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A Simplified Shuttle Irradiation Facility for ATR

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A SIMPLIFIED SHUTTLE IRRADIATION FACILITY FOR ATR

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ABSTRACT

During the past fifteen years there has been a steady increase in the demand for radioisotopes in nuclear medicine and a corresponding decline in the number of reactors within the U.S. capable of producing them. The Advanced Test Reactor (ATR) is the largest operating test reactor in the U.S., but its isotope production capabilities have been limited by the lack of an installed isotope shuttle irradiation system. A concept for a simple "low cost" shuttle irradiation facility for ATR has been developed. Costs were reduced (in comparison to previous ATR designs) by using a shielded trough of water installed in an occupiable cubicle as a shielding and contamination control barrier for the send and receive station. This shielding concept also allows all control valves to be operated by hand and thus the need for an automatic control system was eliminated. It was determined that 4 – 5 ft of water would be adequate to shield the isotopes of interest while shuttles are transferred to a small carrier. An additional feature of the current design is a non-isolatable by-pass line, which provides a minimum coolant flow to the test region regardless of which control valves are opened or closed. This by-pass line allows the shuttle facility to be operated without bringing reactor coolant water into the cubicle except for send and receive operations. The irradiation position selected for this concept is a 1.5 inch "B" hole (B-11). This position provides neutron fluxes of approximately: 1.6×10^{14} (<0.5 eV) and 4.0×10^{13} (>0.8 MeV) n/cm^2*sec.

I. INTRODUCTION

Many of the world's major research reactors[a] are equipped with shuttle facilities capable of inserting small capsules into the reactor core and retrieving them during reactor operations. There are two major purposes for this type of irradiation facility: (1) to provide an economical means of conducting small volume experiments, and (2) for the production of isotopes (particularly medical isotopes) with relatively short half-lives.

The decline in operating reactors in the U.S. and the funding used to support those programs, coupled with a steady rise in the demand for radioisotopes used in nuclear medicine, heightens the need to maximize the capabilities of existing nuclear reactor facilities within the U.S.. Since these radioisotopes are intended for commercial application, it is important that their production be cost effective. Past efforts to design and install an isotope shuttle irradiation facility for the ATR have been deterred by the relatively high cost of these designs.

II. BACKGROUND

Until 1990, the ATR was equipped with a pneumatic shuttle system used for low fluence experiments. The low fluence capabilities of this system, as well as the plastic transport capsules, limited the types of experiments this facility could conduct and, as a result, the system was removed to make room for several New Production Reactor (NPR) experiments.

Since 1990, a number of design studies have been performed to determine the feasibility of installing a new shuttle facility in the ATR. One of these studies was developed into a completed design package (through final design review) in 1994. This design was for transporting a single shuttle into the south flux trap using reactor coolant water as the transport medium. In 1996 this design was modified to accommodate a train of shuttles instead of a single shuttle and its total installation cost was estimated at \$2.4M. The drawbacks of this design were the high installation costs and the use of a flux trap with an irradiation charge of more than \$2M per year.

a. For example, in the United States, the HFIR at Oak Ridge, the University of Missouri Reactor, and the Ford reactor at the University of Michigan all have shuttle facilities.

The primary design criterion used in the current concept was minimization of cost with a goal to reduce the previous estimate by a factor of two or more. Any design features not absolutely necessary from a programmatic or safety standpoint were eliminated. The second design criterion was that the irradiation position must offer reasonably high fluxes (the medium and large I-holes were deemed to be too limiting), but be moderately priced. The irradiation position selected is the southern large hole (B-11) with a total flux that is 40% of the south flux trap, but an irradiation charge of less than 1% of the south flux trap.[b]

Design simplification was accomplished by marrying many features of the 1994 Idaho National Engineering and Environmental Laboratory (INEEL) design with the hydraulic rabbit facility design at Oak Ridge's HFIR reactor. In the 1994 INEEL design, there were 32 mechanical drawings and 60 electrical/instrumentation/computer logic drawings. The current design reduces the electrical/ instrumentation drawings to approximately two. This is done by converting to a totally manual system with only one remote read instrument. Control system simplification is made possible by a unique send/receive station shielding concept and by incorporating a non-isolatable by-pass cooling line.

