MISSOURI S&T
MISSOURI UNIVERSITY OF SCIENCE AND TECHNOLOGY
Formerly University of Missouri-Rolla

May 26, 2016

Dear Sir:

Please find enclosed the Annual Progress Report 2015-2016 for the Missouri Science and Technology Reactor (License R-79, Docket No: 50-123). This report is being filed under the reporting requirements of our Technical Specifications. A copy of this report is also being sent to our NRC Project Manager, Mr. Spyros Teailforos

Sincerely,

William Bonzer

William Bonzer
Reactor Manager

mh

Enclosure

cc: Mr. Spyros Teailforos (NRC)
Document Control Desk (NRC) ✓
American Nuclear Insurers, c/o Librarian
University of Missouri-Columbia Research Reactor (MURR)
Chancellor Cheryl B. Schrader (MST)
Michelle Bresnahan, Radiation Safety Officer (MST)
Dr Hyoung Lee, Chair of Nuclear Engineering Dept. (MST)
Dr. Mark Fitch, Chairman, Radiation Safety Committee (MST)
Dr. Ralph Flori Jr, Chair Mining and Nuclear Engineering Dept. (MST)

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NRR

PROGRESS REPORT

2015-2016

MISSOURI UNIVERSITY OF

SCIENCE AND TECHNOLOGY

REACTOR

PROGRESS REPORT

FOR THE

MISSOURI UNIVERSITY OF SCIENCE AND TECHNOLOGY

(FORMALLY THE UNIVERSITY OF MISSOURI-ROLLA)

NUCLEAR REACTOR FACILITY

April 1, 2015 to March 31, 2016

Submitted to

The United States Nuclear Regulatory Commission

And

Missouri University of Science and Technology

Table of Contents

LIST OF TABLES

LIST OF FIGURES

SUMMARY

During the 2015-2016 reporting period, the Missouri University of Science and Technology Reactor (MSTR) was in use for 348.78 hours. The major part of this time, about 90%, was used for class instruction, research, and training purposes.

The MSTR operated safely and efficiently over the past year. No significant safety-related incidents or personnel exposures occurred.

The reactor facility supported several Missouri University of Science and Technology (Missouri S&T) courses over the year for over 4,180 student-hours. About 3,460 visitors visited the reactor during the past year. There were 820 participants, mostly high school students, in the U.S. Department of Energy Reactor Sharing Program.

The reactor produced 9679.24kW/hrs. kilowatt-hours of thermal energy using approximately 0.423 grams of uranium. A total of 136 samples were neutron irradiated in the reactor with the majority being analyzed in the reactor counting laboratory.

1.0 INTRODUCTION

This progress report covers activities at the Missouri University of Science and Technology Reactor (MSTR) Facility for the period April 1, 2015 to March 31, 2016.

The reactor operates as a University facility. It is available to the faculty and students from various departments of the University for their educational and research programs. Several other college and pre-college institutions also make use of the facility. The reactor is also available for the training of personnel from commercial concerns with legitimate interest in our facility use.

1.1 Background Information

The Missouri University of Science and Technology Reactor (MSTR) (formally University of Missouri-Rolla Reactor) attained initial criticality on December 9, 1961. The MSTR was the first operating nuclear reactor in the State of Missouri. The Bulk Shielding Reactor at Oak Ridge National Laboratory is the basis for the reactor's design. The reactor is a light water, open pool reactor cooled by natural convective flow. The fuel is MTR plate-type fuel. The initial licensed power was 10 kW. The licensed power was up-graded to 200 kW in 1966. During the summer of 1992, the reactor fuel was converted from high-enriched uranium fuel to low-enriched uranium fuel.

The facility is equipped with several experimental facilities including a beam port, thermal column, three pneumatic rabbit systems, and several manual sample irradiation containers and systems. The facility also contains a counting laboratory that has both gamma and alpha spectroscopy capabilities. The gamma spectroscopy system includes germanium and sodium-iodide detectors, associated electronics, state-of-the-art data acquisition, and spectrum analysis software. The alpha spectroscopy system consists of a surface barrier detector and data acquisition equipment. Additionally, there is a thermos-luminance dosimeter reader, digital neutron radiography imager, digital x-ray imager, and liquid scintillation counter for student and faculty usage.

