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A SURVEY OF TRANSPORT METHODS
FOR SHORT TERM IRRADIATION FACILITIES

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A SURVEY OF TRANSPORT METHODS FOR SHORT TERM
IRRADIATION FACILITIES

By

M. K. Mahaffey

Engineering Department
FFTF Project

October 1969

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A SURVEY OF TRANSPORT METHODS FOR SHORT TERM
IRRADIATION FACILITIES

M. K. Mahaffey

ABSTRACT

This report describes methods and systems for achieving short term irradiations in test reactors. Systems discussed include pneumatic facilities for fast operation, quick handling, and low cost; hydraulic rabbits for accommodating higher heat generation rates, or higher induced activities; and trail cables for accommodating larger, heavier test assemblies while maintaining instrumentation and monitoring. Other hybrid facilities are also described.

Also discussed are probable modifications and problem areas which would be encountered in adapting the above principles to be used in the Fast Flux Test Facility.

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A SURVEY OF TRANSPORT METHODS FOR SHORT TERM IRRADIATION FACILITIES

M. K. Mahaffey

1.0 INTRODUCTION

Early in 1966, an AEC directive⁽¹⁾ defining the objectives, requirements, and criteria of the FFTF project suggested the consideration of rabbit systems to provide short term testing in the Fast Flux Test Facility. Conceptual design effort was expended to outline a NaK-cooled, helium operated, pneumatic facility which, at that time, was considered to have the best chance of meeting the LMFBR program requirements as outlined in the directive. However, recent studies of typical experiments to be performed in the FTR for the Liquid Metal Fast Breeder Program have questioned the utility of a pneumatically driven device, while expressing interest in other short term irradiation systems.

A short term irradiation facility is any facility that allows irradiations of less than one operating cycle. Information is presented in this report regarding existing systems in this country and others. Methods which might be adopted for FFTF use are discussed. An attempt is made to compare the various systems with respect to transport speed, weight capability, heat removal capability, radiation hazards, and various reactor interactions.

2.0 SUMMARY AND CONCLUSIONS

By far the largest number of short term irradiation facilities in operation today are pneumatic systems. Included under this general heading are differential pressure systems, vacuum systems, and free blown systems. Air, helium, CO₂, or nitrogen is used in varying instances depending on the availability of the gas, the flux level of the reactor, and the

potential hazards. Argon activation of the air can present a hazard at high flux levels. Most of the pneumatic facilities are located in low power research reactors or neutron generators, and air is the most common transport medium.

Hydraulic transfer systems have been built to accommodate specimens generating more heat than can be tolerated in most pneumatic systems. This added capability requires the sacrifice of some transport speed. Water is the only fluid in routine use in these systems. Other facilities of a hybrid nature have been built to allow irradiations of less than one operating cycle. Examples of these facilities include the GETR Trail Cable, "quickie" facilities operating in the K-reactors at Hanford, Washington, and a Lazy Suzan or Rotary Specimen Rack for low power research reactors.

Potential methods of sample transport in the FFTF include pneumatic, hydraulic, and trail cable systems. The hydraulic system using NaK or Na, although capable of high heat removal rates, must be regarded as potentially hazardous and will require extensive development of operational techniques and components. Depending on the final establishment of facility requirements, both a trail cable and a pneumatic facility are feasible choices. Each system possesses certain potential advantages over the other. The pneumatic facility is faster, and provides for more accurate control of irradiation time. The choice of He for the transport gas allows personnel access to equipment and piping. This facility would require the shortest development program. A trail cable system provides more weight capability, a higher heat removal capability, and a larger test space in addition to in-core instrumentation capability for the capsule. Several parts of the system would require extensive development.

3.0 EXISTING FACILITIES

Facilities for the insertion and removal of test material during the operation of a research reactor or neutron generator are quite common. They are designed to provide sample access to the active region of the reactor or neutron beam, and to allow the removal of the irradiated sample during operation with minimum radiation hazard to the operator or the experimenter. Generally, these facilities can be classified as pneumatic systems, hydraulic systems, or as special devices which fall in neither category.

