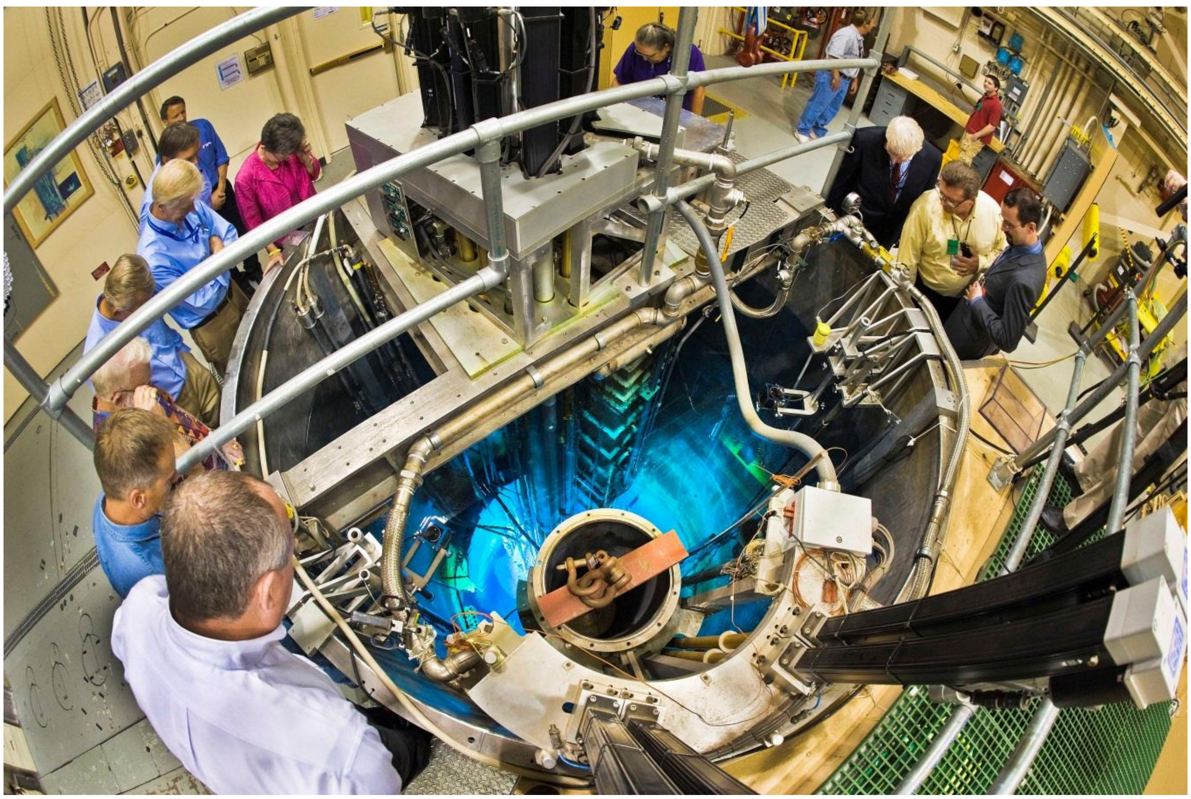
Experiment Handbook
Annular Core Research Reactor



May 2015

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Location

The ACRR is located in Technical Area V (TA-V) at Sandia National Laboratories (SNL) in Albuquerque, New Mexico on Department of Energy (DOE) land. It is situated within the Kirtland Air Force Base (KAFB). Figure 1 displays the location of TA-V in relation to Kirtland Air Force Base, while Figure 2 displays a more detailed map of TA-V. Building 6577 is the perimeter access building.

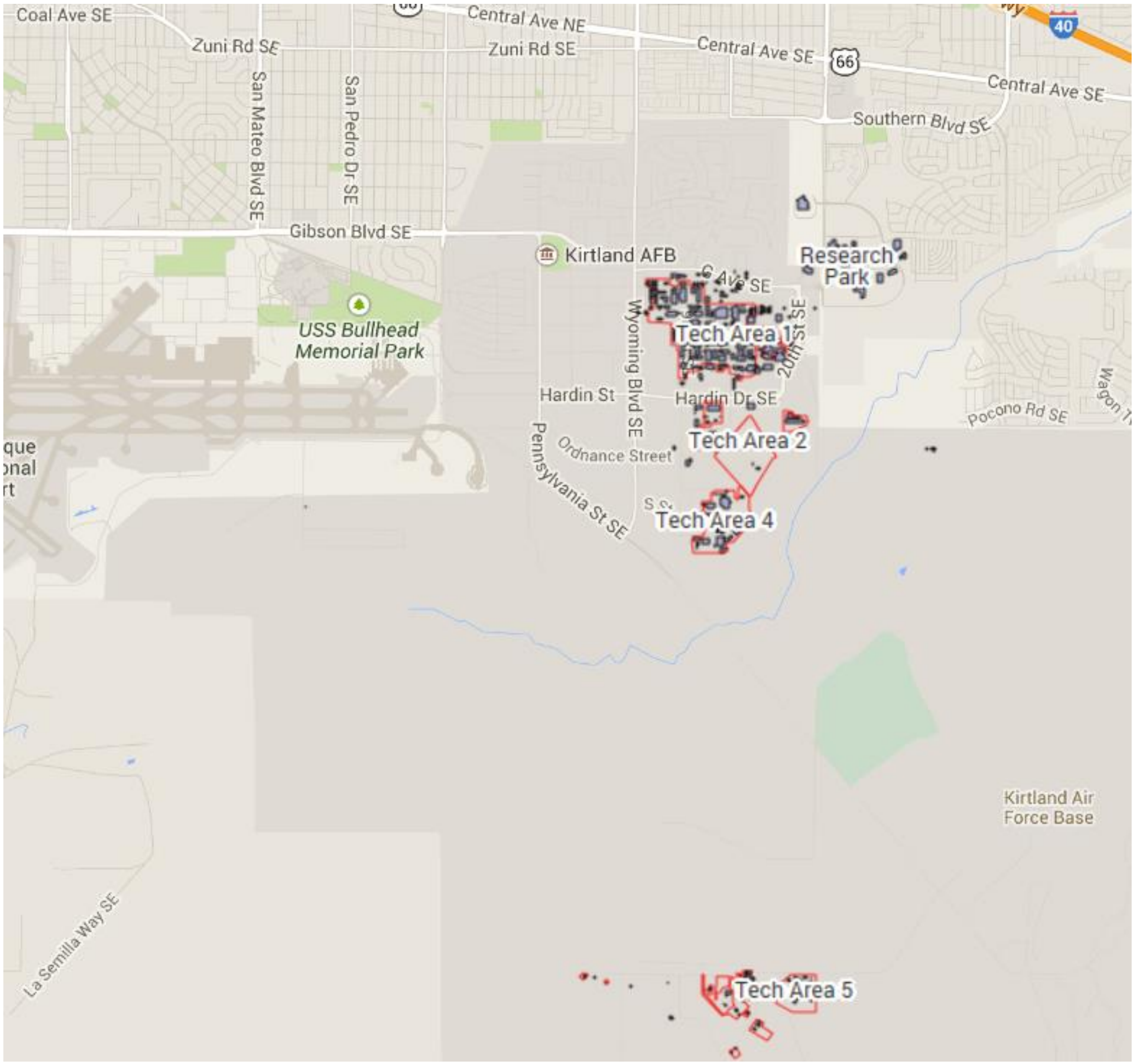


Figure 1. Location of TA-V

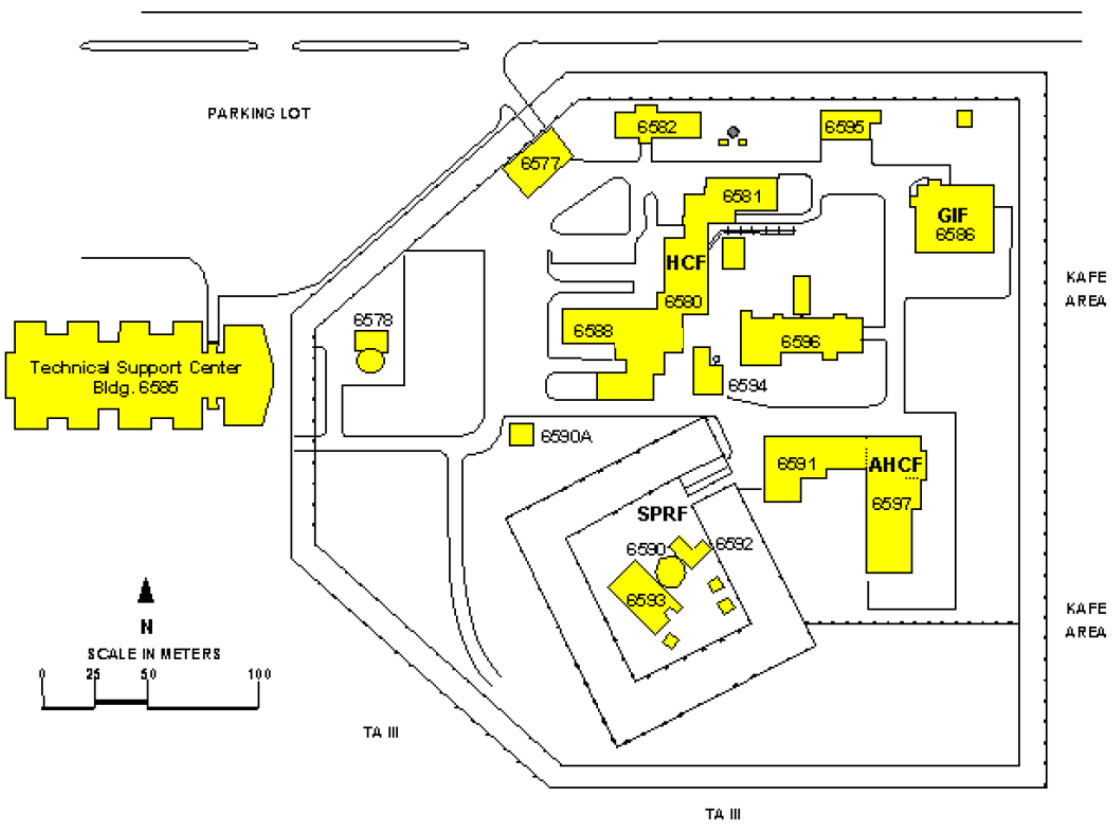


Figure 2. TA-V Detailed Map

Access to TA-V is granted via the SNL Badge Office, which is located at Innovation Parkway SE, Suite A-1, Albuquerque, NM 87124. Requests for visitors must be made by an SNL manager via the Enterprise Person System. The manager of Nuclear Facilities and Applied Technologies (Org. 1380) serves as the initial communication contact and will grant permission to access TA-V. ACRR Operations can be contacted via TAV_nuclear@sandia.gov. Figure 3 displays the location of the IPOC building, which contains the Badge Office. Experimental staff will need to be escorted into TA-V if they do not have current TA-V Hazard, Emergency, and Response Training (HEART). The training takes about 15 minutes to complete and can be accomplished online in advance of the visit, or can be taken at the perimeter access building entering TA-V. Individuals who do not have a security clearance will require an escort, and any additional requirements must be met, prior to being permitted to enter TA-V.

The Visitor's Protocol is a companion document to the Inter-Institutional Visitor Agreement between Sandia Corporation and the Regents of the University of New Mexico (UNM). This document provides additional guidance relating to UNM's process for gaining use of TA-V's experimental facilities. If you are under an Inter-Institutional Visitor Agreement, notify the appropriate Annual Core Research Reactor (ACRR) staff so the protocol may be followed.

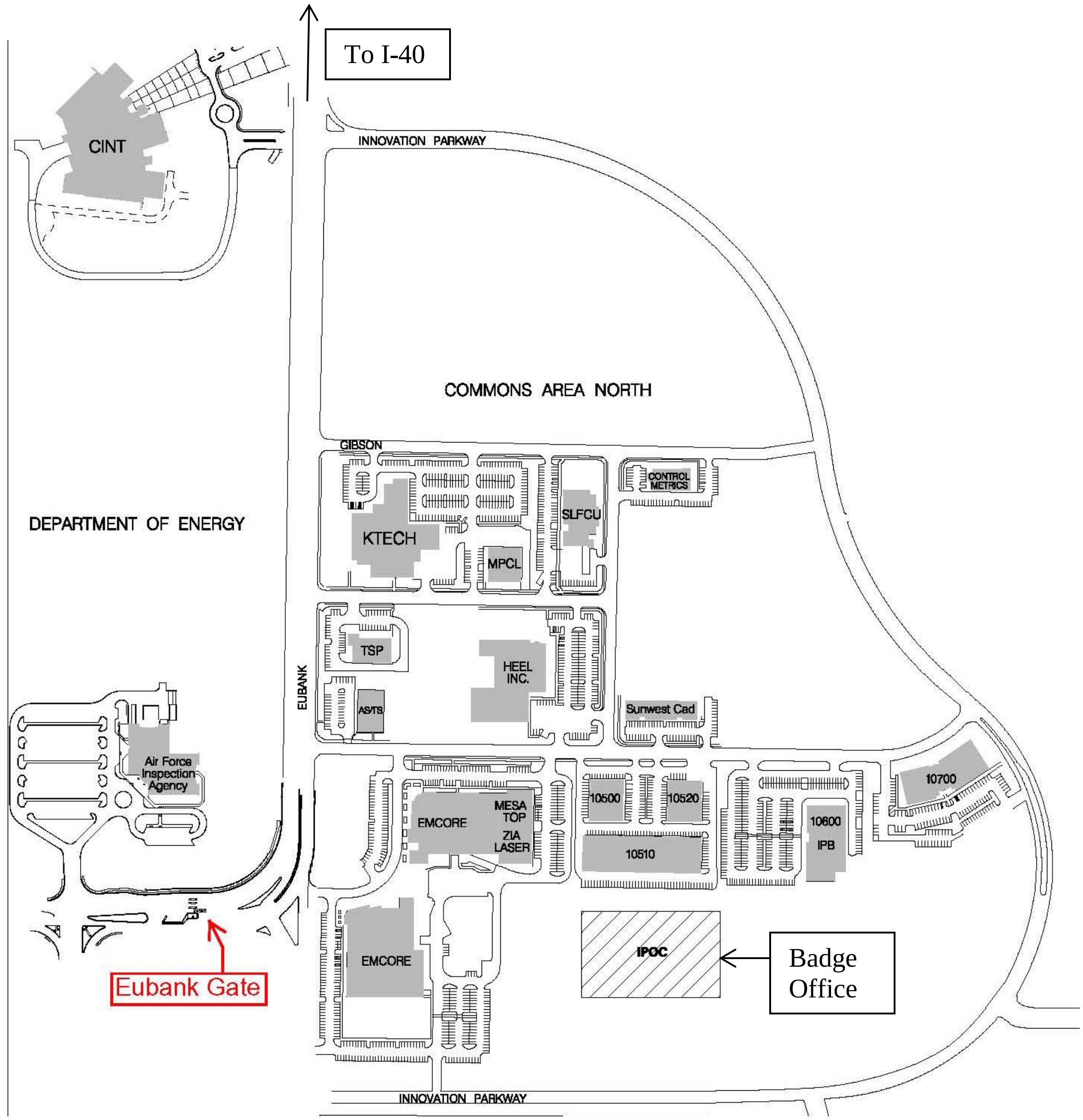


Figure 3. Badge Office Location

Background

The ACRR core is located in an open tank of water which is 10 ft. in diameter and 28 ft. deep. The top of the core is 22.6 ft. below the top of the tank. The water serves as a radiation shield, neutron moderator, and coolant (natural convection). Figure 4 displays the ACRR tank during a pulse operation. The ACRR has demonstrated operational capabilities in the steady-state mode to power levels of 4 MW (t); however, currently the ACRR is licensed to 2.4 MW(t) for steady-state operations.

The ACRR is an epi-thermal pool-type reactor which uses cylindrical UO_2-BeO fuel elements. The standard configuration is 236-fuel elements in the ACRR core and 182-fuel elements in the FREC-II (Fueled Ring External Cavity – version II) facility. The FREC-II fuel is standard Triga Fuel $U0_2$-ZHr.