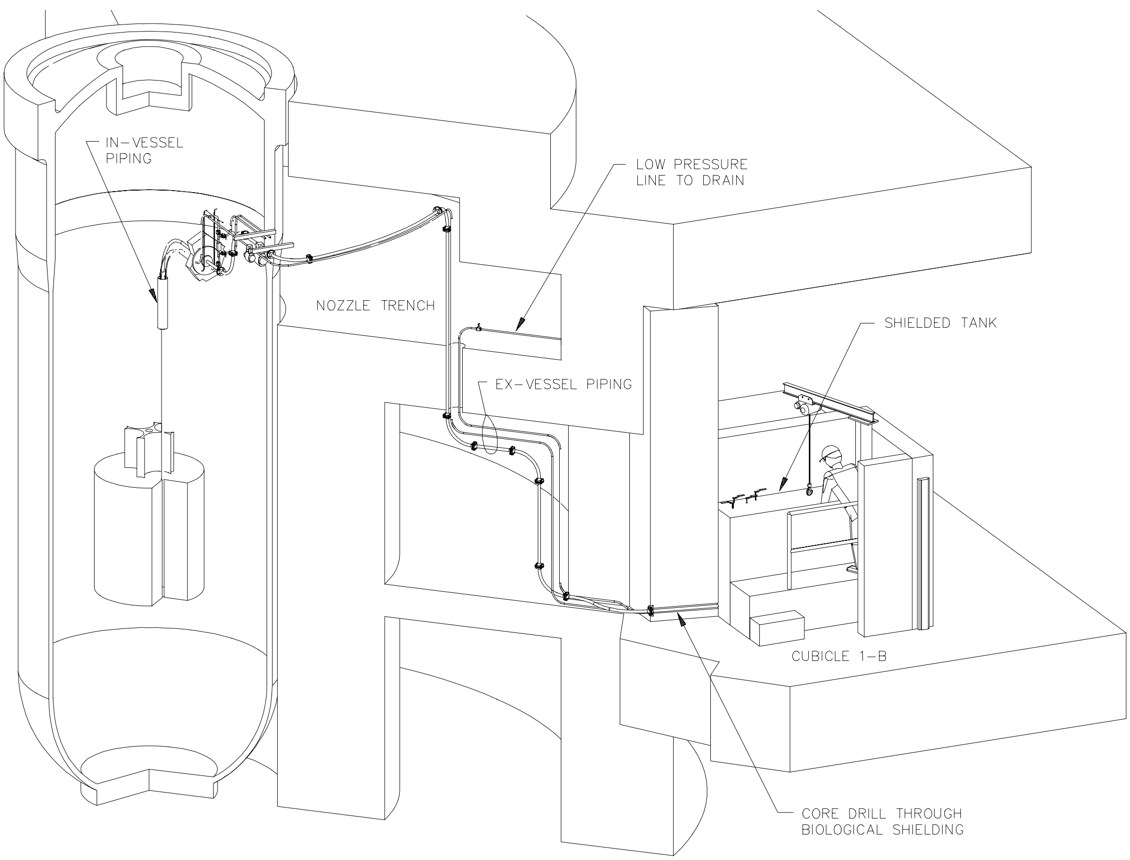

Figure 1. Equipment Layout

b. The published FY-1998 irradiation charges for the south flux trap and large B-holes were $2.7M and $18.2K respectively assuming 25MW lobe power and 280-day operating period. These charges are subject to change.

III. DESIGN CONCEPT OVERVIEW

Figure 1 shows the general equipment layout for the Isotope Shuttle Irradiation System (ISIS). The equipment layout may be divided into three areas: (1) the shielded send/receive station (SRS), control valves,[c] instrumentation, and jib crane in Cubicle 1-B; (2) the transport, high pressure water, other tubing lines, and isolation valves between Cubicle 1-B and the reactor vessel; and (3) the piping and other items within the reactor vessel.