1.2 General Facility Status

The MSTR operated safely and efficiently over the past year. No significant safety-related incidents or personnel exposures occurred.

An independent auditor from the University of Missouri - Columbia audited the reactor facility on December 9, 2015. There were no significant areas of concern. There is an agreement between the MSTR and the University of Missouri-Columbia Research Reactor to audit each other. This has been a very beneficial arrangement for both facilities involved.

The reactor staff has continued to review the operation of the reactor facility in an effort to improve the safety and efficiency of its operation and to provide conditions conducive to its utilization by students and faculty. An "outreach" program, implemented over the past few years, has been continued in order to let both students and faculty in a number of departments across campus know that the reactor could be used to enhance course work and research. As a result, additional classes have been using the reactor facility to augment their programs, including:

1. Chemistry 2, 'General Chemisty Laboratory'
2. Civil Engineering 310, 'Senior Design Class'
3. Engineering Management 386, 'Safety Engineering Management'
4. Mechanical Engineering 229, 'Energy Conversion'
5. Life Sciences 352, 'Biological Effects of Radiation'
6. Physics 107, 'Modern Physics'
7. Physics 207, 'Modern Physics II'
8. Physics 322, 'Advanced Physics'
9. Materials Science & Engineering 348, 'Energy Materials'
10. Materials Science & Engineering 448, 'Advanced Energy Materials'

SOPs were revised, over the past year in order to improve and keep current the operations and efficiency of the MSTR. The following is a list of SOPs revised during the reporting period:

1. SOP INDEX
2. SOP 207 FUEL HANDLING
3. SOP 306 ESTIMATION OF ACTIVITY AND REACTIVITY WORTH OF A SAMPLE
4. SOP 308 RESTORATION OF AC POWER FOLLOWING A POWER OUTAGE
5. SOP 312 CRITICAL EXPERMENT PROCEDURES
6. SOP 501 EMERGENCY PROCEDURES FOR REACTOR BUILDING EVACUATION
7. SOP 653 SEALED SOURCE LEAK TEST
8. SOP 702 IRRADIATION REQUEST FORMS
9. SOP 801 LOG AND LINEAR DRAWER CALIBRATION
10. SOP 811 FIRE AND SMOKE ALARM SYSTEM
11. SOP 816 MSTR POWER CALIBRATION
12. SOP 818 FUNCTION TEST OF THE BUILDING SECURTIY SYSTEM

2.0 REACTOR STAFF AND PERSONNEL

2.1 Reactor Staff

Name	Title
Dr. Hyoung Kohl Lee	Reactor Director
Mr. William Bonzer	Reactor Manager & Senior Operator
Ms. Maureen Henry	Office Support Assistant III
Mr. Craig Reisner	Senior Reactor Operator
Mr. Anthony Alchin[1]	Electronic Technician III & Senior Operator

1. Effective 5-18-2015

2.2 Licensed Operators

	Name	License
1.	William Bonzer	Senior Operator
2.	Craig Reisner	Senior Operator
3.	Anthony Alchin	Senior Operator
4.	Erica Davidson[1]	Reactor Operator
5.	Cody Stuchal	Reactor Operator
6.	Ethan Margherio[1]	Reactor Operator
7.	Jonathan Scott	Reactor Operator
8.	Andrew Bingham	Reactor Operator
9.	Garrett Jones	Reactor Operator
10.	Steve Wagstaff	Reactor Operator
11.	Wesley Tucker	Reactor Operator
12.	Matthew Caddell[2]	Reactor Operator
13.	Jacob Stueck[2]	Reactor Operator
14.	Justen Vinyard[2]	Reactor Operator

1. Termination Date August 6, 2015
2. Effective Date October 15, 2015

2.3 Radiation Safety Committee

The Radiation Safety Committee meets quarterly. The committee met on 6/26/2015, 9/25/2015, 12/7/2015 and 3/16/2016 during the reporting period. The committee members are listed below.