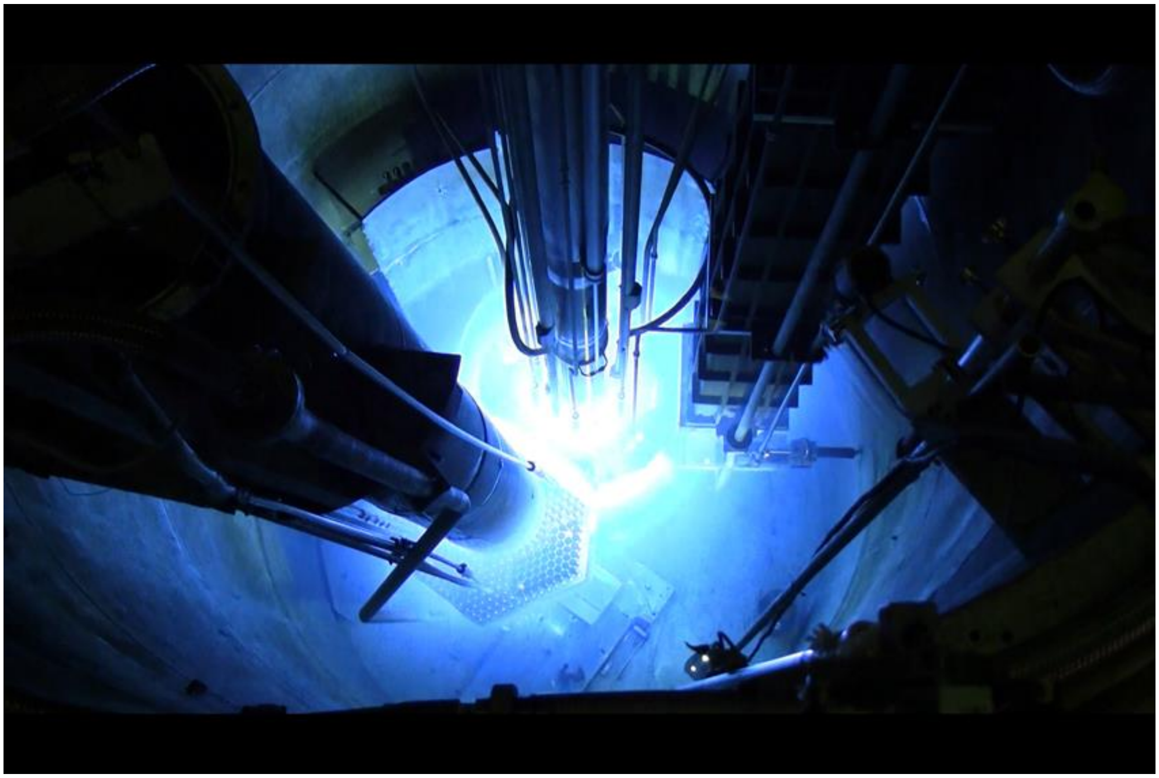


Figure 4. ACRR Pulse

Experimental Facilities

There are four (4) main experimental cavities at the ACRR facility; central cavity, FREC-II cavity, thermal neutron beam tube i.e. the neutron radiography facility, and the Tri-Element facility. The central cavity is a dry irradiation cavity in the center of the annulus. The Tri-Element facility consists of a location made up of three (3) fuel elements within the core grid. This grouping of three elements can be removed; experiments are then placed in the void within the core. The neutron radiography facility allows for neutron radiography of parts at the imaging plane and for thermal irradiation of parts throughout the neutron radiography tube. The base is known as the experiment chamber and experiments can also be placed in this location. The fueled ring external cavity – second version (FREC-II) is a subcritical assembly which is either coupled or decoupled to the ACRR core. The FREC-II cavity is 20 inches in diameter and the central cavity is 9 inches. FREC-II can provide a radiation gradient across the experimental packages.

Central Cavity

The central cavity allows for experimental assemblies to be placed at the center of the core where neutron flux levels are the highest. The central cavity is accessed via the vertical space over the cavity on the reactor bridge. Figure 5 displays the ACRR core with the location of the central cavity in relation to the core elements. Figure 6 is a schematic of the central cavity which shows the location of the shield plug and cavity pedestals in relation to fuel center line. Figure 7 is a detailed graphic displaying the relation of the cavity pedestals in relation to the fuel center line. There are 6-inch, 8-inch, 19-inch, 27-inch, and 32-inch load bearing pedestals available. The pedestals are removable and can be stacked to achieve the desired height. Figure 8 is a diagram of the shield plug, which has a removable 4-inch center plug which allows for rapid loading and unloading of small parts. There are two (2) serpentine groves (1.75-inch) on the shield plug – these grooves allow for the passage of cable bundles for active electronic component testing.

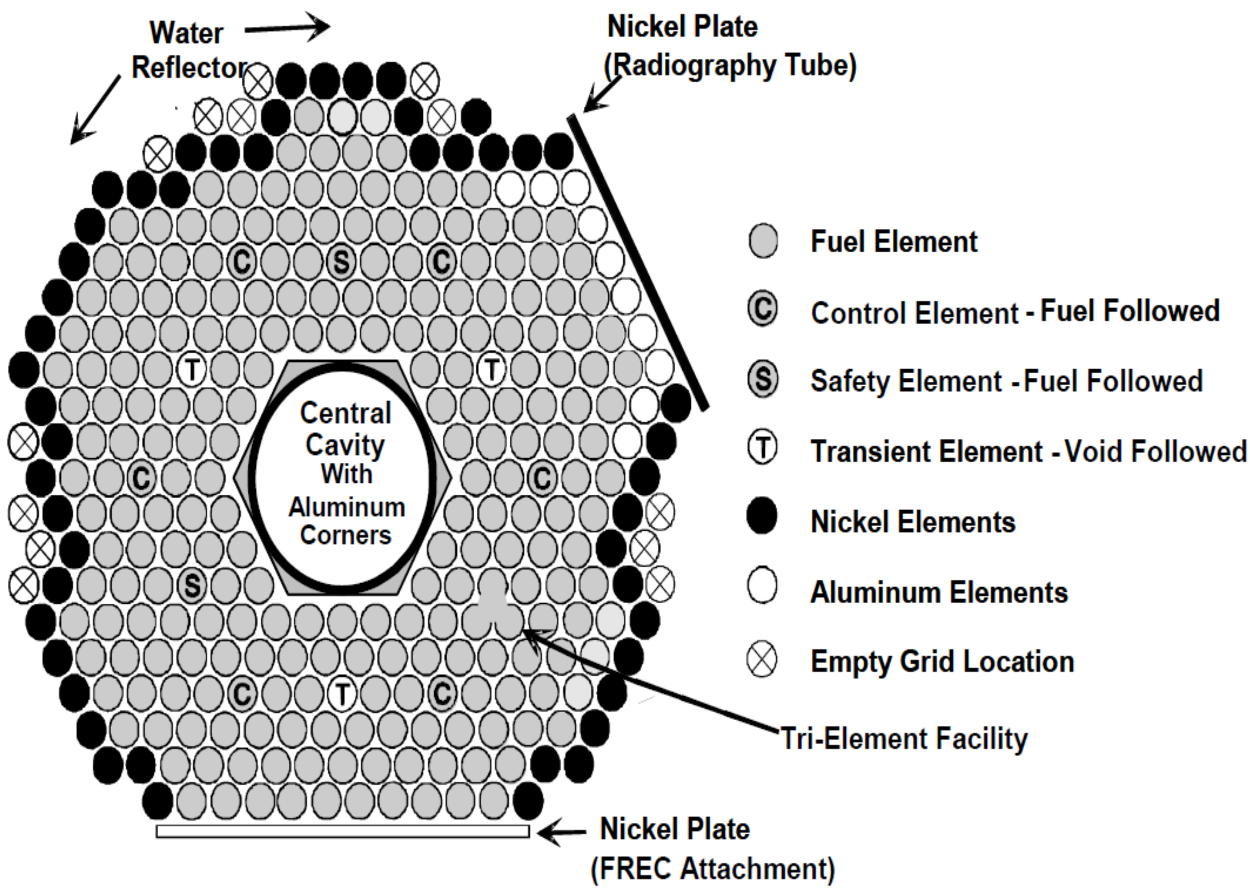


Figure 5. ACRR Core Map

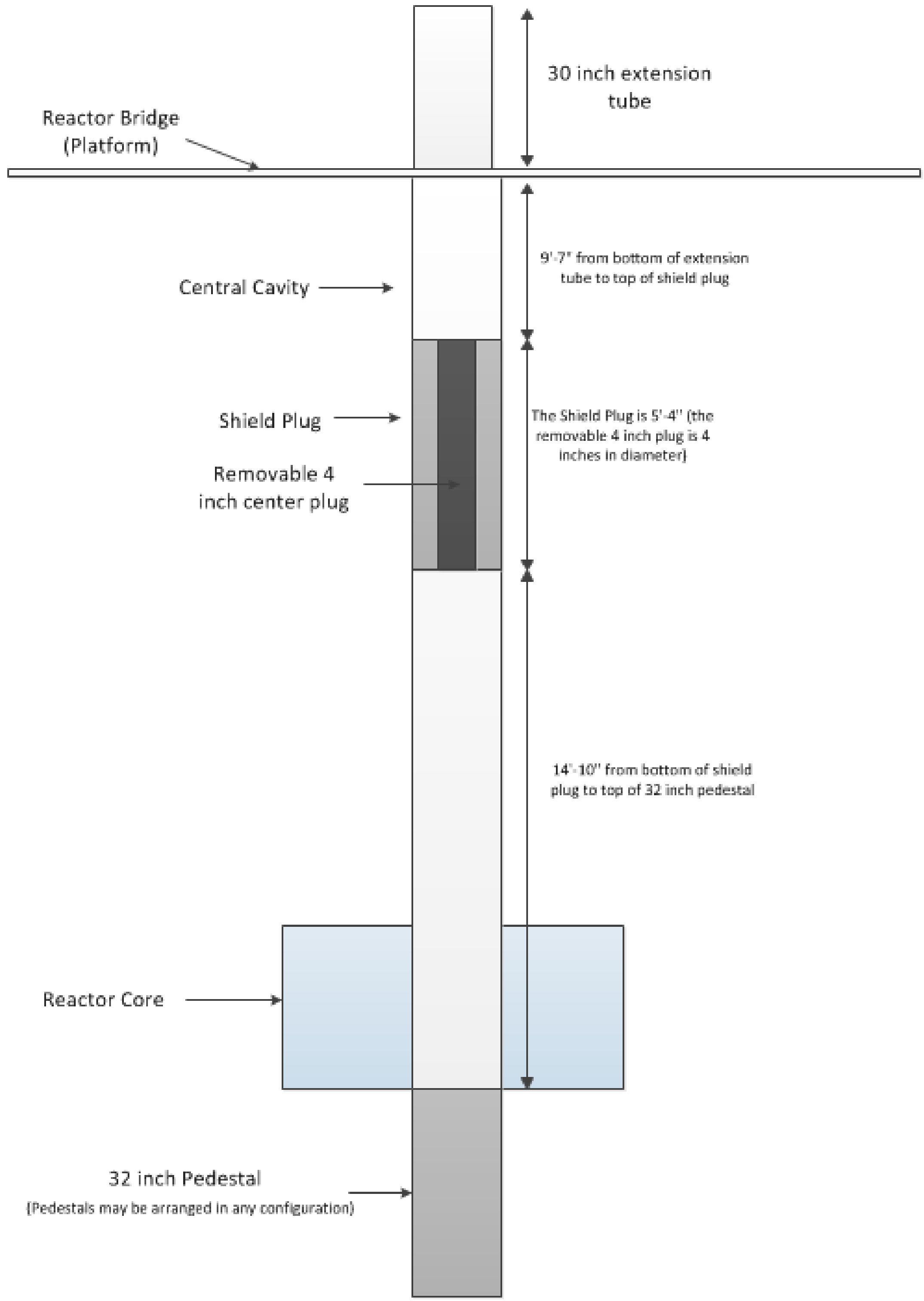


Figure 6. Schematic of Central Cavity

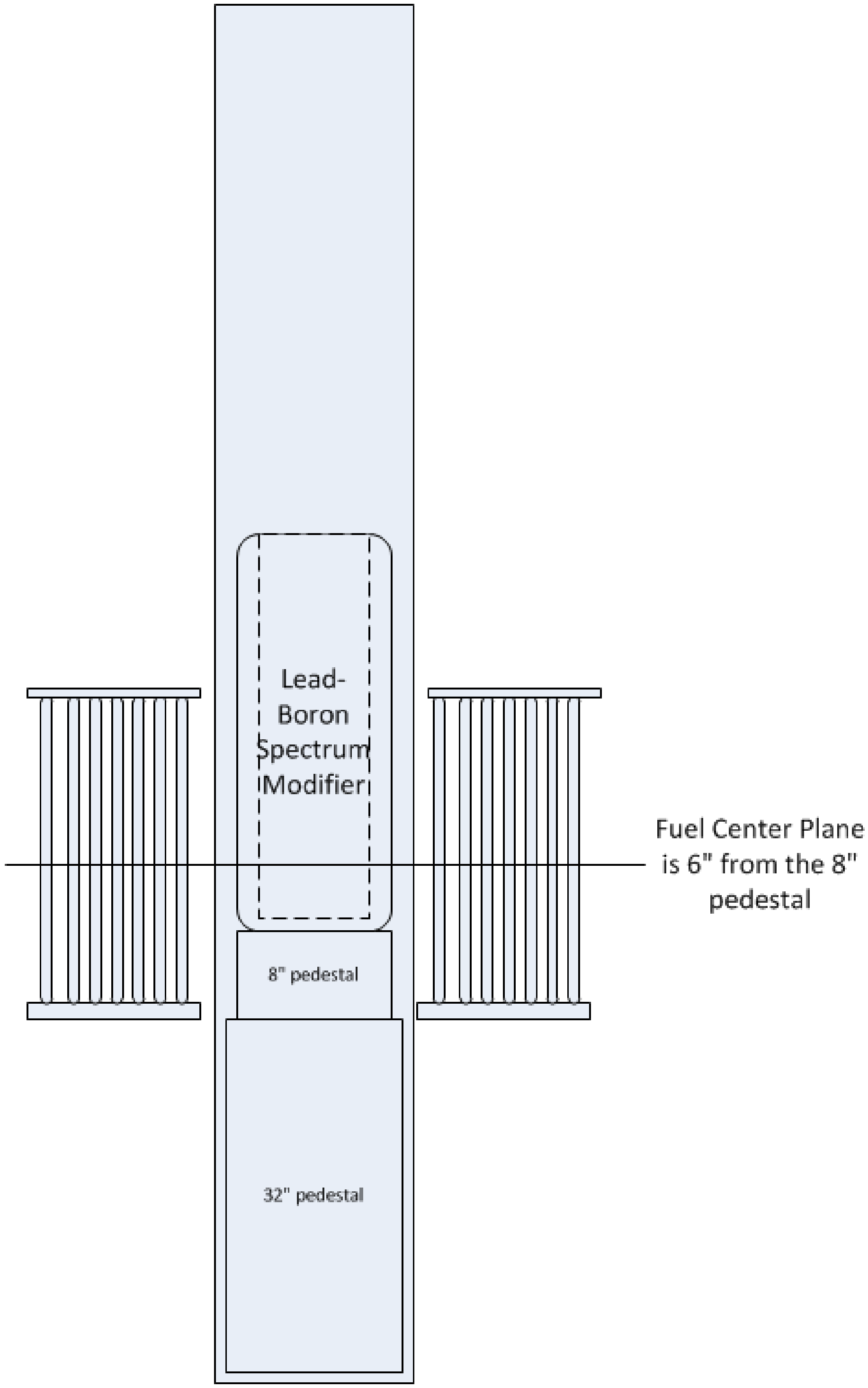


Figure 7. An Example Pedestal Arrangement and Bucket Relation to Fuel Mid-plane (Denoted via the Line)

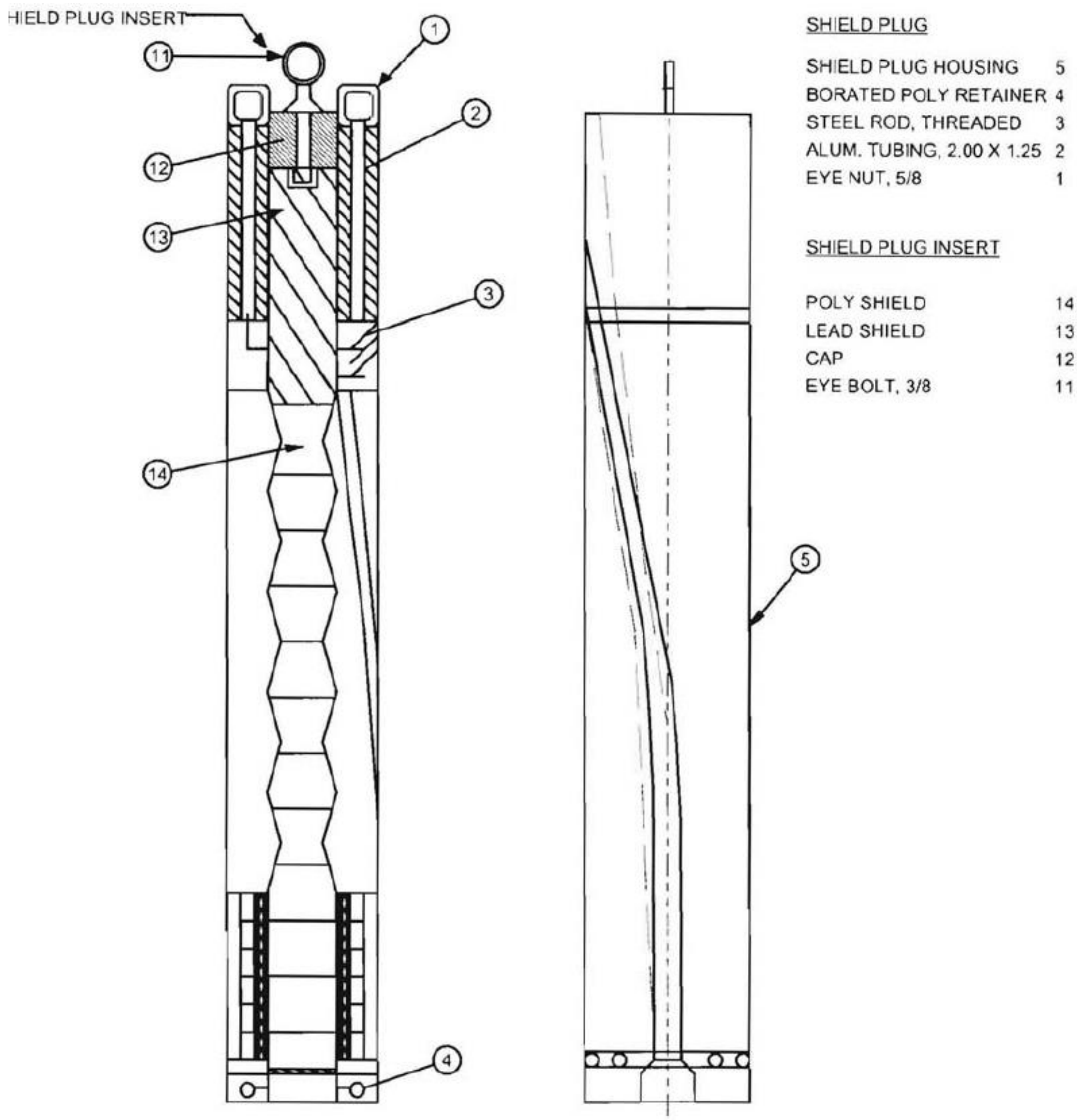


Figure 8. Central Cavity Shield Plug

Table 1, Table 2, and Table 3 display the steady-state, pulse, and radiation characteristics for the 236 standard core configuration. This data assumes FREC-II is decoupled (significant neutron decoupling) from ACRR.

