. Difficult to design coupling mechanism compatible with concept.
2. The linear induction motor could be susceptible to problems from sodium deposition and require sealing through a fast-acting long stroke bellows which would need development.

Figure 4. Hydraulic Drive with Withdrawal Control

Figure 5. Linear Induction Motor

3.1.3.6 Rupture Chamber (Concept F)

This device (see Figure 6) has a pressurized chamber (3) which contains a charge of absorber pellets (4). An explosively actuated rupture disc (5) separates the material in the pressurized chamber from the evacuated chamber (7). Upon receipt of the scram signal, a signal sent through the control line (1) causes the disc to be breached, and the combined action of gravity and the pressure cause the absorber material to be transferred to the chamber in the core region (6). After removal of the device, the head and closure can be removed and the device replaced to serve as a refueling drive.

ADVANTAGES

1. Device is simple and would be relatively inexpensive to fabricate.

DISADVANTAGES

1. The device can't be completely tested.
2. Can only be used once and then must be replaced.
3. Providing adequate cooling for the absorber material would be difficult.
4. No position indication of poison material is provided.
5. Certain amount of "uncertainty" associated with explosive devices—especially within a reactor.

3.1.3.7 Diving Bell Float (Concept G)

This device (see Figure 7) incorporates a diving bell chamber (1) which is filled with an inert gas and provides sufficient buoyancy in the sodium to support the absorber section (10) above the core region (11). The sodium inside the case communicates with primary reactor coolant. To scram the device the scram solenoid (5) pushes the activating tube (4) down against the over-center mechanism (8) and trips it thereby opening the valve (9). This allows the trapped gas to escape and, hence, permits the diving bell and absorber section to sink into the core region.

To retrieve the absorber section after a scram, the cable reel (6) is powered to pull the cable (7) and return the over-centering mechanism to its "ready" position and, hence, close the valve. Inert gas is then introduced through the gas line (2) and forces the sodium out of the chamber. With the buoyancy restored the chamber again rises to a position above the core region.

The entire device is housed in a case (3) that is mounted on the head (14) and extends down through the closure (13). For refueling operations the device would be removed, the closure removed, and the device replaced. Thus, the system could serve as a refueling drive.

ADVANTAGES

1. Device would extend above the reactor closure only a very short distance.

DISADVANTAGES

1. Scram is only effected by gravity; no powered assist is provided.
2. The device is complicated.
3. Position indication would be difficult.
4. Device would have to be removed before the reactor closure could be removed.

3.1.3.8 Floating Control Rod (Concept H)

This device (see Figure 8) was conceived in response to a desire to have a system that would be automatically scrammed in the event of a low coolant level. No sensors or associated instrumentation are needed to actuate the scram.

An absorber segment (1) is held suspended above the core region (14) by the action of the buoyant element (6) and the pressure force of the sodium on Piston A (5) and Piston B (4). The control assembly is neutrally buoyant in this configuration. As the sodium level is lowered, Piston A descends below the port (15) and the high pressure sodium (7) from the high pressure plenum (2) is prevented from acting on the bottom of Piston A and now acts on the top. The control assembly is driven downward and held down with the absorber in the core region.

Figure 6. Rupture Chamber Concept

Figure 7. Diving Bell

Figure 8. Floating Control Rod

To restore the device to a "reactor operating" mode, the motor and screw (10) are actuated and the coupling (8) is lowered and connected to the extension shaft (9). The control assembly can then be elevated slowly to the proper location where buoyant forces and pressure forces will support it. The coupling is then disconnected by an uncoupling actuator (not shown) in preparation for a scram. The screw and motor can be used to trip a scram by pushing the assembly down so that Piston A is below the port (15).

ADVANTAGES

1. Automatically scrams on low sodium level.

DISADVANTAGES

1. Requires considerable length below core support plate so would be difficult to shield core support plate.
2. Would not be operable during refueling if the reactor sodium level were lowered for refueling.
3. Position indication of poison element would be difficult.

3.1.2.9 Pelletized Poison (Concept I)

This device (see Figure 9) incorporates a hopper containing pelletized poison (3). To effect scram, the iris diaphragm (4) is opened and the charge of pellets drops down the tube (11) and enters the core region (6). To withdraw the poison pellets, the retrieval cup (8) is raised via the cable (5) and the reel (2) which is driven by the pneumatic motor (1). After the charge is replaced in the hopper, the iris diaphragm is closed to retain the charge, and the reel is allowed to unwind freely and the cup is lowered to the "ready" position under the force of the weight (7).

The entire sealed unit would be removed from the head (9) before the closure (10) is moved for refueling. The device could be replaced after the closure is removed and could thus serve as a refueling drive.

ADVANTAGES

1. Large core distortions would have no effect on operability.
2. Control absorber element very different from primary.

DISADVANTAGES

1. Pelletized absorber material requires development.
2. Would be difficult to provide adequate cooling for the absorber pellets.
3. Mechanism that operates diaphragm would be complicated.

3.1.3.10 Interstitial Floats (Concept J)

This concept is similar to the hydraulic drive concept with the exception that the absorber elements are dispersed in the interstices between specially shaped fuel channels. This has an advantage of increasing the specific worth of the absorber material due to the decrease in spatial self-shielding associated with the dispersal. See Figure 10.

An absorber section (3) is confined in a guide sleeve (1) housed in the wall of specially shaped fuel channels (6). The absorber is held elevated out of the core region (4) by sodium pressure acting on the bottom of a piston (5). Scram is effected by shutting off the auxiliary sodium pump and allowing the absorber to drop into the core region. The pump could be reversed to achieve a more rapid scram. The spring (2) at the upper end of the absorber assembly serves to cushion the upward and downward motion at the end of stroke.

The auxiliary sodium pump could be mounted on the head and sodium would be pumped through appropriate piping. Low leakage slip joints would be employed in the piping system to facilitate removal of the head. This arrangement would also allow replacement of any components that might fail during the life of the reactor.

An auxiliary pump could be attached to the in-vessel piping after removal of the head. In this way the control system could be adapted to serve as a refueling drive.

ADVANTAGES

1. Increased reactivity worth per absorber unit mass and more even distribution possible.

Figure 9. Pelletized Poison

Figure 10. Interstitial Floats

DISADVANTAGES

1. Alters fuel and core hardware geometry.
2. Repair and maintenance of components would be difficult and time consuming.
3. No control over poison element withdrawal rate.
4. Fabrication would be difficult.

3.1.3.11 Pressurized Manometer (Concept K)

The concept illustrated in Figure 11 utilizes a pressurized lithium-6 manometer system. Liquid lithium (4) is contained in the manometer tubes (8).

Initially, argon is fed through Leg A and forces the liquid lithium level down in the manometer below the core region (6) to about the elevation of the level indicators (7).

Scram is achieved by opening the scram valve (5) and releasing the pressure in the manometer tubes above the core. This allows the lithium to flow into the tubes within the core region. Proper design of the sizes of tubes and of the restriction (9) will minimize oscillation of the fluid level.

The auxiliary line (1) can be used in conjunction with appropriate valving (not shown) to change the pressure over the liquid in the manometer and, hence, cause slight level fluctuations. The level indicators can then provide signals to ensure that the system is in proper order. This operation provides a means of thoroughly testing the entire system, including the scram valves.