	Name	**Department**
1.	Dr. Mark Fitch	Civil Engineering
2.	Ms. Michelle Bresnahan	Environmental Health and Safety Services
3.	Mr. William Bonzer	Nuclear Reactor
4.	Mr. Randy Stoll	Business Services
5.	Dr. David Wronkiewicz	Geological Sciences & Geology
6.	Dr. Shoaib Usman	Mining & Nuclear Engineering

7. Dr. Fadha Ahmed	Environmental Health and Safety Services
8. Dr. Yue-wern Huang[1]	Biological Sciences
9. Dr. Amitava Choudhury	Chemistry
10. Dr. Carlos Castano	Mining & Nuclear Engineering
11. Mr. Tony Hunt	Environmental Health and Safety Services
12. Dr. Robert Aronstam[2]	Biological Science

1. Joined 7-14-2015
2. Resigned 7-30-2015

2.4 Health Physics

The Environmental Health and Safety (EHS) Department provides the health physics support for the Missouri S&T Reactor. The EHS Department is organizationally independent of the Reactor Facility operations group. Health Physics personnel are listed below:

Name	Title
1. Ms. Michelle Bresnahan	Director of Environmental Health and Safety
2. Mr. Brian Smith	Industrial Hygienist
3. Dr. Fadha Ahmed	Health Physicist
4. Mr. Andrew Bingham	Health Physics Technician (part time) Left May, 2015
5. Mr. Alex Swearingen	Health Physics Technician (part time)
6. Mr. Wesley Tucker	Health Physics Technician (part time)

3.0 REACTOR OPERATIONS

Core Confirmation 122W is presently in use. The "W" mode core is completely water reflected and is used for normal reactor operations. The "T" mode (core positioned near graphite thermal column) may be used for thermal column experiments. Table 3-1 presents pertinent core data and Figure 3-1 shows the core configuration of core 122W. The excess reactivity, shutdown margin, and rod worth's were measured in cold, clean conditions.

Table 3-1. Core 122W Technical Data

Parameter	Value
Rod 1	3.958% Δk/k
Rod 2	3.239% Δk/k
Rod 3	1.778% Δk/k
Reg Rod	0.232% Δk/k
Excess Reactivity	0.640% Δk/k
Shutdown Margin*	4.377% Δk/k

*Assumes Rod 1 (highest worth rod) and Reg Rod are fully withdrawn.

A									
B						S			
C					C-4	F-5	F-11	F-17	
D				F-4	F-8	F-14	C-1	F-10	F-1
E				F-9	C-3	F-12	C-2	F-7	F-3
F				CR	F-15	HC	F-13	BR	F-6

Figure 3-1. MSTR Core 122W Configuration

KEY TO PREFIXES

F- Standard Elements	CR- Cadmium Rabbit	HF- Half Element
BR- Bare Rabbit	C- Control Elements	S - Source Holder
CR- Cadmium Rabbit	HC- Hot Cell Rabbit	

Table 3-2: Unscheduled Shutdowns for 2015-2016

Date **Type of Rundown/Cause and Corrective Action Taken**

RUNDOWNS

05/05/2015 Action: 120% demand rundown

Cause: Student did not press 200W scale button hard enough.

Corrective Action Taken: Student reminded to firmly press button

SRO on Duty granted permission to restart reactor.

10/20/2015 Action: 120% demand rundown

Cause: Trainee did not push 200W scale button in firmly.

Corrective Action Taken: Trainee instructed to push buttons in firmly.

SRO on Duty granted permission to restart reactor.

10/26/2015 Action: 120% demand rundown

Cause: Student downscaled instead of upscaled.

Corrective Action Taken: Student instructed to pay more attention to which scale they are pushing.

SRO on Duty granted permission to restart reactor.

11/02/2015 Action: 120% demand rundown

Cause: Student did not fully push in Linear Channel button.

Corrective Action Taken: Student told to press buttons more firmly.

SRO on Duty granted permission to restart reactor.

02/03/2015 Action: 120% Full Power Rundown

Cause: UIC inserted into core too much during power calibration.

Corrective Action Taken: Instructed to not let go of UIC.

SRO on Duty granted permission to restart reactor.

02/23/2016 Action: 120% demand rundown

Cause: Linear channel scale not pushed in all the way.

Corrective Action Taken: SRO talked to trainee about pushing buttons in firmly.

SRO on Duty granted permission to restart reactor.

UNPLANNED SHUTDOWNS

Date **Type of Unplanned Shutdown, Cause and Corrective Action Taken**

Unplanned Shutdowns

12/10/2015 Action: Power Outage

Corrective Action Taken: None. Reactor was secured and operations ended for the day.