Table 1. Steady State Characteristics for 236 Element Core Configurations

Power (kW)	Fast (>10 keV) Flux in Central Cavity (n/cm^2-sec)**	Approximate Fuel Temperature (°C)
500	0.6×10^{13}	300
1000	1.2×10^{13}	550
1500	1.8×10^{13}	700
2000	2.4×10^{13}	850
2500	3.0×10^{13}	950
3000	3.6×10^{13}	1050
3500	4.2×10^{13}	1250
4000	4.8×10^{13}	1350

* Includes six fuel-followed control rods and two fuel-followed safety rods with nickel reflector elements in place.

** Measurements of neutron spectra in central cavity.

Table 2. Pulse Characteristics for 236 Fuel Element Core Configuration

Reactivity Insertion (Dollars)	Pulse Width at Half Maximum (msec)	Peak Power (MW)	Energy Yield (MW-sec)	Approximate Fuel Temperature (°C)
1.50	27.8	1,500	60	220
2.00	13.5	6,900	137	425
2.50	9.3	16,500	210	620
3.00	7.0	30,200	280	850

* Includes six fuel-followed control rods and two fuel-followed safety rods with nickel reflector elements in place. Pulse information based on a pulse rod holdup time of 0.4 seconds.

Table 3. Approximate Central Cavity Radiation Characteristics

Operation	Radiation Characteristic	
Steady-State Operation	Power	2.4 MW
	Neutron Flux (>3 MeV) (>10kev) (total)	 2.0×10^{12} n/cm^2-sec 2.4×10^{13} n/cm^2-sec 4.1×10^{13} n/cm^2-sec
	Gamma Dose Rate	3.1×10^{4} rad/s
Pulse Operation	Reactivity	$3.00
	Energy Yield	280 MJ
	Neutron Fluence (>3MeV) (>10kev) (total)	 3.1×10^{14} n/cm^2 3.7×10^{15} n/cm^2 6.4×10^{15} n/cm^2
	Gamma Dose	3.4×10^{6} rad
* At cavity horizontal and vertical centerline for 236-element pulse configuration that includes six fuel-followed control rods and two fuel-followed safety rods with nickel reflector elements in place.		

The radial and axial flux profiles are provided in Figures 9 and 10, respectivily. The neutron energy spectrum of the ACRR is provided in Figure 11 and the free-field neutron energy spectrum is provided in Figure 12 (flux level based on a 1 MW steady-state operation). This neutron energy spectrum is for a free-field cavity (i.e. no spectrum-modifing buckets). MCNP6 models are avaible to estimate the flux and energy spectrum at any location within the ACRR tank and High Bay area; however, sufficient lead-time is requried to obtain this data if not already known. The experimenter is always encouraged to perform radiation field characterization of a location which has either limited or no characaterization data. At a mimium, activation dosimetry is attached to the experiment to provide information on the incident neutron and gamma flux. Detailed neutron spectrum unfolding is possible; however, the Radiation Meterology Lab (RML) at SNL must be notified well in advance.

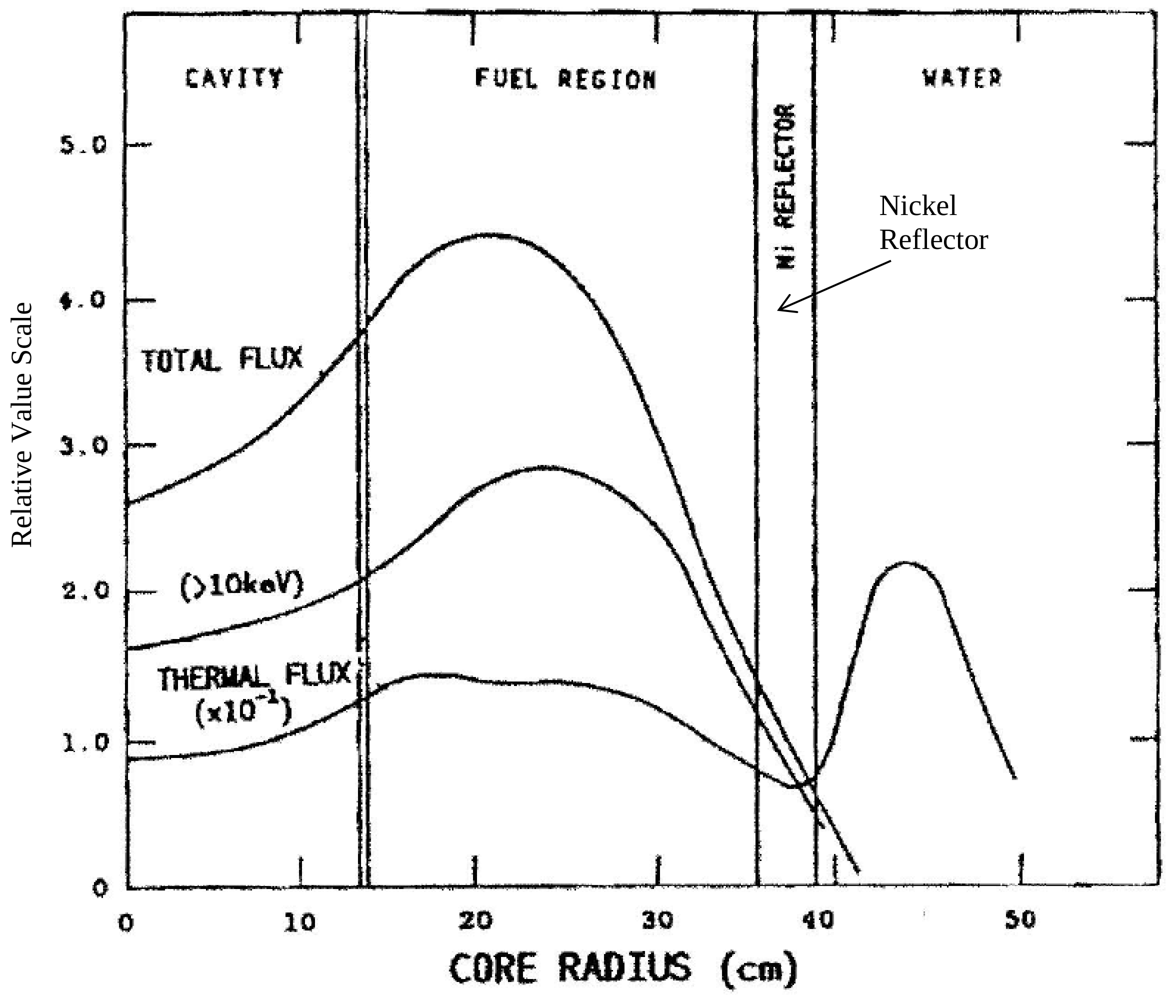


Figure 9. Radial Flux Profile of ACRR

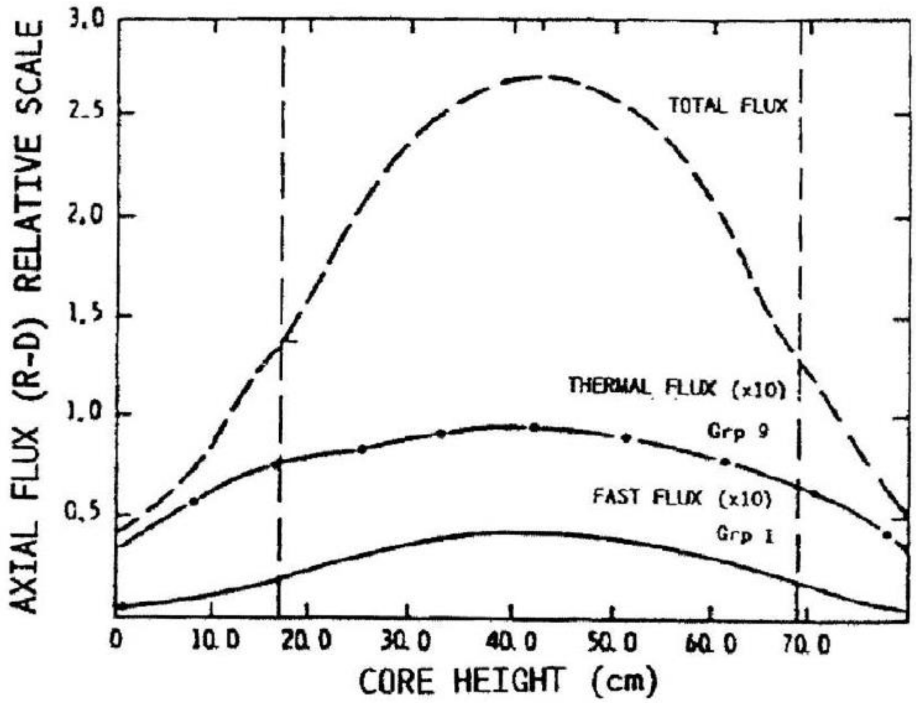


Figure 10. Axial Flux Profile

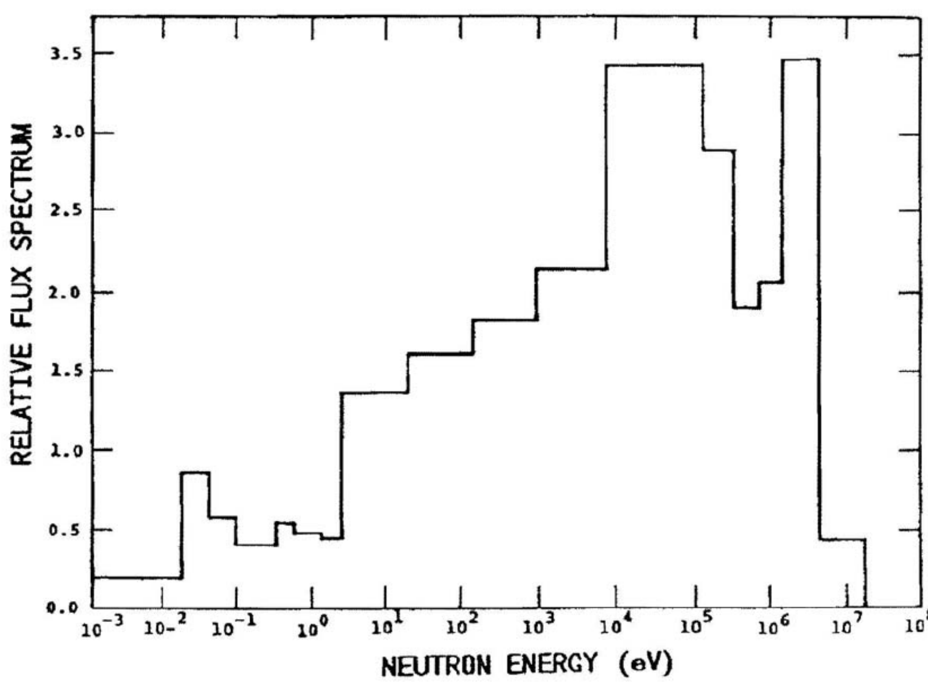


Figure 11. Neutron Energy Spectrum of ACRR Core Region At Midplane

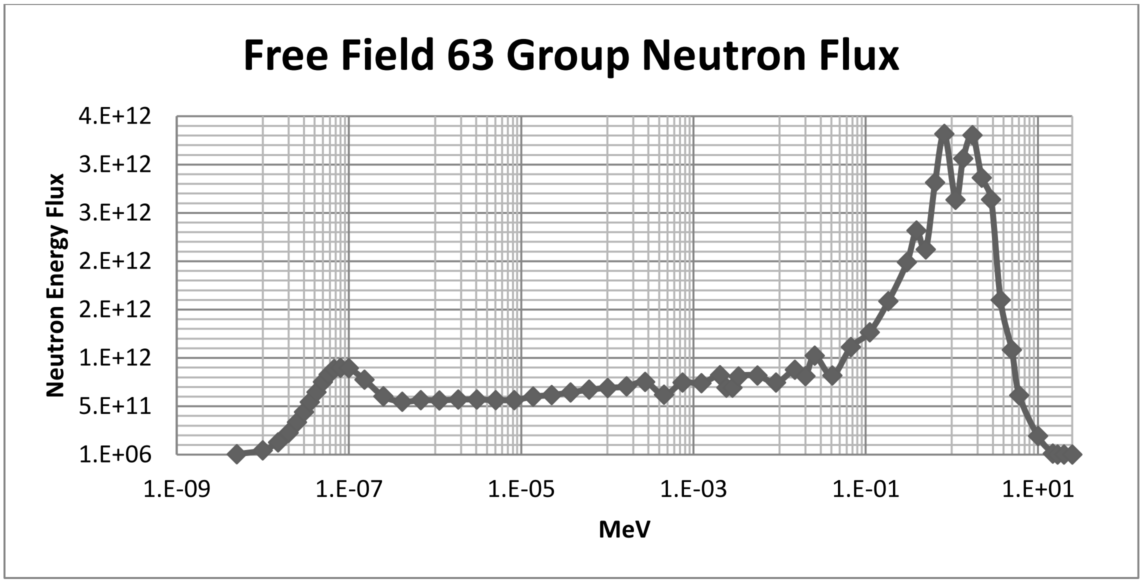


Figure 12. Central Cavity Free-Field 63 Group Neutron Flux

Spectrum Modifiers

The ACRR central cavity has four (4) different experiment buckets avaible for spectrum modification. Figure 13 provides dimensions of the four buckets. There are two (2) lead-boron buckets – one 36-inch and one 44-inch tall buckets. The taller bucket reduces the amount of thermal neutrons entering the bucket. The lead-boron buckets reduce the thermal neutron spectrum and reduces the amount of gamma interaction. There is an aluminium liner in the buckets to reduce beta particles from incident reactions within the lead and boron.

The lead-poly bucket and the poly-lead-graphite bucket increase the amount of thermal neutrons and reduce the amount of gamma interaction of the part. An aluminium bucket is also avaiable to lower parts which are not easily attached to an aluminium stalk. Aluminium has a minimial neutronic effect. There are operational limitations to the buckets due to thermal heating. The 44-inch lead-boron bucket has a port for a thermocouple which allows for monitoring the temperature of the bucket during extened operations. Each bucket has a MJ (integral energy) limit assoicated with it to prevent melting or deformation of the bucket. Table 4, below, displays the total neutron fluence, 1-MeV Equivalent fluence, nickel foil activity, and gamma dose for silicon for the numerous different spectrum configuration for pulse operations.

The payload or experimental package placed within the spectrum modifying buckets must not challenge the physical load bearing capability of the bucket. Most package weights are less than 20 lbs. If the package weights more than 50 lbs an additional evaluation will need to be performed. Packages may be used in the free field condition as well. Proof tested rigging and attachment point evaluation is required for packages greater than 20 lbs. This is the weight that will require a critical lift plan to be completed in conjunction with proof tested rigging and the assoicated hardware. The ACRR Operations staff will help with the rigging inspections and critical lift plans.