3.1 PNEUMATIC FACILITIES

Pneumatic facilities are the most common systems used due primarily to their low cost, simple operation, and uncomplicated design. This group includes vacuum systems, differential pressure systems, and free-blown systems. In brief, vacuum systems move the sample by drawing a vacuum in the system and then, by allowing a gas at atmospheric pressure to leak in behind the sample, cause the sample to move from the high pressure to the low pressure end. With a differential pressure system, high pressure gas from a reservoir or cylinder is released behind the sample as a pressure pulse, causing the sample to move toward the low pressure end. Valves are used to select the direction of motion in both systems. In free-blown systems, a blower or other source is used to circulate gas through the sample tube and move the sample ahead of the flow. Direction is changed by reversing the blower or by valve arrangements.

Vacuum systems are widely used in reactor applications because of their low cost and low gas inventory requirements. In addition, operating the system below atmosphere pressure limits the possibility of the release of radioactivity to the

atmosphere. At the Industrial Reactor Laboratories, Inc. in New Jersey, an exhaustor capable of drawing a vacuum of 40 in. of H_2O is used to propel two activation rabbits and, as an auxiliary in a third system,^(2,3) for irradiations in the 5 MW pool reactor. Farther west, at the University of Michigan in Ann Arbor, four tubes are used as vacuum-operated pneumatic facilities⁽⁴⁾ to irradiate samples in the University's Ford Nuclear Reactor, a swimming pool reactor with a maximum power of 1 MW. An auxiliary system powered by an ordinary vacuum-cleaner motor is used to transfer samples from the receiving station to the counting room. Half-lives down to 11 sec can be handled. Polyethylene carriers are used. A vacuum system is preferred over a compressed air system because the vacuum system minimizes the possibility of contaminating the receiving station with radioactive dust from the tubes. Contamination of this kind can be a severe handicap in activation analysis.

Closer to home, the rabbit facility in the PRTR, Richland, Washington, operated by a vacuum pulled by a blower can also be used to circulate gas past the sample. A schematic of this facility is shown in Figure 1.⁽¹²⁾ Air is used as the transport medium. The facility is located in the reflector of the reactor. The containment valves shown in this figure are air operated solenoid valves designed to containment specifications, and capable of manual operation during an electrical failure. An automatic control system is provided to regulate insertion and removal. Recent changes in the nuclear characteristics of the core have caused a steep gradient in the flux at the rabbit facility, seriously restricting its value.

In the low power TRIGA Mark II Research Reactor at Kansas State University, Manhattan, a similar facility is provided to rapidly insert specimens into and remove them from the reactor core. Specimen containers with a usable volume of approximately

FIGURE 1. PRTR Irradiation Facility Schematic, Richland, Washington

2 in.³ are used. Air is the normally used transport medium. Because activation of argon in the air can occasionally present a problem, provisions have been made for the use of CO₂ in some experiments.

This system includes a blower, a filter, solenoid valves, a control box, and associated tubing, as indicated schematically in Figure 2. Tubing from the blower extends to both the terminus assembly and receiver/sender unit of the pneumatic transfer system to supply a pressure differential (vacuum) for the injection or ejection of the specimen. The pneumatic transfer tube (rabbit tube) and pressure tube join above the reactor core. The rabbit, when injected into the core, comes to rest in a vertical position approximately at the midplane of the core. The receiver/sender of the pneumatic transfer tube may be located at any point limiting total one-way rabbit travel to not more than approximately 100 ft. (17)

CP-5 at Argonne National Laboratory has two pneumatic tubes of nominal 5/8-in. and 1-5/8 in. inside diameters. These tubes are operated below atmospheric pressure. Irradiation times range from 2 sec to 1 hr with an approximate accuracy of ± 0.1 sec. Hardened polyethylene capsules are commonly used. Air is the transport medium. An arrangement of the rabbit laboratory and a typical carrier are shown in Figure 3.