Table 3-3: Maintenance for 2015-2016

Date	Type of Maintenance
6/23/2015	Issue: Period <30s Trip Activated and unable to be cleared Corrective Action: Relay K2 discovered to be failed replaced with suitable replacement relay. Weekly checklist performed to ensure proper operation of Log & N Drawer.
6/24/2015	Issue: Reg Rod joystick threads holding joystick to console stripped beyone usability. Corrective Action: Replaced joystick with a 3 position lever switch originally meant for Auto Permit switch. Verified proper operation. Lever Switch as opposed to joystick should have less strain on the threads holding the switch to console. Replaced Main Control Rods Joystick with a Lever Switch for conformity and to prevent future problems of the same type.
12/03/2016	Issue: Clutch was slipping when rods fully inserted in core. Rod #3 still trying to drive in. Corrective Action: Limit switch replaced and moved to new higher location. Slip Clutch readjusted to take less pressure to slip on insert.
01/11/2016	Issue: Linear Recorder Output erratic and unstable. Corrective Action: Amplifier Module determined cause of issue. Replaced module with one from a spare recorder in the loft. No erratic or unstable output observed after replacement after an hour of continuous running.

Table 3-4. Experimental Facility Usage

Facility	Hours
Bare Rabbit Tube	8.78 hrs.
Cadmium Rabbit Tube	0.00 hrs.
Beam Port	0.0 hrs.
Thermal Column	0.0 hrs.
Other Core Positions	3.94 hrs.
Hot Cell	0.0 hrs.
Gamma Exposures	3.2 hrs.
Total	15.92 hrs.

Table 3-5. Reactor Utilization

1.	Reactor use	348.78 hrs.
2.	Time at power	231.73 hrs.
3.	Energy generated	9679.24 kW/hrs.
4.	Total number of samples, neutron irradiated	136
5.	U-235 Burned	0.423 g
6.	U-235 Burned and Converted	0.500 g

4.0 EDUCATIONAL UTILIZATION

The reactor facility supported several Missouri S&T courses in the past year for a total of over 4,180 student-hours. The number of Missouri S&T students utilizing the facility was 698. This usage is a direct result of an aggressive and continuing campus wide "outreach" program. The reactor facility provided financial support for four students with hourly wages.

Table 4-1 lists Missouri S&T classes taught at the facility along with associated reactor usage for this reporting period.

The Reactor Sharing Program, previously funded by the U.S. Department of Energy, was established for colleges, universities, and high schools that do not have a nuclear reactor. This past year, 479 students and instructors from 140 institutions participated in the program. Table 4-2 lists those schools and groups that were involved in this year's Reactor Sharing Program. The majority of participants were high school students. MSTR coordinates with the Missouri S&T Admissions Office to schedule high school students to see other items of interest at Missouri S&T after they have visited the reactor facility. The students visited the Missouri S&T Chapter of American Nuclear Society, the Computer Integrated Manufacturing Lab, the Foundry, Ceramics Engineering, Mineral Museum, Computer Center, Experimental Mine, Solar Car, Electron Microscope, and Stonehenge. The Reactor Sharing Program serves as a strong campus-wide recruiting tool by attracting high school students to the university and hopefully sparking some interest in nuclear engineering, science, and technology.

The reactor staff continues to educate the public about applications of nuclear science. Over 3,460 persons visited the facility during this reporting period. Tour groups are typically given a brief orientation and/or demonstration by a member of the reactor staff.