Table 4. Spectrum Filter Dosimetry Information

Calculation	Total Neutron Fluence [n/cm^2/MJ]	1-MeV Equivalent Fluence [n/cm^2/MJ]	Ni Foil Activity [Bq/g MJ]	Gamma Dose–Si [Rad/MJ]
ACRR Free Field Central Cavity	2.161E13	8.566E12	588.72	8361.3
FREC-II Cavity Free Field	2.629E12	9.229E11	68.77	1090.0
ACRR Lead-Boron Bucket	1.163E13	6.738E12	335.51	1025.3
ACRR LP1 Bucket	2.495E13	5.017E12	369.25	5143.1
ACRR PLG Bucket	2.361E13	7.157E12	469.92	6814.1

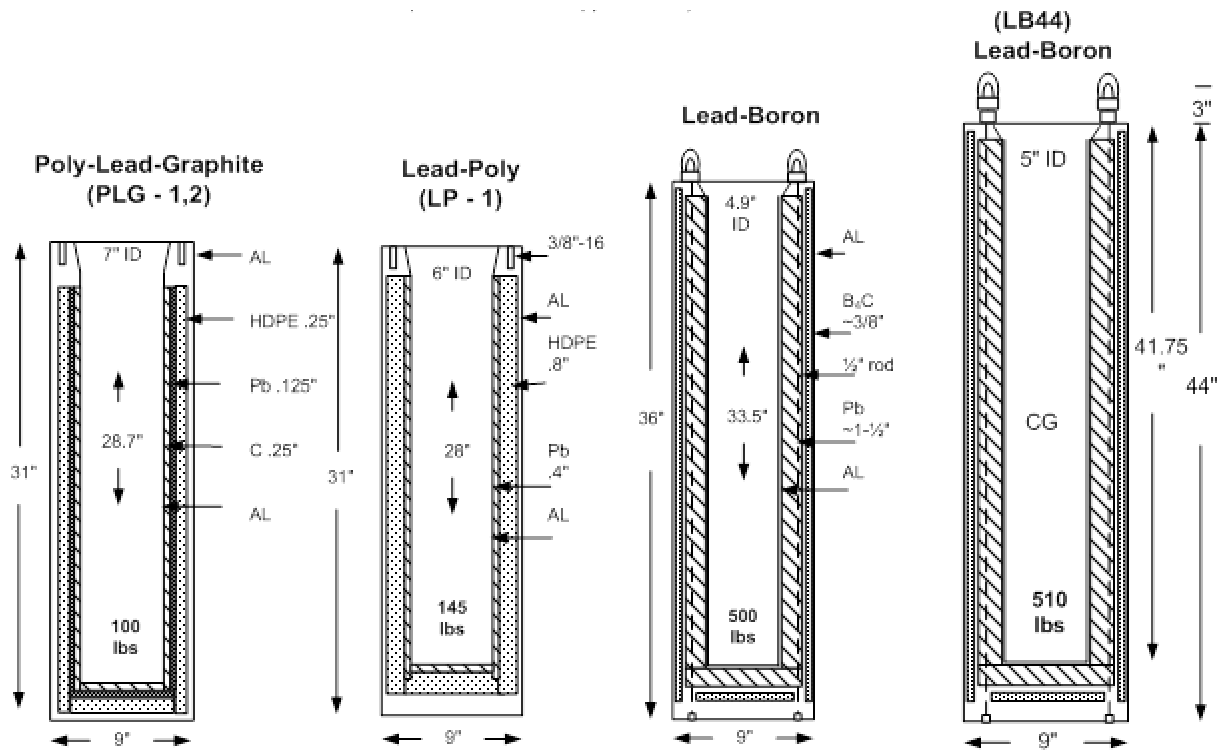


Figure 13. Spectrum Modifiers (Buckets) for the ACRR

Figures 14 through 16 display the neutron energy spectrums for the poly-lead-graphite, lead-poly, and lead-boron 44-inch bucket, respectively. The flux [n/cm^2-s] is based on a 1 MW steady-state operating level. Figure 17 is a sulfur axial map for the lead-boron 44-inch bucket. This allows for placement of packages at different locations within the bucket to be exposed to different levels of neutron flux during the same operation.

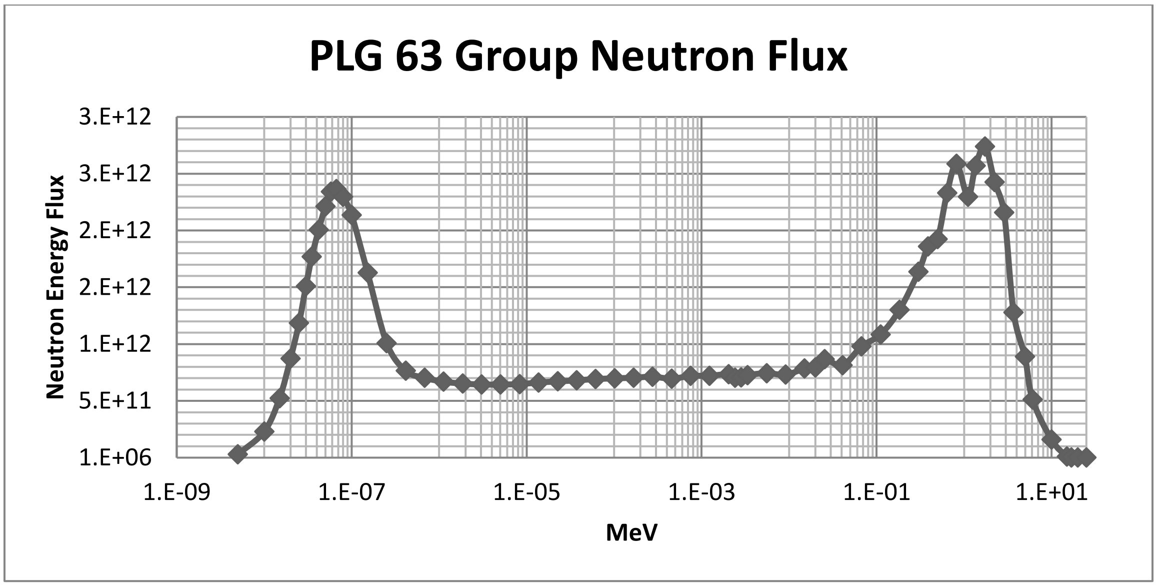


Figure 14. Poly-Lead-Graphite 63 Group Neutron Flux

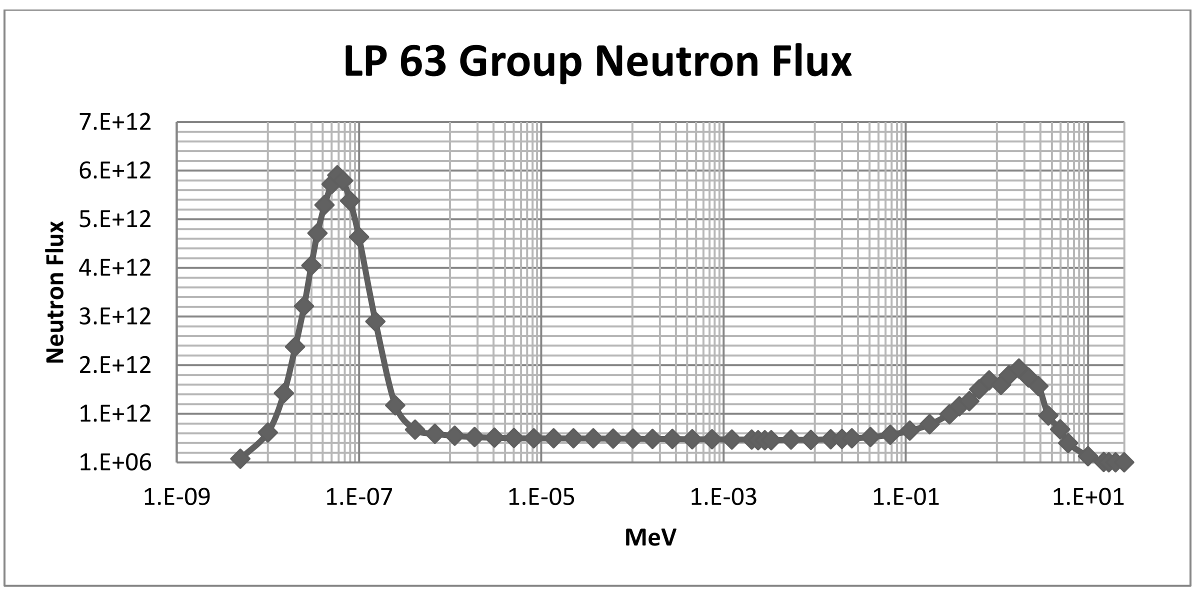


Figure 15. Lead-Poly 63 Group Neutron Flux

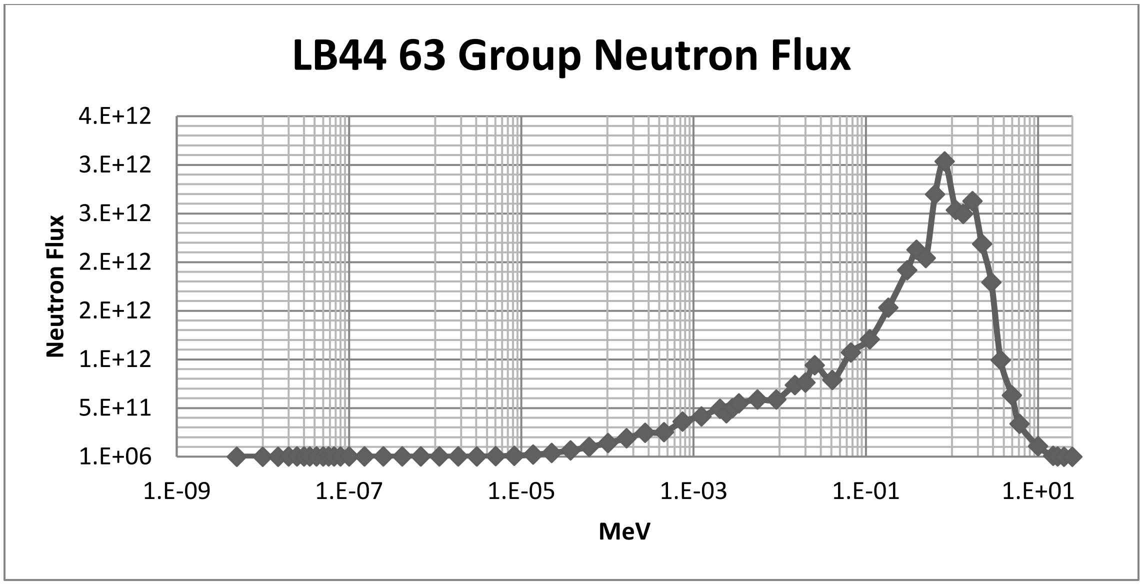


Figure 16. Lead Boron 44-inch 63 Group Neutron Flux

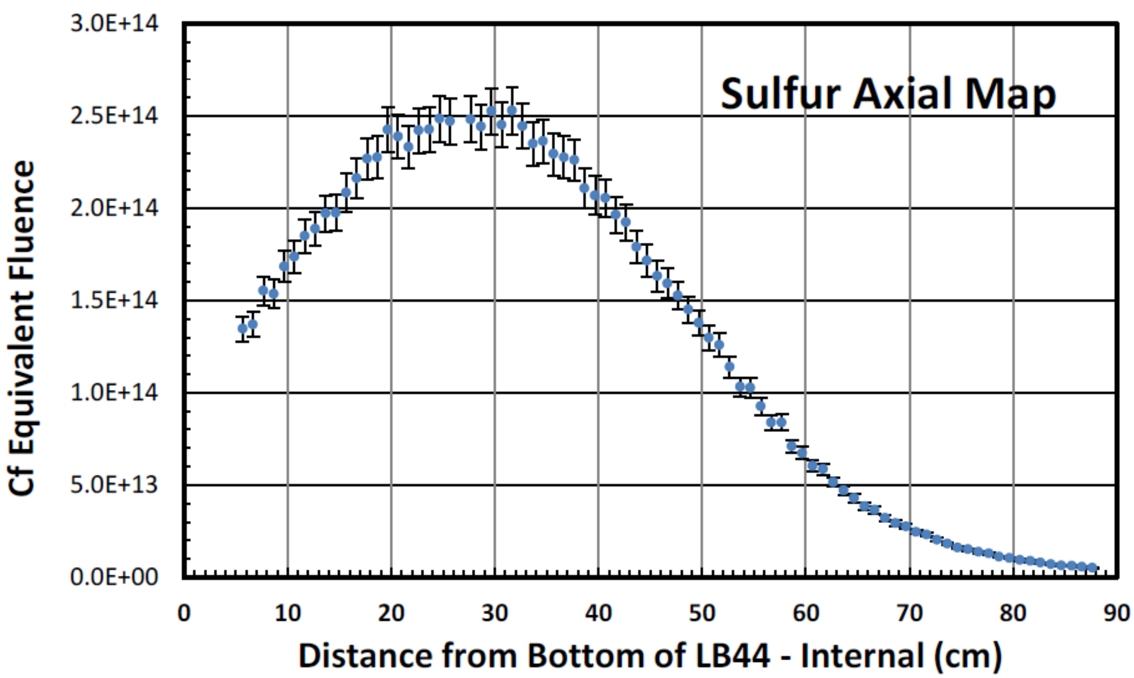


Figure 17. Sulfur Axial Map for the LB44 Bucket on top of the 32 inch Cavity Pedestal

Tri-Element Facility

The Tri-Element Facility is located in rows 3 and 4 of the core. A triangular-shaped cutout in the upper grid plate that is normally filled with three fuel elements can be removed to allow an experiment space up to a diameter of 67 mm (2.63 in). In addition, any of the other approximately 300 single-core grid positions allow for an experiment encapsulated in a special fixture or for a dummy fuel element. A long-term exposure of a relatively small sample is the principal application for this type of exposure capability. Figure 18 displays the location of the Tri-Element Facility and the additional grid positions. The neutron energy spectrum will be similar to that displayed in Figure 11; however, no characterization to date has been performed on the Tri-Element Facility or the additional grid positions which are available.

