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IN-TANK IRRADIATION FACILITIES
AT THE TEST REACTOR AREA
(Standard Practices Guide)

RELEASED FOR ANNOUNCEMENT
IN NUCLEAR SCIENCE ABSTRACTS

R. L. Ackaret and A. S. Richardson

PHILLIPS
PETROLEUM
COMPANY

ATOMIC ENERGY DIVISION

NATIONAL REACTOR TESTING STATION
US ATOMIC ENERGY COMMISSION

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Atomic Energy Division

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ABSTRACT

This document has been prepared as an aid to the experimenter in planning and designing capsule experiments for irradiations in the Test Reactor Area (TRA) facilities. The report represents a complete description of the facilities available for capsule irradiations. Standard capsules and capsule holders or baskets are also described. A generalized discussion of typical designs of various types of capsules is included. In addition, the requirements for irradiation of capsule experiments are presented.

IN-TANK IRRADIATION FACILITIES AT THE TEST REACTOR AREA (TRA)
Standard Practices Guide

TABLE OF CONTENTS

ABSTRACT.	ii
I. INTRODUCTION.	1
II. IRRADIATION FACILITIES FOR CAPSULE IRRADIATIONS . . .	2
A. MTR Facilities.	2
B. ETR Facilities.	8
C. ATR Facilities.	11
D. Critical Facilities	14
E. Capsule Holders or Baskets.	15
F. Flux Monitors	18
III. CAPSULE DESIGN CRITERIA	19
A. Non-Instrumented Capsules	19
1. Hydraulic Rabbits	19
2. Pneumatic Rabbits	21
3. Open-Capsules	21
4. Sealed Capsules	23
B. Instrumented Capsules	25
1. Capsule Design.	25
2. Lead Tube Design.	26
3. In-Tank Connectors.	27
4. Operating Manuals	28
5. Special Problems.	28
C. Critical Facility Mockup Capsules	28

IV.	PROCEDURE FOR IRRADIATION AT THE TRA.	31
A.	Data and Calculations	31
B.	Scheduling.	33
C.	Sample Identification	33
1.	Numbering System.	33
2.	Marking of Samples.	34

INDEX TO TABLES

Table I	- Size of Various MTR Irradiation Facilities . . .	36
Table II	- Size of Various ETR Irradiation Facilities . . .	37
Table III	- Size of Various ATR Irradiation Facilities . . .	38

INDEX TO FIGURES

1.	MTR Reactor Tank Arrangement.	39
2.	MTR One-hole L-piece (LB)	40
3.	MTR Four-hole L-piece (LB-4X)	40
4.	MTR Four-hole L-piece (LB-4N)	41
5.	MTR Four-hole A-piece (AA-4X)	41
6.	MTR One-hole A-piece.	42
7.	MTR Two-hole A-piece (AA-2W).	42
8.	MTR Four-hole K-piece (KB-4K)	43
9.	MTR Two-hole A-piece (AA-2K).	43
10.	MTR B-piece	44
11.	MTR Hydraulic Rabbit Facilities	45
12.	MTR Reactor Vertical Cross Section.	46
13.	Adjustable Lead Tube Clamp - Type A	47
14.	Adjustable Lead Tube Clamp - Type D	48
15.	ETR Reactor Tank Arrangement.	49
16.	ETR Four-hole Core Filler Piece (C-4X).	50
17.	ETR Beryllium Reflector Assembly.	51
18.	ETR One-hole A-piece.	52
19.	ETR One-hole A-piece Liner.	53
20.	ETR Four-hole Reflector Piece (R-4X).	53
21.	ETR Reactor Vertical Cross Section.	54
22.	ATR Reactor Tank Arrangement.	55
23.	ATR Reactor Vertical Cross Section.	56
24.	Basket Identification Markings.	57
25.	X-Basket.	58
26.	L-Basket.	58

27.	D-Basket.	59
28.	S-Basket.	59
29.	N-Basket.	60
30.	B-Basket.	60
31.	K-Basket.	61
32.	R-Basket.	61
33.	O-Basket.	61
34.	Y-Basket.	61
35.	MTR Capsule Holder Reference Points	62
36.	ETR Capsule Holder Reference Points	63
37.	ATR Capsule Holder Reference Points	64
38.	0.555 ID VH-1 and VH-2 Leaky Rabbit	65
39.	0.805 ID VH-4 Leaky Rabbit.	66
40.	Screw Top Capsule	67
41.	MTR VP Polyethylene Rabbit.	67
42.	HR-2 Polyethylene Rabbit.	68
43.	End Protrusion for 1-1/8 inch Capsules.	69
44.	Open Type Capsule	70
45.	Open Type Capsule	70
46.	Sealed Type Capsule	71
47.	Sealed Type Capsule	72
48.	Measuring and Handling Device	73
49.	In-tank Connector	74
50.	Typical Acceptable Capsule Markings	75

IN-TANK IRRADIATIONS AT THE TEST REACTOR AREA (TRA)

I. INTRODUCTION

This manual was prepared to aid experimenters in design and construction of capsule experiments for irradiation in the TRA facilities. The manual supersedes IDO-16428 which should no longer be used.

The majority of experiments irradiated at TRA are capsule experiments because of the ease of construction and handling. The capsule irradiations have been primarily directed toward fuel element and control rod development, radiation damage studies on materials of construction, and radioisotope production. Experimenters are not, however, limited to these types of irradiations in capsule experiments.

II. IRRADIATION FACILITIES FOR CAPSULE IRRADIATIONS

To aid the experimenter in the design of capsule experiments, it is first necessary to describe the facilities available and to point out the utility and limitations of these facilities. Modifications of these facilities can sometimes be made to suit the experimenter's specific needs; however, such modifications are not discussed in detail here. Details of such modifications should be worked out with TRA Project Engineering.

A. MTR Facilities

1. Reactor Lattice Facilities

The framework that normally contains the fuel assemblies, shim rods and beryllium L-pieces is called the reactor lattice. It consists of 45 pieces arranged in five rows of nine pieces each. A row-column numbering system has been adopted to designate the various positions in the lattice. This system, which is shown in Figure 1, consists of the following:

- a. The prefix "L" is used to indicate reactor lattice.
- b. The rows are numbered 1 to 5 starting with the northernmost row.
- c. The columns are numbered 1 to 9 starting with the westernmost column.

The shim rods occupy positions L-22, L-24, L-26, L-28, L-44, L-46 and L-48. A 3 x 9 "north slab core" fuel lattice is maintained, i.e., fuel assemblies occupy all spaces in the 1, 2 and 3 rows not occupied by shim rods. All other positions in the reactor lattice may be utilized for experimental purposes.

Position L-42 has been modified to provide for vertical through-type experiments where access could be available from both the top and bottom of the experiment; however, because of interferences with the upper grid clamp assembly, top access experiments are not normally inserted in this position. Generally this facility is used for in-pile experiments contained in a thimble. Capsule-type experiments are not irradiated in this facility.

Positions L-41, L-43, L-45, L-47, L-49, L-51, L-52, L-53, L-54, L-55, L-56, L-57, L-58 and L-59 normally contain special beryllium pieces designated LB-pieces, each containing one vertical hole for sample irradiation purposes (see Figure 2). The external dimensions are identical with those of the fuel assemblies. The vertical hole through the body of the LB-pieces has a diameter of 1-3/8 inches and is about 37 inches long. The lower end box has a cylindrical hole 1-13/16 inches in diameter as an exit water flow channel. A pin through the lower end box, centered directly below the 1-3/8 inch hole in the

body of the LB-piece, is used to support the capsules or capsule basket. The internal design of the upper end box was modified from that used for fuel assemblies in order to provide more rigidity and permit easy insertion of irradiation samples. The end boxes are constructed of aluminum, and the bodies of the LB-pieces are constructed of beryllium.

To increase the capsule irradiation space in the MTR, special beryllium pieces, designated LB-4X and LB-4N, have been built. Each of these pieces contain four vertical holes for capsule irradiations. Figure 3 is an assembly drawing of the LB-4X piece and Figure 4 is an assembly drawing of the LB-4N piece. The external dimensions are similar to those of the fuel assemblies. The vertical holes in the LB-4X pieces are 1.312 inches in diameter by 33-3/32 inches long, while those in the LB-4N pieces are 0.873 inch in diameter by 33-3/16 inches long. The lower end boxes are identical to the lower end box of the fuel assembly with an internal flow channel 1-15/16 inches square. Capsule holders or baskets are supported by support brackets which rest on the ledge formed by the transition from the four cylindrical holes to the square outlet water channel. The upper end box of these four hole pieces is removable for loading and unloading experiments. As with the LB-pieces, the end boxes are constructed of aluminum, and the bodies are constructed of beryllium. The four 4-hole beryllium L-pieces are interchangeable and can be used in any position in the L-40 or L-50 rows. Normally the LB-4N pieces are used in L-45 and L-55 while the LB-4X pieces are used in the end positions of the L-40 row and any position in the L-50 row.

During reactor operations, the 5 x 9 array of L-pieces and shim rods is aligned and held rigid by an upper guide grid. This special mechanism fits down over the upper end boxes of all of the lattice pieces; therefore, experiments with instrument lead tubes cannot be inserted in the lattice positions.

Because of the effect on reactor reactivity, the irradiation facilities in the L-40 row are restricted to materials which do not contain fuel or otherwise have a high cross section. In general, materials with cross sections in excess of 3 cm²/inch will not be irradiated in these positions. These positions are usually used for irradiation damage tests on materials of construction such as stainless steel, monel, graphite, etc.

Occasionally full-size experimental fuel elements are irradiated in the L-50 row positions. Experimental fuel elements can also be irradiated in fuel positions L-11, L-19, L-31 and L-39.