A preliminary nuclear investigation of the reactivity worth is summarized in Section 3.3.

ADVANTAGES

1. The concept is simple—it has only one moving part.
2. Easily complies with core distortion.

DISADVANTAGES

1. A leak of liquid lithium into the primary sodium could cause a major shutdown.
2. Shielding core support plate would be difficult.
3. Corrugated hose must be removed before closure could be moved.
4. The position indication system would be difficult to develop.

3.1.3.12 Screw Drive (Concept L)

This device (see Figure 12) employs a pneumatic motor (1) to transmit torque through the gear reduction unit (2) and the clutch brake unit (9) to turn the rolling element screw (3). The rotation of the screw causes the roll nut (4) to be raised. The roll nut is prevented from turning by the guide block (5) which translates along grooves in the sealed case (6) which is filled with an inert gas. Elevating the roll nut causes the absorber section (7) to be raised out of the core region (8). After withdrawal, the gears and drive shaft are locked from rotation by the brake (9) and the clutch is disengaged. Scram is accomplished by releasing the brake and allowing the screw to turn freely under the torque resulting from the weight of the roll nut and absorber section. The scram motion is arrested near the end of the stroke by the dampers (10) that are extended by the extension shafts (11) when the cage carrying the roll nut impacts the platform (12).

In reactor operation the sealed case with the device inside will be mounted on the head and will penetrate through the closure into the core region. During refueling the entire sealed case will be removed from the head. The closure will then be removed and the device replaced to serve as a control drive during refueling operations.

ADVANTAGES

1. System is easily replaceable since it is in a sealed can.
2. Position of poison element is indicated at all times continuously.

Figure 11. Lithium Manometer

Figure 12. Screw Drive

DISADVANTAGES

1. Providing adequate cooling for the poison element in the sealed inert environment would be difficult.
2. System has many moving parts which are all subject to failure.
3. The system must be removed before the reactor closure.

3.1.3.13 Rolamite with Constant Torque Spring Motor (Concept M)

The key feature of this device (see Figure 13) is the Rolamite mechanism (6) which rides along a cable (10) within the vertical guide tube (9). A carriage (not shown) supports and connects the system of Rolamite mechanisms. Attached to the Rolamite wheels are spring motors, such as constant torque spring motors which act to apply a torque on the wheels. This torque is applied in such a manner that the wheels tend to accelerate downward with greater than gravitation acceleration. The absorber material (7) is carried on a structure that is directly attached to the carriage that supports the Rolamite mechanism. Consequently, the Rolamite mechanisms, their carriage, and the absorber material move as a single body. Due to the action of the spring motors, the assembly is capable of swiftly inserting the absorber material into the core region (8). Appropriate energy-absorbing devices act to terminate the motion gently when the absorber material arrives at the desired location.

The absorber material and mechanisms assembly is withdrawn from the core region by the power train composed of the pneumatic (argon) motor (3), brake and clutch unit (4), and gear-driven, slow speed winch (5) which raises the carriage via the line (11). The retrieval action causes the spring motors to be rewound. The motor, brake, and clutch are actuated through appropriate control (1) and pneumatic lines (2).

Scram can be accomplished by disengaging the brake and allowing the winch to unwind freely. (This release means is not critical to the operation principle of the Rolamite-spring motor concept. Release can be achieved through any of several possible release mechanisms depending upon the particular implementation). The carriage assembly moves down under the force of gravity and the action of the spring motors as explained earlier. The device is constructed to ensure that failure modes are safe (i.e., loss of power will result in the brake being disengaged and will thus result in automatic scram). The mechanism is sealed in a container (the guide tube) which isolates it from sodium and would require a high rate of circulating inert gas coolant.

ADVANTAGES

1. Sealed unit makes the system easily handled and replaced.

DISADVANTAGES

1. The many working parts make the system complex.
2. Providing adequate cooling for the poison element in the sealed inert environment would be difficult.
3. The system must be removed prior to moving the reactor closure.

3.1.3.14 Compression Cable Actuator (Concept N)

The compression cable actuator as shown in Figure 14 is essentially a large push-pull cable device with a control element (1) attached at one end near the core region. It is actuated at the opposite end by one of several possible devices, such as an accumulator (2) acting upon a pneumatic cylinder (3). The complete cable assembly would be inserted through the vessel wall above the sodium level and down between the core and vessel wall within a guide pipe. It would go through the high pressure plenum into the low pressure plenum and curve up into the core region.

There are potential friction problems associated with the movement and some structural problems in the guide structure. Attractive features of the device are ease of position indication as well as the capability to be tested at periodic intervals.

ADVANTAGES

1. During refueling, position indication is maintained without any structure directly above the core.

DISADVANTAGES

1. Maintenance and repair of the system would be difficult and time consuming.
2. Potential sticking due to high friction.

Figure 13. Rolamite

Figure 14. Compression Cable Actuator—Concept N

3.1.3.15 Bellows Hydraulic Control Drive (Concept O)

The bellows control drive shown in Figure 15 is a long, flexible, metal hose filled with sodium and sealed at both ends with a bellows. When the bellows at one end is compressed, the sodium is displaced into the bellows at the other end, which drives the control element out of the core. When the bellows at the top of the vessel is pulled or elongated, the bellows at the other end contracts to lower the control element. A cable within the hose and connected to the ends of the bellows ensures contraction of the bellows.

The hose would penetrate the vessel above the sodium level and pass down between the vessel wall and the core. It would go through the high pressure plenum and into the low pressure plenum through a guide and curve up into the bottom of the core. The control element would be independent of the hose, and would be lowered in through the top of the core. The reactor flow forces the control element down hydraulically at all times.

ADVANTAGES

1. Possible to use as shim drive during refueling.
2. Concept is simple with few moving parts.

DISADVANTAGES

1. Requires development of suitable bellows.
2. System would be difficult and time consuming to remove and replace.
3. System is sensitive to temperature (expansion of sodium) and hence power level. A compensating control system that might be complicated could be required.
4. Actuator must be removed prior to moving the reactor closure.

3.1.3.16 Bellows-Actuated Drive (Concept Q)

The bellows concept shown in Figure 16 is a self-contained unit that can be lowered in and taken out of the core through a port in the reactor closure. An argon gas line (2) passes down through the closure (3) and pressurizes the outer annulus of the canister (4), thus expanding the bellows (1) and raising the control rod (5) out of the core (6). Main core flow (7) is orificed just below the bellows, then passes around and up to the top of the canister to cool the element. When pressure is released from the bellows, it contracts to its normal position under the weight of the control element and under the weight of the net column of sodium above it.

This device has an inherent failsafe feature as any rupture of the bellows would lower the pressure holding the rod and cause it to descend into the core. It is easily replaced as a unit and is relatively free of any movement problems caused by core shifting. There is a problem of high fluence levels affecting the bellows, but this would have to be factored into its periodic replacement schedule.

ADVANTAGES

1. System is contained as one unit and therefore easily replaceable.
2. System is simple and has few moving parts.

DISADVANTAGES

1. Assembly of the device would be difficult because of the sodium addition.
2. System would be sensitive to temperature (power level) and might require a complicated control system to compensate.
3. Development work on the bellows would be required.
4. Position indication would also need development.

