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AETR NUCLEAR MOCKUP DESIGN

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by

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PREFACE

Since December, 1956, Internuclear Company has performed a series of design studies in the development of a concept of an Advanced Engineering Test Reactor to produce very high neutron fluxes in large diameter experimental facilities. The results of these studies have been reported to the U.S. Atomic Energy Commission in a series of reports.^{1,2,3} The reactor concept is of the "flux-trap" type and consists of a central test hole surrounded consecutively by annular regions of light water, fully-enriched core of aluminum plate-type fuel assemblies, and heavy water which serves as a reflector. In order to prevent perturbation of the neutron flux in the central test space and disturbance of the power distribution in the core, a unique reflector control scheme is employed.

Conclusions of Section 12.0, "Research and Development Program", of Internuc-23³ indicated that a nuclear mockup facility would best supply information concerning the operational characteristics of the reflector control systems; the temperature and void coefficients for the test hole, moderator annulus, core, and reflector; the effects of various materials in the test and moderator regions; the effects of various metal-water ratios in the core; the neutron flux distributions and core power distributions; and the effects of shim poison in the reflector upon neutron fluxes in the test region. In addition, the facility would be a very useful auxiliary to an operating full power AETR in that experiments could receive nuclear check-out before being placed in an AETR. Consequently, in October, 1958, the Commission requested Internuclear Company to

1. conduct a preliminary hazards evaluation of the AETR preliminary conceptual design,
2. construct and test operate pilot plant models of the reflector control systems, and
3. prepare a detailed engineering design of a nuclear mockup facility.

In June of 1959, the Commission modified the scope of the contract de-emphasizing items one and three above, and requesting new efforts directed toward the evaluation of basic technical requirements for advanced engineering test reactors and an evaluation of the capability of the Internuclear Company AETR concept to meet Naval Reactor test requirements.

This report is submitted in fulfillment of the portion of the modified contract AT(11-1)688 dealing with the detailed engineering design of a nuclear mockup facility.

It is impossible to give proper credit to all who furnished information and advice in the preparation of this design. However, Internuclear Company gratefully acknowledges the assistance and co-operation of the following organizations.

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1.0 INTRODUCTION

The AETR nuclear mockup is designed to be a flexible, inexpensive developmental facility which duplicates the reactor portion of the AETR and which would be used to verify the operation of reactor controls. The mockup would also furnish measurements of temperature and void coefficients, flux shapes, and critical mass, and facilitate a reliable AETR design in a minimum time, and with minimum development cost.

For even greater usefulness, the mockup is also designed for use in conjunction with an operating AETR to check the reactivity of experiments and fuel assemblies, and for other annular core reactor development purposes. In these respects, the mockup design embodies the concepts for a very low power nuclear auxiliary outlined in an earlier report.³

The original work scope included a detailed engineering design of the zero-power nuclear mockup facility complete with working drawings and specifications sufficient for contractor bidding, equipment purchases, construction, and assembly. Commercially available units were to be specified wherever possible and detail design was to be limited to those features unique to the facility.

Because of the work scope modification and the fact that no specific site has been selected, detail design has been limited to the reactor assembly and control systems and it is assumed that a simple building with supporting facilities may be readily supplied by private industry or the AEC.

This report contains the results of negotiations with potential vendors and fabricators, a description of the facility components, and design drawings suitable for contractor use. Preliminary quotations from fabricators and suppliers indicate that the facility can be in operation within an eight month period at a total cost not exceeding \$250,000.00 exclusive of U²³⁵ fuel and heavy water.

2.0 GENERAL DESCRIPTION

The AETR nuclear mockup facility consists of three parts: a skid-mounted reactor assembly, a packaged instrumentation unit consisting of control console and instrument panels, and a building complete with utilities and supporting facilities.

2.1 Reactor Assembly

The skid-mounted reactor assembly is a compact pool-type facility which duplicates the reactor portion of an AETR. Because of the small physical size and simplicity of the assembly, it is designed as a self-contained, completely shop-fabricated, portable unit. There are many advantages to be realized through this design concept:

1. The quality of shop fabrication is generally superior to that of field fabrication.
2. The cost of shop fabrication is less than field fabrication.
3. Site preparation and shop fabrication may proceed concurrently and independently thereby resulting in a shorter overall time requirement.
4. Portability enables the nuclear mock-up to be located irrespective of the eventual location of the AETR since shipment to a new location may be easily effected. For example, the mockup may be built in any convenient location and serve as a valuable aid in the detail design of the AETR, after which it may be shipped from its initial location to a site adjacent the AETR and further serve as a critical facility.
5. The design of a self-contained unit enables the entire system to be tested prior to shipment to the site.

In spite of its compact size, the mockup has a variety of fluid systems associated with it. These include a system to circulate light water from the shield pool, and three D₂O reflector systems.

The reflector system closest to the core is the reflector safety control. In addition to provisions for circulating the fluid, a small pump and eductor are used to create a vacuum in the annulus and thereby raise the D₂O therein to the

operating level. Scram is effected by venting the vacuum whereupon the reflector drops from around the core. Boric acid may be added or removed from this system if desired and thereby effect shim control.

Surrounding the safety reflector is another annulus of D_2O which is circulated. Provisions are made for variation of boric acid concentration in this region also, and it is expected that this region will prove to be adequate for shim control.

The third region contains D_2O which serves as a reflector. This is the outermost region and surrounds the other two reflector regions.

Provisions have been made to interconnect various regions, to change directions of flow, and to heat all or independent regions so that the operating characteristics of an AETR may be determined in the nuclear mockup.

The reflector tank with its internals, the piping, valves, tanks, pumps, ion exchangers, shield tanks, and other equipment necessary for the operation of the mock-up are mounted on the skid structure and form the reactor assembly.

2.2 Instrumentation

Instrumentation is purchased as a packaged unit including control console and instrument panels. Multi-strand cables and plug connectors are used to connect instrumentation to the reactor assembly, field installation being kept to a minimum. Because of the work scope modification, it was impossible to go into sufficient detail on this subject.

2.3 Building

A simple prefabricated building, Butler-type, approximately 20x60 feet with a 20 foot height at the eaves provides ample space. An overhead or movable crane of 10 tons capacity can service the entire facility. Provisions for heating, washroom, lighting, etc., are conventional and it is assumed that the location is such that utilities including potable water, heat, power, and sewer are readily available. A concrete floor and pit are all that are required for the reactor assembly. In lieu of a pit, temporary masonry shielding can be placed around the mockup assembly.

2.4 Location

The location for the mockup has not been specified by the Commission and, therefore, present design has been completed on the basis of several assumptions. As stated above, the facility design assumes that there are readily available utilities. Moreover the facility is not self-sufficient in the provisions for supporting personnel. Thus there is no office or laboratory for health physics. There is no shop for instrument or machine repair and there are no facilities for waste disposal.

The mockup has been designed so that, if necessary, it can be relocated very simply once a building with concrete floor and pit has been prepared at the new location. The fuel elements are withdrawn, the control rod drives dismounted, and the water drained from the mockup tanks. Blocks of shielding are removed and the mockup is then ready for shipment to the new location. The same steps in reverse order are required to prepare the mockup for operation once it is installed at the new site.

2.5 Construction

The mockup is designed so that construction may take place in two concurrent phases. One phase is the manufacture and assembly of the reactor assembly in the shop. The reflector tank and the tank for the shield pool are assembled in a rigid steel-framed structure mounted on large steel skids. All pumps, piping, wiring, valves, ion exchange tanks, and helium supply piping are assembled into the skid structure. The largest D₂O tank is located at the bottom of the weldment, within the support skids. In this way, the unit is assembled at one factory location where the facilities for welding and testing are generally superior to and less costly than those available in field construction. Except for fuel elements, water, control console, and an electrical power source, the unit is complete when shipped.

The other phase of construction takes place at the site. Construction requirements are very modest. In addition to footings for a simple prefabricated building, the facility requires a slab floor of conventional poured concrete. At the end of the slab a concrete-lined pit is needed to contain the mockup. This pit measures approximately 23x15x15 feet deep and is designed to support the mockup from the pit floor. It is expected that the pit can be poured accurately so that the mockup structure will fit within it with a minimum clearance. Minor electrical and instrument connections will also be required.

While a pit is desirable for safety reasons and would be included if a new building were built for the nuclear mockup, it is not essential. An existing building with a good concrete foundation could be used and a shield of concrete blocks built around the mockup assembly. A stairway and bridge would also be provided in this case.