2. Reactor Reflector Facilities

The reactor reflector occupies the region between the lattice and the tank wall. It is 39-1/2 inches high, extending 7-3/4 inches above and below the active section of the fuel assemblies. The original MTR reflector was made up of beryllium pieces fitted together to make an essentially solid reflector with a number of horizontal penetrations for the beam holes. To make irradiation space available in the reflector, a number of the removable solid beryllium pieces were replaced with aluminum or beryllium pieces containing vertical holes. These pieces

include 43 A-pieces 3 inches square, three K-pieces 3 inches square, four B-pieces triangular shaped, and one D-piece 6 inches square. These pieces are located as shown in Figure 1.

a. A-Pieces

The A-pieces generally used are designated AA-4X and are interchangeable and essentially identical in construction. They are located in the reactor in the A-positions indicated on Figure 1. Figure 5 shows the details of these pieces. Each piece is constructed of aluminum approximately 3 inches square and 37-1/2 inches long. An end box is attached to the bottom to align the piece in the lower support casting. Each AA-4X piece has four holes 36-13/16 inches deep by 1.312 inches OD. One-half inch diameter holes are drilled from the bottom of these holes to the 1-3/4 inch OD plenum of the end box. In many of these pieces holes are provided for the insertion of 1/4 inch OD flux monitor tubes. Capsules or baskets are supported by two 5/16 inch pins which pass through the lower ends of the 1.312 inch holes.

A-pieces with one or two holes are available for special experiments. Details of these pieces are shown in Figures 6 and 7. Special A-pieces have been constructed by experimenters. After use, these pieces are stored at the TRA for possible future use by others. Availability of such pieces or details of design and construction of new pieces should be worked out with TRA Project Engineering.

b. K-Pieces

The beryllium K-pieces are located in positions between the lattice and the A-pieces along the western edge of the reflector. Figure 1 shows the location of these positions. Details of the K-pieces are shown on Figure 8. Each piece is approximately 3 inches square and 22-1/2 inches long. The pieces set on a special base piece which align them and provide a plenum for flow from each of the three to a special A-piece (AA-2K) in the A-32 position. The AA-2K piece has been modified to support its experiments at the same elevation as the K-pieces and to accept the flow from the K-pieces (Figure 9). Each KB-4X piece has four 1.312 inch OD holes through its entire length. Capsules are supported on two 5/16 inch diameter pins which pass through the lower end of the piece. Hydraulic tests indicate that water flow to these KB-4X pieces can be expected to be about the same as in the AA-4X pieces.

c. B-Pieces

The B-pieces occupy the space between the innermost A-pieces and the liners for the four corner beam hole penetrations. Figure 10 shows the details of the original beryllium B-pieces. These positions are utilized by experimenters who have experimental assemblies not adaptable to the other irradiation facilities because of size or geometry limitations. Experimenters wishing to use these facilities must design and construct their own experiment holder to replace the B-piece. These holders may be constructed of aluminum if desired. Cooling water that flows through the B-piece positions follows a devious

and restricted path and experiments in these positions must be designed with auxiliary cooling systems. Design of facilities for the B-pieces should be coordinated with TRA Project Engineering.

d. D-Piece

The D-piece serves as a plug for the upper end of the discharge tube. Its position is shown on Figure 1. The D-piece is six inches square and the position is normally occupied by a solid beryllium piece. A special aluminum piece is available with eight vertical holes 1.375 inches in diameter by 36-7/8 inches deep. One inch diameter holes are drilled through the lower end of the D-piece to serve as water channels. Experiments or baskets are supported by a 5/16 inch pin near the bottom of each 1.375 inch hole. Cooling water flows through the D-piece, down the discharge tube and then into the main water system through six one-inch diameter ports in the discharge tube below the lower grid support casting. The restricted water flow limits D-piece experiments to those of relatively low heat generation. The D-piece must be removed from its position for experiment and fuel element handling between the reactor and canal. This restricts the D-piece experiments to non-instrumented capsules.

3. Experiment Handling Facilities

Loading and unloading experiments from L-pieces, A-pieces, K-pieces, B-pieces and D-pieces is normally accomplished with the piece in its place in the reactor by using long handled tools from a working platform mounted on the reactor top. It is necessary to remove the LB-4X and LB-4N pieces to the canal for disassembly, experiment unloading, reloading and reassembly. A number of the A-pieces lie partially under the D-tank upper flange which is only 9-15/16 inches above the top of the reflector. These pieces must be removed from under the flange to change experiments. This necessitates the removal of the adjacent A-piece first.

Experiments, pieces, fuel elements and other components are handled between the reactor and the canal through the discharge tube. The upper end of the discharge tube lies directly beneath the D-piece on the east side of the reflector. Material handled in the discharge tube must be of such dimensions that it can be completely enclosed in the tube and not become stuck. The tube can handle material up to 4.75 inches OD. Maximum useable length depends upon diameter; 15 ft - 7-3/4 inches up to 2-3/4 inches OD, 15 ft - 6-3/4 inches up to 3-1/2 inches OD, and 15 ft - 5 inches up to 4-3/4 inch OD.

4. Hydraulic Rabbit Facilities

The MTR hydraulic rabbit facilities provide for the irradiation of capsules in high neutron flux fields for periods ranging from several minutes to several days. No rabbit irradiations are allowed for periods over ten days because of the high demand for these facilities. Hydraulic rabbit facilities are located in VH-1, VH-2 and VH-4 positions seen on Figure 1. The VH-3 rabbit facility has been taken out of service for an indefinite period of time to accommodate a special irradiation facility.

Figure 11 is a schematic of the hydraulic rabbit facilities.

The VH-1 and VH-2 rabbit tubes are 1.000 ± 0.005 inches ID, and the VH-4 tube is 1.313 ± 0.005 inch ID. When a rabbit is forced up into the rabbit tube, it comes to rest against a spider at the end of the tube which prevents it from being forced out into the plenum chamber above the reflector. The irradiation sample can be stopped at positions below the end of the tube by inserting dummy rabbits or spool-like spacers ahead of it. It is cooled by process water that flows up the tube, past the rabbit, through an orifice in the spider and into the process water system.

Capsules in the exposure zone will be in regions of relatively high neutron and gamma flux and cooling may be of prime importance. The amount of cooling attainable depends upon the water flow past the capsule, which in turn depends on capsule design and the water pressure differential.

Rabbits are removed by decreasing the flow rate until the hydraulic force will no longer overcome the weight of the capsule and it falls down. The hydraulic conditions which exist the instant before the capsule begins to fall must be considered in the hazards analysis for the experiment. The VH-1 and VH-4 inlet water lines are equipped with rotameters which can be used to determine the hydraulic flow conditions for an experiment. A rotameter could be installed on the VH-2 inlet water line if desired by an experimenter.

Rabbits with thermal and hydraulic conditions which do not permit lowering the flow for removal may be scheduled so that removal can be made after the reactor has been shut down. This permits the rabbit to cool down and flow can be lowered in the absence of a high neutron or gamma flux.

A low flow reactor scram system is available on the VH-1 and VH-4 facilities. This system is actuated by a series of pressure switches which can be set to correspond to a minimum flow for a particular rabbit which has a high heat flux.

5. Pneumatic Rabbit Facilities

Pneumatic rabbit facilities (VP) are available for short term irradiations in four of the vertical graphite holes. These facilities are portable and are operated from the reactor top. One of the four is equipped to rotate the lower section of the in-pile tube that contains the experiment during irradiation. This rotation is used to insure a uniform neutron flux to all sides of the experiment.

a. HR-2 Rabbit Facility

A pneumatic rabbit facility has been installed in the HR-2 facility. The system is designed to send a special high density polyethylene rabbit with the encapsulated experimental sample from the send-receive station in the MTR basement through a shielded guide tube into the HR-2 facility to a stop in the center of the reactor. The

rabbit is returned to the send-receive station by reversing the air flow. Experimenters interested in the use of this facility can obtain detailed information from TRA Project Engineering.

6. Vertical Graphite Facilities

The MTR has 62 experimental graphite holes, accessible from the top of the reactor. Some of these penetrate into the graphite pebble zone and some into the solid graphite; two are also accessible from the sub-pile room. The latter two holes have been occupied continually for the last several years and will not be available for an indefinite period of time. Six of the vertical graphite (VG) holes are permanently occupied by reactor controls. Four of the VG holes are occupied by the VP rabbit facilities. The VG holes vary in size from 2 inches in diameter to 4 inches in diameter, with one 10 inches square. The thermal flux in the graphite zone varies from 5×10^{10} to 1.3×10^{13} . All of these holes are air cooled and therefore are unsuitable for experiments of high heat generation. Since most capsule experiments at the MTR have higher flux requirements than those available in the graphite holes, a detailed description of these facilities will not be given here. Experimenters interested in the use of these facilities can obtain information from TRA Project Engineering.

7. Other Facilities

In addition to the experimental facilities discussed above, there are a number of others available for use. These include the following:

- Six horizontal beam holes;
- Six down beam holes,
- One horizontal through hole,
- Nine horizontal graphite holes,
- Two vertical gamma thimbles,
- Thermal column facilities.

In general these facilities are used for more complex engineered experiments. Details of the experimental facilities and assistance in designing experiments for them should be coordinated with TRA Project Engineering.

8. Instrumented Capsule Communication

Instrumented capsule experiments requiring communication outside the reactor during irradiation can be accommodated in most reflector positions of the MTR. The leads from these experiments may include, but are not limited to, thermocouple extension wires, electric heater lead wire, gas and liquid lines. These leads must be enclosed in a suitable tube which is brought out of the reactor tank through one of the 36 sloping nozzles in a spool piece just beneath the top plug. Each nozzle will normally accommodate three lead tubes up to 3/4 inch diameter. Metal and rubber ring seals are available for cylindrical tubes from 1/4 inch diameter to 3/4 inch diameter in 1/8 inch increments. Tubes which vary from these standard sizes will require special flanges and seals, the

designs of which should be coordinated with TRA Project Engineering.

Experiment lead tubes are clamped at two elevations between the reflector and the access nozzle as shown in Figure 12. The clamping is required to minimize failure of the lead tubes from excessive flexing resulting from the extreme turbulence of the process water flowing through the reactor vessel. Several different types of clamps may be used, depending upon the location of the tube, in-tank congestion and interferences. Two of these clamps are shown on Figures 13 and 14. The other clamps are built in.