The desire for faster transport speeds, and larger samples without the cost of high-vacuum systems led to the development of the second type of pneumatic system. Today, these differential pressure systems are purchase items and are in extensive use⁽⁶⁾ to shuttle samples into reactors and neutron generators for activation analysis. Advantages of the pneumatic over the air operated vacuum systems include less potential argon activation when cylinder gases are used, choice of transport gas, more rapid transfer times, and better control response. Typical

FIGURE 2. *Pneumatic Transfer Systems, Triga Mark 11, Kansas State University, Manhattan, Kansas*

RABBIT FOR CP-5

FIGURE 3. *Components of the Pneumatic Facility in CP-5, Argonne National Laboratory, Chicago, Illinois*

of these systems is the one used at Industrial Research Laboratories in New Jersey. A 40-psig nitrogen pulse is used to supplement an exhaustor in propelling samples into the thermal column of the I.R.L. ^(2,3) research reactor. Capsules up to 4 oz have been irradiated. Transport speed is about 5 ft/sec. A schematic of the system is shown in Figure 4.

Compressed gas is used to propel carriers in rabbit facilities of the Harwell ⁽⁷⁾ Reactors Dido and Pluto. Two facilities are available. One accommodates carriers up to 1 in. OD and 3 in. in length with 10 W of heat generation. The other facility accommodates samples 1/16 in. in diam and 1/8 in. long with a heat generation rate of 6.5 W.

A rabbit system is described ⁽⁸⁾ which is operated by the Israel Atomic Energy Commission at the research laboratories at Rehovoth. Samples are propelled by compressed air (approximately 0.5 atm). The rabbit system is connected to an auxiliary transport system which provides alternate locations for sample return to either a chemistry laboratory, a future hot laboratory, or to spare lines. A flow diagram for this facility is shown in Figure 5.

Since differential pressure systems have a higher potential transport speed than other systems, ⁽⁶⁾ hybrid systems with low weight capability and extremely high speed have been constructed for activation analysis of short-lived radioisotopes. One such facility has been constructed at the Ford Reactor at the University of Michigan which measures half-lives in the millisecond range. ⁽⁹⁾ Sample speeds are as high as 1000 ft/sec, and irradiation times are of the order of 10 msec. The system is designed to shoot the sample through the core and into a circular ring surrounding a counter. Helium from a hold-up tank, precharged to a high pressure, is released by a specially designed firing valve

FIGURE 4. *Schematic Flow Diagram of the Pneumatic Facility at Industrial Research Laboratories, Inc., Plainsboro, New Jersey*

FIGURE 5 Pneumatic Facility at Rehovoth Research Laboratories, Israel

behind the sample. Polyethylene capsules have been used at speeds up to 500 ft/sec, but difficulties were encountered with capsule materials at higher speeds.

The MTR of the Idaho testing station has four pneumatic facilities designated as out of tank VG pneumatic facilities.^(10,11) They are operated by air pressure and carriers are limited to 15 g in weight, 0.6 in. OD and 1 7/8 in. in length. "One of the four is equipped to rotate the lower section of the in-pile tube...to insure a uniform neutron flux to all sides of the experiment." (11)

The third type of pneumatic system provides slightly more heat removal than the other two systems. Free-blown devices are less frequently used, however, because of slower transport times and lower weight capacities. In some cases, there is little difference between a differential pressure system and a free-blown system, especially with a long pressure pulse or large gas flow. The primary advantage of the free-blown system is that the gas can continue to be circulated for cooling during irradiation. A good example of a facility of this kind is being constructed at the Idaho Test Station for the ETR (Figure 6).⁽¹³⁾ Plant air is circulated for cooling when the facility is energized. Valves are used to control the air flow, directing it for sample insertion, return, or cooling. An emergency gas supply is provided for removal in case of a failure in the plant air system.

Pneumatic systems are extensively used because they are generally easy to operate, inexpensive, and safe. Characteristics of some of these facilities are summarized in Table I. As can be seen, air is the predominant medium due to its low cost, high availability, and the simplicity of the associated equipment.