A. Cubicle 1-B Equipment

The SRS station is a close copy of the SRS used in the hydraulic rabbit facility at HFIR and is immersed in a shielded tank of water (see Figure 2). The water tank provides shielding for transferring irradiated capsules from the SRS, minimizes the consequences of Primary Coolant System (PCS) leaks, and provides contamination control. Shuttle capsules are loaded into the send receive station by racking back the SRS cover tube, placing them in an

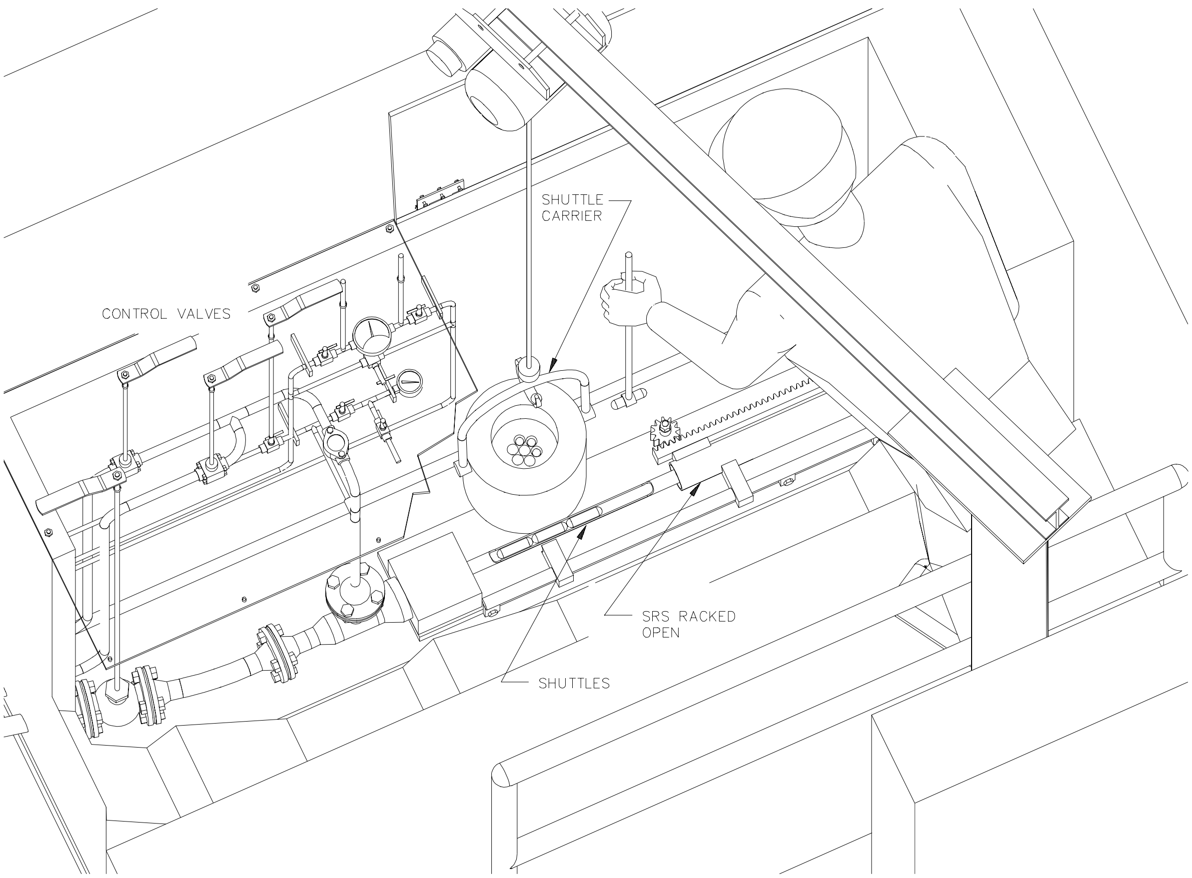

Figure 2. Shielded Tank with Send Receive Station

c. In normal plant process terminology, "control valve" refers to an automated throttling valve; however, in this description, "control valve" refers to an on-off valve used to control the motion of the shuttles or direction of water flow.

exposed slot, and then racking closed the cover tube. Shuttles are inserted or retrieved from the core by operating long stemmed control valves with handles protruding from the tank cover.

A small jib crane is installed next to the tank to lift the shuttle carrier into the shielded tank. Shuttles are removed from the SRS using long handled tools and placed in the shuttle carrier. The carrier lid is then installed and the carrier is lifted from the tank using a hoist or chainfall, wiped down, and placed on a hand truck for transport to an on-site processing facility.