9. Experiment Instrumentation

Instrumentation required for experiments must be provided by the sponsor. Space for instruments is provided in cubicles located near the reactor top. Complete instrument consoles can also be accommodated on the reactor top balconies, the 2nd floor balconies, and on the main floor. The following utilities can be made available at these locations:

- 110 V and 220 V AC 60-cycle electricity,
- 125 psi instrument air,
- 125 psi plant air,
- demineralized water.

Connections between experiment instruments and the reactor top are made in a semi-permanent manner at the time of installation of the instrumentation. Thermocouples are normally connected with copper leads from the instrument to a controlled temperature cabinet maintained at the same temperature as the air in the vicinity of the reactor top. Compensated thermocouple extension wire is installed between the cabinet and amphenol plugs located immediately beneath each access nozzle. Temporary connections between the amphenol plug and the terminal box on the experiment lead tube are made at the time the experiment is installed in the reactor.

A connection to the reactor stack system is available near each of the amphenol connections. These are used for discharging gas when purging the lead tube or for discharge of a gas that may be passed through the capsule and thereby become radioactive. This system includes a built-in trap to prevent liquids from being carried into the stack system.

B. ETR Facilities

1. Reactor Lattice Facilities

Encased within the beryllium reflector pieces is the ETR reactor lattice. It is composed of a gridwork capable of holding 100 three-inch square pieces. Forty-nine of these locations normally contain fuel assemblies and 16 contain shim rods. The four corner pieces are aluminum and are available for capsule irradiations. Figure 15 shows the location of these pieces. Included in the ETR lattice are two 3 inch by 3 inch, three 6 inch by 6 inch, one 6 inch by 9 inch and one 9

inch by 9 inch through holes and two 3 inch by 3 inch non-through holes for experimental purposes. These positions are normally occupied by loop experiments. Three inch square aluminum core filler pieces are available to fill these facilities when they are not being used for loop experiments.

Four-hole core filler pieces designated C-4X pieces (Figure 16), are available for capsule irradiations. These pieces can be used interchangeably in the core corner positions or in any other core position not occupied by a fuel element, shim rod or loop experiment. The external dimensions of these pieces are identical with those of the fuel assemblies. The vertical holes in the C-4X pieces are 1.312 inches in diameter by 36-13/16 inches long. One-half inch holes are drilled from the bottom of the 1.312 inch holes to a 1-13/16 inch plenum in the lower end box. Two 5/16 inch diameter pins pass through the lower ends of the 1.312 inch holes for capsule supports. At least two faces of these pieces are provided with holes for the insertion of 1/4 inch OD flux monitor tubes.

2. Beryllium Reflector Facilities

The beryllium reflector in the ETR completely outlines the reactor core (see Figure 15) and is composed of four large interlocking blocks of beryllium (Figure 17). When assembled, these blocks are 37-1/2 inches high by 34-1/2 inches long by 4-1/2 inches wide. Thirty vertical holes 1.312 inches in diameter by 36-1/2 inches long are available in the beryllium reflector for capsule irradiations. Capsules are supported by 3/8 inch diameter pins.

3. Aluminum Reflector Facilities

Between the beryllium reflector and the reactor tank is the aluminum reflector. It consists of 94 three-inch square pieces and a number of filler pieces around the edges. In addition to these, there are six 3-inch square through facilities in the aluminum reflector. These latter facilities normally are used for loop experiments but are available for capsule irradiations when not occupied by loops. The location of the various pieces in the aluminum reflector are shown in Figure 15.

The aluminum reflector pieces furnished with the reactor contained one hole, 1.533 inches in diameter by 40 inches long. Figure 18 shows the details of this piece. Special liners (Figure 19) are available to adapt the one-hole reflector pieces for use with standard capsule holders.

In order to better utilize the reflector space in the ETR and in an effort to standardize capsule sizes, special 4-hole aluminum reflector pieces, designated R-4X pieces, have been designed and built for use in 94 reflector positions. These pieces (Figure 20) are similar to the C-4X pieces discussed previously but are not interchangeable with them. The external dimensions of these pieces are identical with the one-hole pieces furnished with the reactor. At least two 1/4 inch flux monitor tube holes are provided in the R-4X pieces.

All of the aluminum reflector pieces are interchangeable and are available for capsule irradiations. Experiments with lead tubes can be inserted into most of these positions; however, minor problems exist in getting the leads out of the reactor tank because of interference with reactor fueling, the guide tube support frame and the loop experimental piping.

The reflector filler pieces are located outside of the array of 3-inch square aluminum sections and are shaped to conform with the flat face of the aluminum reflector pieces and the cylindrical tank wall. No provisions have been made for utilizing these pieces as irradiation facilities since they were not designed for remote removal.

4. Experiment Handling Facilities

Loading and unloading experiments from core or reflector pieces is normally accomplished with the piece in its place in the reactor by using long handled tools from a working platform mounted on the reactor top. Occasionally the pieces must be removed to the canal for experiment changing.

Experiments, pieces, fuel elements and other components are handled between the reactor and the canal through the discharge chute. This chute is located on the west side of the reactor tank, opening into the working canal (Figure 21). Material is normally handled through the transfer tube, a 6 inch ID aluminum tube 8 feet 7-1/2 inches long, which is located in the canal adjacent to the reactor. Experiments should be designed to fit the transfer tube, although larger experiments can be discharged directly to the canal if they will fit through the discharge chute.

5. Instrumented Capsule Communication

Instrumented capsule experiments requiring communication outside the reactor during irradiation can be accommodated in both core and reflector positions of the ETR. The leads from these experiments may include, but are not limited to, thermocouple extension wires, electric heater lead wire, gas and liquid lines. These leads must be enclosed in a suitable tube which is brought out of the reactor tank through one of the nozzles near the top of the reactor vessel (Figure 21). The flanges on these large nozzles have small openings with flanges which accommodate the standard lead tube seals. These metal and rubber ring seals are available for cylindrical tubes from 1/4 inch diameter to 3/4 inch diameter in 1/8 inch increments. Tubes which vary from these standard sizes will require special flanges and seals, the design of which should be coordinated with TRA Project Engineering.

Experiment lead tubes are clamped at two elevations between the reflector and the access nozzles as shown in Figure 21. The clamping is required to minimize failure of the lead tube from excessive flexing resulting from the extreme turbulence of the process water flowing through the reactor vessel. Several different types of clamps are used. Figures 13 and 14 illustrate the removable clamps.

The built-in clamp is similar to the one in the MTR and the removable clamps are the same as those used in the MTR. Because of the difficulty in clamping some leads it is often necessary to design and fabricate special clamps. These designs are determined at the time the bending schedule is prepared to route the lead tube around the various interferences encountered in the tank. Bending schedules and special clamp designs are prepared by designers at the NRTS based on the most current interference information.

6. Experiment Instrumentation

Instrumentation required for experiments must be provided by the sponsor. Space for instruments is provided on a balcony in the south bay of the instrument console floor (1st basement) of the ETR building. Instruments must be mounted in instrument cubicles furnished by the experimenter. Cubicles must be designed so that all connections to utilities and experiment leads are made through the top of the cubicle. Utilities available in the vicinity are: 110 V and 220 V AC 60 cycle electricity, 125 psi plant air and 125 psi instrument air. Connections between the experiment instruments and the patch panels on the balcony are made in a semi-permanent manner at the time of installation of the instruments. Temporary connections between the 150 F constant temperature reference boxes in the nozzle trench and the experiment are made at the time of installation of the experiment in the reactor.

A 300 point data logger-scanner is available for experimenters at the ETR. If demand becomes high this logger can be increased to 600 points. The following inputs are programmed into the data logger:

- a. 0-1600 F Iron-Constantan Thermocouple.
- b. 0-2000 F Chromel-Alumel Thermocouple.
- c. 0.1 to 0.5 volt linear millivolt retransmission and linear pneumatic to electric transducers for pressure and level signals.
- d. 0 to 20 millivolt strain gauge transducer.
- e. 12.5 to 62.5 millivolt square root flow signal from pneumatic to electric transducers.
- f. 12.5 to 62.5 millivolt signal to read out digitally 2 to 12 linear.

Readouts from the data logger are automatically taken at least every 30 minutes and are typewritten on a readout sheet. The readouts are in direct reading units, i.e., temperature in °F, flow in gpm, and pressure in psi. Normal, off normal and alarm systems are included. The data logger is not suitable for system control.

C. ATR Facilities

1. Core-Reflector Tank

The ATR is a high flux test reactor providing irradiation space in the Core-Reflector tank for nine loop experiments, twenty-one beryllium I-holes, eight beryllium B-holes, four outer aluminum A-holes, eight center aluminum A-holes and ten aluminum H-holes around the center flux trap. The location of these holes is shown on Figure 22.

a. H-Holes

There are a total of sixteen H-holes around the center flux trap but only ten of these will be available initially for irradiation of experiments. The others will be used initially for reactor control and instrumentation. The H-holes are 0.625 inches in diameter and 107 inches deep. Water leaves each of these holes through a 3/16 inch wide 1 inch long slot to the outside of the flux trap baffle.

b. Inner A-Holes

There are eight inner A-holes, A-1 through A-8. These are located around the center flux trap in the inner extremity of the neck shim housing. These holes are 0.625 inches in diameter and 99-1/8 inches deep to the center of a 1/8 inch diameter support pin. These positions are inaccessible unless the pressure tube locator ties and the center flux trap top flange are removed. Because of their limited accessibility, they will be used only for very long term irradiations.

c. Outer A-Holes

There are four outer A-holes, A-9, A-10, A-11 and A-12. These are located at each outer extremity of the cruciform shaped neck shim housing. These holes are 0.625 inches in diameter and 60.625 inches deep to the center of a 1/8 inch diameter support pin. Special holders, baskets and/or capsules will be designed for these facilities because only 36 inches of vertical headroom is available directly above these facilities.

d. B-Holes

There are eight B-holes in the beryllium, two immediately adjacent to each of four flux trap positions, north, east, south and west. These holes are 0.875 inches in diameter by 52 inches long to the beryllium support plate.

e. I-Holes

There are four I-holes 5 inches in diameter and 16 I-holes 3-1/4 inches in diameter. All are 54-1/2 inches deep. Liner pieces can be designed for these holes to provide irradiation space for experiments of any size up to the full diameter of the hole.