Figure 15. Bellows Hydraulic Control Drive.

Figure 16. Bellows-Actuated Control Drive

3.1.3.17 Through-Head Integral Valve Drive (Concept R)

This device (see Figure 17) incorporates a unique scheme for diverting high pressure sodium to the bottom or top of a piston-type neutron absorber element. Sodium from the reactor high pressure plenum is used both to lift the neutron absorber to its out-of-core position and to scram it. The neutron absorber element (1) moves up or down (for scram) inside a guide tube (2) which has a special configuration at its lower end. This special configuration is compatible with a mating configuration at the bottom of the housing (3) which together produce the valving to operate the drive. Raising the guide tube a short distance allows the valving scheme to divert high pressure sodium (from the high pressure plenum) to the bottom side of the piston (4) which results in raising the neutron absorber element to its out-of-core position. The guide tube can be raised by means of a double-acting cylinder (5) mounted on the reactor closure above. The cylinder and drive system would be connected to the guide tube by means of a connection tube (6) that would couple to the top of the guide tube. The top side of the double-acting cylinder would be continuously pressurized from an accumulator supply. Then, in order to raise the guide tube (and thus raise the neutron absorber element), the bottom of the cylinder would be pressurized sufficiently to overcome the pressure on the top side of the cylinder plus the force of compressing the scram-assist spring (7) plus the weight of the moving parts. Scram can then be effected by either venting the lower side of the cylinder or uncoupling the guide tube, both actions can be made failsafe. One additional safety feature is that loss of sodium pressure in the high pressure plenum results in a gravity-effected scram. During a normal scram, the guide tube moves to its bottom position (about 1 to 2 inches) whereupon the high pressure sodium is diverted to the top of the piston while simultaneously the bottom of the piston is vented to the low pressure plenum. This action results in moving the neutron absorber element to its in-core position. Position indication for this two-position drive can be by means of the same ultrasonic system (8) proposed for the hydraulic control drive.

ADVANTAGES

1. Advantage over concept C (H.C.D.) is that this concept requires no auxiliary pump or piping.
2. Loss of primary flow results in gravity scram.

DISADVANTAGES

1. Integrating a guide tube coupling mechanism with an ultrasonic position indication system would make sealing and assembly of the device very difficult.
2. Ultrasonic position indication system needs development.
3. Withdrawal rate of poison element not controlled.
4. Would be difficult to fabricate.
5. Shielding core support plate could be difficult.
6. Lower control element lifting force margin at low flow.

3.1.3.18 Magnetic Latch Drive (Concept S)

The magnetic latch drive (Figure 18) is similar to the hydraulic drive assembly. The control element (10) is able to move axially within the control assembly guide tube (9). Holes located in the mid-section of the guide tube (9) allow the reactor coolant to flow from the high pressure plenum to the region above the piston (12). A net pressure force is exerted down against the piston (12). Upon receipt of a scram signal, the control element (10) can be released by three actuating functions, each occurring simultaneously. These functions are magnetic actuation, axial shaft actuation, and rotational shaft actuation. Although all three functions occur simultaneously, only one is necessary to actuate a scram.

The novel feature of the magnetic latch drive lies in the cam-actuating mechanism. It consists of a cam-lock release (5) with three grippers (4) that couple with the control element head (6). The release actuators consist of an electromagnetic coupling (2) and (14) and the control shaft (1). The drive shaft (3) serves as a housing for the entire release mechanism assembly. When the control element (10) is in the down position, the drive shaft (3) serves as an extension to engage the latch mechanism with the control element coupling head (6). The sensing rod (13) is used to verify the engagement status of the coupling head (6) with the grippers (4).

Figure 17. Through-Head Integral Valve

Figure 18. Magnetic Latch Drive

3.1.3.18.1 Release Sequence

A. Magnetic Actuation (Refer to Figure 19)

When the electromagnet (2) is deenergized and releases the armature (14), the lower portion of the control shaft (1) is allowed to move downward. Due to the force component contributed by the control element (10) loading, the grippers (4) have the tendency to spread outward. The spreading action of the grippers (4), the weight of the cam assembly, and the release-assist spring (11) move the cam-lock release (5) downward. As the cam-lock release (5) moves further downward, the scram-assist spring (7), control element (10) weight, and the high pressure above the piston (12) pull the coupling head (6) from the grippers (4) and accelerate the control element (10) into the core. The deceleration of the control element (10) during the last several inches of the scram stroke is achieved by the hydraulically damped spring assembly (8).

B. Axial Shaft Actuation (Refer to Figure 19)

Assuming the magnetic decoupling fails, the control element (10) can be released by actuating the upper portion of the control shaft (1) downward. This will move the electromagnet housing (16) downward and disengage the control element as described in Part A.

C. Rotational Shaft Actuation (Refer to Figure 20)

The third actuation release function is generated by the rotation of the control shaft (1). The rotational motion is transmitted to the cam-lock release mechanism (5) and allows the grippers (4) to spread outward. The grippers maintain the tendency to move outward because of the force component contributed by the control element loading. The cam-lock release (5) is rotated until the grippers (4) completely disengage the coupling head (6). The acceleration and deceleration of the control element (10) is the same as described in Part A.

3.1.3.18.2 Coupling Sequence

Assuming the control element (10) is uncoupled and located in the core, the drive shaft (3) is driven down. As the drive shaft is driven against the scram-assist spring assembly (7), the assist spring is compressed, and the coupling head (6) is moved against the cam-lock release (5). Further downward travel of the drive shaft (3) pushes the cam-lock release upward leading the grippers (4) into the clamped position. The armature (14) which is an integrated part of the lower control shaft (1), is driven against the electromagnet (2) face during the clamping sequence. To ensure good magnet-armature contact, the drive shaft is driven further downward compressing the back-up spring (15). Then the electromagnet is energized and the drive shaft (3) is withdrawn to the operating position.

ADVANTAGES

1. Three different actions can scram the poison element although only one is required.
2. Positive control over withdrawal rate of poison element is possible.
3. Electromagnet is in a sealed inert environment so is not susceptible to fouling from sodium.
4. The electromagnet does not sustain the entire control element loading force.

DISADVANTAGES

1. The system is complex requiring many moving parts.
2. Development work needed to determine potential for self-welding in coupling.
3. Development required on bellows, springs, and electromagnet.
4. Position indication not continuous during a scram.

3.1.3.19 Control/Fuel Assembly (Concept T)

This drive system control element actuation is similar to the hydraulic control drive. An electromagnetic control pump develops a pressure higher than the core pressure drop, and the difference in pressure lifts the control element in its guide tube. See Figure 21. The control element and its guide tube replace the center 19-fuel rods of selected fuel assemblies. These control elements are smaller than most of the other control assemblies; therefore, several are manifolded to one pump. When the control pump is energized, all of its associated control elements rise together. Turning off the control pump initiates the scram, and the scram is assisted by the high pressure plenum pressure acting on the top of the control element.