2.6 Data Summary

<u>Design Power, watts</u>	100
<u>Fuel Mass, kg U²³⁵</u>	
Criticality	5.6
Full core loading	12
<u>Neutron Flux, n/cm²-sec x 10⁻⁸</u>	
Volume average in water-filled test hole	
Thermal	12.4
Intermediate	3.1
Fast	6.2
Peak thermal within H ₂ O annulus	13
Average in core	
Thermal	1.82
Intermediate	3.88
Fast	11.5
Peak thermal in reflector	6.47
<u>Core</u>	
Height, in	36
Outside diameter, in	18
Active core thickness, in	2.70
Volume, ft ³	2.72
Volume, liters	76.9
Metal-to-water ratio	0.685
Coolant	H ₂ O

Fuel Assembly

Type	Involute plate
Coolant gap, in	0.073
Plate thickness, in	0.050
Fuel plates per assembly	18
Assemblies per core	20
U235 per assembly, gm	600
Fuel alloy, wt %	
Uranium(fully enriched)	29.5
Aluminum	70.5

Reflector

Material	D ₂ O
Thickness, in	24
Height, in	60

Control

Safety reflector

Thickness, in	4
Total reactivity worth % $\Delta k/k$	18.8

Intermediate shim reflector

Thickness, in	3
Reactivity worth, % $\Delta k/k$ (23 gm/liter D ₃ BO ₃)	16

Regulating rod

Location	reflector capsule tube
Diameter, in	1.25
Reactivity worth, % $\Delta k/k$	0.6

Shielding

Source Flux, (100 watts), Mev/sec	5.4x10 ¹³
-----------------------------------	----------------------

Horizontal Shield

D ₂ O, in	24
Concrete, in	18
Dose rate at outer surface, mrem/hr	5

Vertical Shield

H ₂ O, ft	6
Dose rate at surface, mrem/hr	0.01

3.0 REACTOR ASSEMBLY DETAIL DESCRIPTION

The reactor assembly, (Dwg. 3-D-122) consists of the reactor vessel assembly, control and regulating rod assembly, frame assembly, and piping assembly. All equipment except the control and regulating rod drives, their supporting structure and the reactor area guard railing are below floor level. The reactor control console and instrument panels are located near the reactor and all connecting cables are contained in a trench below floor level.

3.1 Frame Assembly, (Dwg. 3-D-141)

The function of the frame assembly is to provide a structure to support and locate all components and piping associated with the reactor mockup assembly. The frame assembly is a welded steel structure 8-ft 3.5-in wide x 15-ft 5-in high x 15-ft 8.5-in long, and has an angle-iron flange at the top extending 3.75-in on all sides. The longitudinal dimension of the frame is divided into two compartments by an 18-in thick concrete block shielding wall which extends the full width of the frame and vertically from the top to a point 2-ft below the bottom of the reactor core. Structural steel which supports this wall effectively extends the shielding to 2-ft 7-in below the core. The compartment which contains the reactor vessel assembly has a shield pool 8-ft square and 6-ft 5-in deep formed by plates welded into the frame. Control and regulating rod assemblies are supported by a bridge which bolts to the top of the frame above the shield pool. The bottom of the pool is supported by a frame structure which also supports the reactor vessel assembly and attached piping. The equipment compartment contains structures for supporting all other components and attached piping, and is covered by removable steel grating supported on the frame structure. All vessels in this compartment are supported from angle-iron structures and all pumps are supported by a cross beam base which rests on top of the I-beam skids. The two skids, located at the bottom of the structure, are tied together by beams welded between them at the ends. From these beams all vertical framework is supported, and the entire structure is stiffened by crossed diagonal bracing on ends and sides. The I beam skids support the D₂O dump tank (Dwg. 3-D-146) between them. The four lift loops located immediately at the top of the frame and longitudinally symmetrical about the center of gravity of the reactor assembly (with control and regulating rod assembly removed) are removable. The approximate weight of the frame assembly is 13,000 lbs.

3.2 Reactor Vessel Assembly, (Dwg. 3-D-123)

The function of the reactor vessel assembly is to support the core and to provide compartmentalized circulation of the fluids used in the operation and control of the reactor mockup.

The reactor vessel assembly is a welded aluminum unit with elliptical heads. The entire assembly hangs on a shoulder located an inch above the tangent point of the top head. This shoulder rests on a machined steel ring which is welded to the bottom of the shield pool and the assembly is prevented from shifting position by eight hold-down lugs. The joint is sealed by a ring gasket sealed in an annular groove in the bottom flange. The nozzles for the scram valve assemblies and the isolation valve operators extend from the top head while all nozzles for the reflector fluid circulation systems extend from the bottom. A central tube, open at the top, extends the full length of the vessel, separates the light water core region from the D₂O reflector regions, and terminates below the bottom head with a blind flange. A small nozzle extends from this blind flange for connection to the core cooling system to permit circulation of the light water from the shield pool through the core. A connection for a level controller and an alarm float switch for the safety reflector reservoir is welded into the bottom head.

The space bounded by the outer vessel shell and the central tube is divided into three reflector annuli--an outer reflector region, a shim control region, and an inner safety reflector region. The shell is divided vertically into two regions by a multiple plenum chamber. Above the plenum are the reflector regions and below is the scram space into which the safety reflector flows when scram occurs. The plenum itself serves as distributing header for the different reflector regions and these regions are connected to the plenum by internal pipes.

A horizontal pipe extends radially from the outside of the central tube through the outside vessel wall at the midpoint of the core and serves as an instrument well. Another pipe extends vertically downward from a point 2-ft 8.5-in below the core midpoint through the blind flange which covers the central tube and serves as another instrument well.

The reactor core structure assembly (Dwg. 3-D-130) is inside the central tube and is supported by it.

There are six equally-spaced vertical capsule tubes, 1.5-in I.D. open on top to the shield pool and arranged in a circle of such diameter that they pass through the inner

reflector annulus. At the bottom of the core these tubes turn at right angles and open into the central tube. One of these tubes is used for a regulating rod location.

3.3 Scram Valve Assembly, (Dwg. 3-D-137)

The scram valve assembly with its associated structure and electrical components functions as a means to permit equilization of gas pressure on the surface of the fluid at the top of the safety reflector and the fluid in the reservoir of the reactor vessel, thereby permitting the fluid in the safety reflector annulus to fall into the scram reservoir.

The assembly is coupled to the reactor vessel by means of two concentric pipes. The outer pipe extends upward from the reactor vessel to the top of the shield pool. The upper section of the pipe is greatly increased in diameter and is removable by means of a flanged joint. This feature permits access to the scram valves for maintenance. All electrical connections to the scram valves are made through a waterproof connection at the extreme top of the outer pipe. The inner pipe extends upward to the enlarged section of the outer and the scram valves are here connected in parallel to it. The scram valves are solenoid-operated and fail open. The open end of the outer pipe extends into the scram space of the reactor vessel, and the open end of the inner pipe extends to the top of the safety reflector annulus.

When the scram valves are opened gas flows from the scram space through the outer pipe, scram valves, and inner tube into the inner annulus thereby allowing the fluid of the safety reflector to fall.

3.4 Core Support Assembly, (Dwg. 3-D-131)

The main function of this assembly is to locate and support the fuel assemblies. A secondary purpose is to guide the central control rod.

The assembly consists of a long thin cylindrical shell, open at both ends inside a short cylindrical spider which contains the control rod locating guide bushing. The entire assembly is supported by the bottom end of the spider which sits on a shoulder within the central vessel tube. The central tube and the long shell form an annulus which contains and locates the fuel assemblies. Wedge-shaped notches in the upper edge of the spider locate the fuel assemblies circumferentially and slots near the top of the shell match with pins in the fuel elements to maintain vertical alignment.

3.5 Fuel Assemblies. (Dwg. 3 D-132)

There are eighteen involute plate fuel assemblies in a complete mockup core, each made up of sixteen identical curved fuel plates mechanically-bonded between inner and outer aluminum side plates. The side plates and fuel plates, when thus assembled, form a rigid structure. Rigidity is increased by top and bottom connecting plates mechanically bonded to the side plates. These connecting plates are provided with lift holes to be used in core loading. The features of this involute plate fuel assembly have been discussed in an earlier report.³

3.6 Control and Regulating Rod Assembly, (Dwg. 3-D-140)

The principle function of the control and regulating rod assemblies is to provide a mechanism for positioning the rods with respect to the reactor core. A part of the structure for these assemblies functions as a cover for the shield pool and as an observation and servicing platform.

The assembly consists of a round steel ring 2-ft 9-in O.D. with a 0.75-in thick wall 10.5 in long centered over the reactor vessel. Six I-beams, spaced at 60 degree intervals are fastened to the vertical wall of this ring and extend horizontally and radially outward. The ends of these beams rest on and are bolted to the top of the frame assembly. Angle-iron ties connect the beams on top and form locations for six sections of removable steel grating which form a hexagonal platform. The spider which locates and supports the control rod is bolted to three equally spaced angle-iron lugs welded to the inside of the 2-ft 9-in O.D. ring. The regulating rod support is supported by the 2-ft 9-in O.D. ring and is located over a capsule hole. The regulating rod drive is attached by a flange connection to this support which in turn is equipped with positioning screws so that fine adjustment of rod position may be obtained.

The rod drives are package units specified on the drawings. A number of suitable rod drives are available commercially.