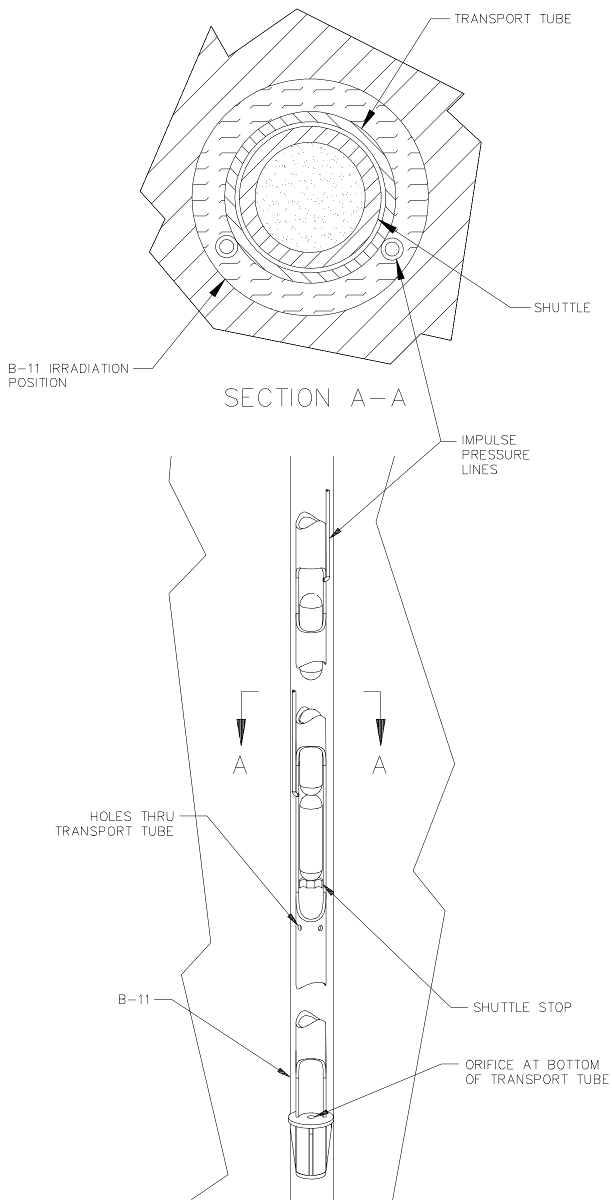

Figure 3. In Core Arrangement

B. Ex-Vessel Piping

Several lines including the transport line, high pressure line, and low pressure line pass through a hole drilled from Cubicle 1-B into the outer shim cylinder corridor and from there through an existing vertical penetration into the nozzle trench. In the nozzle trench, the low pressure water line is piped to a hot waste drain (see Figure 1). The high pressure line and transport line enter the "L-9" flange. Just before entering the L-9 flange, pneumatic operated (air to open spring to close) isolation valves are placed in these lines and a by-pass line is run between them. The remote operated valves and the by-pass line allow the test region to receive adequate cooling without bringing PCS water into Cubicle 1-B. PCS water enters Cubicle 1-B only for short time periods during send and receive operations.

A small flow switch is provided in the by-pass line to verify that a minimum coolant flow is being supplied to the test region. Calibration lines for this flow switch are brought back to Cubicle 1-B.

Small pressure impulse lines also pass between the reactor tank and Cubicle 1-B. These lines carry the differential pressure signal, which indicates the shuttles have seated in the core.

C. In-Vessel Piping and Components

The transport tube passes through the center of the B-11 test position such that there is an annulus between the outside of the transport tube and the inside diameter of the irradiation hole. At the bottom of the irradiation position, an orifice plate with a fairly tight fit results in most of the core pressure drop being taken at this point. Just above the orifice plate, holes are drilled through the transport tube at an elevation below the shuttle stop. The end of the transport tube also has a carefully sized orifice (see Figure 3). By means of these orifices and the control valves in Cubicle 1-B, direction of water flow within the transport tube may be controlled. During insertion and while the shuttles are being irradiated, flow is directed downward. When the shuttles are to be ejected, flow is reversed and passes upward through the shuttle stop, ejects the shuttles from the core, and returns them to the SRS.[d]

Two small impulse lines are tapped into the transport line to take differential pressure readings across the region

d. This is the same basic flow reversal scheme employed at HFIR.

in which the shuttles are irradiated. When shuttles are not in place, the differential pressure between the two locations is very low (being just the pressure drop over a short length of smooth pipe). When shuttles are seated in the core, they provide an obstruction to flow and the pressure drop is an easily measurable 20-30 psi.