FIGURE 6. ETR Pneumatic Rabbit Facility, Idaho Falls

TABLE 1. *Pneumatic System Characteristics*

Facility	No.	Gas	Size, Weight	Heat Removal, W	Temp, °C	Fluxes	Location
Harwell Dido, Rabbit	-	Choice	1 in. diam × 3 in. long	10	125	Fast 10^{10} Ther 10^{13}	Reflector
Fast Rabbit Harwell	-	Choice	1/16 in. diam × 1/8 in. long	6.5	200	Fast 10^{12} Ther 10^{14}	Core
MIR VG Rabbit	4	Air	0.6 in. diam × 1 13/16 in, 15 g		Ambient	1.3×10^{13}	Graphite Reflector
MIR HR2 Rabbit	1	Air	1 in. × 1 1/2 in.				Core Center
EIR Rabbit	1	Air	0.6 in. diam × 1 13/15 in, 15 g	-			Above Reflector
Industrial Research Laboratories, 5 MW	2	Air					
Industrial Research Laboratories, 5 MW	1	N ₂ Air	1 15/16 in. diam 4 1/2 in., 4 oz.			10^{11}	Thermal Column
University Michigan Ford Research R.	4	Air	1/2 in. diam.			10^{12}	Beside Core in Pool
University Michigan Ford Research K.	1	He	1/2 in. diam			-	Through Port
CP-5 Argonne	1	Air	1 7/16 in. × 3 1/4 in.			10^{13}	Under
CP-5 Argonne	1	Air	1/2 in. diam × 1 1/2 in.			10^{13}	In Core
Israel Rehovoth	1	Air					-
PKTR Hanford	1	Air					Reflector
TRIGA Mark 11 Kansas State U.	1	Air CO ₂	2 cu in.			10^{12}	Core

Other recent purchasers of pneumatic systems include the National Bureau of Standards, U.S. Steel Corporation, International Business Machines, Lawrence Radiation Laboratory, Radiation Physics Division - Sandia Corporation, Accelerator Division - Sandia Corporation, Research Division - Sandia Corporation, Babcock and Wilcox, General Dynamics/Fort Worth, and various universities.

3.2 HYDRAULIC SYSTEMS

In response to requests for short term irradiations of materials in quantities or for quality producing high heat generation rates, hydraulic facilities have been provided in a few reactors. These hydraulic systems use headers on an auxiliary flow system to propel the sample. Although relatively slow, these facilities furnish heat removal capability above that of ordinary gas transport systems. Depending on the design of the receiving end, the water can have an additional benefit as both a radiation shield and a heat removal medium after the sample is returned from the reactor. Operating experience at NRTS, Idaho has even shown hydraulic systems to be more dependable than pneumatic facilities.

Typical of these systems is the hydraulic rabbit used at the General Electric Test Reactor at Vallecitos, Figure 7.⁽¹⁴⁾ The facility is located in the pool surrounding the reactor. Sample loading and return operations take place under 10 ft of water. Coolant flow forces the capsule down into the reactor and a reversal of the flow is used to return the capsule to the sending station. Table II is abstracted from a list of system characteristics in Reference 14. A standard carrier is shown in Figure 8. Since flow reversal is used to return the samples, a zero flow rate condition exists for a short time. This condition limits the heat transfer capability of the device.

FIGURE 7. *Hydraulic Shuttle Facility, GETR*

FIGURE 8. *Standard Shuttle Tube Carrier, GETR*

TABLE II. *GETR Hydraulic Rabbit Characteristics*

Location	Pool
Coolant Inlet Temp	100 °F
Coolant Flow Rate (max)	8 gpm
Capsule Surface Temperature (max)	220 °F
Average Thermal Neutron Flux (<0.17 eV)	1.25×10^{14} nv
Average Fast Flux (>0.18 MeV)	1.3×10^{13} nv
Irradiation Capsule Dimensions	
Maximum (recommended size)	1 in. OD $\times$ 4 in. long
Minimum	0.5 in. OD $\times$ 0.5 in. long
Carrier Dimensions	
Length	5 in.
OD	1.810 in.

At MTR, three hydraulic rabbits (Figure 9)(11,15) are in use which are designed to avoid this zero flow condition in the active zone. Coolant flow is used to push the samples into the core region from below. Decreasing the flow rate causes the samples to fall back out of the core. This minimum flow condition is the critical design point. Characteristics of the MTR hydraulic transfer systems are listed in Table III.