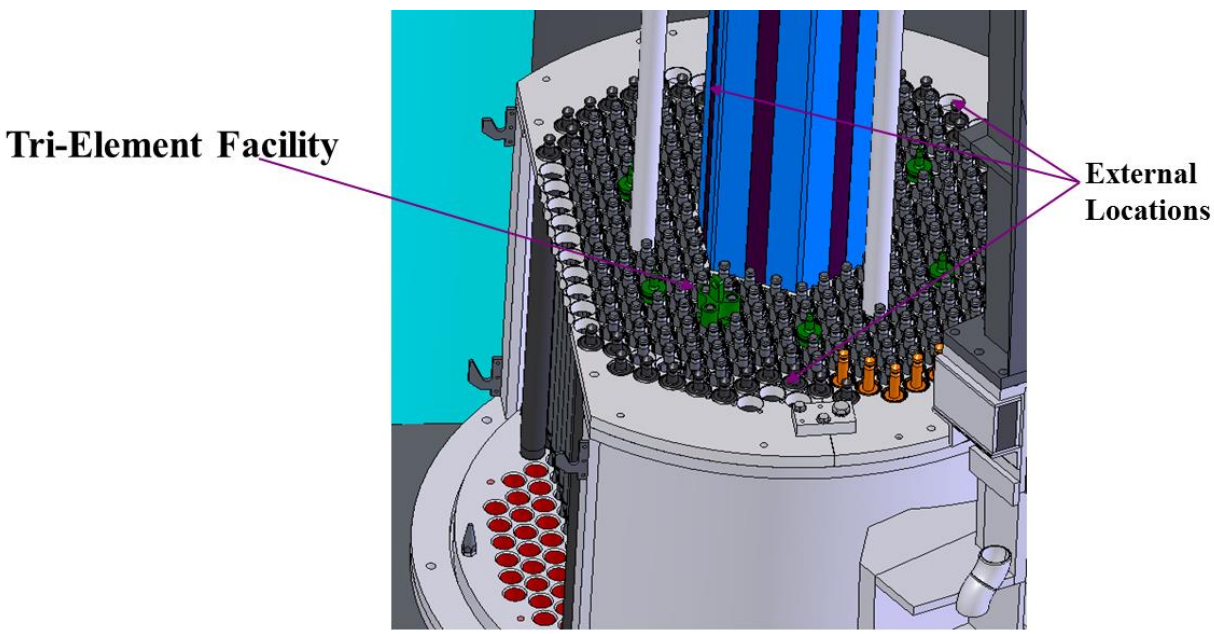


Figure 18. Tri-Element Facility

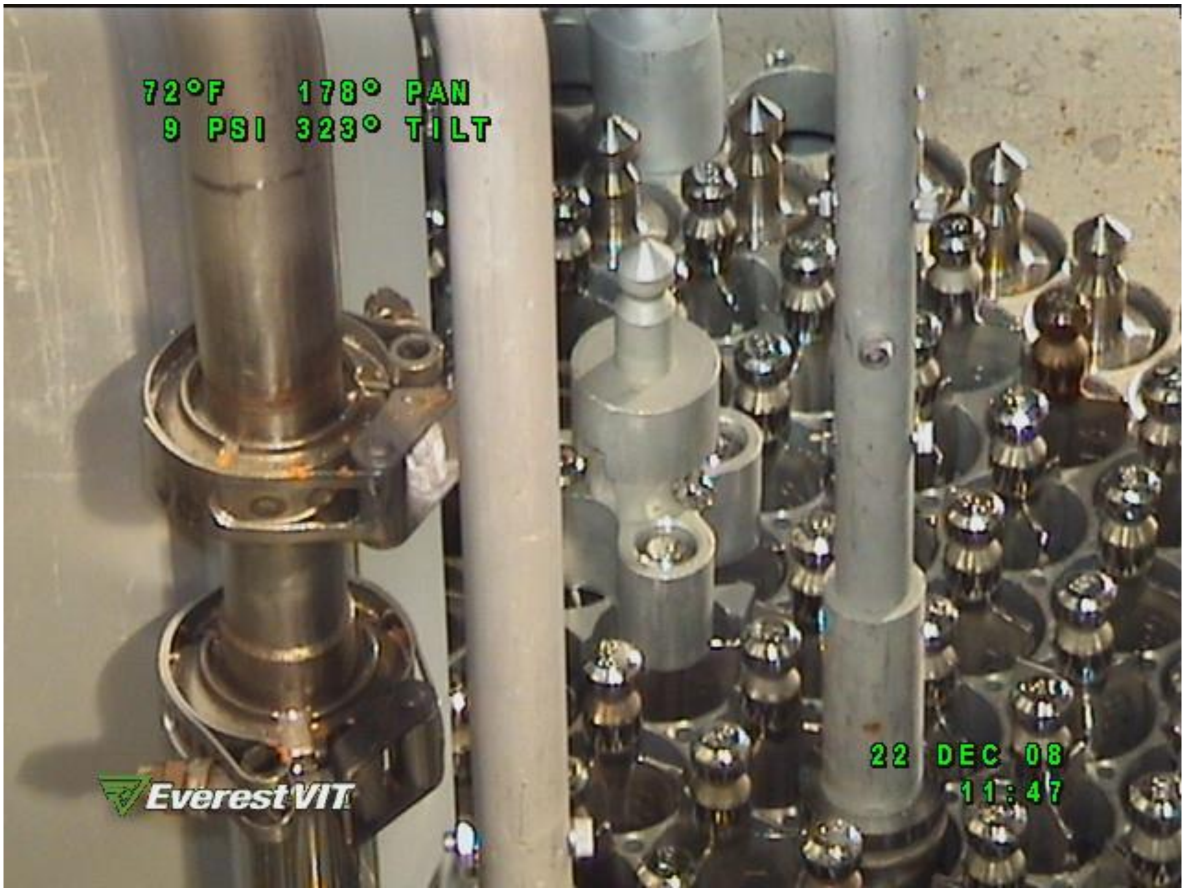
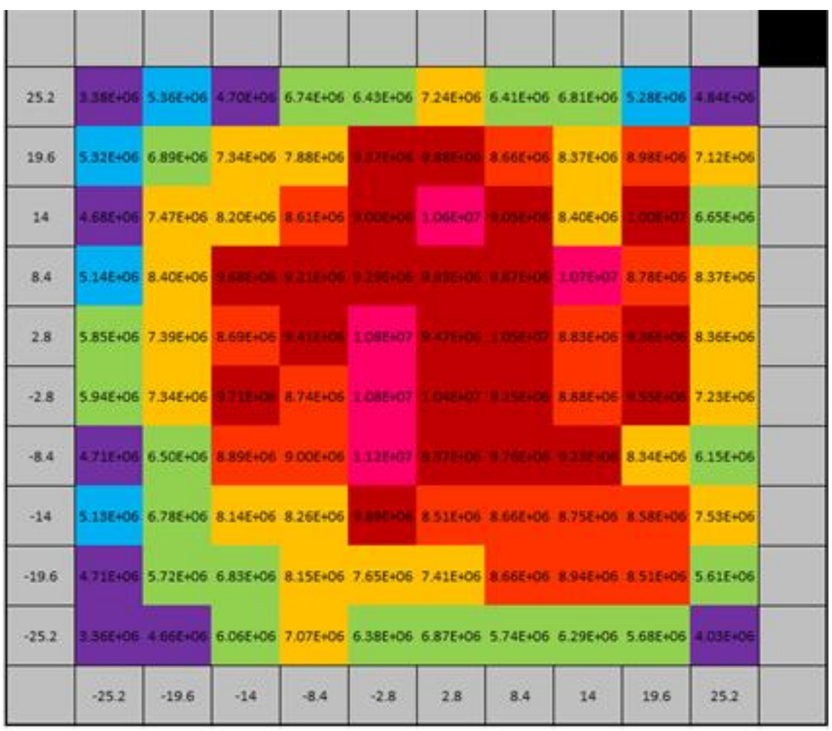


Figure 19. Photograph, Tri-Element Facility

Neutron Radiography Tube

The neutron radiography tube can be used for a variety of applications. Neutron radiography can be performed on the imaging plane of the neutron radiography tube. Figure 20 is a photo of the imaging plane of the neutron radiography tube. The imaging area is approximately 25-inches x 25-inches. The imaging plane has been characterized via MCNP6 and dosimetry foils. The imaging plane does contain a gradient as displayed by Figure 21. The gradient will change depending upon the aperture. Settings in the collimator assembly used to control beam imaging area.

Figure 20. Neutron Radiography Imaging Plane



25.2	3.38E+06	5.36E+06	4.70E+06	6.74E+06	6.43E+06	7.24E+06	6.41E+06	6.81E+06	5.28E+06	4.84E+06	
19.6	5.32E+06	6.89E+06	7.34E+06	7.88E+06	9.37E+06	9.88E+06	8.66E+06	8.37E+06	8.98E+06	7.12E+06	
14	4.68E+06	7.47E+06	8.20E+06	8.61E+06	9.00E+06	1.06E+07	9.05E+06	8.40E+06	1.00E+07	6.65E+06	
8.4	5.14E+06	8.40E+06	9.68E+06	9.21E+06	9.29E+06	9.93E+06	9.87E+06	1.07E+07	8.78E+06	8.37E+06	
2.8	5.85E+06	7.39E+06	8.69E+06	9.41E+06	1.08E+07	9.47E+06	1.05E+07	8.83E+06	9.36E+06	8.36E+06	
-2.8	5.94E+06	7.34E+06	9.71E+06	8.74E+06	1.08E+07	1.04E+07	9.25E+06	8.88E+06	9.55E+06	7.23E+06	
-8.4	4.71E+06	6.50E+06	8.89E+06	9.00E+06	1.12E+07	9.37E+06	9.76E+06	9.23E+06	8.34E+06	6.15E+06	
-14	5.13E+06	6.78E+06	8.14E+06	8.26E+06	9.89E+06	8.51E+06	8.66E+06	8.75E+06	8.58E+06	7.53E+06	
-19.6	4.71E+06	5.72E+06	6.83E+06	8.15E+06	7.65E+06	7.41E+06	8.66E+06	8.94E+06	8.51E+06	5.61E+06	
-25.2	3.36E+06	4.66E+06	6.06E+06	7.07E+06	6.38E+06	6.87E+06	5.74E+06	6.29E+06	5.68E+06	4.03E+06	
	-25.2	-19.6	-14	-8.4	-2.8	2.8	8.4	14	19.6	25.2	

Figure 21. Neutron Radiography Imaging Plane MCNP Model of Gradient

There is a collimator which provides apertures (L:D ratios) of 65:1, 125:1, and 250:1. Each of the aperture setting will provide different effective imaging areas. An aperture of 500:1 is possible with slight modification to the collimator assembly. Each of the three (3) apertures have been characterized and detailed characterization is available upon request. The approximate peak flux at 2.16 MW for the 65:1 aperture is 8E6 neutrons per square centimeter. The collimator may be removed from the neutron radiography tube and experiments can be placed at any height or position within the tube. The base of the neutron radiography tube, called the experiment chamber has a neutron flux of 6 orders of magnitude greater than the imaging plane. The base has deuterium blocks to thermalize the spectrum. Experiments can be placed in spectrum modifiers and placed in the experiment region of the neutron radiography tube. Figure 23 displays the location of the neutron radiography base to that of the ACRR core. The collimator is easily removed to allow for irradiation of experiments in the base of the tube.

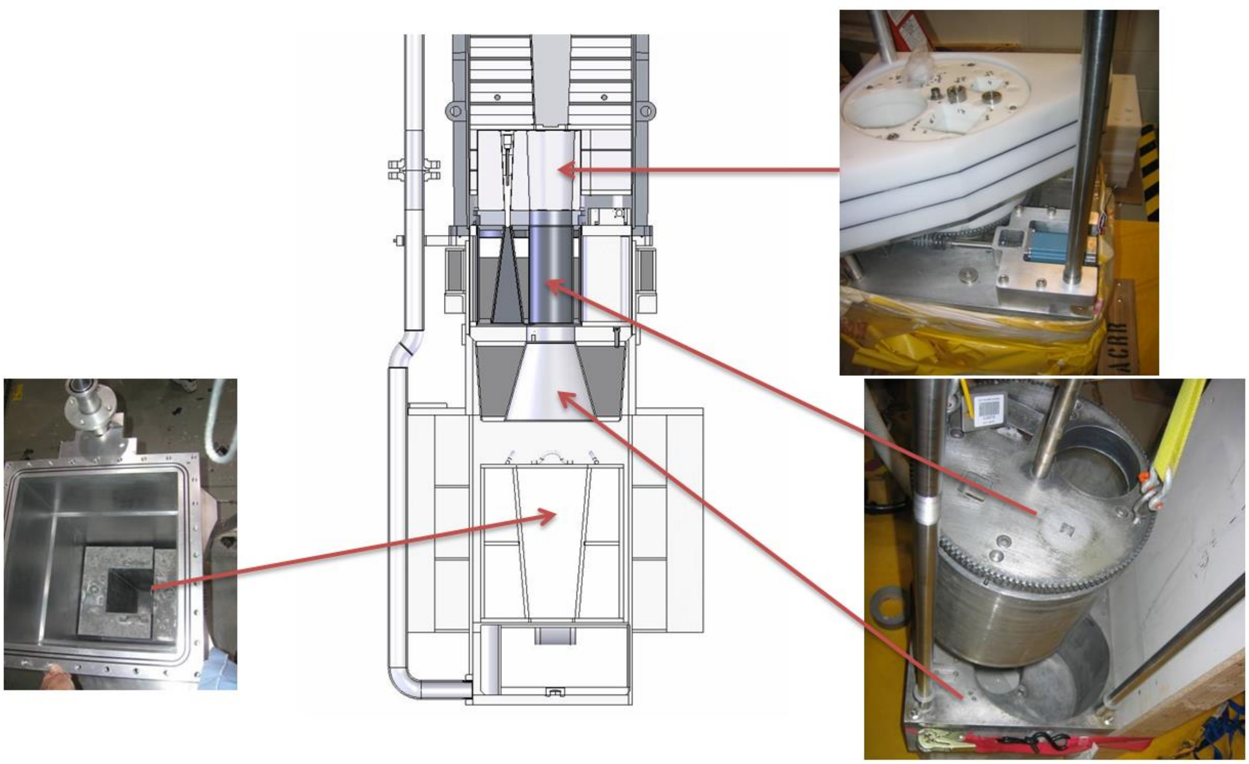


Figure 22. View of Neutron Radiography Collimator Base

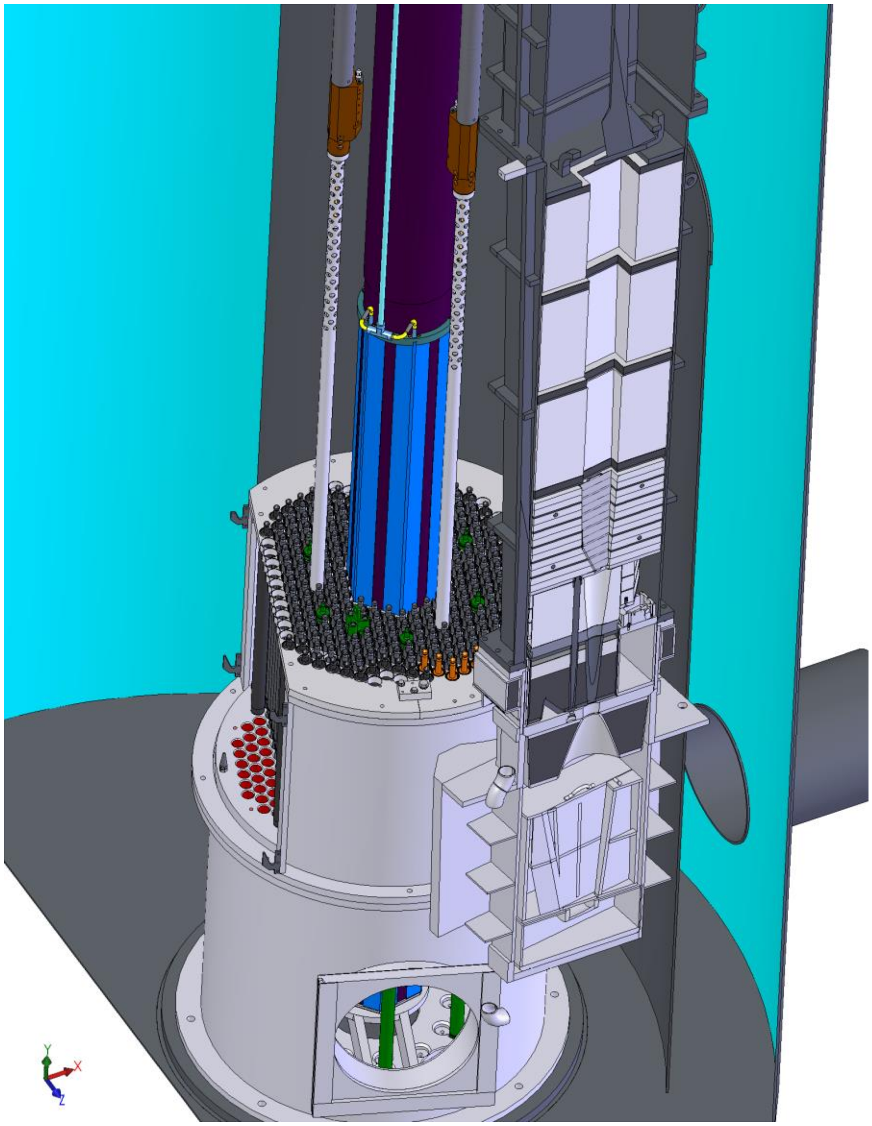


Figure 23. Neutron Radiography Tube

FREC II

The FREC-II provides an external cavity next to the ACRR core. Figure 24 displays the relation of FREC-II to that of the ACRR and the neutron radiography tube. Figure 25 displays the FREC-II core map. There are three (3) void chambers in FREC-II which allow for streaming of neutrons to the fuel element clusters on the back of FREC. FREC-II has a cavity diameter of 20-inches. Table 4 contains the FREC-II cavity characterization for free-field. There are two (2) FREC-II buckets: Lead-boron and cad-poly, which may also be used; however, characterization is in progress for these two spectrum fields.

FREC-II is operatorated in either the coupled or decoupled position for operations. Experiments are loaded into the FREC-II cavity and then FREC-II is placed in the coupled poistion for the operation; however, experiment packages may also be placed in FREC-II and then decoupled – this configuration requires FREC-II rods to be in the down position.

Experimental packages can only be loaded or unloaded into FREC-II when FREC-II is an a interim back condition (i.e. FREC has been coupled and then slightly adusted to allow for experiment loading). The operations staff performs the coupling or decoupling. This change in assembly or condition typically takes a ½ day to complete. There are two (2) shield plugs for the FREC-II cavity – standard plug and the 2T1 plug. Figures 28 and 29 display the plugs, along with the serpentine groves which allow for the passage of cable bundles. Figure 27 is a photo of the removal of the FREC-II standard shield plug.