D. Operation

A simplified Piping and Instrumentation Diagram (P&ID) is provided as Figure 4. Valve lineups for each of the operational modes are provided on the face of the diagram as an aid to understanding the operation of the facility.

IV. KEY DESIGN ISSUES

A number of critical design issues were taken into account in the formulation of this shuttle irradiation concept and these are described in the following sections.

A. Misalignment of Control Valves and Minimum Cooling Flow

One of the intended strengths of this design is that it should be nearly immune to misalignment of the control valves. Because the by-pass line cannot be blocked by mismanagement of the control valves, a minimum coolant velocity will be maintained through the core region of the transport tube regardless of valve position so long as all valves are either full open or full closed. Flow can only be stagnated in the core region by precise throttling of one or more control valves to just balance the eject pressure against the by-pass flow pressure.

OPERATION	VALVES OPEN	VALVES CLOSED
SEND SHUTTLES	HV–1, HV–2, AV–12, AV–13	HV–4
IRRADIATE		HV–1, HV–2, HV–3, HV–4, AV–12, AV–13
RETRIEVE SHUTTLES TO SRS	HV–1, HV–3, AV–12	HV–2, HV–4, AV–13
REMOVE/LOAD SHUTTLES	HV–4	HV–1, HV–2, HV–3, AV–12, AV–13