Figure 19. Linear Release Sequence

Figure 20. Rotational Release Sequence

SECTION "A-A"
(FULL SIZE)
19 FUEL PINS OMITTED TO
PROVIDE SPACE FOR CONTROL ROD

ENLARGED FUEL/
CONTROL ROD ASM.
(NOT TO SCALE)

Figure 21. Control/Fuel Assembly

ADVANTAGES

1. More uniform distribution of poison material.
2. Slenderness of poison elements means built-in flexibility.

DISADVANTAGES

1. Difficult to integrate with internal core clamping system.
2. Position indication would be difficult.
3. Poison element withdrawal rate is not directly controllable.
4. Would be difficult to integrate the manufacturing, stocking, handling, and processing of a combined fuel/control assembly.
5. Replacement of auxiliary control line would be difficult and time consuming.

3.1.3.20 Closure Mounted Pump (Concept U)

The design mounts the E.M. pumps on top of the closure. See Figure 22. The E.M. pumps are mounted vertically with their inlets and outlets coaxial and located on the bottom of the pumps. The inner of the two coaxial elements is the pump outlet that continues down through a guide tube in the closure to a slip joint located at an elevation just above the top of the fuel channels but outboard radially from them. The guide tube is welded into the closure at the top and bottom for sealing purposes. The slip joint is located in the core restraint area and the control pipe continues down to another slip joint at the core support plate. From there the control pipe is routed to sockets in the bottom of the control rod assemblies.

The outer element of the coaxial pump pipes is the inlet that extends downward to a point below the sodium operating level. This piping arrangement allows disassembly of the system into modules. The first module would be the pump assembly with the length of outlet piping that terminates at the slip joint out the top of the core restraint. The next module is the piping that is routed through the core restraint and could be a semi-permanent part of the core restraint package. The last part of the piping would be an integral part of the core support and would be removed with it.

ADVANTAGES

1. Has advantage over concept C (H.C.D.) in that no penetrations through the reactor vessel are required.

DISADVANTAGES

1. Would require considerable reactor closure space for pumps and shielding.
2. Pumping hot sodium through closure and inlet plenum could cause difficult thermal stress problems.
3. Poison element withdrawal rate is not directly controllable.
4. Position indication requires development.

3.1.3.21 Cable Release Latch/Spring-Actuated Drive (Concept V)

This device combines a unique cable-operated coupling with a spring-assisted scram motion (other modes of scram assist can be considered in combination with the cable-operated coupling, but this description is limited to the spring-scram assist mode).

Basically, this drive operates as follows. Referring to Figure 23, the collet is extended down from the reactor closure until it engages the socket provided at the top of the control element. With the collet and socket engaged, the collet is held stationary while the coupling actuation cable is pulled up a short distance. This moves the linkage to bear against the collet fingers, thereby preventing deflection of the collet fingers and detachment of the control element. The control element can then be lifted out of the core by pulling up on the connection tube while maintaining the proper tension in the coupling actuation cable. This action results in arming the scram-assist spring.

Figure 22. Closure-Mounted Pump

Figure 23. Cable Release Latch/Spring-Actuated Drive

Scram is then effected by releasing the tension in the coupling actuation cable. The linkage could also be designed to allow an emergency pull force (on the cable) to disengage the coupling by pulling the linkage through its most restrictive position. However, the linkage would then have to be reset before further operation.

Position indication can be by means of any system that can "follow" the motion of either the cable or the connection tube (since there is a direct connection to the control element).

Coupling engagement and proper cable tension could possibly be determined by using load cells to measure the compressive and tensile forces.

ADVANTAGES

1. Positive control over poison element withdrawal rate is possible.
2. Use of slender cable accommodates greater lateral movement between reactor closure and core.

DISADVANTAGES

1. Development work needed to determine potential for self-welding of coupling.
2. Position indication is not continuous during a scram.
3. Spring and bellows (for sealing) would need development work.

3.1.3.22 Lithium Filled Bellows (Concept W)

The double bellows control rod uses liquid lithium as the control medium. The lithium is contained in a pair of metal bellows that are sealed at one end with their open ends joined and attached to a bulkhead. See Figure 24. The bulkhead is positioned in a flow tube in the control assembly at an elevation that locates the lower of the two bellows to be just above the reactor core when the bellows is in a retracted or compressed condition. The top bellows would extend upward from the bulkhead a distance equivalent to the control element stroke when it is in an extended condition.

The bottom end of the channel inserts into the core support structure and the lower end of the flow tube is coaxial to and extends slightly beyond the channel end. With the control assembly inserted into the core support, the lower end of the flow tube engages a sodium hydraulic control source and the control assembly lower end receives the reactor high pressure plenum. The flows are ducted such that the sodium from the high pressure plenum acts on the top bellows and the control sodium acts on the bottom bellows.

In operation, the control sodium enters the flow tube at a pressure somewhat greater than the sodium from the high pressure plenum. The resulting pressure drop across the bellows common bulkhead causes the bellows on the core side of the bulkhead to compress and the upper bellows to extend. When the control flow is terminated by a scram signal, the pressure drop across the bulkhead reverses. The upper bellows then compresses and the lower bellows extends into the core. The lithium would now be positioned in the core.

ADVANTAGES

1. Operating principle is simple.

DISADVANTAGES

1. Bellows would need development.
2. Poison material withdrawal rate is not directly controllable and position of poison material could shift with changes in sodium temperature (power level).
3. Position indication requires development.
4. Leak of lithium into sodium could cause major shutdown.

Figure 24. Lithium-Filled Bellows

3.1.3.23 Buoyant Control Element (Concept X)

The buoyant control rod uses lithium as the control medium. The lithium is contained in a light metal (titanium) cylindrical element that has a piston on its top end. See Figure 25. On the top of the piston is a bellows actuated scram latch. The latch is a pair of metal fingers pivoted at the top so that their bottoms protrude from the housing $\sim 1/8$ inch. Each finger has a downward angled slot that is engaged by a cross pin that is attached to the top of a bellows. The bellows in turn is attached to a hollow piston that is part of the top of the lithium filled cylinder. The piston has a vent on its bottom side so that a pressure drop across the piston from top to bottom compresses the bellows thereby retracting the latch fingers. This control element travels vertically in a flow tube that is located in a control assembly in the core. The flow tube plugs into the core support and is open to the high pressure plenum such that the high pressure sodium acts on the bottom of the piston in an upward direction. The bottom of the control assembly inserts into a control sodium line and sodium is ducted into the annulus between the flow tube and the channel wall. This annulus carries sodium from the control line up to act on the top of the piston in a downward direction.

Figure 25. Buoyant Control Element

Under normal operating condition, the control element is held below the core by establishing the control sodium at a pressure slightly greater than the high pressure plenum sodium. When the reactor is scrammed, the high pressure sodium inserts the control element into the core where it is held by the piston mounted latch.

To release the latches in order to move the control down and out of the core requires that the control flow purposely be reinstated and pressure increased so that it is greater than that of the high pressure plenum. This compresses the bellows which withdraws the latch fingers allowing the control element to move out of core.

Since the total immersed weight of the lithium filled titanium control element is less than the displaced sodium, a total loss of sodium flow would allow the element to rise up into the core where it would latch into scram position.

ADVANTAGES

1. Principle of operation is relatively simple.

DISADVANTAGES

1. Poison material withdrawal rate is not directly controllable.
2. Position indication would require development.
3. Achieving adequate buoyancy of control element could be difficult.
4. Leak of lithium into sodium could cause major shutdown.