The regulating rod is a 1-in diameter aluminum tube coated with .010-in thick cadmium contained within a second closely-fitting aluminum tube. When welded together at the ends, a hollow rod is formed which has a radial clearance of 0.125-in in the 1.5-in I.D. capsule tube when coupled to the rod drive. The safety control rod is a 6.5-in O.D. cylinder with a 0.25-in wall of cadmium clad with aluminum and supported by two three-legged spiders which are in turn attached to a central rod. This is guided below by the control rod

locating and guide bushing located in the core support assembly and coupled at the top to the control rod drive.

3.7 Piping Assembly, (Dwgs. 3-D-147, 148, 149)

All the piping except that for the helium system passes from the reactor vessel compartment below the shielding wall to components in the equipment compartment of the mockup assembly. The helium line runs along the top of the frame, past the shield wall, and across the shield pool to the scram line. Branches go downward from this line to components in the equipment compartment. The ion beds, tanks, and pumps are arranged to give the most economical runs consistent with good general arrangement, accessibility and ease of fabrication.

The helium lines and the safety reflector reservoir level controller alarm line are located by the shop and fabricated as bent aluminum alloy tubing. All other lines are aluminum alloy pipe of welded fabrication, with flanged connections where needed.

3.8 D₂O Dump Tank, (Dwg. 3-D-146)

This tank functions as a liquid storage container large enough to hold a major portion of the D₂O in the reflectors and the circulation systems which drain to the tank.

The tank is a welded aluminum structure 1-ft 1.75-in high, 7-ft wide, and 14-ft 5-in long. It holds 850 gallons and has a helium line connection and a fill nozzle welded into the top. A sleeve is welded into the tank to permit the sump suction pipe to pass through. Lugs welded integrally into the top of the tank are threaded for bolts which support the tank from the frame and locate it between the I-beam skids of the frame assembly.

3.9 Poison D₂O Head Tank, (Dwg. 3-D-145)

The function of this tank is to serve as a reservoir for storing a concentrated solution of borated heavy water, as a point for adding boric acid to the system, as a vessel to catch overflow from and permit expansion of liquid in the shim reflector system, and to keep the pressure in the central shim annulus equal to that outside.

The tank has a volume sufficient to contain enough saturated boric acid solution to bring the liquid in the shim reflector system to one-half of saturation. This will provide approximately 16% negative reactivity.

The tank is 2-ft O.D. x 3 ft 3.25-in long and is built up from a piece of standard aluminum pipe with welding cap ends. It has diametrically opposite lugs on the sides which support it from the frame structure. A 4-in nozzle for a liquid level alarm is on one side. A 3.5-in nozzle for connection to the expansion pipe of the shim reflector system and a 1.5-in nozzle for connection to the suction of the poison injection eductor of the shim reflector system are in the bottom of the tank. A nozzle for connection to the helium system and a nozzle for a liquid addition stand pipe are in the top.

3.10 Expansion Tank, (Dwg. 3-D-145)

The function of this tank is to catch overflow and permit expansion of the liquid in the outer reflector region, and to equalize pressure on both sides of the multiple header.

The tank is 1-ft 2 in O.D. and 2-ft 9.5 in long and is built up from a piece of standard aluminum pipe with welding cap ends. It has diametrically opposite lugs on the sides which support it on the frame structure. A 1.5-in overflow nozzle and a 1.5-in nozzle for connection to the outer reflector system extend from the bottom. A nozzle for connection to the helium system is welded to the top of the tank.

3.11 Ion Exchange Beds, (Dwg. 3 D 145)

Two beds, I-1 and I-2, are used one at a time to remove chemicals and impurities from the heavy water in the shim reflector. The piping provides isolation valves for these beds to permit replacement of resin without shutdown of the reactor and valves to shift flow from one bed to the other but does not permit flow through both at the same time.

One bed, I-3, is used continuously to purify the liquid passing through the outer and safety reflector systems. The life of this bed when used to purify unpoisoned liquid will be very long, but its added capacity might be required if it is decided to poison the safety reflector system. All three ion exchange tanks are the same size and are located in the equipment compartment.

Ion beds are 2-ft diameter and 5-ft high with removable heads and resin baskets. A single 1-in nozzle is in each top and bottom head. They are of aluminum alloy and welded construction. The baskets have a capacity of approximately 10-ft³ of resin. By accepting an impurity "leakage" of 20% in the resin bed effluent, each ion bed has the capacity to remove 35 lbs of borate ion from the shim system before its operation is effected appreciably.

Thus each ion bed is capable of removing twice as much borate ion as the maximum amount contained in either the shim or safety reflector.

3.12 Pumps, (Dwg. 3-D-142) 147, 148, 149

The three centrifugal pumps for the D₂O reflector systems are horizontally mounted near the floor of the equipment pit. Each is of bronze construction in order to minimize corrosion and mechanical seals are used to reduce the leakage of D₂O to a negligible amount. The pumps are driven by integrally-mounted electric motors.

The largest pump is rated at 710 gpm and is used to circulate D₂O through the safety reflector or through the outer reflector and safety reflector in series, depending on the valve arrangement selected. The pump uses a three-phase motor of 7.5 hp. The pump for the intermediate reflector is similar, but smaller, and rated at 250 gpm. This pump requires a three-phase motor of 3 hp. The smallest pump, that for the safety reflector eductor, pumps only 10 gpm in order that the safety reflector is raised at a slow rate during startup. This pump uses a single-phase motor of 1/4 hp.

A fourth centrifugal pump of bronze construction is used to circulate shield pool water when necessary. This pump is rated at 110 gpm and is driven by an integrally-mounted three-phase 3/4 hp motor.

3.13 Eductors, (Dwg. 3-D-142) 147, 148, 149

There are two bronze eductors located in the equipment compartment and used in the reflector systems. The smaller is the one through which the 10 gpm pump discharges to develop a vacuum to raise the D₂O in the safety reflector annulus.

The larger eductor uses the full flow of the intermediate reflector cooling system to develop a continuous suction which is used to introduce poisoned D₂O from the boric acid makeup tank at a rate of several gallons per minute if required.

3.14 Helium Blanket System, (Dwg. 3-D-142) 147, 148, 149

The helium blanket system located in the equipment compartment is used to prevent the D₂O from absorbing water or other impurities from contact with air. It also maintains

all the D₂O systems at a pressure of 2 psig. slightly above atmospheric pressure.

The helium is supplied to the systems in the equipment pit from portable bottles of compressed helium, T-4 and T-5. The pressure is reduced and applied through 0.5-inch tubing connected to the dump tank, poison D₂O head tank, safety reflector reservoir, and the expansion tank. A relief valve near the helium flasks vents excess pressure from these bottles or any other source before damage is caused.

The helium system also provides an effective means for leak detection. After isolating the helium supply tanks, loss of pressure under isothermal conditions indicates leakage. If the helium should be lost, helium leak detectors which are exceptionally sensitive, may be used to locate the leak.

3.15 Float Switches, (Dwg. 3-D-142) 147, 148, 149

One float switch, connected to the safety reflector reservoir, functions in conjunction with a level controller and alarm instrument to signal high or low level of liquid in the safety reflector reservoir. The high level signal indicates the safety reflector system is dangerously full, that there is only a space large enough for one scram above the liquid level in the reservoir, and the electrically operated valve V-7 opens. The low level signal indicates that the safety reflector system contains the proper amount of liquid and that there is a two-scram space above the liquid of the reservoir, and the valve V-7 closes.

Another float switch connected to the D₂O dump tank functions in conjunction with an alarm to signal a high level of liquid in the tank. A high level of liquid in this tank indicates that some reflector system is not filled or that the entire system has been over-filled.

A third float switch, connected to the poison D₂O head tank, functions in conjunction with an alarm to signal a high or low level of liquid in the tank. A high level of liquid in this tank indicates that the shim reflector system is filled to the top permissible level, and a low level signal indicates the low permissible level.

3.16 Shielding Installation, (Dwg. 3-D-122)

Shielding for the mockup is largely furnished by the reflector and shield water and secondarily by the concrete pit and fill material adjacent to the mockup pit. In addition however the

mockup requires an 18-in thick wall of ordinary concrete between the reactor vessel and the equipment area of the mockup pit. It is planned that the installation of this concrete should be in the form of solid blocks. In this way removal of the concrete is simplified. The prime requirement that the joints between the blocks be staggered is readily attained in normal masonry practice. Steel framing shown (Drawing 3-D-141) provides a 1-in clearance for the nominal 18-in wall. If the nuclear mockup is above grade, a similar concrete block wall, but thicker, would be placed around the entire structure.

4.0 INSTRUMENTATION DETAIL DESCRIPTION

The AETR monitoring and control system employs commercially available equipment of standard design. This type of instrumentation has certain important advantages: 1) circuits can be easily removed and replaced with readily available components and 2) proven circuitry may be obtained with substantial savings in time, effort and development cost.

Although the detailed design of the instrumentation is not complete, the design shown is sufficiently complete so that a description of the functions of components can be made. The system has a desirable feature in that component failure generally does not result in shutdown. Moreover, the failed component usually can be easily removed and replaced.

While the instrumentation described is from a particular supplier,* it is thought that other suppliers have similar equipment and designs.