Table 5. FREC-II Neutron Flux

Flux	ACRR FF	FREC-II Bare
Φ (E > 3 MeV)	1.027E13	2.050E12
Φ (E > 10 keV)	1.280E14	2.048E13
Φ total	2.022E14	4.217E13

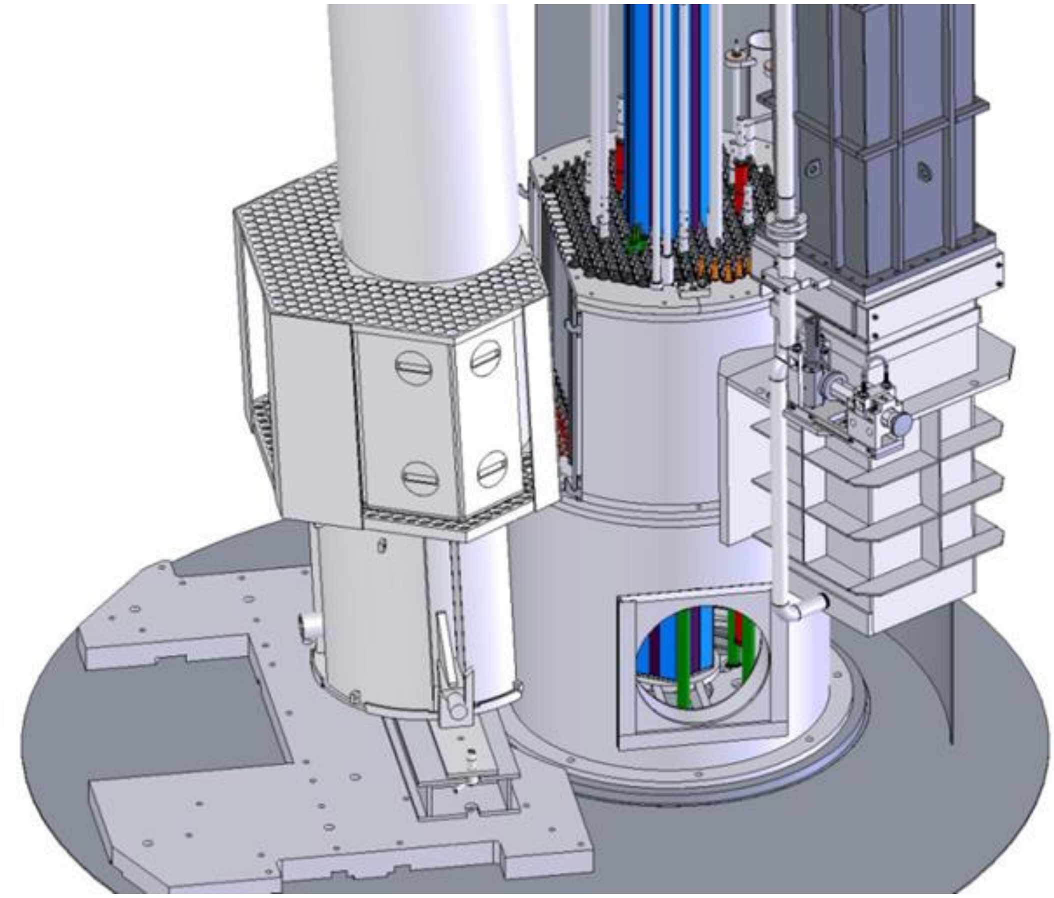


Figure 24. FREC-II in Relation to ACRR and Neutron Radiography Tube, Uncoupled

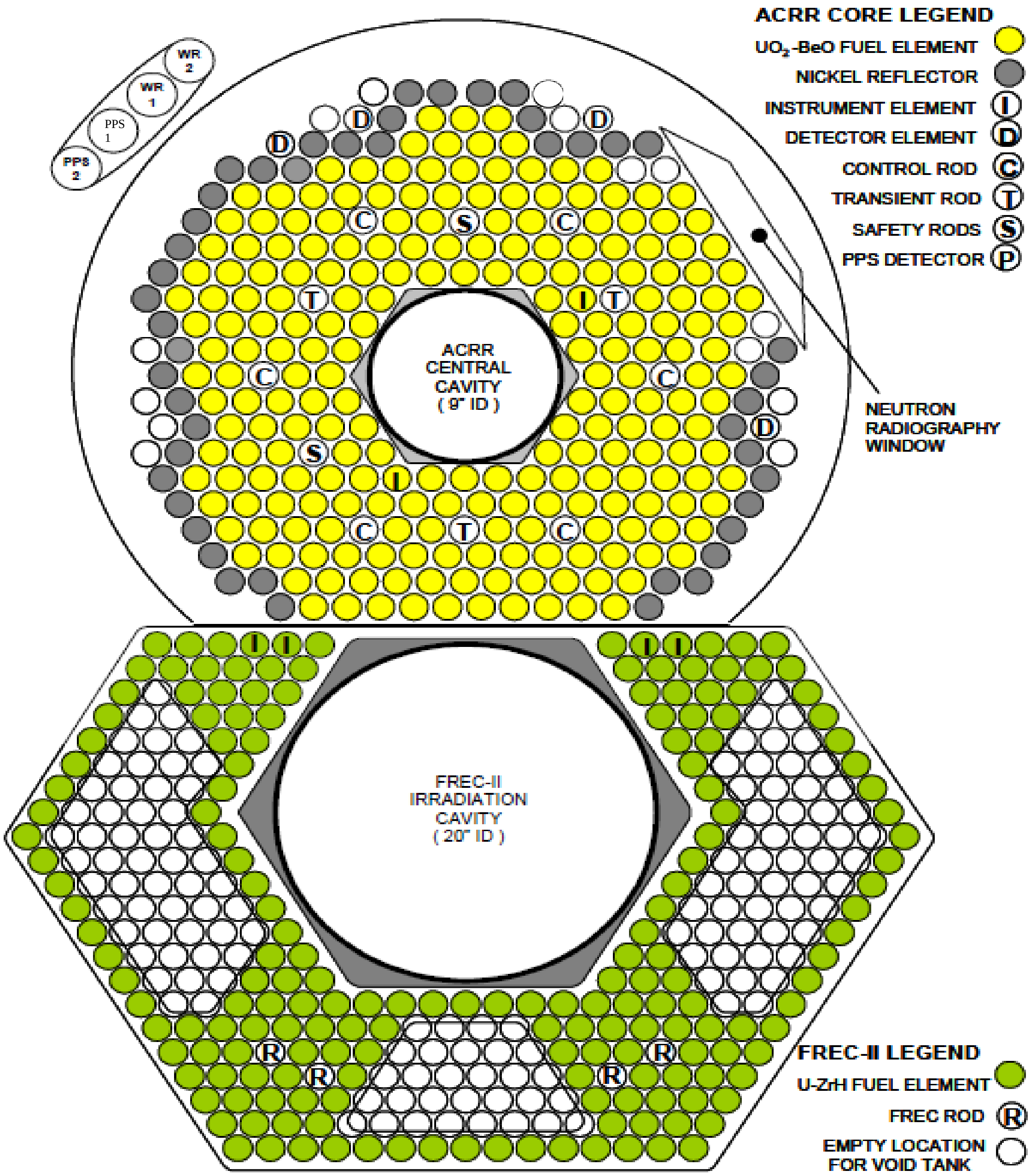


Figure 25. FREC-II Core Map

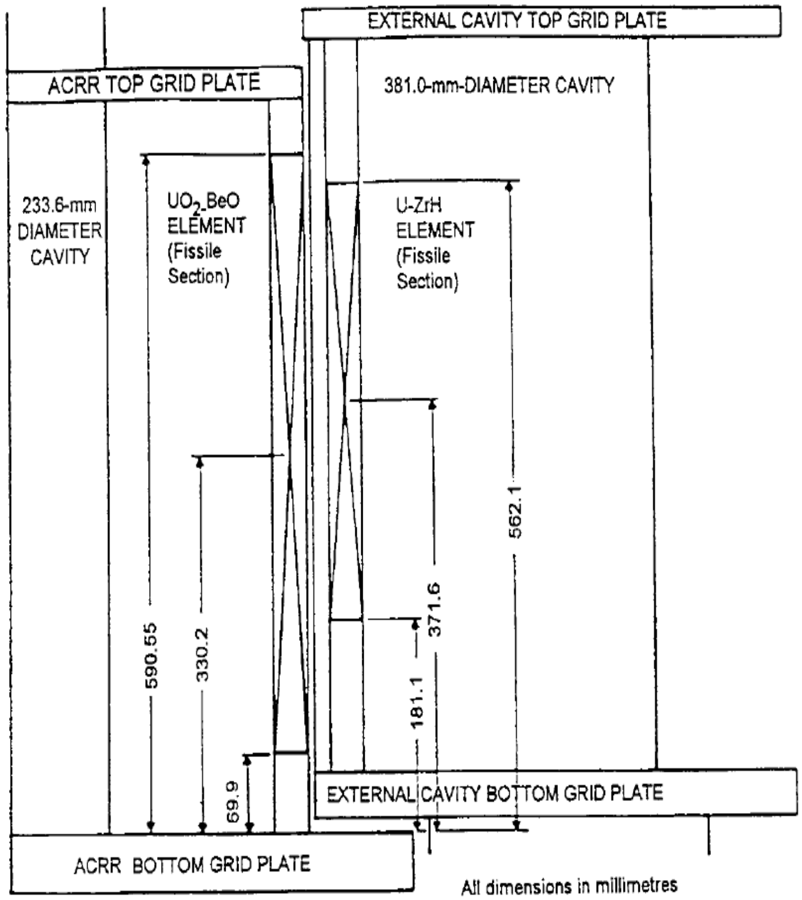


Figure 26. FREC-II Fuel Height Relative Location Compared to ACRR, Coupled

Figure 27. Photo of FREC-II Standard Shield Plug

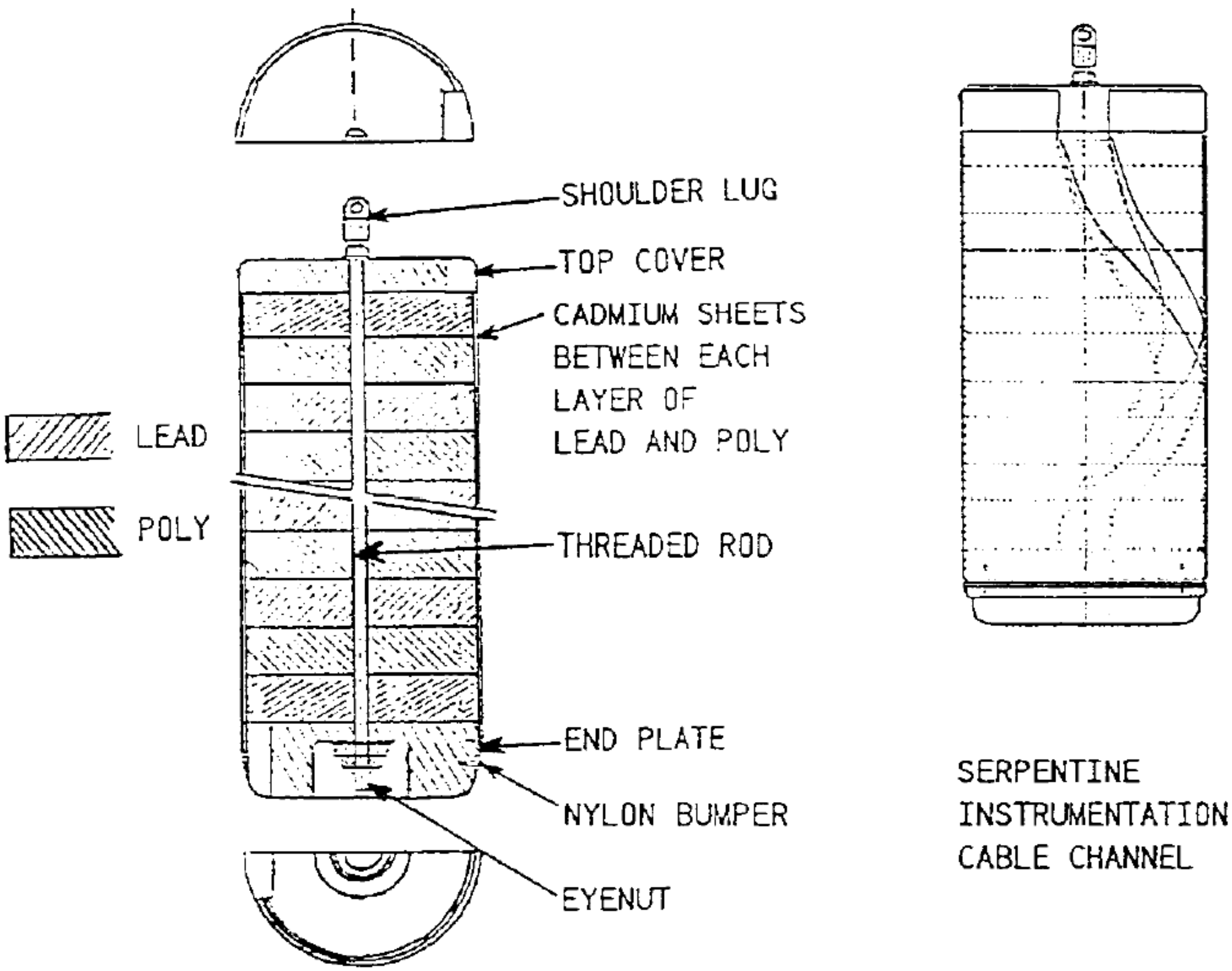
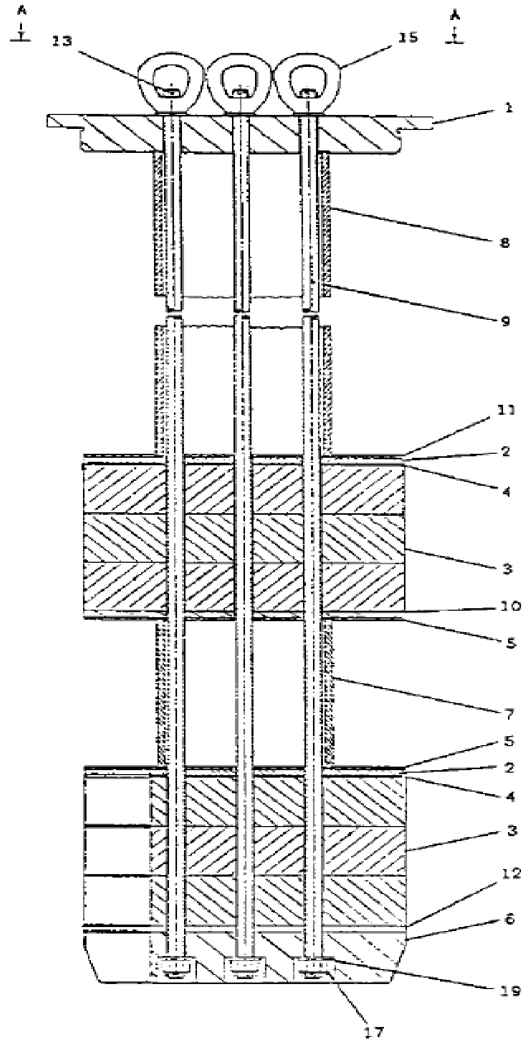
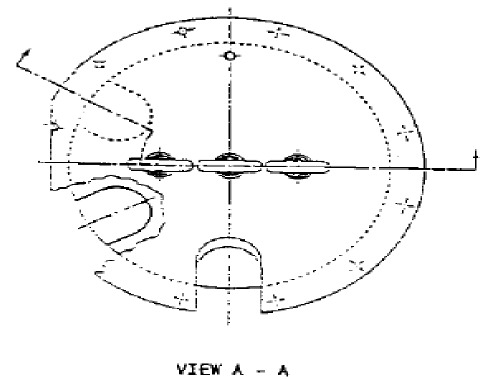


Figure 28. Standard FREC-II Shield Plug





1	TOP COVER
2	LEAD SHIELD
3	BORATED POLYETHYLENE SHIELD
4	FLEX BORON SHIELD
5	ALUMINUM SHIELD
6	LOWER ALUMINUM PLATE
7	SEPARATION PIPE
8	SEPARATION PIPE
9	THREADED ROD
10	UPPER NYLON SHIELD
11	UPPER ALUMINUM SHIELD
12	LOWER NYLON SHIELD
13	COTTER PIN
15	DROP-FORGED EYENUTS
17	NUTS
19	WASHERS

Figure 29. FREC-II 2T1 Shield Plug

Spectrum Modifiers

FREC-II currently has two (2) spectrum-modifying buckets that may be used to achieve the desired radiation environment. Figure 30 displays the cad-poly and the lead-boron buckets. There is limited characterization data regarding these buckets.

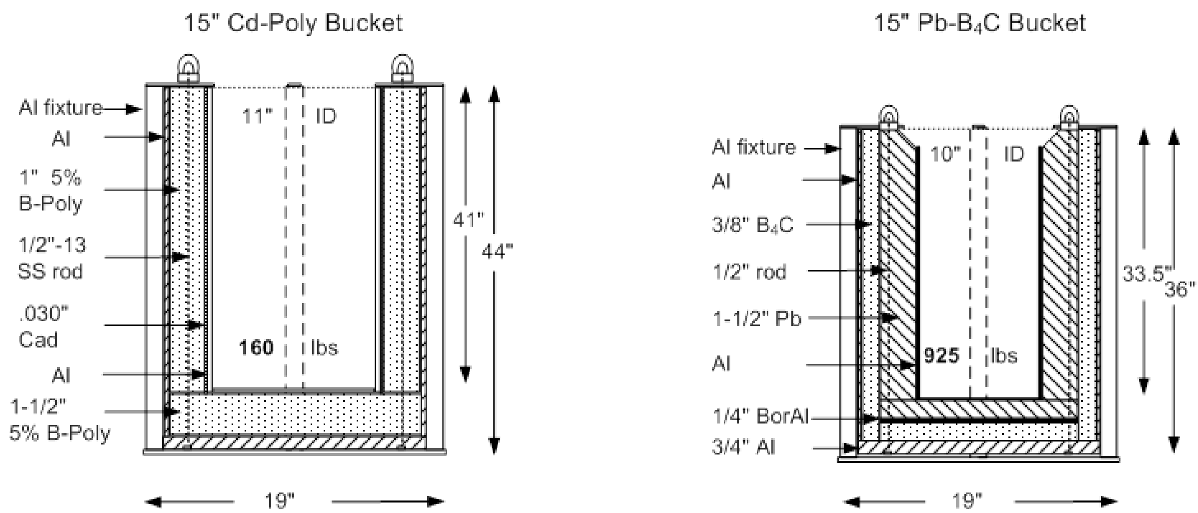


Figure 30. FREC-II Spectrum Modifying Buckets

Dosimetry

Standard dosimetry packets of nickel (5 mil or 10 mil), sulfurs, and CaF_2 TLDs (thermoluminescent dosimetry) is readily available for attachment to all experimental packages. The sulfur foils will provide a fluence result at 1- MeV Silicon-Equivalent and for neutrons greater than 3 MeV. The nickel foil results are typically provided via a gamma-spectrum analysis. The TLD output is provided in Grays. Gamma spectrum analysis of an experimental part is available upon request.