3.1.3.24 Nosepiece Piston Hydraulic Control Drive (Concept 25)

In this concept,¹ as shown in Figure 26, a solid absorber operates within a special guide tube, and is maintained in its cocked position above the core by an auxiliary sodium flow or pressure, acting against a loose-fitting piston and piston rod. Trip is accomplished by relieving the auxiliary sodium pressure.

While any piston arrangement is susceptible to binding, the loose fit of the piston and its operation in an area of relatively low damage potential reduces, but does not eliminate, the possibility of binding. For example, the presence of foreign material or sodium oxide in the cylinder could also produce binding. The absorber section can also be designed with generous clearances to minimize the possibility of binding. However, since the absorber trips by gravity, small interferences due to distortion or damage to the guide tube may prevent full entry of the absorber into the core region.

ADVANTAGES

1. Piston is out of core region and is not effected by radiation swelling.

DISADVANTAGES

1. There is no positive control over poison element withdrawal rate.
2. Position indication must still be developed.
3. Providing adequate shielding for the core support plate would be difficult.

3.1.3.25 Spheres Element Hydraulic Control Drive (Concept 26)

This concept,¹ as shown in Figure 27, has absorber balls aligned and contained within a tube inside the control assembly. By use of restraining screens at the limits of travel, the large aligned spheres could be replaced by small shot. In all cases, the absorbers are supported by an auxiliary upward sodium flow, and trip is effected by stopping or reversing the auxiliary flow.

The principal problem areas are self-welding (if shot are used), and jamming by accumulation of debris deposits brought about by the continuous flow. If small thoughtubes are employed in a fuel assembly, there is also the danger of disablement due to distortion of or damage to the thoughtubes.

ADVANTAGES

1. Articulated concept for control element makes it relatively insensitive to core distortions.
2. Concept principle is simple.

DISADVANTAGES

1. Position indication would be difficult.
2. Would be difficult to fabricate absorber balls.
3. Positive control over poison element withdrawal is not provided.
4. Development work is required to determine potential for self-welding of absorber balls.

¹. Superscript numbers refer to References.

Figure 26. Nosepiece Piston Hydraulic Control Drive

Figure 27. Spheres Element Hydraulic Control Drive

3.1.3.26 Cable Hoist (Concept 27)

This concept,¹ as shown in Figure 28, employs absorber segments, mounted on a flexible stainless steel cable and operates within a guide. The upper end of the cable is attached to a lifting mechanism located within or above the top shield. The normal position of the absorber segments is below the active core region, and trip is accomplished by rapidly lifting the absorber segments into the core. By selecting the proper material for the uppermost link, and machining it to a bullet shape, it should be possible to pull the absorbers up into the core region, even if the guide tube has suffered severe deformation. The fact that the absorber is pulled, rather than pushed, affords a degree of diversity relative to the primary safety system, and eliminates the possibility of column buckling. A further advantage is that inadvertent top-shield rotation would draw the absorbers into the core.

The principal objection to this concept is that it is not fail-safe with respect to power failure. Also, in the event of even minor mechanical interferences, it might be difficult to reset the unit following actuation.

ADVANTAGES

1. Articulated concept for control element makes it relatively insensitive to core distortions.

DISADVANTAGES

1. Thermal stress and cooling problems are associated with annular absorber elements.
2. Position indication would not sense a sticking control element because the cable would go slack.
3. Poison is out of core during refueling.

3.1.3.27 Lithium Syphon (Concept 28)

This concept¹ has many variations, only one of which is shown in Figure 29. In the concept shown, liquid poison is stored in the lower chamber of a special capsule. On receipt of a trip signal, gas pressure is used to transfer the poison to the upper chamber which is located in the core region. The system is readily restored to the standby condition by pressurizing in the opposite direction. In another variation, the poison drains by gravity from an external tank into the thimble to shut down the reactor; piping is also provided for returning the poison to the storage tank.

ADVANTAGES

1. System is self-contained and therefore easily replaceable.

DISADVANTAGES

1. Position indication would be difficult.
2. Providing adequate cooling to the lithium could be difficult.
3. Lithium leakage into primary sodium could cause major shutdown.
4. System must be removed prior to removal of the closure.
5. Routing pressure control lines would be difficult.

3.1.4 Criteria

During the initial phase of the PA-64 project, the LMFBR Alternate System criteria were prepared and the first draft submitted to RDT March 30, 1972. During the screening evaluation these were the reference criteria. The following two sections reorganize the criteria items into requirements and goals. In the screening section that follows, the letter-number designations will refer to their particular criterion as given here. The number in parentheses at the end of each criterion refers to its section in Appendix A of the First Quarterly Report.⁷ RDT criteria comments were received in the closing weeks of this quarter, but not in time for influence on this report.

3.1.4.1 Concept Requirements

- R1. *Speed of Response* — Currently, only relative response speeds between concepts may be considered until gross fuel damage is defined; the worst case anticipated accident is identified, and then the specific speed of response determined.
- R2. *Reactivity Worth* — Currently, only relative reactivity worth between concepts may be considered.

Figure 28. Cable Hoist

Figure 29. Lithium Syphon

- R3. *Fail-Safe* — Any part of service normally required to maintain the Alternate Shutdown System in its most reactive position, either mechanical or electrical, shall fail safe. Such a failure will not result in a reactivity increase. (4.1)
- R4. No single failure within either the primary or alternate system will prevent the total shutdown system from functioning. Multiple failures resulting from a common mode failure should be treated as a single failure. (4.2)
- R5. An alternate shutdown system scram should not be prevented due to possible common mode failures that could disable the primary safety system. (4.3)
- R6. Redundancy or backup provisions will prevent single failures from resulting in significant primary sodium contamination or significantly increase the probability of local flow blockage. (4.4)
- R7. *Testability* — Appropriate instrumentation and/or procedural testing techniques shall verify that the control poison is ready to scram. This testing shall have a minimal effect on reactor availability. (5.0)
- R8. Position indication of the most reactive and least reactive condition during all operational modes. (7.0)
- R9. The Alternate Shutdown System shall be operable during all environmental conditions, plant operating parameters, and reactor configurations that initiate a scram. (8.1)
- R10. The Alternate Shutdown System shall be capable of maintaining its functional capability for postulated events up to but not including events in the HCDA category. (HCDA is a hypothetical core disassembly accident.) (8.2)
- R11. Physical limitations or other means shall prevent the neutron absorber of the Alternate Shutdown System from significantly overshooting its least reactive core position. (9.1)
- R12. The Alternate Shutdown System must be replaceable or permit replacement of components during a refueling outage without causing undue delay. (9.2)
- R13. During the hypothetical core disassembly accident, parts of the Alternate Shutdown System shall not become missiles that could affect the function of the containment system or permit coolant venting outside the primary vessel boundary. (9.3)
- R14. A unique keying or mechanical sizing design shall prevent placing a fuel assembly in an alternate shutdown core position. (9.4)
- R15. The life of the in-core portion will be designed for at least one refueling cycle. (9.5)
- R16. The in-reactor portion shall be compatible with typical LMFBR program temperatures and with the reactor cover gas. (9.6)
- R17. Sufficient shielding shall be included in the allocated core position to adequately protect the reactor core support structure or the vessel wall or both. (9.9)
- R18. The Alternate Shutdown System must be able to accommodate expected LMFBR core heights between 30 inches and 36 inches. (9.12)