4.1 Neutron Flux Monitoring Channels

There are three essentially independent neutron flux monitoring channels for the AETR, namely: 1) pulse channel, 2) logarithmic channel and 3) safety channel.

4.1.1 Pulse Channel

During the initial reactor startup from source level, the pulse channel or start-up channel is the only channel sufficiently sensitive to monitor the neutron flux. As shown in Figure 4.A., the neutrons are detected by non-integrating type fission or BF₃ chambers that produce electrical pulses for each neutron event. The output of the chambers after pre-amplification (6919) is fed to a linear pulse amplifier (6914) which amplifies the pulse.** The output pulses of the linear pulse amplifier are counted by a conventional scaler and also integrated by the log count rate-period meter to give a counting rate signal and a period signal which are fed to recorders. This furnishes a printed indication of neutron multiplication during the sequence of initial reactor startup operations.

* Leeds & Northrup Company

** The numerical module designation used is identical to that furnished by Leeds and Northrop Company.

The pulse channel covers four decades from source level to the start of the intermediate or logarithmic channel.

4.1.2 Logarithmic Channel

As the pulse channel approaches the end of its range, the logarithmic-period channel begins to respond. The detector is a compensated ion chamber which produces a current proportional to flux level. This current is the input of a log n period amplifier (6919). The logarithmic amplifier produces a linear 0-10 m.v. signal proportional to the logarithm of the current input or flux level. The 0-10 m.v. output covers the range of 0.001% to 300% full power. An RC network in the amplifier module differentiates the logarithmic power level signal to give the time rate of change of flux or reactor period. A 0-10 m.v. signal is produced in the period network covering a range of minus 30 to plus 3 seconds. These two signals are fed to the log n recorder and the period recorder. The period recorder is the same recorder as in the startup channel and is automatically switched as the startup channel reaches its upper limit.

4.1.3 Safety Channel

The purpose of the safety system is to cause fast reactor shutdown (scram) in the event of unsafe reactor operation. This is accomplished in the AETR mockup by de-energizing solenoid valves which drop the safety reflector and by de-energizing the electro-magnet which releases the safety rod. When an unsafe condition arises, the currents to the electro-magnets and the solenoid valves are reduced rapidly to values which can no longer support the rods or energize the solenoids. Consequently, the reactor is shut down. The two principal unsafe conditions that initiate fast shutdown are:

1. Reactor neutron flux level exceeds a preset limit.
2. Reactor power level increases at too fast a rate (short period).

With respect to flux level, it is highly desirable to limit the time delay between detector response and the command to the output actuator (in this case electro-magnetic clutch or solenoids) to less than five milliseconds. The direct-coupled electronic amplifiers described, in the absence of electro-magnetic devices in the signal path, are more than capable of meeting this requirement.

As shown in Figure 4.3, the modules designated as level safety (6922) and period safety (6923) each contain a single preamplifier, a sigma amplifier, and a fast scram circuit. Therefore, the number of safety amplifiers is exactly equal to the number of primary input signals. Each safety amplifier has its own filament transformer. Plate and bias voltages are obtained from the safety power modules (6929) with the positive voltage also providing the power for an uncompensated ion chamber. The signal outputs from the safety amplifiers are auctioneered. Therefore, the voltage at the sigma bus is determined by the highest safety amplifier output. The plug-in feature of input amplifier allows for prompt removal from the system if failures occur in individual modules.

The safety monitor (6926) adequately monitors and warns the operator should abnormal conditions arise in the safety systems. The safety monitor also permits the measurement of the necessary quantities to calibrate and test the entire safety system. It performs the following functions.

1. Continuous indication of power level as measured by the level safeties and the reactor period as measured by the period safety.
2. Measurement of the output voltages of the safety power modules.
3. When a failure annunciation occurs, controls allow the operator to locate the faulty supply quickly.
4. Measurement of cathode current in every magnet amplifier. This measurement permits location of a faulty circuit in the event of a failure. Incipient failures can also be located before complete breakdown.
5. Measurement of each safety pre-amplifier output. Calibration of each safety amplifier is possible with this measurement and a calibrated test signal located at each level safety input.
6. Measurement of total current in each solenoid or electro-magnet, and high current alarm.
7. Measurement of sigma bus potential.
8. Measurement of all load-shared output current.

4.2 Manual Control

The control scheme described below is designed for the control system where the poisoned shim reflector is the middle reflector and the safety reflector is the region of D_2O nearest the core. This is shown in Drawing 3D-121. Minor modifications would make the instrumentation adaptable to other control methods.

The filling of the poisoned reflector system with D_2O is done manually through a series of solenoid or other type valves operated from the reactor control console. After the shim reflector is completely filled with D_2O and poison is added to the D_2O head tank, poison-saturated D_2O is injected into the shim reflector giving negative reactivity sufficient to prevent start-up as the safety and outer reflectors are subsequently filled with D_2O .

To accomplish startup, the regulating rod is withdrawn approximately half way and the safety rod, a backup for the reflector safety system, is withdrawn completely under manual control. The safety reflector then is slowly raised. With the safety reflector completely raised the shim region should have sufficient negative reactivity to keep the system sub-critical. To increase reactivity for criticality, solenoid valve V-3 (Dwg. 3-D-121) is opened from the control console to remove some of the poison from the shim system. The monitoring of power level and rate of change of power level (period) is accomplished with the neutron monitoring channels described in Section 4.1.

Manual operation brings the power to approximately 90% of desired power level after which the automatic control mode is normally placed into operation.

4.3 Automatic Control

A means for automatic operation is required so that the neutron flux in test regions can be maintained constant. While the general scheme for automatic reactor control can be described, the exact operating characteristics are obtained only after installation of reactor equipment. For this reason, and in view of the changes in contract scope, exact values for the following were not determined.

- a. Ion bed lag time and rate of poison removal.
- b. Lag time before eductor can add poison to reflector and rate at which poison is added in this way.

- c. Flow rates through valves V-3 and V-15 in Dwg. 3-D-121.
- d. Maximum permissible rate of removal of poison with valve V-3 open.

A simple block diagram of the proposed control system is shown in Figure 4.C. The key valves, V-3 and V-15, are remotely-operated. Both valves are fail-safe in that V-3 closes and V-15 opens upon loss of power. Ideally, as an optimum control condition, both V-3 and V-15 are closed and the poison concentration in the shim reflector is constant for constant power, neglecting leakage and poison burnup. More practically, each of these valves is occasionally pulsed to keep the neutron flux at the desired control point.

In operation, a gamma-compensated ion chamber measures the neutron flux and feeds a current proportional to the flux level to a micro-microammeter. This meter has 18 ranges covering six decades of current input. The output, proportional to the input, is fed to a recorder with integral means for varying the set point. This use of a micro-microammeter instead of a single range linear amplifier allows automatic control over six decades instead of only one, thus adding flexibility to the system.

The difference between the set point of the recorder and the actual flux level is fed into an adjusting type control unit as an error signal. Polarity of the error signal depends upon whether the recorder pen, the flux level, is above or below the set point. This determines whether one of two relay coils is energized. Depending upon which of these two relays is energized, control impulses are sent to the control elements, valves V-3 and V-15. Below the control set point, the relay for valve V-3 is energized. The other relay, energized above the control point, is connected to valve V-15. The length of time that either relay is energized depends on the distance that the recorder pen is away from the control point (proportional action), the time that the recorder pen is away from the control point (reset action), and the rate of movement of the recorder pen (rate action).

Use of one adjusting type control unit as outlined above limits the flexibility of the control since the proportional, rate, and reset actions of the single controller apply to both control valves. If the lag times for poison addition and poison removal cannot be made sufficiently alike, one may have to use a second controller. This enables greater flexibility in controller adjustment to be attained although actual operation is much the same as outlined.

A manual-automatic selector switch and a manual control switch are mounted on the controller. In this way for one or for two controllers, one may select either automatic or manual control. In addition, the recorder may be used directly as a means of overriding other signals to close valve V-3 and open valve V-15 when necessary, as during a short-period condition.

5.0 BUILDING DETAIL DESCRIPTION

The building can be a simple prefabricated structure of the Butler-type and measure 20 feet x 60 feet with a 20 foot height at the eaves. A ten ton overhead or portable crane must be supplied for mockup installation as well as conventional utilities for normal operation.

The concrete pit, Dwg. 3-D-143, is approximately 15-ft 6-in deep and the perimeter of the opening has an angle iron insert for protection of the corners. The pit clears the frame on the reactor vessel compartment end and on the two sides by 2 inches and on the equipment compartment end by 4.5-ft. The resulting opening at the floor level is covered by steel grating. The 2 foot 10 inch rise at 45 degree inclination at the midpoint of the walls and the extra length of the pit provide maintenance space. There are 3 foot high guard rails on all sides of the pit opening. These are detachable by slipping the vertical posts of the rails from sockets imbedded in the floor of the building. The reactor frame lies on the floor of the pit, and the top of the pit and frame are flush. A sump is located in the bottom of the pit for collecting fluids

6.0 SHIELDING

Shielding is required to protect personnel in the immediate vicinity of the AETR nuclear mockup. The design of proper shielding is simplified by the fact that the mockup operates at low power. For most measurements, the power need only be in the few watt range. For shielding purposes, however, the design is based on 100 watt power level.