TABLE III. *Characteristics of the MTR Hydraulic Rabbits VH Series*

Location	Core
Irradiation Time (max)	10 days
Tube ID's	
VH-1, VH-2	1.000 ± 0.005 in.
VH-4	1.313 ± 0.005 in.

A high flux hydraulic rabbit facility⁽¹¹⁾ has been proposed for insertion into the ATR at the National Reactor testing station in Idaho. Characteristics of the proposed system are summarized in Table IV.

FIGURE 9. MTR Hydraulic Rabbit Facilities

TABLE IV.   *Characteristics of Proposed ATR
Hydraulic Rabbit*

<u>Location</u>	<u>Core, Flux Trap</u>
Rabbit OD, in.	1 1/8
length, in.	6
Coolant	Demineralized Water
Pressure, psig	80
Flow Rate, gpm	20

3.3 SPECIAL FACILITIES

To meet requirements for test space or sample sizes larger than could be practically accommodated in a rapid transfer facility, or to provide irradiation space where rabbits are not available, various hybrid devices have been constructed. One such device in this category is the Trail Cable Facility in the GETR at Vallecitos (Figure 10).(14) Two of these facilities are available, located in the pool outside the reactor vessel. These facilities have the capability of inserting or removing capsules between scheduled shutdowns. The capsule is suspended from a trail cable which may consist of a wire rope for non-instrumented capsules or instrument leads from instrumented capsules. Cooling flow can be provided from the trail cable water system, capsule header, or auxiliary headers.

The trail cable water system can provide higher flow rates (up to 60 gpm) than the capsule or auxiliary headers. Flux levels available are of the order of 9×10^{13} n/cm²/sec. The curvature of the access tube determines the length and diameter of the capsule which can be accommodated. Capsules up to 3-1/2 in. diam or 50 in. in length can be irradiated. Transfers from the tube to an examination laboratory can be accomplished by a specially designed transfer cask.

Another facility capable of inserting and removing samples during operation is in use in the K Production

FIGURE 10 Trail Cable Facility in GEFR

Reactors at the Hanford Operation (Figure 11) near Richland, Washington. Small capsules with negligible heat generation are irradiated for short time periods. A rod equipped with pockets for holding the capsules is inserted into the reactor for the required exposure, then withdrawn and rotated to permit the selected capsule to fall down a chute into a cask. (16) These facilities are described as "Quickie Facilities."

Another type of irradiation rig is a part of some pool research reactors such as the TRIGA Mark II.⁽¹⁷⁾ The rig is appropriately called a "Lazy Suzan" and consists of a rotary rack of specimen holders surrounding the core. Samples are lowered through an access tube into a position in the rack by an electrically operated latching mechanism. When the sample is in position, the latch is released and the lead is withdrawn. The sample is then rotated to its desired irradiation position (Figure 12). When exposure is complete, the sample is rotated to the access position, the latching mechanism is lowered and automatically catches the specimen. Sample and latch are then withdrawn. The facility is designed to accommodate polyethylene capsules with negligible heat generation.

4.0 TRANSPORT METHODS FOR THE FFTF FACILITY

Most of the short term irradiation facilities which have been previously described are located in water moderated, low power, pool type test reactors which are, in most cases, cooled by natural convection of the water moderator. Only the General Electric Test Reactor is enclosed in a vessel. In this case, however, the test facilities at GETR described in this report are located in the water pool clustered around the vessel. An open pool type reactor has obvious experimental advantages over the closed system planned for the FFTF. The use of liquid sodium at high temperature requires inert gas blanketing of the system to prevent violent sodium-air reactions. Any penetration of the system for experiments must be well sealed to prevent air from leaking in, or the release of radioactive sodium.