Table 4-1 Missouri S&T Classes at Reactor Facility

Semester	CLASS NUMBER/TITLE	# OF STUDENTS	TIME AT RECTOR	STUDENTS HOURS
2015-2016	Graduate Students Project	4	56.5	226
SS 2015	NE 2406	30	26	780
SS 2015	NE 4438	25	6	150
SS 2015	NE 1105 Tours	17	1	17
SS 2015	NE 1105 Tours	18	1	18
4/8/2015	NE 4312	16	2	32
4/9/2015	NE 4312	16	2	32
4/10/2015	NE 4312	12	2	24
4/14/2015	NE 1105 Lab	17	1	17
4/17/2015	NE 1105 Lab	16	1	16
4/20/2015	Economics Class	20	1	20
4/21/2015	Chem Lab 1319	60	1	60
4/22/2015	Chem Lab 1319	60	1	60
4/22/2015	NE 4312	20	2	40
4/22/2015	Chem Lab 1319	60	1	60
4/23/2015	NE 4312	16	2	32
4/24/2015	NE 4312	12	2	24
FS 2015	NE 2406	17	42	714
9/4/2015	NE 1105 Tour	31	2	62
9/5/2015	NE 1105 Lab	17	1	17
9/6/2015	NE 1105 Lab	19	1	19
FS 2015	NE 4428	35	30	1050
12/2/2015	NE 1105 Power change	30	8	240
SS 2016	NE 2406	31	44	132
2/10/2016	NE 1105 Tour	14	1	14
2/13/2016	NE 1105 Tour	15	1	15
3/23/2014	NE 4312	24	2	48
3/24/2016	NE 4312	25	2	50
SS 2016	NE 4438	21	10	210
	Total	698	252.5	4,180

Table 4-2 Reactor Sharing Program 2015-2016 (Reporting Period)

DATE	EVENT	VISITORS	TIME
4/2015	Visitor's	5	2
4/16/2015	Fort Leonard Wood	3	2
5/2015	Visitors	16	3.5
6/2015	Visitors	22	4
6/9/2015	Jackling	22	3.5
6/11/2015	Jackling	23	3.5
6/15/2015	Nuclear Engineering Camp	46	6
6/16/2015	Career Opportunity	7	1
6/17/2015	Venturing Crew	11	1
6/22/2015	Jackling	24	3
6/25/2015	Jackling	27	3
7/2015	Visitors	20	14
7/15/2015	Fort Leonard Wood	5	3
7/16/2015	Kanas City Group	3	2
8/2015	Visitors	2	1
8/7/2015	Equity, Diversity & Inclusion Group	7	1
8/25/2015	Rep. Jason Chapman	1	1
8/28/2015	Group From Illinois	6	5
9/2015	Visitors	13	4.5
9/18/2015	Col Parker Fema tour	10	1
9/28/2015	NRC Test	1	30
10/20/2016	NRC	1	8
10/21/2016	DNN Radiological Security Partnership	3	3
10/28/2016	USMC	19	2
10/29/2016	Canberra	2	1
11/2015	Visitors	8	2
11/19/2015	East Central	21	2
11/20/2015	Central Security	2	3
12/1/2015	Columbia Audit at Reactor	2	8
12/3/2015	Rolla High School	32	2
1/12/2016	Fire Department	2	1
1/28/2016	Gasconade County Scholarship	20	1
2/1/2016	Boy Scouts	28	3
3/23/2016	Stem All Girl groups 3 sets	63	3
	TOTAL	479	126.5

5.0 REACTOR HEALTH PHYSICS ACTIVITIES

The health physics activities at the Missouri S&T Reactor facility consist primarily of radiation and contamination surveys, monitoring of personnel exposures, airborne activity, pool water activity, and waste disposal. Releases of all by-product material to authorized, licensed recipients are surveyed and recorded. In addition, health physics activities include calibrations of portable and stationary radiation detection instruments, personnel training, special surveys and monitoring of non-routine procedures.

5.1 Routine Surveys

Monthly radiation exposure surveys of the facility consist of direct gamma and neutron measurements. No unusual exposure rates were identified. Monthly surface contamination surveys consist of 20 to 40 swipes counted separately for alpha and beta/gamma activity. No significant contamination outside of contained work areas was found.

5.2 By-Product Material Release Surveys

There were no shipments of by-product material released off-campus. There were no by-product releases on campus.

5.3 Routine Monitoring

Seventy-five reactor facility personnel and students involved with the operations in the reactor facility are currently assigned Mirion Technologies, Thermo-Luminescent dosimeters (TLDs). Three of the Reactor Staff have beta, gamma, neutron dosimeters which are read twice monthly. There are four area beta, gamma, neutron dosimeters and two TLD ring dosimeter, which are also read twice monthly. There are three environmental TLDs outside the reactor building which are read quarterly. There are also five other beta, gamma, neutron dosimeters used by the health physics personnel and four other area beta, gamma, neutron dosimeters that are read monthly. The remaining dosimeters detect beta and gamma radiation only and are read monthly. In addition, six digital, direct-reading dosimeters and six chirper dosimeters are used for visitors and high radiation work. There have been no significant personnel

exposures during this reporting period. Visitors are monitored with direct reading dosimeters. No visitors received any reportable or significant exposure.