6.1 Vertical Shield

The shield above the mockup reactor is a pool of light water extending 6 ft above the top of the core. In this way the water serves as a dependable bulk shield without appreciably hindering core access or observation. The radiation penetrating the water shield is limited to gamma and fast neutron radiation and is significant during reactor operation only. Due to the efficiency of hydrogen as a moderator, the fast neutron radiation from the core is attenuated rapidly in the shield pool and the fast and thermal neutron dose rates at the water surface are negligible.

The gamma radiation is more penetrating and determines the minimum pool depth. The gamma dose rate was calculated on an IBM 704 machine using a shielding program which accounts for the annular core geometry and the axial variation in reactor power. The program calculated separately the penetration for each of five gamma photon energy groups. At the water surface the maximum gamma dose rate was found to be 0.01 mrem/hr. Thus, with the reactor operating at 100 watts, the dose at the water surface for 40-hr weekly exposure is less than 0.5% of the permissible maximum.

6.2 Equipment Compartment Shield

In addition to the vertical shield described above, horizontal shielding is also required. With the core in a pit 7.5 feet beneath the ground floor of the facility, horizontally-emitted radiation is safely absorbed in soil, concrete, or fill material everywhere except in the direction of the equipment which adjoins the reactor.

Between the reactor core and the mockup system equipment, radiation from the core is attenuated by the 2-ft D_2O reflector which normally surrounds the reactor, by the 18-in concrete shield wall between the reactor tank and the equipment pit, and by the distance from the core to the equipment area. There is small likelihood of personnel exposure at this wall since the area in front of the wall

near the reactor is almost completely occupied by large tanks containing the ion exchange beds as shown in Dwg. 3-D-122.

The biological dose rate at the shield wall due to gamma radiation was calculated as before using an IBM 704 program which accounted for various photon energy groups, annular geometry, and the axial variation in core power. At 100 watts, the maximum gamma dose at a point on the wall opposite the core center is found to be 4 mrem/hr. In addition there is a fast neutron contribution. Based upon WANDA calculations and studies of the reflector neutron flux spectrum, the fast neutron dose is 0.8 mrem/hr and the total biological dose approximately 5 mrem/hr. Thus the equipment area can be occupied if required during operation at 100 watts.

7.0 OPERATION

The principal reason for building a nuclear mockup of the AETR is to verify the performance predicted for novel features of the control system. For this reason the nuclear mockup incorporates a control scheme similar to the AETR plus additional capability for emergency shutdown and test loop experiment simulation.

In the paragraphs below each of the four mockup controls is described together with an outline of the manner in which these controls are integrated to assure safe and reliable mockup operation.

7.1 Shim Control

A reactor shim control is required to make the large, relatively slow changes in reactivity which are necessary during startup, for fuel burnup, fission product accumulation, and large temperature changes. For the AETR the shim control device is a varying concentration of boric acid in the D_2O reflector.

Two regions of the mockup reflector can be chemically poisoned to serve as shim controls. One of these regions is the 4-in thick safety reflector annulus. A boric acid concentration of one-tenth saturation in this area is sufficient to suppress 19% reactivity. The other reflector region which can be chemically poisoned is the 3-in thick intermediate reflector. Since it is farther from the core, a higher poison concentration is required for the same reactivity effect. For example, boric acid concentration of one-half saturation in this volume suppresses 16% reactivity. However this reflector region is small so that the total weight of boron required is about the same for both reflectors. Thus, mockup operation will determine which of these two reflectors gives the best and most reliable shim control. One has the choice between an inner reflector requiring low poison concentration and a thinner, smaller intermediate reflector requiring a higher concentration of boric acid poison for the same reactivity worth. Also to be considered is the interrelation between shim and safety reflectors which, while difficult to predict analytically, can be determined relatively easily with experiments.

With either region poisoned, operation is largely the same. To add reactivity, borate ion is removed from the shim reflector by circulating a fraction of the borated D_2O through an ion-exchange resin bed. By restricting this flow to a low rate by means of a throttle valve or an orifice, the rate at which reactivity is added can be made arbitrarily slow. A flow of

13 gpm, for example, adds $4\% \Delta k/k$ in 10 minutes. This removal process is initiated from the reactor control panel by means of a remotely-operated control valve (V-3) in the ion bed inlet. The system diagram is shown in Dwg. 3-D-121.

The addition of boric acid from a makeup tank to the shim reflector system is accomplished from the reactor control panel in a similar manner by means of a second remote control valve, V-15 in the above drawing. This valve permits D_2O saturated with boric acid to flow from the makeup tank to the suction of an eductor. By pumping the entire flow of D_2O for the shim reflector through an eductor, sufficient pressure differential is available at all times to inject promptly whatever boric acid poison may be needed. For example, to remove $4\% \Delta k/k$ in 10 minutes only 3 gpm saturated boric acid is added. The volume of D_2O displaced by the injected poison solution is returned to the boric acid makeup tank. In use, the concentration in this tank is gradually reduced. By means of occasional sampling, the additional amount of boron required in the makeup tank can be determined and the proper amount added.

7.2 Regulating Control

The regulating control is used to compensate for rapid transient changes in reactivity. Thus if the shim control system has a slow response or if the reactor and test loop are sensitive to transient changes in reactivity, then a regulating control is required. However in an effort to simplify the AETR and possibly eliminate the flux perturbation associated with an additional reactivity control, an effort has been directed and will continue to be directed toward eliminating the need for a regulating rod. This represents an incentive to increase the negative temperature coefficient of the reactor and is an excellent reason for seeking a shim control with very rapid response. However, until mockup operation proves a regulating control to be unnecessary, a regulating control rod is included in the mockup design in order to be certain of control system capability.

The regulating rod is installed in one of the light water-filled 1.5-in I.D. capsule tubes which pass through the thermal flux peak in the safety reflector. Here the importance is relatively high and installation is simple. The worth of a 1.25-in hollow control rod was estimated from first order perturbation⁴ theory and found to be $0.6\% \Delta k/k$. Lesser worth, if necessary, can be obtained easily even after construction by making the rod shorter or by substituting a smaller less-heavily poisoned rod.

7.3 Reflector Safety Control

The primary safety control for the AETR is the droppable reflector. In operation, a partial vacuum from the eductor maintains the inner D₂O reflector in an elevated position until an electrical scram signal opens valves (V-25 through V-28) to release the vacuum and permit the D₂O to fall from around the core. In this way a very large amount of reactivity is removed due to the high leakage of neutrons from the relatively small core.

The drop time of the safety reflector has been experimentally determined on a geometrically similar model of the safety reflector.⁵ In these experiments the rate of fall was measured and the resulting loss of reactivity determined through careful calculation. Indications are that the shutdown rates are comparable to the shutdown rates in the ETR and generally superior to the rates of reactivity removal in research reactors and critical experiments.

The safety rod is included in the mockup facility in order to more easily simulate experiments and also to serve as a second emergency shutdown device. This guarantees safety with the relatively novel reflector controls.

As stated in Section 3.6, the safety rod is a 6.5-in O.D. tube of cadmium clad with aluminum and located on the axis of the reactor just within the fuel assemblies. The water usually filling the reactor vessel supplies ample damping when the safety rod falls into a close-fitting socket near the bottom of the core. In order to maximize worth, the center of the rod is hollow and the additional moderation of the water aids the rod in capturing a higher proportion of the incident neutrons of all energies.

A number of control rod drives were investigated and for the relatively simple requirements of the mockup, a number were found suitable. The safety and regulating rod drives are identical except that regulating rod drive does not need the magnetic clutch to release the control rod for scram. Each of the two drives employs an electrical motor for power and has means to determine rod position for display at the reactor control console. The designs considered have been proven in similar reactor applications.

7.4 Operation

Two typical operations, loading and startup, are described below for the nuclear mockup. Other procedures will vary depending on the type of experiment to be run.

A detailed study and operating manual for the experiments will need to be made prior to operation.

7.4.1 Core Loading Procedure

The shim reflector is filled with D_2O , the circulating pump is started, and concentrated boron solution is added until the desired maximum shim reflector concentration is obtained. The safety control rod is raised. The scram valves are closed and the safety reflector elevated around the core so that it may be used for emergency shutdown. The outer reflector region is gradually filled with D_2O . The shield pool is filled with light water. A neutron source is introduced into the core region.

All nuclear instrumentation and safety circuits are energized and they are checked for proper working order. All pumps, valves, etc., are also checked. The initial neutron count rate is recorded.