2. Outer Reflector Facility

The outer reflector irradiation facility is located outside the Core-Reflector tank. Figure 22 shows the location and arrangement of the outer reflector. This facility is composed of 34 aluminum filler

pieces. Thirty of these are interchangeable and are 4.46 inches square by 69.5 inches long. Fifteen have one 3 inch diameter by 56.813 inch deep holes and fifteen have five 1.312 inch diameter by 56.813 inch deep holes. The other four pieces are triangular in shape and occupy the corners next to the Core-Reflector tank. These pieces each have one 1.312 inch diameter and one 0.875 inch diameter hole 56.813 inches deep.

Although the square pieces are interchangeable, there are 10 positions for these pieces that are not particularly suitable for experiment irradiation. The 10 southernmost positions do not have water flow that is predictable or dependable enough for use as coolant flow for capsule experiments. Experiments in these positions would require independent cooling systems.

3. Experiment Handling Facilities

Loading and unloading experiments from the various facilities is normally accomplished from the reactor top through the elliptical access ports with long handled tools. Some positions and/or experiments may require the design of special handling tools. A full scale mockup of the reactor vessel and components is available for checking any special handling problems.

Experiments, pieces, fuel elements and other components are handled between the reactor and the canal through the drop tube and canal transfer device. Material can be handled directly through the drop tube into the canal without using the canal transfer device if desired. Material 29 feet long can be handled in the transfer tube without any of the inserts in place. The minimum diameter of the drop tube is 15-15/16 inches and the minimum diameter of the transfer tube is 13 inches. Two transfer tube inserts are available and provide easier handling of components that are small enough to fit inside them. One is 8 inches ID by 69 inches long and the other is 11-1/2 inches ID by 120 inches long. A 21 inch long spacer is available for use in the 11-1/2 inch ID insert.

4. Hydraulic Rabbit Facility

A high flux hydraulic rabbit facility has been proposed for one of the unused flux trap positions on the east side of the reactor. This rabbit facility would accommodate 1-1/8 inch OD rabbits up to 6 inches long. The facility would be operated with low pressure (80 psig) demineralized water with about 20 gpm flow. The facility provides for removal of high heat flux rabbits without reversing flow while the capsule is in the reactor core. Water that flows past the rabbit is discharged to either the warm or hot drain.

5. Instrumented Capsule Communication

Instrumented experiments requiring access outside the reactor can be accommodated in some of the positions. Each position would have to be investigated at the time irradiation was desired to determine the problems of egress through the various interferences. The lead tubes would exit through horizontal nozzles located several feet below the top head. To install or remove lead experiments would require lowering the

water level about 7 feet below the normal working level during shutdown. This may present some special radiation exposure problems. The flanges on these nozzles are presently blank flanges but it is anticipated that flanges to accommodate the standard lead tube seals will be fabricated as required. These metal and rubber ring seals are available for cylindrical tubes from 1/4 inch diameter to 3/4 inch diameter in 1/8 inch increments. Tubes which vary from these standard sizes would require specially designed flanges and seals. The design and fabrication of these would have to be coordinated with TRA Project Engineering.

Experiment lead tubes will be clamped at two elevations between the reflector and the access nozzles as shown in Figure 23. The clamping is required to minimize failure of the lead tube from excessive flexing resulting from the extreme turbulence of the process water flowing through the reactor vessel.

Experiment lead tubes will have to be pre-bent to avoid in-tank interferences. A bending schedule will be prepared by designers at the NRTS based on the most current interference information. A dummy lead tube can then be bent and inserted into the full scale reactor mockup to check the bending schedule.

6. Experiment Instrumentation

Instrumentation required for experiments must be provided by the sponsor. Space for instruments is provided on the first basement level. Instruments must be mounted in instrument cubicles furnished by the experimenter. Cubicles must be designed so that all connections to utilities and experiment leads are made through the top of the cubicle. Utilities which are available in the vicinity are: 110 V and 220 V AC 60-cycle electricity, 125 psi plant air, 125 psi instrument air, low pressure demineralized water and warm drain.

Connections between experiment instruments and the nozzle trench will be made in a semi-permanent manner at the time of installation of the instrumentation. Connections to the experiment leads are made at the time the experiment is installed in the reactor.

Forty data logger points are available for 0-2000 F chromel-alumel thermocouples for instrumented capsule experiments. The output will appear on typewriter sheets with hourly logging except for off-normal conditions which are printed out at the time of detection. The data system also has a punched tape output available. The system has the capability of expansion or modification to handle more points or different type of input.

D. Critical Facilities

Experience in the operation of the test reactors has shown that reactor physics calculations cannot accurately or conveniently provide all the data necessary to support test reactor operation. This is especially true in cores with complex configurations such as the ETR and ATR cores. For this reason the ETR Critical Facility (ETRC) and the ATR Critical Facility (ATRC) were designed and built to supply

accurate and timely data on (a) rod worths and calibrations, (b) excess reactivities, and thus, charge lifetimes, (c) neutron flux distributions, (d) gamma heat generation rates, (e) fuel loading requirements, and (f) effects of the insertion and removal of experiments. Although most of these measurements could be accomplished in the test reactor, the measurements would be much more difficult, would reduce the duty cycle of the reactor, and in some cases would be less accurate.

1. The ETRC

The ETRC is located in the ETRC building which joins onto the southeast corner of the MTR services building. It has its own canal and is so constructed to make it possible to maintain the entire ETRC building free from significant radioactive contamination.

The ETRC is a full size nuclear duplicate of the ETR and all of the core components are interchangeable insofar as core dimensions are concerned. Inpile irradiation facilities extend only a few inches above the core in the ETRC whereas, in the ETR, some of them extend several feet. The ETRC reflector is a good nuclear mockup of the ETR reflector but it was designed to use surplus MTR beryllium reflector pieces and is therefore not a physical duplicate.

2. The ATRC

The ATRC is located in an extension of the ATR storage canal on the west side of the ATR building. The entire region within the core reflector tank is a nuclear duplicate of the ATR and many of the components, including fuel elements, are interchangeable between the two facilities. Inpile irradiation facilities extend only a few inches above the core in the ATRC whereas, in the ATR, many of them extend several feet. The outer reflector facility is not mocked-up in the ATRC; however, it has been demonstrated by ATRC measurements that experiment changes outside the Core Reflector tank do not measurably affect the nuclear balance of the reactor.

E. Capsule Holders or Baskets

Capsule holders or baskets have been designed to facilitate the insertion and removal of capsule experiments in the irradiation facilities of the MTR, ETR and ATR. These baskets are available at the TRA. The upper ends of these baskets are slightly different (Figure 24) to provide an easy method of identification. Experiments which vary from the sizes indicated in Tables I, II and III will require special approval.

1. X-Basket

An X-basket (Figure 25) is a thin aluminum sleeve used to hold up to 36 inches of experimental capsules. It contains four vertical grooves, which are designed to center the capsules and provide an annulus for water flow along the entire surface of the capsules. On the lower end of the basket is a 5/8 inch thick spider used to support the capsules. A groove is provided on the bottom of the spider to allow basket orientation as well as to prevent rotation of the basket. The upper end of the X-

basket is provided with slots for handling purposes. The usable portion of the X-basket is 36 inches long. Capsules for this type of basket should be 1-1/8 inches in diameter. Capsules less than 1-1/8 inches in diameter will not be centered by the grooves and may rest against the wall of the basket, thus minimizing uniformity of cooling.

The X-basket was originally designed for use in the four-hole MTR reflector pieces. It is also used for the single-hole MTR L-pieces, the four-hole ETR core and reflector pieces and in some of the ETR beryllium reflector positions. Because of the tapered configuration in the upper end box of the single-hole L-piece (Figure 2), it is necessary to raise the expanded head of the X-basket to prevent sticking. This is done by inserting a two-inch long tubular spacer under the X-basket. Special liners (Figure 19) are available to adapt the one-hole ETR reflector pieces for X-basket insertion. Experiments normally are loaded and unloaded in X-baskets in the MTR or ETR canal. The loaded basket is inserted into or removed from the core or reflector piece with the facility positioned in the reactor tank. Occasionally, it is necessary to remove the piece with its loaded baskets to the canal for handling. Because of the fragile nature of the X-basket, no attempt is made to reuse it after irradiation of samples is completed.

Although capsules to which experiment leads are attached can be inserted and removed by gripping the lead tube with long-handled tools, it is recommended that the experiments be constructed to fit inside X-baskets. When the lead is cut, the experiment may drop down into the facility and be difficult to grapple if not in a basket.

2. L-Basket

The L-basket is used for holding capsules in the LB-4X four-hole MTR L-pieces. The L-basket is identical to the X-basket with the exception that it is 34-1/2 inches long instead of 37-1/4 inches. The usable length of the L-basket is 33-3/32 inches (Figure 26).

3. D-Basket

The D-basket is used for holding capsules in the eight-hole MTR D-piece. The inside dimensions and length are the same as those of the X-basket. The major difference in the D-basket is the wall thickness. If an X-basket gets stuck in an irradiation facility, the facility can be easily removed to the canal where the basket can be pushed out from the bottom of the piece. In the case of the D-basket, this cannot be done since the D-piece cannot be discharged easily. The thicker wall of the D-basket gives it greater strength and thereby makes it less likely to be damaged during handling. Figure 27 shows the details of the D-basket.

4. S-Basket

It is sometimes desirable to irradiate capsules which are 5/8 inch in diameter in irradiation facilities designed to take large capsules. A special capsule holder known as an S-basket is available for this purpose. This basket is shown on Figure 28. It is similar to

an X-basket except that the inside is designed for centering $5/8$ inch diameter capsules. This basket has been designed so that it can be used in any of the following pieces: LB, AA-4X, R-4X, C-4X and ETR beryllium reflector.