Airborne activity in the reactor bay is monitored by a fixed filter; particulate continuous air monitors (CAM). Low levels of Argon-41 are routinely produced during operations.

Pool water activity is monitored monthly to ensure that no gross pool contamination or fuel cladding rupture has occurred. Gross counts and spectra of long-lived gamma activity are compared to previous monthly counts. From April 2015 through March 2016 sample concentrations averaged 8.44×10^{-6} μCi/ml.

Release of gaseous Ar-41 activity through the building exhausts is determined by relating the operating times of the exhaust fans and reactor power during fan operation to previously measured air activity at maximum reactor power. During this period, an estimated 36,519.22 μCi of Ar-41 was released into the air.

5.4 Waste Disposal

Solid waste, including used water filters, used resins, and contaminated paper/gloves is stored and/or transferred to the campus waste storage area for later shipment to a commercial burial site. Water is analyzed for radioactive contamination and approval is required before the water is released. During this period there were no waste disposed from the reactor facility.

5.5 Instrument Calibrations

During this period, portable instruments and area monitors were calibrated annually.

6.0 PLANS

The reactor staff will be two major projects during the next reporting period distant education program and continuation of the reactor operator training program.

6.1 Distant Education

A distant education system has been developed to conduct laboratory sessions with students of the Missouri S&T Campus and other universities. Due to the size of the Missouri S&T Nuclear Engineering classes, the distant education system allows students to participate in lab sessions as one group in larger a classroom than what is available for room in the MSTR building.

Equipment has been installed to replace the existing rod drive motors and rod height indicators to output rod height information over the internet. Audio/video equipment is used for students to watch reactor staff performing the labs, to ask questions to the staff and obtain data from the control room instrumentation.

The reactor staff has conducted distant education with the Missouri S&T Nuclear Engineering Department, Missouri S&T Chemistry Department and University of Illinois Nuclear Engineering students at Urbana, Illinois. These departments are providing feedback from students participating in the labs to improve our presentation techniques and provide suggestions regarding audio/video equipment improvements.

6.2 Reactor Operator Training

The MSTR had three students obtain their Reactor Operator lienses. The reactor staff is limiting operator training to around ten students with a very strong desire to obtain the license and assist reactor staff with reactor operations. The new training program has proven to be effective in keeping the students that want the license and work with reactor staff. At the end of the reporting period eight students were training for an operator's license to take in the fall of 2016 and three for the spring of 2017.

APPENDIX A.

STANDARD OPERATING PROCEDURES

CHANGED DURING THE 2015-2016

REPORTING YEAR

SOP 100-199 Routine Reactor Operation

SOP 200-299 Facility Operations

SOP 300-399 Special Operations

SOP 400-499 Reserved for Future Use

Revised By: Maureen Henry

Maureen Henry

Approved By: William Bonzer

William Bonzer

Revised By: Maureen Henry

Maureen Henry

Approved By: William Bonzer

William Bonzer

SOP 700 – 799 Experiments

SOP 702	Irradiation Request Forms
SOP 710	Insertion and Removal of Experiments
SOP 711	Beam Hole Facility
SOP 712	Thermal Column Facility

SOP 800 – 899 Reactor Instrumentation

SOP 800	Annual Checklist	
SOP 801	Log and Linear Drawer Calibration	
SOP 802	Linear Channel	
SOP 803	Log Count Rate (LCR) Channel	
SOP 804	Safety Amplifier System	
SOP 806	Temperature Channel	
SOP 810	Weekly Check	
SOP 811	Fire and Smoke Alarm System	
SOP 812	Confinement and Ventilation System Check	
SOP 813	Rod Drop Time Measurement	
SOP 816	UMR Power Calibration	
SOP 818	Function Test of Building Security System	Rev

Revised By: Maureen Henry

Approved By: William Bonzer

A. PURPOSE

To provide for the safe and efficient movement of fuel elements and control rod fuel elements to and from the core and the Fuel Storage Rack.