3.1.4.2 Concept Goals

- G1. Minimize additional failure modes that could have significant adverse effects on plant availability. (4.5)
- G2. Minimize additional failure modes that could significantly increase the need for protective action. (4.6)

- G3. Provide fault detection instrumentation (5.0)
- G4. Periodically record scram times. (5)
- G5. Operational capability during refueling. (8.3)
- G6. Compatibility with open-cell and under-the-head refueling. (8.4)
- G7. Permit reactor startup without significant downtime following system actuation. (8.5)
- G8. Be simple and use proven components where possible. (9.7)
- G9. The in-reactor portion should use primary Na as its coolant. (9.8)
- G10. Should accommodate the internal core clamping system. (9.10)

3.1.5 Concept Screening

Each of the concepts presented in Section 3.1.3 was reviewed using the criteria as a checklist and comment format. A summary of this review is presented in the following tabular format. References to the criteria are made through R and G designators; FN refers to the footnotes at the end of the tabular section. Further discussion of the "maintained" concepts occurs in Section 6.

Generally, failure to meet a requirement is sufficient to reject a concept. However, in some cases a concept was maintained when it failed to meet a requirement; yet it appeared attractive and possible modification might overcome the weakness.

3.2 SYSTEM DESIGN

In determining the scope of the Alternate Shutdown System (ALSS), one must consider it in relation to overall Plant Protection System (PPS) requirements. That is, is the ALSS to be treated as a subsystem within the PPS or classified as a separate system not subject to the same criteria? If included in the PPS, what is its relationship with the Primary Shutdown System (PSS) and to what degree must it independently meet PPS criteria (namely, RDT Standard C16-IT)? The following sections address themselves to these "system" aspects and recommendations concerning classification, scope and functional design requirements.

3.2.1 Classification

Section 4.1.3 of RDT Standard C16-IT states "Only PPS equipment shall be used to automatically initiate protective action." Therefore, if the ALSS is to be considered as an automatic system, its inclusion within the PPS is required.

Another alternative is required to classify the ALSS as an emergency backup system which requires manual initiation only in the event of gross failure of the reactor shutdown system. This, however, defeats the purpose of providing a diverse set of actuators designed to protect the core in the event all primary devices fail due to some common mode occurrence. Operators cannot respond quickly enough to guarantee this sort of secondary protection. Also, it is questionable whether or not all PPS criteria can be met with only one set of like shutdown devices.

For the above reasons, it seems unreasonable to relegate the ALSS to a junior system outside the scope of the PPS. Rather, the ALSS should be classified as a subsystem within the PPS and subject to PPS criteria. This is not to say that the ALSS must independently meet all PPS criteria, but that it, in conjunction with all other PPS subsystems, must collectively satisfy the criteria. It is not felt that a separate RDT standard for the ALSS is required or necessary.

3.2.2 Relationship to Primary Shutdown System

Once it is established that the ALSS is a part of the PPS, it then remains to determine the physical scope of the system. Many options can be exercised and still meet overall PPS criteria.

Table 1
CONCEPT SCREENING

Concept Letter Designation	Concept Title	Maintained	Rejected	Concept Evaluation Summary FN_ - See footnotes. R_ and G_ - See Criteria	Reason for Maintaining or Rejecting
A	Valve-Actuated Hydraulic Control Drive		X	Speed: Slow Worth: FN1 Fails to meet R7 Marginally satisfies G5 Other Comments – Main coolant flow rates below 35% may not be adequate to raise the control element	Slowness plus inability to operate at very low reactor flow rates
B	Electromagnetic Hydraulic Control Drive	X		Speed: FN2 Worth: FN1	Ability to meet criteria
C	Hydraulic Control Drive	X		Speed: This concept is the current GE Demonstration Plant reference and as such provides the reference from which the other concepts are relatively evaluated. The ESADA program testing yielded scram times of approximately 1 second Worth: FN1 Fails to fully meet R7.	Testability problem (R7) can be overcome by slight concept modification
D	Hydraulic Control Drive with Upstop	X		Speed: FN3 Worth: FN1	Ability to meet the criteria
E	Linear Induction Motor		X	Speed: Within acceptable range Worth: FN1 Fails to meet R5, drive shaft similar to primary drive	Conceptual similarity to primary shutdown drive

Table 1 (Continued)

Concept Letter Designation	Concept Title	Maintained	Rejected	Concept Evaluation Summary FN_ - See footnotes. R_ and G_ - See Criteria	Reason for Maintaining or Rejecting
F	Rupture Chamber		X	Fails to meet R3, R7, R8, G4, G6, and G7. Marginally satisfies G3	Failure to meet several criteria
G	Diving Bell Float		X	Speed: Slow Worth: FN1 Meeting R7 highly questionable Fails to satisfy G6 Satisfy G8 questionable	Criteria problems plus difficulty providing the required valve mechanism
H	Floating Control Rod		X	Speed: A little slower than the hydraulic control drive (Concept C) Worth: FN1 Fails to meet R5, R7, R9 Meeting R17 questionable Fails to satisfy G6 Weak for G1 and G5	Criteria problems, mainly failure to operate over the reactor power range
I	Pelletized Poison Rod		X	Speed: Slow Worth: Probably lower than primary control element Satisfying G1, G5, and G9 marginal	Suspected problems with pelletized poison, cooling, and refueling
J	Interstitial Floats		X	Speed: FN3 Worth: Probably better than primary system control element or equivalent Fails to meet R7 and R8 Fails to satisfy G10	Criteria problems plus suspected problems with hardware and position indication system
K	Pressurized Manometer	X		Speed: Approximately 3/4 second, FN3 Worth: FN4 Fails to meet R3 if leak occurs Difficult to meet R6 and R17 Fails to satisfy G1 and G6 Weak for G2 and G8	Desired to consider a lithium concept further Attempt to reduce problem areas through additional design

Table 1 (Continued)

Concept Letter Designation	Concept Title	Concept Evaluation Summary		Reason for Maintaining or Rejecting	
		Maintained	Rejected		
L	Screw Drive	X		Speed: Slow Worth: FN1 Fails to meet R5 Questionable if R3 met Fails to satisfy G6 and G9	Desire to consider further, in general, a special mechanism, uniquely different from the other concepts. Concept M is included in this general grouping and the combina- tion of L and M creates a single conceptual unit for follow-up investigation
M	Rolamite with Spring Motor	X		Speed: Within acceptable range Worth: FN1 Fails to meet R5 Questionable if R3 met Fails to satisfy G6 and G9 Weak for G5	
N	Compression Cable Actuator	X		Speed: Within acceptable range Worth: FN1 Fails to meet R3 Difficult to meet R17	Potential modifications to this concept could make it more attractive
O	Bellows Hydraulic Control Drive		X	Speed: FN2 Worth: FN1 Difficult to meet R15 and R17	Suspected problems with bellows near the core region and flexible cable design
Q	Bellows-Actuated Control Drive		X	Speed: Slow Worth: FN1 Fails to meet R7 Difficult to meet R15 and R17 Fails to satisfy G10 Weak for G1 and G6	Suspected problems with bellows near the core region
R	Through-Head Integral Valve	X		Speed: FN2 Worth: FN1 Fails to meet R7 Weak for G1 and G5	Potential to improve with further design effort