VALVE LINEUPS FOR SHUTTLE OPERATIONS

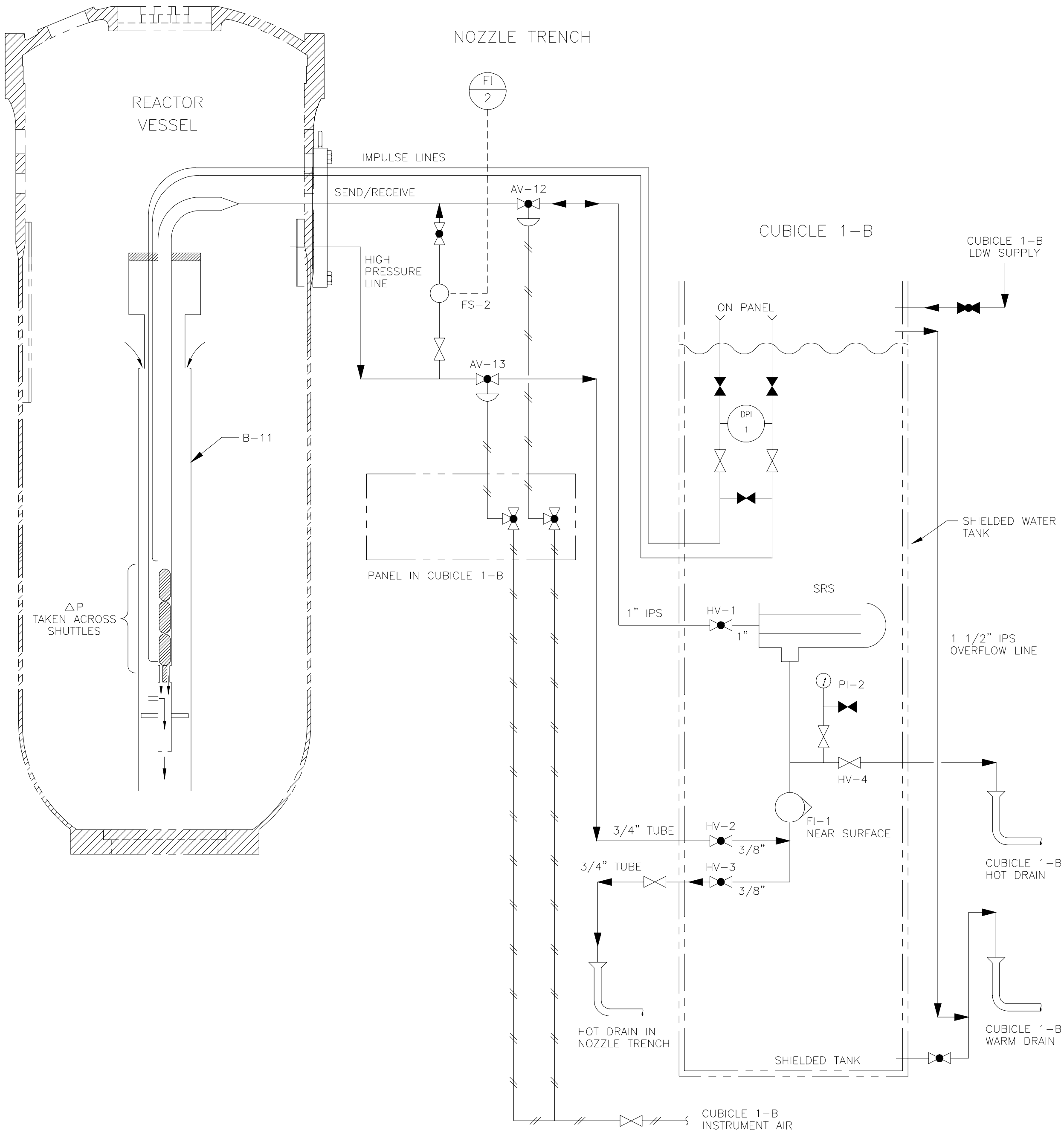

Figure 4. Piping and Instrumentation Diagram

It is not intuitively obvious that with a by-pass line, which essentially provides a short circuit between the high pressure line and the transport line, that: (1) sufficient pressure is available to eject the shuttles from the core and return them to the SRS, and (2) cooling can be maintained in any valve configuration

Scoping thermal hydraulic calculations were made to answer these and other questions. According to these scoping calculations, a minimum cooling flow of 1 gpm is needed to cool the shuttles and a minimum eject flow of 2 gpm is required to return them to the SRS.

The scoping calculations show both criteria may be satisfied fairly easily. However, as expected, there is a trade off between cooling flow and eject flow. As seen in Figure 5, as the by-pass line size is increased, allowing more cooling flow during irradiation, less flow will be available for shuttle ejection.

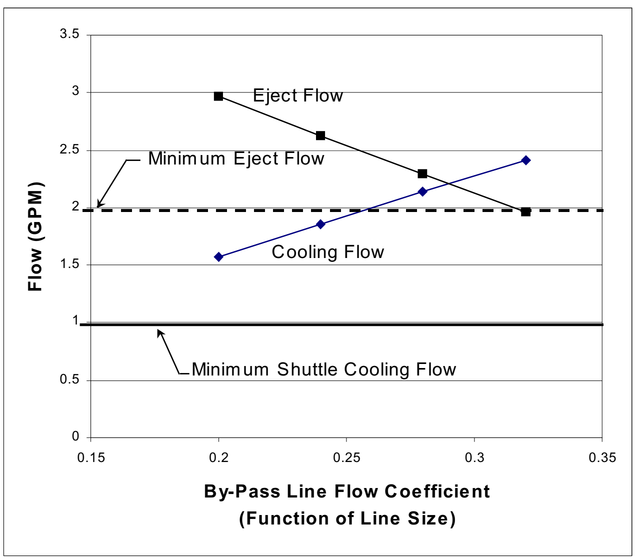

Figure 5. Shuttle cooling flow and eject flow as a function of by-pass line size.

Calculations were also made to determine the reduction in shuttle cooling flow due to valve mismanagement. It was determined that even if the high pressure line is inadvertently left open to drain (valves AV-13, HV-2, and HV-3 open), the shuttle cooling is reduced less than 2%, and if all valves are left open the cooling flow actually increases. This is because there is very little pressure drop between the high pressure line inlet and the by-pass tie-in point. Almost all the pressure drop is taken in the drain line (low pressure line).

B. Indication of Shuttles' Insertion and Return

Preliminary calculations predict that the pressure drop across a train of four or more shuttles will be a very measurable 29 psid. When the isolation valves in the nozzle trench are closed (by-pass cooling alone condition) the differential pressure will drop considerably (to about 3.6 psid), but should still be measurable.

The 1994 design included a means to determine whether the shuttles had returned to the SRS. This feature is not a necessity in the submerged SRS design. Operations at HFIR are based on simply opening the SRS and visually verifying shuttle return. If one or more shuttles have not returned, the insertion and return procedures are repeated and the SRS is again opened and a count made.