FIGURE 11. Quickie Facility in KE and KW Reactors at Hanford

FIGURE 12. *Triga Mark II Reactor Showing Location of Rotary Specimen Rack and Pneumatic Facility*

Three systems have been discussed which might be modified for FFTF use. These systems are the pneumatic rabbit, the hydraulic rabbit, and the trail cable. All these systems will be most useful if they can provide experimental access to the core region during reactor operation. In order to provide this capability, the facility must penetrate into the sodium environment of the core. Consideration of the advantages and disadvantages of each system is not directly influenced by the selection of the final reactor concept, nor is the consideration of a transport medium.

4.1 PNEUMATIC SYSTEM

Much of the early design effort at PNL has been expended on a pneumatic system. One possible transport system is shown as a schematic in Figure 13. The system can operate in several modes including differential pressure, free-blown, or vacuum. The blower can be used to circulate gas through the carrier tube during irradiation. Due to the possibility of contact with primary sodium, air and oxygen can probably be eliminated from consideration as transport mediums. Nitrogen is characterized by a short-lived induced activity when inserted into the primary system, and also might cause nitriding of structural materials at high sodium temperatures with a deteriorating effect on the strength of the facility. Argon has a high induced radioactivity and, if used in the system, could present an extreme hazard in the event of a leak in the gas system. The disadvantage of helium is the high cost of the gas itself. Not shown in Figure 13 is the auxiliary heat removal system probably needed to maintain system temperature below that of the primary sodium system. This system is tentatively described and illustrated in Reference 20. Figure 14 shows the logic required for automatic operation of the pneumatic system.

FIGURE 13. *Pneumatic System Schematic for FFTF Rabbit Facility*

FIGURE 14. Automatic Operation of a Possible FFTF Pneumatic System

Possible reactor interactions with a pneumatic system are largely undetermined beyond the obvious chemical effects of contact between the gas and primary sodium. If a pressurized system is used, a gross failure could cause a large sodium void at the periphery of the core which might propagate to other areas of the core and result in gross fuel meltdown. The reactivity effects of bubbles interjected into the system by small leaks might complicate control by causing reactor oscillations.

The pneumatic system does, however, constitute a proven system and is widely used. It has the potential for developing good transfer speed and has a fast controlled response. The choice of helium will allow personnel access to the sample and gas lines. This system should be able to meet the shorter irradiation time requirements, and the minimum weight requirements for the FFTF. Additional study is needed to ensure that sufficient heat transfer capability can be provided. Testing of fuel may be limited to such small quantities that the experiment may be of little value.

4.2 HYDRAULIC SYSTEM

A hydraulic system presents another possible method of inserting and removing samples. However, severe limitations are placed on the transport medium by safety design criteria. No hydrogenous or organic liquid will be allowed where a failure could cause the liquid to come in contact with primary sodium. From a nuclear standpoint, the addition of hydrogenous material to the core has a moderating effect on the flux spectrum, causing the reactivity in the core to increase. The effects of carbon and oxygen impurities in primary sodium include plugging of small channels, material deposition, and preferential carbon transfer. For these reasons, the most desirable choice of a transport medium for in-core use would

be either NaK or sodium. Unfortunately, due to Na^{22} activity, both sodium and NaK would become radioactive during their passing through the core. Shielded lines of significant length would be needed to transport the rabbit. These lines would be subject to leakage and might present a serious hazard to personnel in case of a sodium or NaK spill. Use of sodium would require all the lines to be equipped with heaters with sequential control for selective heating. Recovery of the carrier from the radioactive sodium or NaK would require remote handling in sodium and also decontamination provisions.

It is also doubtful if a hydraulic system could supply the shorter irradiation times with any degree of reproducibility, especially in a flow reversal system where the inertia of the moving liquid must be overcome before the sample can begin returning. Sample speed is limited in a hydraulic system by the velocity of the liquid which is, in turn, determined by the pipe size and head available.

The primary advantage of the hydraulic system is its high inherent heat transfer capability. The use of sodium or NaK instead of water would only increase this capability. Unfortunately, Na or NaK operated rabbits do not represent existing technology, and problems of remote sample manipulation under radioactive liquid metals would require resolution by an extensive development program before successful use of the facility could be made.