2

Table 1 (Continued)

Concept Letter Designation	Concept Title	Concept Evaluation Summary		Reason for Maintaining or Rejecting
		Maintained	Rejected	
S	Magnetic Latch Drive	X		Speed: FN2 Worth: FN1 Weak for G8 Ability to meet the criteria
T	Control/Fuel Assembly		X	Speed: FN3 Worth: Several small elements Fails to meet R7 and R8 Fails to satisfy G10 Suspected problems with hardware and position indication
U	Closure-Mounted Pump Hydraulic	X		This concept locates the control pump on the reactor closure, thus eliminating the control piping through the vessel wall. This source of control flow can be applied to any of the concepts utilizing control flow For further consideration with Concepts D and C
V	Cable Release Latch Plus Spring Actuate	X		Speed: FN2 Worth: FN1 Weak for G1 and G4 Ability to meet criteria
W	Lithium-Filled Bellows		X	Speed: FN3 Worth: FN4 Fails to meet R7 Difficult to meet R6, R10, R15 Weak for G1 and G8 Suspected problems with bellows in the core region
X	Buoyant Control Element	X		Speed: FN3 Worth: FN4 Fails to meet R7 Difficult to meet R15 Weak for G8 Desired to consider a lithium concept further

Table 1 (Continued)

Concept Letter Designation	Concept Title	Maintained	Rejected	Concept Evaluation Summary	Reason for Maintaining or Rejecting
				FN_ - See footnotes. R_ and G_ - See Criteria	
25	Nosepiece Piston		X	Speed: Slow Worth: FN1 Fails to meet R7 and R17	Suspected space and shielding problems
26	Spheres Element Hydraulic Control Drive	X		Speed: Slow Worth: Low Fails to meet R7 Difficult to meet R8 Weak for G1 and G8	Desire to give further consideration to articulated control elements in general
27	Cable Hoist	X		Worth: Low Fails to meet R8 Weak for G1 and G8	Desire to give further consideration to articulated control elements in general. Rejected actuation concept
28	Lithium Syphon		X	Speed: Slow Worth: Low Fails to meet R3, R7, R8 Difficult to meet R17 Weak for G6 and G10	Criteria problems plus potential for bubbles in the core.

FOOTNOTES (FN) TO TABLE 1

FN1 Nearly equal to a primary system control element.

FN2 Similar to the hydraulic control drive (Concept C) without control pump reversal.

FN3 Similar to the hydraulic control drive (Concept C).

FN4 Calculations indicate a total 7\$ to 8\$ potential range for a shutdown system consisting of three control assemblies. See Section 3.3.

Figure 30 illustrates one option where the ALSS represents nothing more than a diverse set of shutdown devices not subject to the same failures as the primary devices. In this configuration, the ALSS loses its "system" identification in that it shares the same logic train and initiating signals as the Primary Shutdown System (PSS) devices. Utilization of diverse initiating parameters, redundancy, isolation, and separation principles can enable this configuration to meet all PPS criteria.

Figure 31 illustrates separation into two subsystems. This method offers the possibility of greater diversity than that of Figure 30 and therefore, increased protection against common mode failures. Once this separation is accomplished, the question then is to what extent does each system independently meet PPS criteria?

From a safety standpoint, one might suggest that each system be independently designed to PPS criteria without regard to the other. However, this is an unrealistic approach when one considers diversification criteria. For each system (i.e., primary and alternate) to be diverse within itself would require double the number of sensors, signal conditioners and trip units. This is not felt to be practical, economical, or even necessary. Also, it is questionable whether or not design limitations would permit the ALSS to provide the same degree of protection as the PSS.

A more sensible approach is to consider the two systems as collectively meeting PPS criteria and then designing each system to be as independent from the other as is practical to achieve. With this in mind, the following goals are recommended:

1. For each postulated accident against which the PPS must defend, the primary variable to be monitored should provide the input to the primary system, while a diverse variable should be used to provide the input to the alternate system. This establishes functional diversification between initiating parameters providing protection against the same accident.
2. If the sensors and signal conditioners of both systems which provide protection against the same accident are necessarily of the same type, then equipment diversity between systems should be employed. However, equipment diversity between redundant channels within a particular system is not recommended. It is felt that this would place an unnecessary burden on operating procedures, maintenance, testing, and spare parts inventory. The end result might be a decrease in system reliability due to utilization of inferior equipment and human factors affected by the more complex system.
3. If the uses of anticipatory signals are justified for inclusion in the PPS (e.g., loss of primary pumping power), then they should provide input to the primary system, but not require backup in the alternate system, the reason being that by nature anticipatory trips monitor for conditions that will result in some plant parameter exceeding safety limits, and protection against this transient will have already been offered in both systems.
4. The degree of redundancy and type of coincidence logic employed in the ALSS may be identical to that in the PSS. However, equipment and component diversity will be employed between the two systems. The purpose of the ALSS is to protect against common mode failures by providing a diverse backup to the PSS. The degree of redundancy and type of coincidence logic do not relate to this purpose.
5. The ALSS shutdown devices (including actuators) must employ both functional and equipment diversity from the PSS. These devices (along with sensors) operate in the environment where the accident is occurring, and therefore, are most subject to failure of performance due to unexpected conditions.
6. The sensors, signal conditioners, and logic should independently meet all redundancy, isolation, separation, and single failure criteria.
7. Operational features, quality assurance, testing, structural, and identification requirements should be independently applied to each system.

Figure 30. Shared Logic and Initiating Parameters

Figure 31. System Separation

The next question to be considered is whether both systems have to limit the consequences of a particular accident to the same severity level. Interpretation of RDT C16-IT (Section 3.4, 4.2.3 and 4.2.4) concerning "Secondary Protective Functions" is that differences are allowed, but justification must be established.

If appropriate justification is not possible, or interpretation by others is that both systems must limit damage to the same level, then the following complications arise:

1. Required response time to the initiating parameters for the ALSS would have to be the same as that for the PPS.
2. The "stuck-rod" criteria would have to be applied to both systems.

Because of design limitations it is recognized that these could be difficult to achieve for the ALSS. It might be that the most reliable diverse shutdown device is inherently slower and/or has reactivity limitations.

A solution to the problem can be achieved by coupling between the two systems as shown by the dashed line of Figure 31. Equivalent protection for all initiating parameters may now be met by having the ALSS initiating parameters actuate the PPS shutdown devices as well (and vice-versa). An added advantage of the coupled system is that additional protection against double subsystem failures is provided. The disadvantage is that coupling the two systems could increase their susceptibility to some common mode failure mechanism. However, it is felt that proper isolation and design techniques can offset this disadvantage. As such, this may prove to be the more practical approach.

However, for the present it is recommended that the design goal be directed toward independent systems, with an option to coupling if necessary to meet response criteria or if it is judged that coupling would benefit overall system performance.