More exotic dosimetry is also available to perform a full spectrum unfolding. The RML performs the spectrum unfolding and is capable of counting exotic dosimetry with sufficient notice. Fission foils (Pu-239, U-235, U-238, and Np-237) are also available for characterization of radiation fields. Additional controls are required for use of fission foils.

It is the experimenter's responsibility to ensure that the dosimetry is separated from the experiment package post irradiation and is processed and then sent to the RML.

Experiment Packages

Experiments may be attached to aluminum stands as displayed in Figure 31. The experiment packages can be set to different heights above or below the fuel mid-plane via the use of these stands or via different central cavity pedestals. Packages can also be lowered on top of the cavity pedestals.

Figure 31. Experiment Examples

Explosives

Experiments with explosives components are allowed at ACRR; please contact the ACRR staff for more details. The ACRR staff maintains a minimum of two (2) staff members who are qualified to handle bench-safe explosives; however, the expectation is that the experimental staff will handle and process all explosives.

EXPERIMENTS that are intended to be placed in the central cavity, FREC-II, or on the neutron radiography facility and that contain explosives in excess of the uncontained explosives limits shall have a containment boundary that is designed to withstand internal projectiles and twice the impulse that is expected from a detonation of the explosive material to be irradiated, including any impulse from internal projectiles associated with the detonation. The safety factor on sustained pressure shall be 2 or greater.

Experiment Plan

The experiment plan covers the entire cradle-to-grave process for the experiment package. Special consideration in the planning of the experiment package is crucial to minimize radioactive waste and production of extremely long activation products. The sample size should be kept to a minimum (i.e. no material beyond what's necessary should be irradiated). Materials that have low neutron absorption cross-sections should be selected to minimize activation. Active electronics should have cable connectors several feet above the fuel mid-plane to reduce activation of the soldered connections and to extend the cable's lifetime. The cables must fit within the shield plug's serpentine grooves; therefore, only necessary cables should be used as there may not be room to accommodate redundant cables.

All experimental packages shall be bagged immediately upon removal from the reactor. This reduces the chance for spreading contamination throughout the High Bay. The bag shall be labeled with the experimenter's name, contact information, and disposition path. The ACRR is capable of disposing radioactive and mixed waste; however, depending upon the experiment package a project/task or funding source will need to be provided. ACRR has limited storage capabilities and retention of irradiated packages for greater than six (6) months is not desired.

The experiment plan is written in accordance with the *ACRR Experiment Safety Maintenance Procedure* (ACRR-MP-020; available upon request). A reactor supervisor will be assigned to work with each experimenter to assist in writing the experiment plan. Figures 32, 33, and 34 display the experiment plan flowchart, operations flow chart, and post irradiation flow chart, respectively.

Irradiated experiment packages can be shipped back to the customer's location either within Sandia National Laboratories or offsite (either DOE or NRC sites). Gamma spectrum analysis is required when shipping offsite. A copy of the receiving site's NRC license is also required prior to shipment if it is a NRC licensed facility. The typical time frame for shipping irradiated material offsite is limited to the gamma spectrum results. These results must be accepted at the receiving site prior to shipment. Typically, dead time associated with the gamma spectrum counting equipment dictates the dose rate levels associated with the package. Longer decay time is often needed to allow for a quantitative gamma spectrum analysis. A package decay time of 2 to 8 weeks (depending upon the size of the energy exposure) is required prior to performing gamma spectrum analysis. It typically takes 1 to 2 weeks to complete the gamma spectrum analysis and review. Once the ACRR Operations staff receives confirmation from the receiving site's radiation safety officer or equivalent the package can then be shipped; shipment typically takes 1 week.

If shipping internally to Sandia National Laboratories a movement survey is required and the destination location will need to be setup with the appropriate radiation and/or contamination controls and postings. Customers internal to Sandia National Laboratories may also request gamma spectrum analysis.

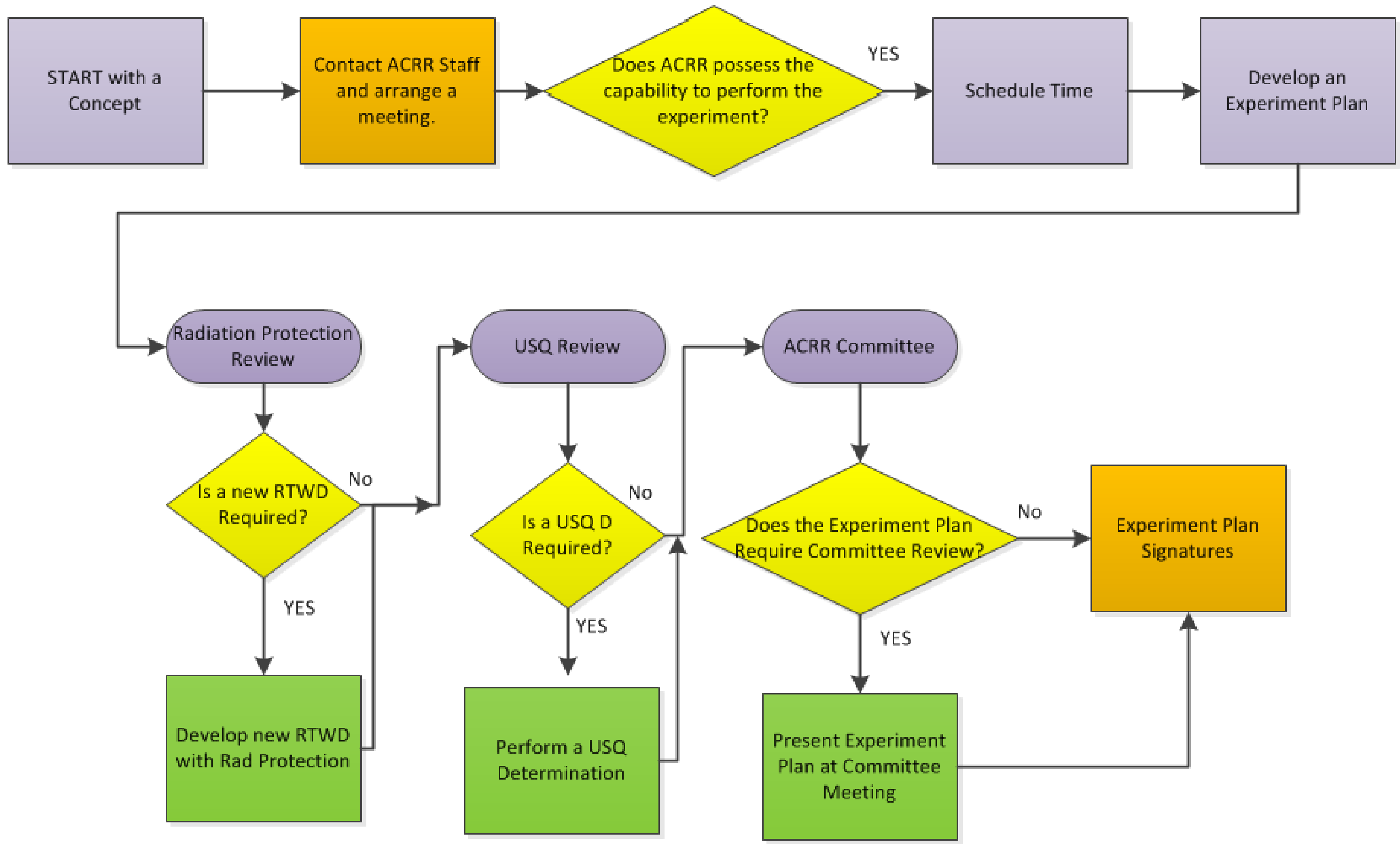


Figure 32. Experiment Plan Flow Chart

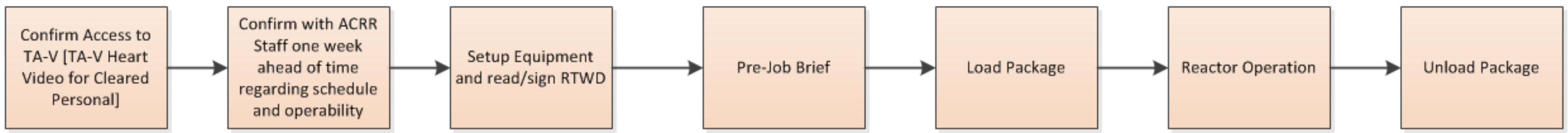


Figure 33. Operation Flow Path

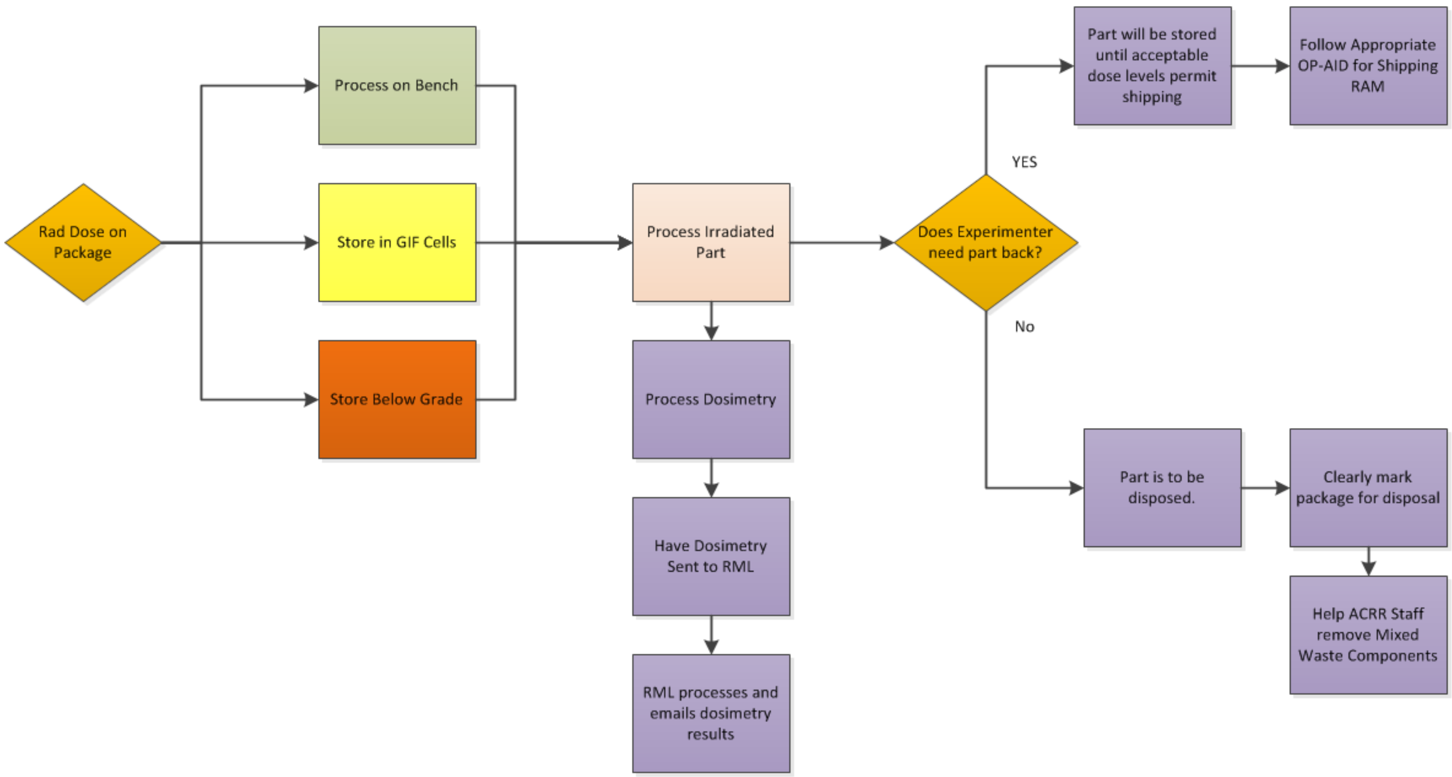


Figure 34. Post Irradiation Flow Path

Experiment Classes

Experiment plans are categorized as "classes." The experiment class determines the rigger and type of review required prior to implantation of the experiment plan. There are four (4) classes of experiments, as follows:

Class I Experiment

Class I experiments do *not* require committee review and may be reviewed and approved by an ACRR reactor supervisor. Class I experimenters can be conducted in any of the following locations:

- Central Cavity
- Neutron radiography tube ABOVE the water line (this includes the imaging plane)
- In an external cavity
- In the reactor pool (including the core grid)
- In supporting holsters or adjacent locations

Class I experiments must also meet the following 16 requirements. If one of the conditions is not met, the experiment must be evaluated using Class II criteria:

1) Contains no explosives or stored-energy devices such as gas generators; charged capacitors; sealed containers encapsulating materials that might produce gases when irradiated; pressurized gases; rotating components; or any other form of inherent, potential, or kinetic energy that exceeds a level of 500 J (TNT equivalent of 0.1 g). Commercial wet or dry batteries that are incapable of short-term energy release are not considered energy-storage devices for the purpose of this definition of Class I experiments. Energy storage devices may have current limiters.
2) Contains no fissile material with an enrichment that exceeds 1%, except in standard fission foils. Commercial fission chambers and similar neutron detection devices containing less than (<) 2 grams of fissile materials are exempted from this limitation and may be used in a Class I experiment regardless of enrichment. This exemption includes uranium-loaded aluminum dosimetry wire (containing 1 weight percent uranium enriched to 93% U-235). Foils that do not meet this criteria may still be used applying the guidelines for Class II (or above) fissile material.
   a) A standard fission foil meets the following requirements:
      i. Containing one of the following isotopes in the oxide form: U-235, U-238, Np-237, Pu-239;
      ii. Fissile material of any enrichment provided the isotopic mass does not exceed 1.1 grams;
      iii. At least single encapsulation of foils containing either U-235, U-238, or Np-237, and;
      iv. At least double encapsulation of foils containing Pu-239. Foil covers (such as cadmium, nickel, or vanadium) are acceptable containment.

         NOTE: These foils may contain a mixture of small amounts of the other fissile isotopes. This fact should not affect the safety aspects of their use in Class I experiments.
   b) Fission foil limitations – Fission foils must be in a boron ball when exposed to the core neutron flux.
   c) Fissile material exposure levels must be limited to:
      i. 5×10^{15} neutrons/per square centimeter (>10 keV) in steady-state mode

OR

ii. 2×10^{15} neutrons/per square centimeter (>10 keV) pulse in a single operation.

3) Operate at a temperature in excess of the boiling point of oxygen (90.16 K).

4) Have an estimated or measured reactivity worth in the range of positive $1.00 to negative $3.50.

5) Provide at least single-containment for toxic materials that, if released, would pose an identifiable health hazard.

6) Contain no biologically hazardous materials.

7) Contain no highly flammable materials that could be released and ignited.

8) Contain no materials that are expected to melt by virtue of the heat produced by the gamma or neutron fluence to which the sample is to be exposed, taking into consideration the possible advantages of cooling the sample.

9) Will not in some manner disintegrate, thus making it difficult to retrieve.

10) Contain no moving parts that may in any way be activated or moved while the reactor is in any condition other than shut down.

11) Will not produce significant damage to the reactor or reactor facility if dropped during the course of the experiment.

12) Does not, in the opinion of a reactor supervisor, present any unacceptable hazards to the operation of the reactor or to the personnel operating the reactor or conducting the experiment.

13) Contains no explosives unless they are fully contained or hand-safe and it is a neutron radiography experiment on the upper-end of the neutron radiography beam tube or within the neutron radiography beam tube above the water line, and;

14) Contains no more than 0.5 grams of TNT equivalent explosive per device, and;

15) Have a total TNT equivalent explosive charge of no more than 5 grams per exposure.

16) Contain lasers that are at or below laser Class 3B

OR

17) Contain lasers that are above laser Class 3B but cannot be seen (directly or reflected) outside of the cavity.

Additionally, Class I activities include the investigation of non-routine reactor characteristics including:

a) The measurement of single fuel element worth by positive period techniques or delayed critical measurements.

b) The installation, removal, or change of position of detectors, fuel holsters, thermocouples, flux wires and other items with reactivity worth less than $0.10 within the pool, the reactor core or an external cavity.

c) The handling, gauging, interchanging, or replacing of standard fuel elements, even if the core excess reactivity is altered, as long as the total number of fuel elements and the core positions occupied by those elements are not altered.

Class II Experiment

A Class II experiment requires review and approval from the ACRR Committee. Class II experiments can be conducted in the following locations:

- Central Cavity
- Neutron Radiography Tube; above and below the water line
- In an external cavity
- In special configurations within the reactor pool (including the core grid).