5. N-Basket

The N-basket (Figure 29) is used for holding capsules in the LB-4N four-hole L-pieces. This basket is designed to hold capsules which are $5/8$ inch in diameter. The N-basket is $33-3/16$ inches long and has a usable length of $32-13/16$ inches.

6. B-Basket

Standard X-baskets cannot be used in all of the ETR beryllium reflector positions because a small shift of the blocks has reduced the effective diameter of the hole. B-baskets (Figure 30) was designed for use in the ETR beryllium reflector where X-baskets cannot be used. This basket is limited to capsules one inch in diameter. It is very similar to an X-basket except that it is smaller in diameter and has a thicker wall. Although specifically designed for use in the ETR beryllium reflector, the B-basket also can be used in LB, AA-4X, C-4X and R-4X pieces.

7. K-Basket

The K-basket is used to hold $1-1/8$ inch diameter capsules in the K pieces and the AA-2K piece of the MTR. It is the same as the X-basket except it is 23 inches long and has a usable length of $21-7/16$ inches. This basket is shown in Figure 31.

8. R-Basket

The R-basket is used for holding $1-1/8$ inch diameter capsules in the 1.312 inch diameter holes in the outer reflector facilities of the ATR. It is essentially the same as an X-basket except it is $57-11/16$ inches long. The usable length of the R-baskets is $56-1/8$ inches. The R-basket is shown in Figure 32.

9. O-Basket

The O-basket (Figure 33) is used to hold $5/8$ inch diameter capsules in the 0.875 inch diameter holes in the corner filler pieces of the outer reflector facility of the ATR. It is essentially the same as an N-basket except it is $57-11/16$ inches long. The usable length of the O-basket is $56-5/8$ inches.

10. Y-Basket

The Y-basket (Figure 34) is used to hold $5/8$ inch diameter capsules in the 0.875 inch diameter B-holes in the ATR Core Reflector. It is essentially the same as an N-basket except it is $60-7/8$ inches long and has a pedestal attached to the spider in the bottom. The pedestal sets on the beryllium support plate. The usable length of the Y-basket is 59 inches.

11. Reference Points on Capsule Holders in MTR, ETR and ATR

Figure 35 shows the relative positions of the various capsule holders in the MTR. Figure 36 shows the relative positions of the various capsule holders in the ETR. Figure 37 shows the relative positions of the various capsule holders in the ATR.

12. Size of Various MTR, ETR and ATR Irradiation Facilities

Tables I, II and III are summaries of the minimum facility diameters and the required gauge sizes for irradiation samples. Samples will be checked before insertion in the reactor and will be rejected if they do not pass through the designated gauge.

F. Flux Monitors

Sponsoring organizations frequently desire to obtain flux data concurrently with the irradiation of their experiments. It is recommended that flux monitoring devices be incorporated within the outer shell of the capsule whenever possible. Under certain circumstances, a sponsor might find it imperative to affix a flux monitoring device to the outside of his capsule. Such deviation from recommended practices must be specially approved by TRA Project Engineering. Any monitor wire or other flux measuring device affixed to the outside of a capsule must be so constructed that it will not accidentally come off under normal handling and irradiation conditions. It furthermore must not present any hazards to the reactor or personnel.

Many of the four-hole pieces used in the MTR and ETR (e.g., Figure 5) contain holes in two or more faces into which standard flux monitor wands can be inserted. Fairly continuous flux plotting of both reactors is done using these facilities and unoccupied irradiation positions. Recent flux plots of specific reactor positions are available from TRA Project Engineering. Similar flux monitoring will be done in the ATR.

III. CAPSULE DESIGN CRITERIA

A. Non-Instrumented Capsules

1. Hydraulic Rabbits

The design criteria for hydraulic rabbits is the same, except for dimensions, at all reactors at TRA where hydraulic rabbit facilities are available. There are presently three such facilities in the MTR, none in the ETR and one proposed for the ATR. The basic requirement for capsules are as follows:

- a. They must pass freely through the most severe bends in the rabbit tube piping (4 foot minimum radius at MTR - 6 inch maximum length on 1-1/8 inch diameter rabbit at ATR).
- b. They must permit adequate water flow past the capsule for proper cooling.
- c. They must not float.
- d. They must not be affected by the MTR process water or ATR low pressure demineralized water.
- e. They must be constructed and assembled so that mechanical shock upon reaching the stop at the end of the facility will not cause them to rupture.
- f. They must pass through the gauge indicated in Table I.
- g. They must carry proper identifying markings (see Figure 50).

Many of the experiments irradiated in the hydraulic rabbit facilities are small samples encapsulated in quartz or aluminum. These capsules vary widely in size and are re-encapsulated in standard perforated irradiation containers, referred to as "leaky rabbits". These leaky rabbits are available at the TRA in sizes to fit all the hydraulic rabbit facilities. Details of the leaky rabbits are shown in Figures 38 and 39. A leaky rabbit consists of a perforated 6061 aluminum tube and end caps held together with an aluminum band. The capsule to be irradiated is placed inside the leaky rabbit and braced against vibration or moving by stainless steel springs. The use of aluminum foil as packaging is sometimes necessary; however, this method of vibration dampening is not recommended. Coolant water passes through the perforations in the leaky rabbit and over the capsule. The use of quartz ampoules for containers is discouraged because of excessive breakage. Any material encapsulated in quartz ampoules must be re-encapsulated in a sealed metal container. Such containers will not be opened at the TRA but will be returned to the sponsor intact. A screw-top capsule, shown in Figure 40 is satisfactory for this purpose. When used in the VII-1 or VH-2 facility of the MTR, standard end caps are banded directly to the

capsule. When used in the VH-4 facility, the capsule is placed inside a VH-4 leaky rabbit. Screw-top capsules are available at the TRA. Approval for the use of these capsules must be obtained from TRA Project Engineering.

Sponsors are not restricted to the use of leaky rabbit capsules for irradiation in the hydraulic rabbit facilities. In the design of capsules for these facilities, the basic requirements must be met and, in addition, the following items should be considered:

- a. Deviations from the external dimensions of the containers shown in Figures 24 and 26 are subject to TRA Project Engineering approval. It is recommended that any such deviations be checked with TRA Project Engineering prior to capsule construction.
- b. For the rabbit to move smoothly with minimum chance of holdup, the edges should be rounded. The assembled capsule should be somewhat dumbbell shaped.
- c. The weight of the rabbit or capsule should be such that the available water pressure will keep it in position in the rabbit facility. A discussion of the hydraulics for the rabbit facilities is presented in IDO-16368, "Hydraulic Flow Calculations for Experiments in the MTR and ETR".
- d. The capsule must be so designed that the surface temperature of any portion exposed to the water will be below the boiling point of the water at that location. It must be remembered that to remove an MTR rabbit, it is necessary to lower the flow. The conditions which will exist during the instant before the capsule begins to fall must be considered in the hazards analysis.
- e. The materials of construction which will be in contact with the water must not corrode, slough off, or in any way cause deleterious effects on the high quality process water. The use of copper, silver, cadmium and/or lead cannot be tolerated. Recommended materials include aluminum or aluminum alloys (of less than 0.5% copper), 347 or other stabilized stainless steel, and Zircaloy. Helium arc welding is recommended for joining metallic parts. Silver solder is unacceptable as a brazing compound.

In general, three types of capsules are handled in the hydraulic rabbit facilities. These include: (1) the leaky rabbit discussed above, (2) an open capsule where the samples to be irradiated are in plate or rod form and are supported in an open-end tube which acts as the outer capsule shell, and (3) a sealed capsule where the specimen is totally enclosed within the confines of the outer capsule shell. The latter two types are similar to those irradiated in the reflector or lattice

positions and will be discussed more fully in another section.

2. Pneumatic Rabbits

a. MTR VP Rabbits

For small, short-term samples to be irradiated in the pneumatic rabbit facilities in the MTR vertical graphite holes, a standard polyethylene capsule is available at the TRA. Figure 41 is a drawing of this capsule. If a sponsor desires to use another material of construction for his capsule, he must maintain the outside dimensions shown on Figure 41 and a maximum loaded weight limitation of 15 grams. Because of the shielding problem on the top of the reactor, only materials of low initial and/or induced activity can be irradiated in this facility. As an upper limit, a maximum activity of 10^9 d/sec at the time of removal from the pneumatic rabbit facility has been established. The activity of the sample (including the capsule) should be calculated using the method outlined in IDO-16621, "IBM-650 Program to Calculate Neutron-Induced Radioactivities and Tables of Values for MTR Facilities."

b. MTR HR-2 Rabbits

For small, short-term samples to be irradiated in the MTR HR-2 pneumatic rabbit facility, a standard polyethylene capsule is available. This capsule comes in two pieces and is spin-welded together at the time of insertion. Loose material to be irradiated must be pre-packaged in small plastic tubes. Details of the HR-2 capsule are shown in Figure 42. Plans for the use of this facility must be coordinated with TRA Project Engineering.

c. ETR Pneumatic Rabbit

An ETR pneumatic rabbit will use the same polyethylene capsule as the MTR VP facilities. This rabbit facility has limited usefulness because it terminates above the reflector.

3. Open-Capsules

In order to simulate conditions which will exist in many proposed reactor systems, it may be necessary to direct the flow of cooling water directly over the samples being tested. This can be done most effectively in open capsules. These capsules normally consist of an aluminum shell perforated on the ends or sides or both with the samples being held rigidly inside this shell. Cooling water then passes through the perforations, directly cooling the surface of the specimens. Occasionally flow directors are affixed to the ends of the capsule to insure proper water flow through the shell.

All 1-1/8 inch non-instrumented capsules must be fabricated with an end protrusion on the top or upper end of the capsule. Figure 43 shows the size and shape preferred. The protrusion is used as a handling device and also as a means of identifying the top end of the capsule. Open-type capsules should have protrusions on both ends to assure water flow. Only the top protrusion will be round. The bottom protrusion

should be square or hex so that orientation of all capsules will be uniform.