Each fuel assembly is brought to the edge of the shield pool individually, coupled to a grappling tool, and slowly lowered into the fuel annulus. The count rate is measured, recorded, and plotted before loading the succeeding assembly. The usual plot of reciprocal multiplication versus number of fuel assemblies is used to predict criticality. The process is continued until the core annulus is completely filled with fuel assemblies, or until the plot predicts criticality for the next assembly. With proper boron concentration in the shim reflector, the entire core should be loaded without reaching criticality. Should dangerous supercriticality be reached accidentally, the safety circuits will scram the reactor.

7.4.2 Reactor Startup

The startup procedure for the nuclear mockup is similar to the loading procedure. It is assumed the light water shield is filled and the fuel elements are in place. All neutron instrumentation and safety circuits are energized and checked for proper working condition with the neutron source in place. All other pumps, valves, etc., are checked for proper operation. The safety control rod is raised and the regulating rod is inserted to approximately mid-position.

The boron concentration in the shim reflector is checked and adjusted. The shim reflector is filled if necessary with the circulating pumps. The safety reflector is slowly raised. The reactor should not go critical with the safety reflector completely filled. If necessary, the boron concentration

the shim reflector can be increased. The remaining approach to criticality is achieved by intermittent cleanup of the poisoned shim reflector system. At criticality, the regulating rod is placed into automatic servo operation to maintain reactor power constant.

634 009

REF. DWGS.	
NO	TITLE
AETR 3 D 460	CONTROL AND REG. ROD ASSEM
41	FRAME ASSEMBLY
148	PIPING ASSEMBLY
149	PIT
133	REACTOR VESSEL ASSEMBLY

international company

7 N. Broadway Blvd.
Clayton & Missouri

AETR

REACTOR MOCKUP ASSEMBLY

SCALE: 1" = 1'	DATE	DRAWING NO.
DESIGNED: E.A. MARR	DRAWN: E.A. MARR	PROJECT: AETR 3C

REFERENCE DWGS.	
No.	TITLE
AETR-3-D-124	REACTOR ELEVATION
AETR-3-D-137	SCRAM VALVE ASSEMBLY
AETR-3-D-138	ISOLATION VALVE ASSEMBLY

DESIGNED BY	REV. APP'D	NO.	REVISION
DATE	DATE		

7 W. Grandwood Blvd. Clayton, N. Carolina	
A.E.T.R. REACTOR VESSEL ASSEMBLY	
SCALE: 1/2" = 1'-0" DESIGNED BY: M.J. KORNBLAU CHECKED BY: M.J. KORNBLAU APPROVED BY: M.J. KORNBLAU	DATE: _____ DRAWING NO.: _____ AETR-3-D-123 PROJECT AETR-3C

TOP HEAD

VERTICAL SECTION

ENLARGED VIEW "A" ENLARGED VIEW "B"

BOTTOM HEAD
(VIEW LOOKING UP)

NO.	QTY.	DESCRIPTION	UNIT	QTY.	DESCRIPTION	UNIT	QTY.	DESCRIPTION	UNIT
N17	1	AL. CENTRAL TUBE	18	40	150" AM. STD.				
N16	1	AL. CENTRAL TUBE	18	40	150" AM. STD.				
N15	1	AL. SCRAM	4	40	150" AM. STD.				
N14	1	AL. SCRAM	4	40	150" AM. STD.				
N13	1	AL. WELL	2 1/2	40	PIPE				
N12	1	AL. WELL	3	40	PIPE				
N11	1	AL. LEVEL ALARM	1/2	40	PIPE				
N10	1	AL. OVERFLOW	2	40	150" AM. STD.				
N9	1	AL. EDUCTOR DISCHARGE	1 1/2	40	PIPE				
N8	1	AL. OUTSIDE REFLECTOR #2	3	40	PIPE				
N7	1	AL. EDUCTOR SUCTION	1 1/2	40	PIPE				
N6	1	AL. POISON OUT	4	40	PIPE				
N5	1	AL. SAFETY IN	5	40	PIPE				
N4	1	AL. SAFETY OUT	6	40	PIPE				
N3	1	AL. OUTSIDE REFLECTOR #1	5	40	PIPE				
N2	1	AL. POISON IN	3	40	PIPE				
N1	1	AL. DRAIN	2	40	150" AM. STD.				

NOZZLE SCHEDULE

NO.	QTY.	DESCRIPTION	UNIT	QTY.	DESCRIPTION	UNIT	QTY.	DESCRIPTION	UNIT
PL 5	1	POISON IN							
PL 4	1	OUTSIDE REFLECTOR #1							
PL 3	1	SAFETY IN							
PL 2	1	OUTSIDE REFLECTOR #2							
PL 1	1	POISON OUT							

PLENUM SCHEDULE

NOTES:
1. NOZZLES N4, N9 & N10 EXTEND INTO HEAD APPROX. 3/4".
2. NOZZLES N1, N4, N5, N9, N10, N11, N12 & N13 AND CORRESPONDING NECKS SHOWN ON THIS DWG.
3. NOZZLES N2, N3, N6, N7, N8, N14 & N15 AND CORRESPONDING NECKS SHOWN ON DWG.

NOTES:
2. MATERIAL TO BE ALUMINUM ALLOY 6061-T6.
3. VESSEL TO BE BUILT IN ACCORDANCE WITH A.S.M.E. CODE.
4. STAMP NOT REQUIRED.

NO.	REFERENCE DWG.	TITLE
N1	AE-3-D-125	REACTOR ELEVATION SECTIONS
N2	AE-3-D-126	REACTOR PLAN SECTIONS
N3	AE-3-D-127	CENTRAL TUBE
N4	AE-3-D-128	REFLECTOR & PLENUM ASSEMBLY

<p>A.E.T.R. REACTOR ELEVATION</p>	
<p>SCALE: 1/4" = 1'-0"</p>	<p>DATE: _____</p>
<p>DESIGNED BY: M.J. SCHNEIDER</p>	<p>DRAWING NO.: AE-3-D-124</p>
<p>CHECKED BY: M.J. SCHNEIDER</p>	<p>PROJECT: AE-3-C</p>

REFERENCE DWGS.	
Nº	TITLE
AETR-3-D-124	REACTOR ELEVATION
" 3-D-126	REACTOR PLAN SECTIONS
" 3-D-127	CENTRAL TUBE
" 3-D-128	REFLECTOR & PLENUM ASSEMBLY
" 3-D-135	INTERNAL PIPING DETAILS
" 3-D-136	INTERNAL PIPING DETAILS
" 3-D-137	SCRAM VALVE ASSEMBLY
" 3-D-138	ISOLATION VALVE ASSEM.

CHGKED	REV. APPD.	NO.	REVISION

		7 H. Brentwood Blvd. Clayton, N. Carolina	
		AETR REACTOR ELEVATION SECTIONS	
SCALE: 1/8" = 1'-0"	DATE	DRAWING NO.	REV.
DESIGNED BY: J. KORNELIUSSEN		AETR-3-D-125	
CHECKED BY: J. KORNELIUSSEN		PROJECT AETR-3-C

SECTION A-A
See AETR-3-D-125

SECTION B-B
See AETR-3-D-125

SECTION C-C
See AETR-3-D-125

SECTION D-D
See AETR-3-D-125

NO	REFERENCE DWGS
AETR-3-D-124	REACTOR ELEVATION
" -3-D-125	REACTOR ELEVATION SECTIONS

REVISION	REV	DATE	BY	APPD

		7 N. Broadway Blvd. Clayton, N. Missouri	
A.E.T.R. REACTOR PLAN SECTIONS			
SCALE: 1/4" = 1'-0"	DATE:	DRAWING NO.	REV.
DESIGNED: H. J. KANAKIS	CHECK: AETR-3-D-126	PROJECT: AETR-3-C	

0339 043

INNER & OUTER ANNULUS
CAP PLATES

NOTES:
1. MATERIAL TO BE ALUMINUM ALLOY
6061-T6.

REFERENCE DWGS.	
No.	TITLE
AETR-3-D-124	REACTOR ELEVATION
- 3-D-125	REACTOR ELEVATION SECTIONS

		A.E.T.R. REFLECTOR & PLENUM ASSEMBLY	
		SCALE: 1/4" = 1'-0" DATE: DRAWING NO. PROJECT: AETR-3-D-128	

REVISION	NO.	DATE	BY	APP'D.

PART No. 12
1 REQD

REFERENCE DATA	
NO.	1
DESCRIPTION	REACTOR CORE STRUCTURE
DATE	10/1/50
BY	J. H. HARRIS
CHECKED BY	J. H. HARRIS
APPROVED BY	J. H. HARRIS
REVISION	

INTERNATIONAL
COMPANY
 A.E.T.R.
 REACTOR CORE STRUCTURE
 VERTICAL SECTION
 DRAWING NO. AETR-3-D-150
 10/1/50

SECTION A-A

PART N° 18
20 READ

BOTTOM VIEW
ORIENTATION OF SIDE PLATES
(FUEL PLATES NOT SHOWN)

PART N°	NAME	DESCRIPTION
5	TOP BAR	SEE DETAIL
4	BOTTOM BAR	SEE DETAIL
3	FUEL PLATES	SEE DETAIL
2	INSIDE PLATE	AETR-3-D-133
1	OUTSIDE PLATE	AETR-3-D-134

MATERIAL LIST

REVISION	DATE	BY	APP'D

REFERENCE DWGS	TITLE
N°	
AETR-3-D-133	FUEL ASSEMBLY INSIDE PLATE
- 3-D-134	FUEL ASSEMBLY OUTSIDE PLATE

internuclear company
7 W. Broadway Blvd., Dayton 2, Ohio

AETR
FUEL ASSEMBLY

SCALE: FULL DATE: DRAWING NO. REV.