4.3 TRAIL CABLE SYSTEM

A trail cable system could be designed for use in the FFTF. Although not technically a rapid transit device, it could provide irradiations of shorter term than one operating cycle. Rapid removal of a sample would be impossible in such a facility because of reactivity perturbations induced by sample movement and limitations in the removal mechanism itself. The principal

advantage of this facility is its ability to accommodate larger (up to subassemblies) test assemblies. Control rod drives could be used to move test samples in and out of the active zone of the core if that is all that is required. The test samples could then be removed during a normal shutdown. The ability to position the sample in various fluxes and adjust the sample as core characteristics change is also a potential advantage of a trail cable facility.

There are many design problems with a trail cable facility in the FFTF. Exclusive of concept, these would include containment provisions for both sodium and cover gas, selection of material for the cable itself, selection of the fuel handling scheme, and other interfaces. The facility has been used before, but outside the vessel in the pool of the GETR. Locating the facility inside the vessel of the FFTF amplifies containment problems. Located outside the vessel, the facility has dubious value due to serious doubts that sufficient heat removal capability can be provided, or that significant flux levels can be attained.

5.0 CONCLUSIONS AND RECOMMENDATIONS

It is extremely difficult at this conceptual stage of design to make unequivocal statements as to what would be the "best" transport method for a rapid transit facility to be installed in the FFTF. It is especially difficult when no baseline criteria such as objectives and requirements have been established. All that can and perhaps should be done is to review existing facilities and select the methods that have the best chance of meeting a range of requirements for the future facility. These requirements should include not only design requirements and total cost, but schedules for design, construction, and initial operation of the FFTF. On this basis a comparison of the three methods proposed can be made.

In the area of design requirements, admittedly tentative at this time, the pneumatic system shows good promise of meeting minimum size and weight requirements. It is capable of automatic operation and would provide the most accurate control of insertion and removal. Most of the uncertainty surrounds the heat removal capability of the device. Helium appears to be a good choice for a gas, especially if He is used for the reactor cover gas, or in the inert gas exam cells. Large uses of helium would provide a supply and purification system as part of the reactor complex. Alternate gases could be CO_2 and N_2 . Carbon and oxygen are both activated but have low cross sections; while nitrogen is activated but the nuclide is a beta emitter. Argon is activated and could present serious hazards in the case of a gas system leak.

Maximum heat removal capability is provided by a hydraulic system, but other design requirements may not be as easily met. Sample transfer speed is limited by the velocity of the transport fluid. Some uncertainty is connected with accessibility of the sample and, as mentioned before, with decontamination requirements. A radioactive, liquid-metal, hydraulic system may be incompatible with activation analysis.

Neither the design requirements for irradiation times nor the accessibility requirements for activation analysis can be met by a trail cable. These shortcomings are, however, outweighed by its exceeding the requirements for sample size and providing the capability for adjusting its position while in the core. A trail cable facility may be desirable in the FFTF, not as a substitute for a rapid transit facility, but as a short term irradiation facility for fuel or materials tests.

Although no formal estimates have been made, facility construction costs should be of the same order of magnitude. The development costs of sample insertion and removal operations

for the hydraulic facility and the trail cable, however, should be significantly higher than for the pneumatic facility. Operating costs of the three facilities should not be a significant factor in their evaluation. It appears, then, that the pneumatic facility should have the lowest total cost.

The pneumatic facility appears to be sufficiently close to existing technology so that extensive development would not be needed, and current schedules of the project could be met. PNL design effort has proceeded with the assumption that a pneumatic facility would satisfy design requirements. For this reason, no major back-off in design would be required. Less work has been done on the other transport systems, but significant delays would not result since the design effort up to this point has not been a major undertaking. Conceptual System Design Description preparation would be delayed but, with significant emphasis and funds, development programs would be completed on schedule.

On this basis, then, it appears that design work should continue to be directed to the definition of a pneumatic system, and that the major uncertainty of heat removal capability be investigated by further analysis and study. A hydraulic system should be reserved as a back-up facility in case the pneumatic system is proven to be unsatisfactory. The possible utility of a trail cable facility should be determined by the test requirements study currently in progress, and increased emphasis should be placed on the design of a feasible FFTF system.

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