The general requirements for open-type capsules are as follows:

- a. They must be of the proper diameter to fit the irradiation facility to be used. Gauge dimensions are shown on Tables I, II and III.
- b. In general, they should not exceed the length of the irradiation facility to be used (see Figures 35, 36 and 37). In order to insure proper placement of capsules in the irradiation facilities, minimum lengths of 2 inches for 1 inch and 1-1/8 inch diameter capsules, and 1-1/2 inches for 5/8 inch diameter capsules have been established. Capsules shorter than these lengths require special approval.
- c. The assembled capsule must not float in water.
- d. The capsule must be so designed that the surface temperature of any portion exposed to the process water will be below the boiling point of the water at that position. Hot-spot hot-channel analyses of these capsules are required for Safeguard Committee approval. An outline of this analysis is presented in IDO-16343, "Calculated Surface Temperatures for Nuclear Systems and Analysis of Their Uncertainties."
- e. The materials of construction of the parts exposed to the reactor process water must not corrode, slough off or in any other way cause deleterious effects on the high quality process water. Copper, silver, cadmium and/or lead cannot be used. Recommended materials include aluminum or aluminum alloys (of less than 0.5% copper), 347 or other stabilized stainless steel and Zircaloy. Heliarc welding is recommended for joining metallic parts. Silver solder is unacceptable as a brazing compound.
- f. Clad specimens must be leak-checked to insure the integrity of the welds and cladding.
- g. They must carry proper identifying markings (see Figure 50).

Figure 44 is an exploded view of a typical open capsule containing sample plates. This capsule was designed for use either in the VH-4 hydraulic rabbit facility or in an X- or L-basket in the MTR tank. The plates contained fuel or other materials clad with a corrosion resistant cover. For heat removal considerations the edge of the fuel should not extend to the edge of the plate, since the edge is held rigidly in the outer shell. In this construction, cooling water entered through the end caps which were held in place with Allen-head screws. The outer shell beneath the screws was drilled out to accommodate flux monitor wires.

Another typical open capsule is shown in Figure 45. In this case three stainless steel clad fuel rods were held in position but separated from each other and from the aluminum outer shell by stainless steel ferrules. These were attached to the fuel tubes by welding. The aluminum outer shell was perforated both on the ends and the sides to allow process water to flow over the surface of the fuel tubes. Small protrusions were attached to the ends of the outer shell to separate this capsule from others placed above or below it. This separation is essential to prevent blockage of the perforations in the ends of the shell. Space within the protrusions was utilized for small flux monitors.

Possibilities for design of open capsules for irradiation at the TRA are in no way limited by the examples described herein. Any reasonable design is acceptable provided the sponsor can show by his calculations that there will be no boiling on the surface of his specimens.

4. Sealed Capsules

Since the MTR, ETR and ATR are water-cooled, low-pressure reactors, most capsules to be irradiated are of the sealed type. Frequently sealed capsules are designed to expose the sample to conditions which will exist in a proposed reactor, including environment, temperature, pressure and others. In general, a sealed capsule consists of an outer shell, which contains the specimen to be tested, suspended in a heat transfer medium. Heat is removed by cooling water flowing over the surface of the outer shell.

All 1-1/8 inch capsules sent to TRA for irradiation will be fabricated with an end protrusion. Figure 43 shows the size and shape required. Each sealed capsule will have only one protrusion; the other end of the capsule normally will be flat. The protrusion is used as a handling device and also as a means of identifying a capsule upper end when necessary. In all cases, the protrusion will be in the "up" position.

The general requirements for sealed-type capsules are as follows:

- a. They must be of the proper diameter to fit the irradiation facility to be used. For example, a capsule to be irradiated in an X- or L-basket must be 1-1/8 inches in diameter. Gauge dimensions for all facilities are shown on Tables I, II and III.
- b. They must not exceed the length of the irradiation facility to be used. For example, the maximum allowable capsule length in an L-basket is 33-3/32 inches. (See Figures 35, 36 and 37.) Deviations from this requirement require special approval. In order to insure proper placement of capsules in the irradiation facilities, minimum lengths of 2 inches for 1 inch and 1-1/8 inch diameter capsules, and 1-1/2 inches for 5/8 inch diameter capsules have been established. Capsules shorter than these lengths require special approval.

- c. The capsule must not float in water.
- d. The capsule must be so designed that the surface temperature of any portion exposed to the process water will be below the boiling point of the water at that position. Hot-spot hot-channel analyses of these capsules are required for Safeguard Committee approval. An outline of this analysis is presented in IDO-16343, "Calculated Surface Temperatures for Nuclear Systems and Analysis of Their Uncertainties."
- e. The materials of construction of the outer shell, which will be in contact with the water, must not corrode, slough off or in any other way cause deleterious effects on the high quality process water. The use of copper, silver, cadmium and/or lead cannot be tolerated. Recommended materials include aluminum or aluminum alloys (of less than 0.5% copper), 347 or other stabilized stainless steel and Zircaloy. Heliarc welding is recommended for joining metallic parts. Silver solder is unacceptable as a brazing compound.
- f. No material of construction shall be used which, under irradiation, will produce corrodable or soluble products--for example, the production of mercury from gold.
- g. The corrosion effects of the materials contained in the capsule must be taken into consideration. Special precautions, such as double encapsulation, must be taken to insure the containment of liquid metals.
- h. After fabrication the capsule must be leak-checked and radiographed to insure the integrity of the welds and the capsule walls. Radiographs must be submitted to the TRA Project Engineering for examination.
- i. In cases where capsules are pressurized or are likely to become pressurized under irradiation conditions, stress calculations must be made to prove the safety of the design.
- j. They must carry proper identifying markings (see Figure 50).

Figure 46 is a simplified sketch of a typical liquid-metal filled, sealed capsule. The specimen should be suspended in the liquid metal by suitable supports to assure adequate insulation. After loading the specimen and the liquid metal in the "can", the top cap is heliarc welded on. Other closure methods are acceptable; however, heliarc welding facilitates the maintenance of an inert atmosphere above the liquid metal in the capsule. Helium is suggested as the medium for the gas space because of its inertness and because of its usefulness in testing the integrity of the welds. Single containment of liquid metals should be limited to small amounts.

Screw-top capsules (see Figure 40) are available at the MTR-ETR stockroom. These capsules have found wide use for the irradiation of small quantities of materials where the heat generation problem is not too great. Approval for the use of these capsules must be obtained from TRA Project Engineering.

In some cases a sponsor may wish to obtain a high temperature burn-up on a fuel specimen. This is frequently accomplished by utilizing an inert gas annulus as a heat dam. Helium and/or nitrogen are generally used for this purpose. Temperature is determined by the thickness of the inert gas heat dam and the mixture of gases used.

When designing capsules for fuel irradiation, it is generally desirable first to encapsulate or clad the fuel material to contain the fission products and the unreacted fuel. Any cladding scheme is acceptable, provided the integrity of the cladding is satisfactory. Often it is convenient to clad several small samples into a single unit. One of the most satisfactory methods of doing this is by use of the so-called "picture frame" technique. Figure 47 is an exploded view of a specimen and capsule assembly in which this technique is employed. The specimens are placed in the openings of the picture frame, and cover plates are welded in place. The frames are cut so that the specimens will just fit.

After welding on the cover plates, the clad specimens are then leak-checked to insure the integrity of the assembly. In the capsule shown in Figure 47 the clad specimens are immersed in NaK in the outer capsule. This capsule is a special design that is rectangular in shape rather than the usual right circular cylinder. In order to properly control heat transfer for this design it was necessary for the sponsor to design and construct a special capsule holder to be inserted into or to replace the standard basket.

The examples described above are in no way intended to limit the sponsor in the design of his capsules. The details of design of sealed capsules must of necessity be worked out by the sponsor, since only he knows what he wants the experiment to do. It is advisable to discuss preliminary designs of new and/or unique capsules with TRA Project Engineering prior to starting fabrication.

After final assembly all capsules must be leak-checked and radio-graphed. Acceptable leak check methods include helium leak-checking with the outer shell of the capsule under a vacuum and weight gain by autoclaving.

B. Instrumented Capsules

1. Capsule Design

Instrumented experiments are generally of the sealed capsule type and the design requirements for the capsule itself are identical to those discussed in the preceding section.

2. Lead Tube Design

The lead tube, its contents and its connection to the capsule must be designed to meet the following requirements:

- a. A double bulkhead seal must be provided to isolate the space in the lead tube from the capsule. All thermocouple leads, heater leads, gas tubes, etc., passing from the capsule to the lead tube must be brazed through each of these bulkheads. Silver solder is not acceptable as a brazing material. Epoxy seals have been used in lieu of the brazed bulkhead joints but generally have proved unsatisfactory and approval for their use must be obtained from TRA Project Engineering.
- b. The lead tube must be welded to the capsule to form a leak-proof joint. This joint should be designed to provide a maximum of mechanical strength to insure that flexing of the lead tube will not cause a failure of the joint.
- c. A 1/8 inch purge tube is required in each lead tube. This must terminate in the bottom of the lead tube just above the top bulkhead. It must extend out the upper end of the lead tube with the other leads.
- d. The extreme turbulence of process water causes flexing of the lead tubes and experience has shown that aluminum tubes are generally unsatisfactory. Stainless steel is recommended for the tubes.
- e. The lead tube should be a continuous length of 25 feet. This length is sufficient to carry the leads from any position in the reactors through the access nozzles and flanges to the outside of the vessel. If it is not practical to make the lead tube a continuous length a minimum number of welded joints should be used.
- f. Leads within the tube must be two feet longer than the tube itself and they must be permanently identified every six inches for the top ten feet.
- g. For accommodation in standard available flanges and seals, the lead tube must be cylindrical tubing from 1/4 inch OD to 3/4 inch OD in 1/8 inch increments.
- h. Experiments should be designed so that only one lead tube is required for a single capsule.
- i. A measuring and handling device is required. The top of this device is to be 48 inches above the bottom of the capsule. The bottom of the capsule is defined as the lower extremity of the assembled unit including spacer

if permanently affixed (see Figure 48 for examples). The measuring and handling device is to be a flat ring 1/4 inch to 3/8 inch thick and have an outside diameter 1/2 inch + 1/64 inch greater than the outside diameter of the lead tube. There should be no holes in the ring except that one through which the lead tube goes. The ring is to be tack welded to the lead tube on the underside of the ring only. Welds should be strong enough to permit the use of this ring for handling of the experiment with a crows-foot type handling tool.