DESIGNED BY: M. J. GENTILELLO CHECKED BY: DATE:

APPROVED BY: M. J. GENTILELLO PROJECT: AETR-3C

REFERENCE DWGS							
NO	T T L E					<u>AETR</u> <u>FUEL ASSEMBLY</u> <u>INS DE PLATE</u>	
AETR 3 D 32	FUEL ASSEMBLY					SCALE: FULL & NOTED DATE: _____ DESIGNED BY: <u>W. L. BARNFIELD</u> CHECKED BY: _____ REV BY: _____ DATE: _____ NO. _____ REVISION: _____ PROJECT: <u>AETR 3 D 133</u> <u>PROJECT AETR 3C</u>

SECTION A-A

DIMPLE LOCATION

BOTTOM END VIEW
FUEL PLATE GROOVES NOT SHOWN

ENLARGED VIEW "B"

ENLARGED VIEW 'B'
(DIMENSIONED)

REFERENCE DWGS						<u>AETR</u> <u>FUEL ASSEMBLY</u> <u>OUTSIDE PLATE</u>	
NO	TITLE					SCALE/FULL & NOTED	DATE
AETR-3-D-132	FUEL ASSEMBLY					DRAWING NO. AETR-3-D-134 PROJECT AETR-SC	
						DESIGNED BY J. MOSEFIELD CHECKED BY J. MOSEFIELD DATE 11/17/64	
ENGINEER	NEW APP	NO.	REVISION

PART N° 1
3 REQD
(INTERNAL PIPING FOR NOZZLE N°6)

PART N° 3
3 Rego
(INTERNAL PIPING FOR NOZZLE N°3)

FRONT ELEVATION

SIDE ELEVATION

SECTION A-A

PART N° 2
1 REQD
(INTERNAL PIPING FOR NOZZLE N7)

PART N° 4
2. REQ.
(INTERNAL PIPING FOR NOZZLES N° N14 & N15)

PART N° 5
3 REQD
(INTERNAL PIPING FOR NOZZLE N5)

NOTES
1 ALL PIPE & PIPING FITTINGS TO BE
SCH 40 ALUMINUM ALLOY 6061-T6

REFERENCE DWGS								AETR			
No. TITLE								INTERNAL PIPING			
AETR 3-D 125 REACTOR ELEVATION SECTIONS											
-3-D 126 REACTOR PLAN SECTIONS								DETAILS

(INTERNAL PIPING FOR NOZZLE N2)

REFLECTOR TEST TUBES

INTERNAL PIPING FOR NOZZLE N6

1. ALL PIPE & PIPE FITTINGS TO BE
SCH 40 ALUMINUM ALLOY 6061-T6

internuclear	7 N. Brookwood Blvd.
	company	Clayton, N. Missouri
<u>A.E.T.R.</u>		
<u>INTERNAL PIPING</u>		
<u>DETAILS</u>		
SCALE: 1/4" = 1'-0"	DATE:	DRAWING NO.
DESIGNED BY: M. KOHNFIELD	CHECKED BY: M. KOHNFIELD	AETR-3-D-136
		PROJECT AETR-3-C

informa
company

7-16 Standard 104
Chapter 4, Standard

AETR
REACTOR VESSEL
EXPLODED ELEVATION

NO.	DATE	REVISION
1	10/1/68	1
2	10/1/68	2
3	10/1/68	3
4	10/1/68	4
5	10/1/68	5
6	10/1/68	6
7	10/1/68	7
8	10/1/68	8
9	10/1/68	9
10	10/1/68	10
11	10/1/68	11
12	10/1/68	12
13	10/1/68	13

PROJECT AETR-30-138
PROJECT AETR-30

NO.	TITLE
1	AETR 3-D-140 CONTROL AND REG ROD ASSEMBLY
2	AETR 3-D-141 CONTROL AND REG ROD ASSEMBLY
3	AETR 3-D-142 CONTROL AND REG ROD ASSEMBLY
4	AETR 3-D-143 CONTROL AND REG ROD ASSEMBLY
5	AETR 3-D-144 CONTROL AND REG ROD ASSEMBLY
6	AETR 3-D-145 CONTROL AND REG ROD ASSEMBLY
7	AETR 3-D-146 CONTROL AND REG ROD ASSEMBLY
8	AETR 3-D-147 CONTROL AND REG ROD ASSEMBLY
9	AETR 3-D-148 CONTROL AND REG ROD ASSEMBLY
10	AETR 3-D-149 CONTROL AND REG ROD ASSEMBLY
11	AETR 3-D-150 CONTROL AND REG ROD ASSEMBLY

NO.	DATE	REVISION
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internuclear company
7 H. Breunel Blvd.
Clyde, N. H.

A.E.T.R.
CONTROL AND REG ROD ASSEMBLY

SCALE: 1/2" = 1"
DATE: _____
DRAWING NO.: _____
REV.: _____
AETR 3-D-140
PROJECT AETR-3C

033 157

[illegible][illegible]

SECT A-A

4' 9"

5'

1' 9"

1" x 10" FLT MS

SECT DD

SECT E

SECT CC

SECT FM

2 ALL MTL AS NOTED OR STRUCTURAL STEEL
1 WELDED CONSTRUCTION
GENERAL NOTES

REF DWGS.

NO	TITLE
AETR-30122	REACTOR ASSEMBLY

**internuclear
company**
7 N. Dearfield Blvd.
Clayton, S. Missouri

AETR.
FRAME ASSEMBLY

SCALE: 3/4" = 1'	DATE	DRAWING NO.	PS
DESIGNED		AETR-3 D-141	
DRAWN	6-1-80		
CHECKED			
APPROVED	AULEONARD	PROJECT AETR 3C

SECT BB

REF DWGS.	
N.O.	TITLE
AETR 3-D-11	REACTOR MOCKUP ASSEMBLY

internuclear company <small>7th, Broadway St. New York 10, N.Y.</small>	
AETR REACTOR PIT	
SCALE: 1" = 1'-0" DRAWN: J. J. J. CHECKED: J. J. J. DATE: 10/1/58	REVISION NO. 1 DATE: 10/1/58

SECT BB

SECT CC

SECT. D.D. TYPE.

③
PLATFORM GRATING
6 REQ.

OBSERVATION PLATFORM
REG AND CONTROL ROD
SUPPORT
1 REG P

CONTROL ROD SUPPORT SPIRER
1 REQ'D.

ALL MTL-MS.
NOTES:

<u>REF DWGS</u>	
<u>NO.</u>	<u>TITLE</u>
AETR 3040	CONTROL AND REF ROD ASSEMBLY

CHECKED	REPLY BY	NO.	REVISION

internuclear company		7 H. Broadhead Rd Clayton & Muncast	
	<u>A.E.T.R.</u> CONTROL AND REG. ROD STRUCTURE DETAILS			
SCALE: 1" = 1' DRAWING NO. AE/REG DATE: 1-8-57	DRAWING NO. AETR-20-141 REVISION: 100-0		NET

SECT. B-B

SECT. A-A
1 1/2\"/>

ION TANKS
1 1/2\"/>

EXPANSION TANK
1 1/2\"/>

POISON D.O. HEAD TANK
1 1/2\"/>

REF. DWGS.	
NO.	TITLE
1	ACTR-50-145 PIPING ASSEMBLY

internuclear
company
7 W. Broadway St.
Chicago 5, Illinois

A.E.T.R.
TANK DETAILS

SCALE	5/8\"/>
DATE	12/1/54
DESIGNED BY	W. J. BROWN
CHECKED BY	W. J. BROWN
APPROVED BY	W. J. BROWN
REVISION	
NO.	DATE
1	12/1/54
2	12/1/54
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PROJECT ACTR-50

				<u>A.E.T.R.</u> D.O DUMP TANK	
				SCALE: 1/8" = 1' DRAWING NO.	DATE
				DESIGNED DRAWN: C.E. HARRIS CHECKED MILLINGTONVILLE	AETR-3-D-146 PROJECT AETR-3C
APPROVED INV. APPRO. NO.	REVISION

**internuclear
company** 7 N. Broadway Blvd.
Chapen S. Miami

A. E. T. R.
D₂O DUMP TANK

REF DWGS.

NO.	TITLE
NETR-3-DW1	PIPING PLAN AT 11'-0" EL.
NETR-3-DW2	PIPING ELEVATION AT 3'-0" EL.
NETR-3-DW3	PIPING ELEVATION AT 10'-0" EL.

internuclear company
7 H. Brewster Blvd.
Clayton, N. Missouri

AETR
PIPING PLAN AT 0'-0" EL.