C. Impact of Shuttles at Stops

The HFIR rabbit system incorporates hydraulic brakes at both the in-core stop and SRS stop. Preliminary calculations indicate impact velocities of about 3 ft/sec at these stops, which is equivalent to a free drop in air of less than 2 inches. Clearly the titanium shuttles can and must be durable enough to handle a free fall of a few inches onto a hard surface. Impacts with stops appear to be of minimal concern and the complication of adding hydraulic brakes is unwarranted.

D. Shuttle Design

The 1994 INEEL design team showed that a titanium shuttle is several orders of magnitude easier to shield in the first few minutes after irradiation compared to an aluminum shuttle. (The aluminum shuttle even dominated the total field contribution when compared to 2500 Ci of Ir-192.) So although titanium shuttles will be significantly more expensive to produce compared to aluminum, the extra cost appears justifiable.

E. Radiation Shielding Capability of Water Tank

Because dense, efficient shielding materials can be used on the tank sides, it is not too difficult to reduce the radiation field to whatever is desired in this plane. However, shielding in the vertical direction is provided only by water and so tank depth becomes the limiting factor for determining the maximum shuttle plus target source term.

For the purposes of this conceptual design, International Isotopes Idaho, Inc. (I-4) has suggested maximum isotope loadings of 2500 Ci of Xe-125 (intermediate product in the production of I-125) and 150 Ci of I-131. Figure 6 summarizes shielding calculations performed for these two isotopes as well as an empty 50 g titanium shuttle irradiated for 30 days at 0.5×10^{13} n/cm^2-sec thermal[e] .

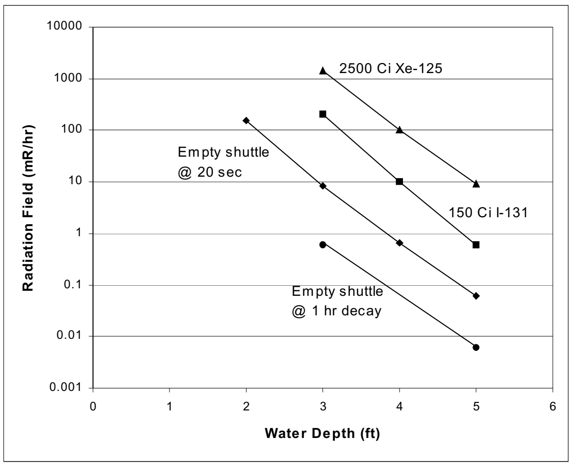

Figure 6. Shuttle and target shielding.

The 2500 Ci of Xe-125 is clearly the limiting case yielding a radiation field an order of magnitude greater than the 150 Ci of I-131. It appears that target loadings of this magnitude are acceptable for tank depths of 4 – 5 feet, which from a practical standpoint seems to be a reasonable size for this design concept. Greater depths of water, say 6 – 7 feet, will allow much higher Curie loadings (i.e., the Xe-125 field is dropping at about a decade per foot of water), but whether such a deep tank is practical in Cubicle 1-B is not clear.

F. Shuttle Carrier Size

One of the features of this design concept is that the shuttle carrier must be small so as to be immersible in the water tank and to be easily transportable in and out of Cubicle 1-B and to the on-site processing facility. The amount of carrier shielding required is dependent upon how much time is allowed for Xe-125 to decay to I-125, an isotope that is very easy to shield. Shielding calculations were performed and it was determined that a carrier weighing in the range of 300-600 lb would provide sufficient shielding given a decay time of 2 to 5 days.

V. CONCLU.S.IONS

1. The rising demand for medical isotopes in the U.S. has increased the need for an isotope shuttle irradiation system for ATR.

2. A relatively low cost, manually operated, shuttle irradiation system appears to be feasible for ATR.

3. Submerging the send receive station in small water trough in an occupiable cubicle appears to be a viable concept.

4. Providing a small by-pass line between the high pressure line and transport line is feasible and provides adequate cooling water under any valve lineup.

5. Because the shuttle capsule is made of low activation titanium and the target isotopes of interest are fairly easily shielded, a small hand truckable carrier may be used to transport the shuttles to the processing facility.

ACKNOWLEDGEMENTS

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e. Actual thermal neutron fluxes are expected to be on the order of 1.6×10^{14} n/cm^2-sec, however, most exposures will be less than 30 days. In any event, the calculations performed show that the fields from the shuttles' payloads greatly dominate bare shuttles alone. Note that the assumed target isotope loadings are not based on any particular neutron flux, but are simply the desired production quantities furnished by I-4.