Deviations from the foregoing must be negotiated on an individual basis with TRA Project Engineering.

- j. Experiment lead tubes are terminated 12 to 24 inches outside the access nozzle flange. A pressurized terminal box must be attached to the end of the tube and all leads brought through suitable seals in the box. Electrical circuits, including thermocouple leads, are brought through brass studs sealed with polyethylene. Fluid lead tubes are brought through ports in the terminal box and sealed with drilled out Swagelok fittings. The purpose of the pressurized terminal box is to prevent the spread of contamination due to "breathing" of the tube, to prevent process water from flooding the reactor top in the event of lead tube failure, and to prevent the release of radioactive material into the reactor building in the event of a sample failure.

A vent line and valve is installed on the box and can be connected to the pile vacuum exhaust.

Standard terminal boxes are available at TRA to accommodate most lead experiments. Design of non-standard boxes must be coordinated with TRA Project Engineering.

- k. Lead tube, connections, and components must be designed to withstand the following test pressures without leakage.

MTR	100 psig
ETR	300 psig
ATR	400 psig

Before insertion into the reactor each lead tube is pressure tested with helium and leak checked. The test is repeated after insertion.

- l. Radiographs of lead experiments must show the bulkheads and lead tube-capsule connection.

3. In-Tank Connectors

Handling problems in the ETR and ATR dictate the use of an in-tank connector. This permits the stiff lead tube to be handled in

two sections. Generally it is not necessary to break the leads at this point since a bundle of wires and small tubes is relatively flexible. However, if a bundle of leads becomes too stiff to handle, a connection will have to be designed for incorporation into the connector. Details of an acceptable connector are shown in Figure 49. The location of this connector is determined by the designer preparing the lead tube bending schedule and is shown thereon.

4. Operating Manuals

Each lead experiment must be provided with an operating manual. The manual should be prepared in accordance with IDO-17045, "Preparing Operating Manuals for Instrumented Experiments at TRA".

5. Special Problems

Special problems are sometimes encountered in the design of an instrumented capsule experiment because of the communication to the outside and the associated hazard of conducting radioactive materials to this area. Over the years several problems have been uncovered and restrictions imposed because of them.

- a. Exposed tantalum is not permitted in the lead tube or in the capsule where it might be conducted outside the capsule by flowing control gases.
- b. Radiation monitors are required on flowing gas control systems of fueled experiments and non-fueled experiments if one of the gases becomes radioactive (e.g. argon).
- c. The use of sodium as a primary heat transfer medium is discouraged unless provisions are made to insure that it is molten before reactor power is applied.
- d. Organic material and glass thermocouple insulation must not be used in the lower 1/2 feet of the lead tube. Transition from sheathed thermocouples must be made above this point.

It is recommended that design of instrumented experiments and their control systems be closely coordinated with TRA Project Engineering beginning as early as possible. In this way difficulties can be avoided or worked out with a minimum loss of time.

C. Critical Facility Mockup Capsule

A concerted effort was made in designing the critical facilities to duplicate the cores of their respective parent reactors. In line with this effort it is required that each experiment in the ETR core or inside the ATR core reflector tank have a nuclear duplicate in the appropriate critical facility. The use of a one-cycle capsule for its own mockup is not permitted. It is desirable of course that the mockup be an exact duplicate of the prime sample but to avoid costs it is acceptable, with prior approval of TRA Project Engineering, to substitute

some materials for others and to compromise minor detail in the mockup design. In case of such deviations, however, the sponsor is required to supply a data package comparing the mockup to its prime sample in sufficient detail that one can determine from the data whether or not the deviations are acceptable. The data package will include but need not be limited to a comparison of the following items:

1. Pertinent dimensions.
2. Material contents in grams.
3. Macroscopic thermal and epithermal absorption cross sections.
4. Macroscopic thermal and epithermal scatter cross sections.
5. Appropriate self shielding factors.
6. Metal-to-water volume ratios.

Deviations in the mockup from its prime sample must be evaluated on an individual basis but some guide lines follow:

1. Items 2 through 6 above may be considered on the basis of homogenized samples, provided that self shielding factors are properly accounted for. A value applying to any 3 inch length of the mockup must be within 10% of the corresponding length in the prime sample. In this connection, provision must be made in the mockup to adjust fuel or burnable poison from cycle to cycle when the prime sample is scheduled for more than one cycle of irradiation in the ETR or ATR.
2. Some acceptable material substitutions are:
 - a. Aluminum for sodium, zirconium, or small amounts of beryllium.
 - b. Air for most gases or vacuum.
3. Materials for construction of parts exposed to reactor water must not corrode, slough off, or in any other way cause deleterious effects on the water. Copper, cadmium, and/or lead cannot be used. Recommended materials include aluminum or aluminum alloys, stainless steel and Zircalloy. Heliarc welding is recommended for joining metallic parts. Silver solder is unacceptable as a brazing compound.
4. The weight of the assembled mockup must be such that it will not float in water.
5. Mockups with evacuated or gas-filled regions must be leak-checked.
6. Special handling tools should be avoided where possible. If special tools are required they must be furnished by the sponsor.

Mockup capsules are to be marked in the same manner and in accordance with the same system as irradiation samples (see Section IV-C).

IV. PROCEDURE FOR IRRADIATION AT THE TRA

The general policy and procedures regarding irradiation in the MTR and ETR are outlined in a document entitled "Policy and Procedure in the Operation of the Materials Testing Reactor and the Engineering Test Reactor (Revised)." Copies of this document are available to all sponsors with active or prospective irradiation programs. This document may be obtained by writing to:

Manager
Project Engineering Branch
Phillips Petroleum Company
P. O. Box 2067
Idaho Falls, Idaho

The following information is presented as an aid to the experimenter in the preparation of his request for an irradiation.

A. Data and Calculations

It is the responsibility of the sponsor to supply to TRA Project Engineering a document which fully describes his proposed experiment. This document must be complete enough so that the responsible Project Engineer will have the following information:

1. Sufficient data to be able to request and obtain the approval for the irradiation from the Reactor Safeguard Committee.
2. Instructions on how to schedule the experiment.
3. Instructions for the instrumentation and electrical hookup of the experiment. This includes anticipated and/or desired operating parameters, danger points, drawings, etc.
4. Handling instructions, including installation, operation, removal, etc. Drawings must be included.
5. A listing of the utility requirements, if any.
6. Shipping instructions. A copy of the Bureau of Explosives approval letter and a set of drawings must be on file with TRA Project Engineering before any shipping container will be used.

In order for the Project Engineer to prepare his request for approval, he must have a statement of the purpose or objective of the experiment and the following data:

1. Capsule surface temperature, °F. (In the case of open-type capsules, this should be the temperature of the heat transfer surface.)
2. Central core temperature, °F.

3. Fissionable material in grams per inch of specimen (in the case of plate-type experiments, this must also be reported in grams per square centimeter).
4. Heat output in watts per inch of effective capsule length.
5. Heat flux in Btu/hr-ft² of capsule surface.
6. Thermal conductivities of all materials including the fissionable material.
7. Capsule OD and overall length in inches.
8. Weights of all materials in grams (this includes specimen, cladding, container, coolant, etc.).
9. Thermal and/or fast flux desired and the acceptable range.
10. Reactor location, if applicable.
11. Irradiation time in cycles or nvt (for estimating purposes, an MTR cycle is approximately 700 megawatt days at 40 megawatt power level, and an ETR cycle is approximately 3500 megawatt days at 175 megawatt power level).
12. Other pertinent data concerning operating parameters, thermal stress, cross section in cm²/inch, etc.

It is desirable to present the above data in tabular for clarity. In addition to listing the foregoing data, it is the sponsor's responsibility to furnish a complete set of calculations to support these data. These calculations must be confirmed by the Project Engineer prior to requesting Safeguard Committee approval.

A detailed drawing showing dimensions of the capsule and contents is required. Radiographs of the assembled capsule are required.

A further requirement for Safeguard Committee approval is the presentation of a complete hot-spot, hot-channel analysis of the experiment performed in the manner outlined in IDO-16343, "Calculated Surface Temperatures for Nuclear Systems and Analysis of Their Uncertainties."

The document also should include the following additional information:

1. Description of the construction of the outer container and lead tube if any. The type and description of welding used and the procedure to be used for repair of the experiment if necessary.
2. In the case of temperature monitor or control circuits, the thermocouple designation by junction location, thermocouple material, color coding, and tested resistances must be given.

3. For experiments which contain electrical heaters, heater circuit diagrams, ratings, coding and tested resistances must be supplied. (See IDO-16395, "Instrument and Electrical Standard Practices for MTR and ETR.")
4. A description and results of all tests performed by the sponsor to check capsule integrity or other capsule characteristics.
5. Instructions regarding special handling, if desired, during pre-insertion testing, insertions, irradiation, removal and canal handling.
6. Cutting instructions for preparing instrumented experiments for shipment.
7. Complete operating instructions, if any. All instrumented experiments must be accompanied by an operating manual prepared in accordance with IDO-17045, "Preparing Operating Manuals for Instrumented Capsule Experiments at TRA."

B. Scheduling

Scheduling of experiments for insertion in the MTR, ETR and ATR is completed one week prior to the time of shutdown. Shutdown for experiment changing occurs on a three-week basis in the MTR and on a six-week basis in the ETR and ATR. Before an experiment is considered for insertion, the Safeguard Committee approval must have been obtained and all preliminary testing of the experiment and installation of experimental instrumentation at TRA must have been completed prior to the day the reactor is scheduled.