Class II experimenters must also meet the following nine (9) requirements. If one of the conditions is not met, the experiment must be evaluated using the Class III criteria. Class II experimenters or activities do not present any unacceptable hazard to the operation of the reactor or to personnel:

1) May contain up to 10 g of U-235 OR 3 grams of Pu-239 in the oxide form (2.64 g Pu) if not contiguous with explosives. If contiguous with explosives, the material at risk (MAR) must be limited to less than or equal to 1 g Pu-239 equivalent.

   NOTE: Experiments containing plutonium in any form other than oxide or fissile material not described by the Class I or Class II limits are Class III or higher. Any plutonium or fissile materials in an experiment must be contained except as described previously under Class I.

2) Have a reactivity worth in the range of positive $2.00 to a negative $3.50, if unsecured.

   If secured, has a worth in the range of positive $2.00 to a negative $6.50.

3) Provide at least single-containment for toxic materials that, if released, would pose an identifiable health hazard.
4) Contain no biologically hazardous materials.
5) Does not have the potential for producing significant damage to the reactor or reactor facility if dropped during the course of the experiment loading or unloading.
6) Does not present any unique or unusual hazards to the operation of the reactor or to personnel.
7) Contains no explosives exceeding Class I limits unless they are fully contained or hand-safe.
8) Contains lasers above laser Class 3B OR lasers that can be seen outside the cavity.
9) Operates at a temperature in excess of the boiling point of oxygen (90.16 K).

Class II activities can also be any operations defined below:

1) Alterations to the reactor core or external cavity loading except as specified as Class I. This includes load to “critical” operations and changes to the reactor core or external cavity loading or fuel element arrangement.
2) Installation of other than standard fuel elements or standard thermocouple elements, use of new types of instrumented elements, change of location of the instrumented element used for plant protect systems and other such related changes to the reactor core or the external cavity.
3) Operations of the reactor control system in other than a normal manner (e.g. operation of the control rods in an unbalanced manner for flux tilting purposes).

Class III Experiment

A Class III experiment requires review and approval from both the ACRR Committee and the Nuclear Facility Safety Committee (NFSC). The following conditions automatically classify an activity as Class III or higher:

1) Experiments or activities having a reactivity worth greater than positive $2.00 OR less than negative $3.50, if unsecured.
2) Experiments or activities having a reactivity worth greater than positive $2.00 OR less than negative $6.50, if secured.
3) Experiments or activities operating at temperatures below the boiling point of oxygen (90.16º K) that will be exposed to the reactor flux.
4) Experiments that exceed Class I or Class II limitations and do not exceed the TSRs or introduce a USQ.

Class III experiment must meet the following nine (9) requirements; otherwise it will become a Class IV experiment.

1) May have a reactivity worth more positive than negative $1.00 if un-secured in the steady-state mode.
2) May have a reactivity worth more positive than negative $4.25 if un-secured in the pulse mode.
3) May have a combined worth (due to the motion of a moveable experiment AND the transient rod bank) of less than positive $4.25.
4) May contain up to 9,600 grams of Pu-239 equivalent metal/ceramic OR 10 grams of Pu-239 equivalent when vaporization is credible if not contiguous with explosives. If contiguous with explosives, the material at risk must be limited to less than or equal to (≤) 1 g Pu-239 equivalent.
5) Safety-significant experiment containment is required for experiments containing more than 0.5 g of Pu-239 equivalent. Containment must be designed to withstand applicable thermal, explosive, and pressure insults due to reactor operations.

   NOTE: Experiments containing plutonium in any form other than oxide or fissile material not described by the Class I or Class II limits are Class III or higher. Any plutonium or fissile materials in an experiment must be contained except as described previously under Class I.
6) May contain up to 500 Ci of gaseous tritium.
7) Fission foils may contain up to 5 grams of Pu-239 equivalent.
8) Total number of fissions planned in an experiment in pulse/TRW mode is less than or equal to (≤) 10^{17} per reactor operation,

   <u>OR</u>

   Total fission power planned in a steady-state experiment is less than or equal to (≤) 50 kW.
9) ACRR has the capability to handle explosives please contact the staff for further details.

Class IV Experiment

Any experiment that exceeds the TSRs or introduces an Unreviewed Safety Question (USQ) is a Class IV experiment and, after review by the ACRR Committee and the Nuclear Facility Safety Committee, is submitted to DOE/NNSA for review and approval.

Data Acquisition

The ACRR has numerous pulse diagnostic detectors surrounding the core. These detectors aid in the determination of pulse size and the amount of MJs produced. A standard steady-state diagnostic is provided in Figure 35 and a pulse diagnostic of data acquisition is provided in Figure 36. Printouts are available for the experimental staff. Data points of various parameters are logged throughout the operation and are available upon request.

Shot Information		Predicted Values	
Run Number	10928	Expected Fuel Temp	141.1
Operator			
Date \ Time	5/5/2014 12:45		
Experimenter Name			
Experiment Plan #	1161, 1141		
Package Worth	-5.988		
Expected Reactor Power	0.2		
Comments	2E15 parts in LB44		

DETECTOR INFO:	Ave (MW)	CH-1	CH-2	CH-3	CH-4	CH-5	CH-6
Detector		DE4-9					
Detector Calibration		45.3					
Channel Type		3					
PEAK DATA:							
Peak (MW)	0.215	0.215					
Total Yield (MJ)	373.279	373.279					

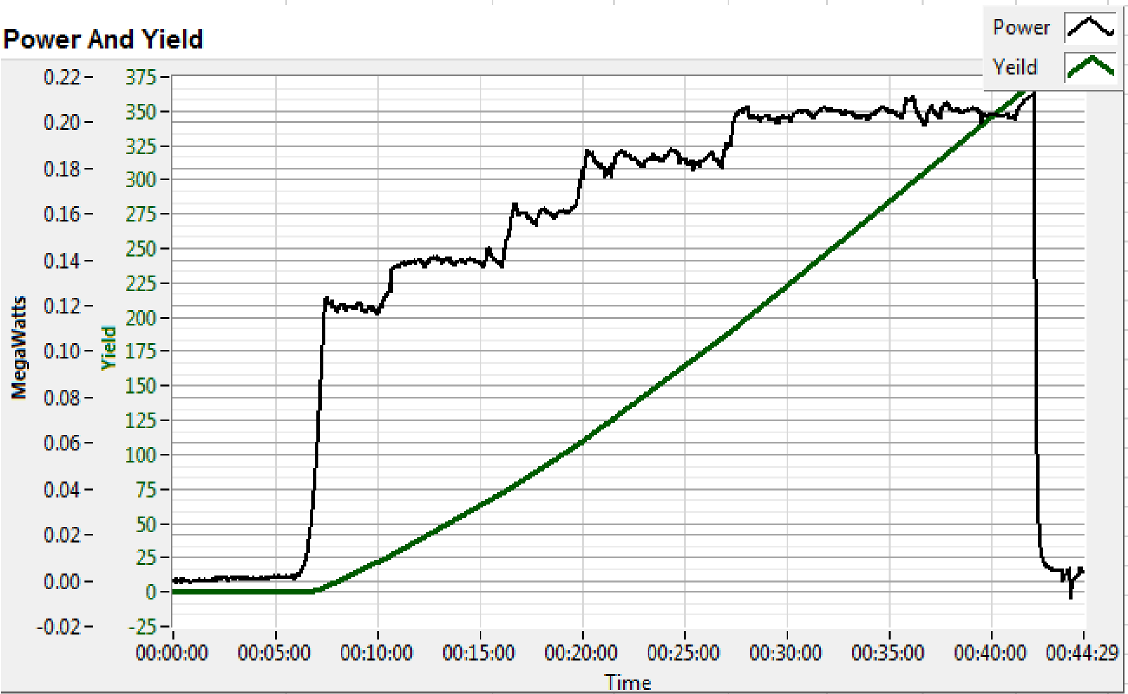


Figure 35. Steady-State Data Acquisition Example

Shot Information		Predicted Values	
Run Number	10822	Expected MW	17000
Operator		Expected TTP	0.3208
Date \ Time	2/24/2014 12:42	Expected MJ	210.85
Experimenter Name	ACRR Staff	Expected Fuel Temp	618.9
Experiment Plan #	OP-2	Dialed In MW	15842.56
Package Worth $	-0.08		
Shot Worth $	2.501		
Rod Hold Up (sec)	0.4		
FREC Mode	Decoupled		
FREC RODS	DOWN		

Comments	Tour Pulse & Pulse Diagnostics Evaluation

	Average	CH-1	CH-2	CH-3	CH-4	CH-5	CH-6
Detector		DE5-1	DE4-9		DE5-8	DE2-98	
Detector Calibration		44.1	45.3		48.3	53.6	
Channel Type		PXI Amp	SR570 Amp		PXI Amp	Terminated	
Average Used		Both	Both		Both	Peak	
Period Used		Yes	Yes		Yes	Yes	
PEAK DATA:							
Peak (MW)	**14692.9**	14947.8	14336.5		15796.3	13711.1	
TTP (sec)	0.311	0.31088	0.31112		0.31088	0.31096	
FWHM (sec)	0.0094	0.0094	0.0094		0.00936	0.00936	
LEHM (sec)	0.0046	0.00456	0.00452		0.00452	0.00464	
TEHM (sec)	0.0048	0.00484	0.00488		0.00484	0.00472	
Ratio (LE/TE)	0.958	0.942	0.926		0.934	0.983	
Shot Worth	2.326	2.553	2.622		2.458	2.905	
YIELD DATA:							
Total Yield (MJ)	**181.825**	181.375	185.107		192.064	202.016	
TTP+3fwhm (MJ)	156.977	159.52	153.157		168.57	146.622	
Yield @ Peak (MJ)	75.714	75.986	72.444		80.144	71.766	
Min Period (sec)	0.002435	0.002076	0.001987		0.002213	0.001689	

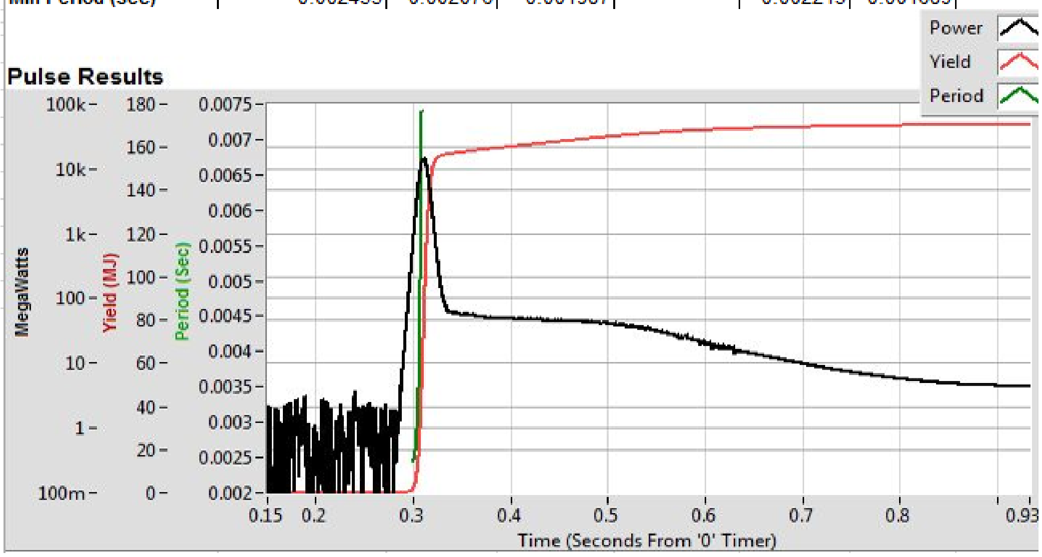


Figure 36. Pulse Data Acquisition Example

Operation Guidelines and Expectations

The High Bay is open by 7:30 AM Monday through Friday for experimental setup and disassembly. The operations staff strives to be ready for the first operation by 8:30 AM and aims to have the last operation completed by 4:30 PM allowing for end-of-day securing and shut-down operations. The operations staff will perform all operations involving a crane in the High Bay and may assist with experimental package handling. A pre-job brief is conducted and the entire experimental staff associated with the operation are expected to attend. This ensures all the appropriate safety precautions and operational plans are communicated. Everyone has the authority to stop work if something appears to be unsafe. Operations staff has restart authority.

Radiation Protection

Sandia General Employee Radiological Training (GERT) (RAD102) is required to enter the ACRR High Bay without ACRR operations staff member escorted access. Sandia Rad-Worker I or Rad-Worker II training is required to be present in the High Bay when certain radiological conditions are present. The ACRR operations staff is more than capable of handling radioactive packages on behalf of the experimental staff if Sandia Rad-Worker training is not obtainable.

ACRR is capable of shipping activated and radioactive material back to the customer. There is limited storage at the ACRR for storing packages. Estimated dose levels prior to irradiation of the package is desired in order to plan operations and to minimize the time in storage.

All radiological work is conducted on Radiological Technical Work Documents (RTWD). In order to perform radiological work in the ACRR High Bay, the individual must be read in on the appropriate RTWD. Separate RTWDs may need to be written to accommodate different radiological conditions as a result of an exotic experiment.

Figure 37 provides an estimate of activity for 1 gram of material in the central cavity after a 10 MJ pulse for 316-Stainless Steel, gold, and 6061 Aluminum on contact and at one foot. It is desirable to limit the amount of long lived radionuclides both from a radiological protection standpoint and from a waste disposition consideration.

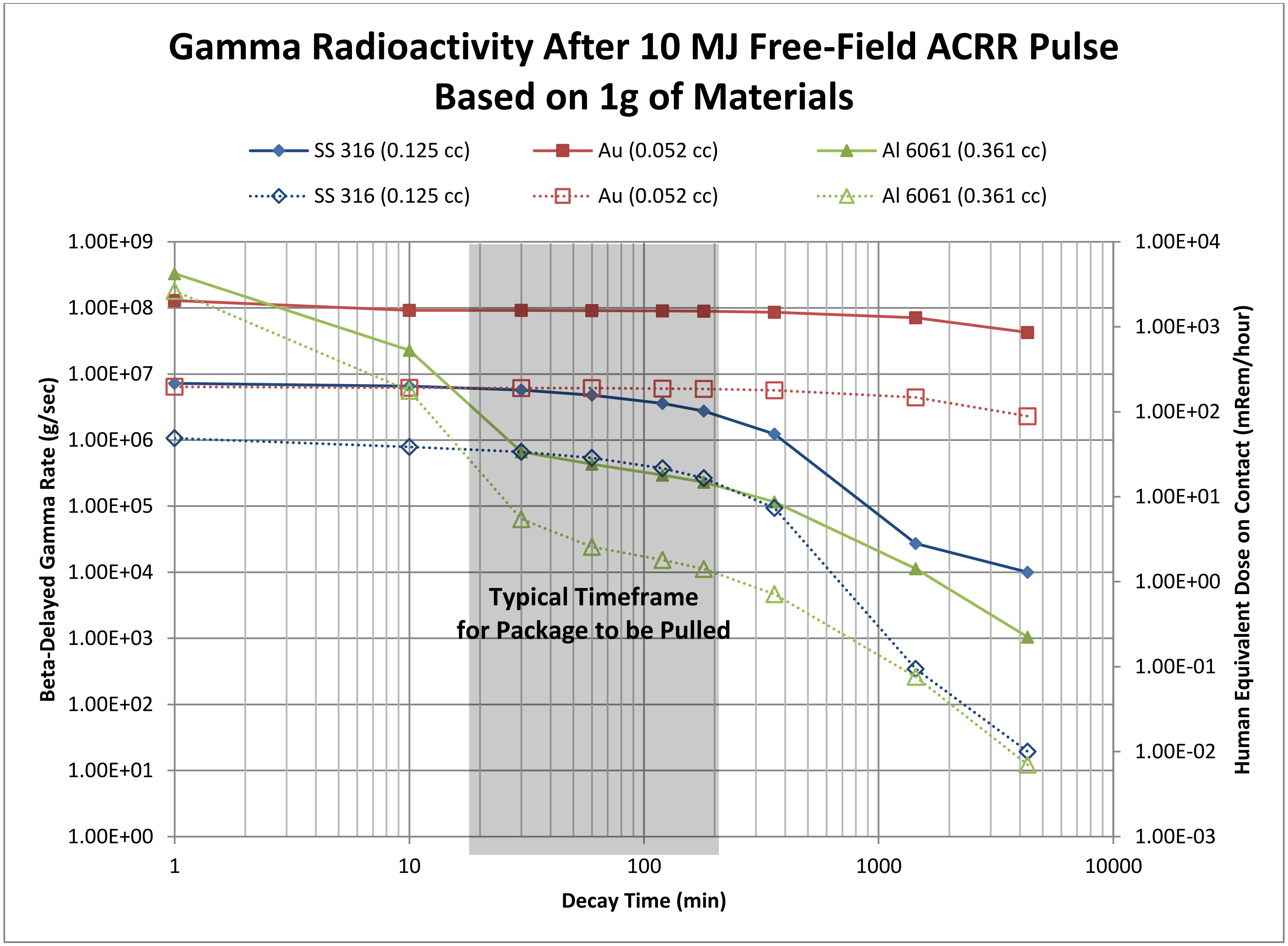


Figure 37. Radioactivity Estimate