3.2.3 Logic Design

3.2.3.1 Degree of Redundancy and Coincidence

It can be shown that almost any redundant array can be made reliable enough such that it does not present a limiting factor in PPS design.^{1,4} Therefore, the selection of say a 2-out-of-3 or 2-out-of-4 system should be a designer's choice dictated by compatibility with the balance of plant and economic considerations. A 2-out-of-3 scheme is recommended for the ALSS.

3.2.3.2 Mixed versus Individual Logic

Logic systems can be classified as either mixed (general) or individual (local). Mixed logic schemes involve those whereby any two coincident trips of channels will monitor the same parameter. For example, in a 2-out-of-3 mixed logic, a single high temperature trip in channel A coincident with a single high pressure trip in channel B would initiate shutdown, whereas a 2-out-of-3 individual logic scheme would not.

With individual logic, shutdown would occur only in the presence of two high pressure trips or two high temperature trips.

The advantage of individual logic is to reduce the possibility of inadvertent shutdowns resulting from spurious trips in two unrelated channels. The disadvantage is that communication between redundant channels is required for generation of a trip signal. This complicates isolation requirements and testing procedures.

It is argued that use of individual logic increases the possibility of common mode failures. Also, that PPS equipment is usually reliable enough, such that the probability of coincident trips of unrelated channels is not likely, thus complicating the system to include individual logic is unwarranted.

However, in the case of the LMFBR, sensor reliability (especially in the sodium process area) has not been established to a high enough degree. The possibility of a sensor failure (and subsequent channel trip), coupled with the desire to continue operation until a more opportune time for repair, is considered likely. If mixed logic were employed this would result in a 1-out-of-2 coincidence logic for all other parameters. In this situation a single spurious trip in any two channels would initiate shutdown.

Because of the above, an individual logic system is recommended. Proper design can provide appropriate isolation and overcome the testing complications.

3.2.3.3 Solid State versus Relay Logic

A literature search did not reveal any conclusive studies which established superiority of either solid state or relay systems. Jacobs² states "adequate systems can be built using either approach," and in a comparison study, O'Sullivan³ concludes that "Both relay and solid state logic systems have a place in today's reactor safety systems."

Therefore, this is felt to be a designer's choice, dictated by whichever he feels will best meet system requirements.

3.3 PRELIMINARY NUCLEAR EVALUATION OF THE LITHIUM MANOMETER ALTERNATE SHUTDOWN SYSTEM

A preliminary nuclear design study was made of an alternate shutdown system utilizing Lithium-6. This system is based on 3 control assembly locations for the alternate shutdown control.

The primary consideration in this preliminary study was to evaluate the alternate shutdown control system worth using Lithium-6 manometers as represented by the pressurized manometer, concept K, section 3.1.3.11. A summary of individual rod worths and safety system worth is presented in Table 2.

Table 2
EVALUATION OF LITHIUM-6 SHUTDOWN SYSTEM

Number of rods	3
Natural boron rod worth in safety position	\$1.70 ^(a)
Ratio of Lithium-6 to natural boron cell worth	1.20
Worth of Lithium-6 rod in safety position	\$2.04 ^(a)
Ratio of diameters to approximate Lithium-6 worth in tube contour	1.29
Worth of corrected Lithium-6 rod	\$2.64
Total worth of Lithium-6 safety system	\$7.9

(a) Includes all correction factors (i.e., transport).

3.3.1 Description of Calculations

All calculations are based on the target core at the beginning of cycle condition.

All cross-section data for the alternate absorber material (Lithium-6) were obtained from reference 4. These data were added to a 60-group generalized file.

The Lithium-6 cross-sections were then used in a 60-group one-dimensional diffusion theory cell calculation, using the computer code DEMON⁵ to determine the worth of the Lithium-6 control compared to the worth of B₄C from similar cell calculations. The cell, as described in Figures 32 and 33, is representative of one control assembly, discretely described, and surrounded by a uniform mixture of six fuel assemblies with stainless steel structural material and associated sodium coolant.

Calculations for Lithium-6 and natural boron were performed in the heterogeneous cell geometry for both the rod-in and rod-out condition.

ROD IN REGION	FUEL	STEEL	Na	B ₄ C
I	0	0.11	0.28	0.61
II	0	0.18	0.82	0
III	0	0.20	0.80	0
IV	0.34	0.22	0.44	0
ROD OUT	FUEL	STEEL	Na	B ₄ C
I	0	0.08	0.92	0
II	0	0.08	0.92	0
III	0	0.20	0.80	0
IV	0.34	0.22	0.44	0

Figure 32. Target Core One-Dimensional Cell Description (Natural Boron)

ROD IN REGION	MATERIAL VOLUME PERCENT			
	FUEL	STEEL	Na	LITHIUM-6
I	0	0	0	1.0
II	0	1.0*	0	0
III	0	0.20	0.80	0
IV	0.34	0.22	0.44	0
ROD OUT				
I	0	0.08	0.92**	0
II	0	1.0*	0	0
III	0	0.20	0.80	0
IV	0.34	0.22	0.44	0
*REDUCED DENSITY STEEL				
**REDUCED DENSITY SODIUM (VOID CANNOT BE CALCULATED)				

Figure 33. Target Core One-Dimensional Cell Description (Lithium-6)

The density of natural Lithium was obtained from the Handbook of Chemistry and Physics.⁶ Two corrections were applied to the density to produce the 0.412 (g/cc) density of Lithium-6 used in all calculations. A correction, by the ratio of molecular weights (Li_6/Li_7), was applied and a second correction for the temperature expansion to 720°F was applied in a ratio consistent with that of sodium.

For the purpose of the cell calculations the Lithium-6 was confined to an inside diameter of 2.5 inches, which neglects the Lithium-6 within the tube bellows contour. Based upon this diameter the Lithium-6 control worth is 20% greater than a B_4C control element with a cross-sectional area of 3.5 square inches and using natural boron (20% B^{10}).

The control element worth versus enrichment calculation results in a \$1.70 worth for a natural boron safety rod. Applying the 20% increase in the Lithium-6 worth results in a \$2.04 rod worth for a Lithium-6 safety rod.

3.3.2 Discussion of Results

The results are preliminary and are based upon a ratio of the cell worth of natural boron to that of Lithium-6. Natural boron was used for comparison purposes as the unit worth appeared approximately equal to that of Lithium-6, and sufficient information relating to calculations with natural boron existed for a direct comparison.

The cell calculations for Lithium-6 did not include the Lithium-6 within the tube bellows contour. An estimate, based upon a ratio of diameters, of the increase in worth when the Lithium-6 within the tube is considered, results in a rod worth of \$2.64. The Lithium-6 safety system worth, based on this estimate, is \$7.9.

3.3.3 Conclusions

From the neutronics calculations it appears that the Lithium-6 safety system has sufficient strength to be further considered as an alternate backup system.

3.4 FUEL DAMAGE DEFINITION AND CORE DISTORTION MODEL

During this quarter, work on the fuel damage definition and the core distortion model made progress; however, the results are currently preliminary and not ready for publication. These topics are planned for inclusion in the next criteria revision.

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4. ADMINISTRATIVE

4.1 TRIPS

None.

4.2 VISITS

None.

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