In order to insure consideration for scheduling, the following minimum deadlines must be observed:

1. Capsule irradiation and design data: 21 days prior to shutdown.
2. Non-instrumented capsule delivery: 15 days prior to shutdown.
3. Instrumented capsule delivery: 21 days prior to shutdown.

Experiments not scheduled into the reactor because of lack of space at the desired flux are given a priority over new experiments at the next shutdown.

C. Sample Identification

1. Numbering System

In order to properly maintain and keep track of irradiation samples, a standard identification or numbering system has been established.

- a. Each indivisible (by ordinary means) irradiation specimen will be identified by the program number followed by a

serial or item number. The first number, the program number, is that assigned by the program-approving agency on the "Irradiation Services Purchase Order," form AED-22 or "Request for Commercial Irradiation Service," form AED-220. Examples of this program number are WAPD-14, ANL-6, KAPL-28, etc. The second number is an item number. Each capsule or unit will carry a separate and distinct item number. Subsequent irradiations or multicapsule insertion would be ANL-6-25, ANL-6-26, etc. The first number is necessary to denote the program. The capsule number identifies the capsule in that program.

- b. Each capsule or specimen holder assembly will be identified by the program number followed by an alphabetical letter or letters. Examples would be WAPD-49-H, BETT-81-C, etc. These holders can be used an indefinite number of times with different specimens.
- c. Capsule holder assemblies containing multiple capsules which are loaded at places remote from the reactor canal will, in addition to the program number and a letter designation, be assigned an insertion serial number to designate the specific assembly. Such an assembly will contain a different set and/or different arrangement of specimens than any other serial number of that particular assembly. The serial number will not be engraved on the holder assembly. Examples would be WAPD-49-H-101, BETT-81-C-203, etc.
- d. Standard TRA type capsule holders or baskets will not normally be numbered except when flux monitor wires have been attached. They will be identified by the experiment number followed by a second serial number.

For example, an X-basket, with flux wire attached, designated BMI-43-5-2 would be the second basket with flux wire attached in which the BMI-43-5 experiment was irradiated.

- e. Flux monitor assemblies, used for flux determination only, are to be designated with the program number followed by FM and a serial number. Examples would be BETT-51-FM-27, KAPL-68-FM-4, etc.

Correspondence to and from TRA must contain the program number and capsule number(s) under discussion rather than simply referring to a curium or thorium sample.

2. Marking of Samples

- a. All markings will be done at the experimenter's laboratory with a Burgess Vibratool, or equivalent, in broad letters readable through 20 feet of water. Typical acceptable markings are shown in Figure 50.

- b. It is not necessary to irradiate capsules in numerical order. However, it is logical to assign item numbers consecutively regardless of the order in which they are shipped to TRA, how they are irradiated, or returned to the sponsor's laboratory. It is preferred that all numbers be used eventually so that a glance at the record will indicate the total number of items irradiated.

TABLE I
SIZE OF VARIOUS MTR IRRADIATION FACILITIES

<u>Facility</u>	<u>Minimum Facility Diameter (inches)</u>	<u>Gauge Size* (inches)</u>
LB One-hole L-piece	1.375	1.3125 +0.000 -0.050
LB-4X Four-hole L-piece	1.312	1.290 +0.000 -0.040
LB-4N Four-hole L-piece	0.873	0.8125 +0.000 -0.015
AA One-hole A-piece	1.375	1.3125 +0.000 -0.050
AA-2W Two-hole A-piece	1.553	1.4687 +0.000 -0.050
AA-4X Four-hole A-piece	1.312	1.290 +0.000 -0.040
DA-8D Eight-hole D-piece	1.375	1.3125 +0.000 -0.050
Hydraulic Rabbit VH-1 and VH-2	0.995	0.8125 +0.000 -0.015
Hydraulic Rabbit VH-4	1.308	1.125 +0.000 -0.015
X-basket	1.154	1.125 +0.000 -0.015
L-basket	1.154	1.125 +0.000 -0.015
D-basket	1.154	1.125 +0.000 -0.015
S-basket	0.650	0.625 +0.000 -0.015
N-basket	0.650	0.625 +0.000 -0.015
B-basket	1.060	1.000 +0.000 -0.015

*Samples must be constructed to be straight and to pass through a 6-inch long, tubular gauge cut to the maximum dimensions shown. If the sample is designed to replace a basket, the gauge must be as long as the basket.

TABLE II
SIZE OF VARIOUS ETR IRRADIATION FACILITIES

<u>Facility</u>	<u>Minimum Facility Diameter (inches)</u>	<u>Gauge Size* (inches)</u>
One-hole A-piece	1.553	1.4687 +0.000 -0.050
R-4X Four-hole A-piece	1.312	1.290 +0.000 -0.040
C-4X Four-hole core filler piece	1.312	1.290 +0.000 -0.040
Beryllium reflector piece	1.312	1.290 +0.000 -0.040
X-basket	1.154	1.125 +0.000 -0.015
B-basket	1.060	1.000 +0.000 -0.015
S-basket	0.650	0.625 +0.000 -0.015

*Samples must be constructed to be straight and to pass through a 6-inch long tubular gauge cut to the maximum dimensions shown. If the sample is designed to replace a basket, the gauge must be as long as the basket.

TABLE III
SIZE OF VARIOUS ATR IRRADIATION FACILITIES

<u>Facility</u>	<u>Minimum Facility Diameter (inches)</u>	<u>Gauge Size* (inches)</u>
H-holes	0.625	0.585 +0.000 -0.015
A-holes	0.625	0.585 +0.000 -0.015
B-holes	0.875	0.8125 +0.000 -0.015
I-holes (large)	4.905	4.850 +0.000 -0.050
I-holes (small)	3.178	3.125 +0.000 -0.050
O-piece (small hole)	0.875	0.8125 +0.000 -0.015
O-piece (standard hole)	1.312	1.290 +0.000 -0.040
O-piece (large hole)	3.000	2.950 +0.000 -0.050
R-basket	1.154	1.125 +0.000 -0.015
O-basket	0.650	0.625 +0.000 -0.015
Y-basket	0.650	0.625 +0.000 -0.015
I-can (large)	4.613	4.565 +0.000 -0.050
I-can (small)	2.863	2.8125 +0.000 -0.050

*Samples must be constructed to be straight and pass through a 6-inch long, tubular gauge cut to the maximum dimensions shown. If the sample is designed to replace a basket, the gauge must be as long as the basket.

Figure 1. MIR Reactor Tank Arrangement

Figure 2. MTR One-Hole L-Piece (LB)

Figure 3. MTR Four-Hole L-Piece (LB-4X)

For Details See Dwg. MTR-D-4873

Figure 4. MTR Four-Hole L-Piece (LB-4N)

PP C6-D-4611

For Details See Dwg. MTR-D-4453

Figure 5. MTR Four-Hole A-Piece (AA-4X)

Fig. 6 MTR One-hole A-piece

Figure 7. MTR Two-Hole A-Piece (AA-2W)

Figure 8. MTR Four-Hole K-Piece (KB-4X)

Figure 9. MTR Two-Hole Piece (AA-2K)

77

Figure 10. MTR B-Piece

Figure 11. MTR Hydraulic Rabbit Facilities

Figure 12. MTR Reactor
Vertical Cross Section

ASSEMBLY

SECTION A-A

1/2 13 NC 2 HEAVY HEX NUT

1/2 13 NC 2 HEX HEAD BOLT

FOR DETAILS SEE DWG. MTR-D-3773

P.P. Co-D-4617

HOLDING TOOL BODY

Section A-A

Ref: Drawing
MTR-D-6707

Figure 14. Adjustable Lead Tube Clamp - Type D

Figure 15. ETR Reactor Tank Arrangement

For Details See Dwg. ETR-E-1060 P.P.C. C-4621

Fig. 16 ETR Four-hole Core Filler Piece (C4X)

Figure 17. ETR Beryllium Reflector Assembly

Figure 1C. ETR One-Hole A-Piece

Figure 19. ETR One-Hole A-Piece Liner

Figure 20. ETR Four-Hole Reflector Piece (R4X)

Figure 21. ETR Reactor Vertical Cross Section

Figure 22. ATR Reactor Tank Arrangement

Figure 23. ATR Reactor Vertical Cross Section

Figure 24. Basket Identification Markings

Figure 25. X-Basket

Figure 26. L-Basket

Figure 27. D-Basket

Figure 28. S-Basket

Figure 29. N-Basket

Figure 30. 3-Basket

Figure 31. K-Basket

Figure 32. R-Basket

Figure 33. O-Basket

Figure 34. Y-Basket

Figure 35. MTR Capsule Holder Reference Points

Figure 36. ETR Capsule Holder Reference Points

Figure 37. ATR Capsule Holder Reference Points

BOTTOM CAP

TOP CAP

ASSEMBLY

For Details See Dwg. AED-C-1929

TUBE

PP Co.-C-4628

Figure 38. 0.555 I.D. VH-1 and VH-2 Leaky Rabbit

BOTTOM CAP TOP CAP ASSEMBLY

For Details See Dwg. AED-C-1934

TUBE

Figure 39. 0.805
I.D. VH-4
Leaky Rabbit

For Details See Dwg. MTR-B-5180

PP Co. - B-4632

Figure 40. Screw Top Capsule

For Details See Dwg. MTR-C-4275

PP Co. - B-4633

Figure 41. MTR VP Polyethylene Rabbit

Figure 42. HR-2 Polyethylene Rabbit

Figure 43. End Protrusion for 1-1/8 inch Capsules

Figure 44. Open Type Capsule

Figure 45. Open Type Capsule

Figure 46. Sealed Type Capsule

P P C₀-A-4639

Figure 47. Sealed Type Capsule

Figure 48. Measuring and Handling Device

PPCo-B-6913

Figure 49. In-Tank Connector

Ref: Drawing ETR-D-2416

Figure 50. Typical Acceptable Capsule Markings

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