DESIGNED	REV. APP'D	NO.	REVISION	SCALE: 1/8" = 1'	DATE	DRAWING NO.	REV.
BY	DATE					NETR-3D148	
APPROVED	DATE					PROJECT AETR-3C

Figure 4.1

Startup and Intermediate Channels for AETR Mockup

Figure 4.2
Safety System for AETR Mockup

$\left. \begin{matrix} S_1 \\ S_2 \\ S_3 \\ S_4 \end{matrix} \right\} = \text{Inner reflector dump solenoids}$
 A = Rod electromagnet

Figure 4.3

Schematic Control System for AETR Mockup

1. Refer to Figure AETR-3-D-121 for Complete Piping Diagram.
2. If two (2) controllers are used the RL contact in #1 and the RH contact in #2 will not be used.
3. Period Override simultaneously opens V-15 and closes V-3.

8.0 REFERENCES

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3. Leyse, C.F., et al, "An Advanced Engineering Test Reactor", Report AECU-3775, March 1958.
4. Wolfe, B., and Fischer, D.L., "Perturbation Theory of Control Elements", Nuclear Science and Engineering 4, 785-793, 1958.
5. Larson, A.M., Delicate, W.S., "Advanced Engineering Test Reactor Reflector Control Model Experiments and Analyses", Report INTERNUC-47, 1959.
6. Claiborne, Copenhaver, Bertini, Fowler, "Calculating Gamma Heating in Reactor Structures", Nucleonics 15, No. 10-115, 1957.
7. Glasstone, S., Principles of Nuclear Reactor Engineering, D. Van Nostrand Co., Inc., 1955.
8. Goldstein, H. The Attenuation of Gamma Rays and Neutrons in Reactor Shields, Chapter 5, p 141, U.S. Atomic Energy Commission, 1957.
9. Chapman, G., Storrs, C., "Effective Neutron Removal Cross Sections for Shielding", AECD-3978, 1955.
10. Foderaro, A., Obenshain, F., "Fluxes from Regular Geometric Sources", WAPD-TN-508, 1955.
11. Rockwell, T.III, ed. Reactor Shielding Design Manual, D. Van Nostrand Company, Inc. p 54, 1956.

APPENDIX A AETR SUGGESTED FABRICATION PROCEDURE
REFLECTOR TANK ASSEMBLY

Refer to Drawing 3-D-139

1. Roll, side seam weld, and machine central tube.
2. Machine top head complete.
3. Machine inner annulus cap plate.
4. Insert capsule tubes and all pipe stubs into cap plate and weld. Weld isolation valves into pipe runs (stubs to terminate in straight runs after respective bends away from annulus).
5. Slide cap plate assembly over central tube to locating shoulder and make weld. Weld capsule tubes into central tube.
6. Cut and drill bottom 1/2-in thick multiple plenum plate. Insert and weld in nozzles and penetrations. (Note! Flatten nozzles to allow insertion in plenum and room to weld).
7. Drill flanged heads (which form tops of plenums) for respective nozzles. Insert nozzle stubs and weld into heads. (Stubs to terminate in straight runs, after respective bends, aligning with straight runs of nozzle stubs in cap plate).
8. Weld flanged heads with nozzles to plenum bottom plate and to each other starting with innermost head.
9. Roll, side seam, and bell end of inner cylinder.
10. Slide inner belled cylinder into plenum assembly and weld at top and bottom of plenum.
11. Tack weld deflectors (over through nozzles) to innermost flanged head.
12. Machine central annulus cap plate.
13. Insert and weld pipe stubs to cap plate (stubs to terminate in straight runs after bends away from annulus). Roll, side seam, and bell end of outer cylinder.

14. Weld cap plate with nozzles to outer belled cylinder.
15. Slip assembly over inner belled cylinder and weld to top of plenum and to inner belled cylinder.
16. Insert instrument well and weld to inner and outer belled cylinders.
17. Bend pipe plenum ring, MK. P1 N5, and drill for nozzles.
18. Attach ring to plenum assembly by welding to jumper nozzles and butt welding ends to nozzle MK N3. (Note! pipe ring plenum terminates at nozzle MK N3 and does not intersect.)
19. Weld in feed nozzle N2.
20. Roll and side seam internal skirt.
21. Insert skirt and weld to plenum and pipe ring plenum.
22. Test each plenum and all welds.
23. Slide entire assembly over central tube assembly, aligning top and bottom nozzle stubs with straight connecting pipe and backing rings.
24. Make connecting pipe welds and weld annuli cap plates together.
25. Machine bottom head for nozzle penetrations.
26. Slip bottom head over nozzles and around central tube.
27. Weld to central tube and to outside edge of plenum. Weld all nozzles into head.
28. Set flanges and weld to nozzles and central tube.
29. Test assembly.
30. Make joint central tube to top head. Weld isolation valves and nozzles to top head.
31. Form and fit wrapper and weld.
32. Final test.

APPENDIX B. SHIELDING CALCULATIONS

Both gamma and neutron radiation was determined at critical points by the methods described below.

B.1 Gamma Shielding

The gamma shielding computation for the nuclear mockup employed a numerical program (previously developed) for the IBM-704 computer. This program treats a large number of core volume-elements as mathematical point sources. At a given dose point, the contribution from each of these sources is determined using the shielding point kernel, a process which is exact in the limit as each source volume becomes small.

The energy spectrum of the source is the same as that reported for measurements in the Oak Ridge BSR.⁶ This data is similar to that reported in Glasstone⁷, but is more recent. For purposes of numerical calculation, this spectrum was divided into five discrete energy groups, as shown in Table C.1 along with the corresponding absorption coefficients for the material of interest.

Table C.1

Gamma Shielding Constants

Average Group Energy, Mev	Absorption Coefficients, cm ⁻¹				
	0.5	1	2	4	6
Core	.176	.119	.080	.058	.051
Aluminum	.23	.17	.143	.0836	.072
H ₂ O and D ₂ O (200°F)	.0932	.0682	.0474	.0323	.0262
Ordinary Concrete	.0868	.0633	.0445	.0316	.0267
Source Energy, 10 ¹⁰ (Mev/watts-sec)	8.8	12.4	14.5	5.46	1.19

B.2 Neutron Shielding

The most critical neutron shield is that between the mockup core and the equipment area. This shield is composed of D₂O, aluminum, and concrete.

In analyzing this shield, the experimental value⁹ of the D₂O removal cross section(2.76 barns) was employed to determine neutron attenuation in the reflector. Conventional

values⁷ for fast neutron attenuation lengths in aluminum and concrete were used. Following the methods of Foderaro and Obenshain¹⁰ for the dose rate from a self-absorbing cylindrical source, the fast neutron dose rate was determined. Inasmuch as the core is assumed to be a cylinder rather than a hollow annulus, this treatment is slightly conservative.

If additional shielding is desired, barytes or iron concrete blocks may be employed instead of ordinary concrete. The neutron dose rate is then reduced by a factor of 5 and 20 respectively.

The vertical pool of light water above the core is in comparison a less critical shield due to the greater distance to the pool surface from the core and the large amount of self-shielding in a vertical direction within the core. The preliminary method used is based on an elementary surface-source. The source neutrons, determined from the average core power, were attenuated according to the experimental measurements quoted in Rockwell.¹¹ Since this showed the maximum surface dose rate to be 0.04 mrem/hr, a negligible amount, no further analysis of the vertical neutron shielding was performed.

APPENDIX C. MOCKUP FACILITY COST ESTIMATE

Although not required by the contract, many of the costs of the nuclear mockup facility have been obtained as a by-product of negotiation with vendors and fabricators. This data is summarized below in Table B.1 in an attempt to complete the design information in this report. Except where indicated, all values represent quotations. No allowance for contingency, escalation, or additional engineering is included.

Table B1

Estimated Cost of an AETR Mockup Facility

A. Reactor Vessel, Equipment, and Structure	
Material, valves, fittings pumps	\$20,883
Reactor vessel	38,060
Assembly & fabrication labor	25,843
Steel structure	8,580
	<hr/>
	\$93,736
B. Control Rods	
Regulating rod drive	3,100
Safety rod rod drive	8,000
Safety and regulating rods*	1,000
	<hr/>
	\$12,000
C. Reactor Instrumentation	45,000
D. Building and Site*	35,000
E. Miscellaneous Hand Tools and Instruments*	20,000
	<hr/>
	Total \$ 205,836

* Estimated Values

The fuel assembly costs for this reactor were investigated through consultation with three fabricators. Each stated his belief in the soundness and feasibility of the fuel assembly, but that some development was required, principally due to the variable thickness of the uranium-aluminum meat

alloy within each fuel plate. This is shown in Drawing 3-D-132.

For these fuel assemblies, the development costs quoted by the fabricators ranged from \$5,000 to \$17,000. A quotation for fabricating an initial core loading (22 fuel assemblies) was \$27,000 with a much lower price (\$625 each) for larger numbers of fuel assemblies, as required for an operating test reactor.