B. PRECAUTIONS, PREREQUISITES, AND LIMITATIONS

1. All rearrangements of the core, fuel movement, and associated Health Physics monitoring, or other actions involving fuel shall be under the direct supervision of a Senior Reactor Operator.

2. All fuel movements shall be logged in the permanent log book.

3. Prior to any fuel movement, a completed Transfer Order Form must be filled out and approved by either the Reactor Manager or Reactor Director.

4. When moving fuel elements, the fuel handling tool must be kept in a vertical attitude.

5. A licensed operator shall visually confirm that there are no unoccupied internal lattice positions in the core before a new core is taken critical.

6. When loading to a new core configuration, measure the core excess reactivity, shutdown margin, and rod worths prior to exceeding a power of 1 kW. Log this information on a Core and Rack Storage Form.

7. When loading to a new core configuration that involves a reactivity change greater than 0.2% delta-k/k or changes in control rod locations, excess reactivity and shutdown margin must be determined for both the "W" and "T" modes.

C. PROCEDURE

I. Unloading of Fuel Elements (unrodded) from the Core to the Fuel Storage Rack.

1. Complete a Start-Up Checklist (SOP 102).

2. Withdraw shim/safety Rods 1, 2 and 3 to shim range.

3. Unlock the fuel handling tools.

4. In accordance with the Transfer Order Form, the person with the fuel handling tool will request permission to move the fuel element. Example: "Request permission to move fuel element F1 from grid position D7 to rack storage R10".

5. With the Control Room Operator's approval, latch the fuel element with the handling tool. Announce, "Tool latched".

6. The Control Room Operator will then grant permission to remove the fuel element from the core.

7. Withdraw the assembly from the core. When the fuel handling tool and attached element have cleared the core grid plate, announce, "Element clear".

8. Move the element to the fuel storage end of the pool.

9. Rotate the fuel element 180° so that the bow of the fuel element remains toward the center of the pool.

10. Insert the fuel element into the designated location and check to ensure that it is properly seated in the fuel rack. Announce "Element seated".

11. Unlatch the fuel handling tool.

12. The Control Room Operator shall log the fuel movement in the permanent log book.

13. Transfer the element identification tag from the core status board to the fuel storage status board.

14. Repeat Steps 4 through 13 to remove additional elements from the core.

15. Lock the fuel handling tool in its holder and return the key to the safe.

16. Complete the necessary information on the Transfer Order form.

17. Perform a Reactor Secured Checklist (SOP 105) as appropriate.

II. Unloading of Control Rod Fuel Elements from the Core to the Fuel Storage Rack.

1. Unload fuel elements from the core (per Section I of this procedure) such that the core loading is below one-half of a critical mass. A single control rod fuel assembly may be removed from the core with this loading.

2. Unload all of the fuel elements from the core if two or more control rod fuel elements are to be removed.

3. Disconnect and uncouple the control rod drive, shroud and magnet extension.

4. Remove the shroud and magnet extension from the control rod element.

5. Remove the control rod from the element, if desired.

6. To unload, complete Steps 3 through 17 of Section I of this procedure.

Note: The control rod fuel element may be transferred to an appropriate "basket" to facilitate easy movement within the pool.

III. Loading of Fuel Elements from the Fuel Storage Rack to the Core

1. The Control Room Operator must comply with SOP 312 (Approach to Critical) during the loading of the core. The Control Room Operator will be responsible for collecting the necessary data, constructing the 1/M plot and instructing fuel handlers as to assemblies that may be loaded.

2. All control rod fuel elements and control rods must be installed in the core per Section IV prior to the loading of any fuel element.

3. Control rod drop times must be completed per SOP 813 on all rods of control assemblies that have been moved or that have had their magnet assemblies removed and reinstalled prior to the loading of any fuel element.

4. Complete Steps 1, 2, and 3 from Section I of this procedure.

5. In accordance with the Transfer Order Form, the person with the fuel handling tool will request permission to move the fuel element. (Example "Request permission to move fuel element Fl from storage rack RlO to grid position D7.")

6. With Control Room Operator approval, latch and remove the fuel element from the storage rack, transport the element to the edge of the core grid plate and announce, "Approaching core".

7. Wait for the Control Room Operator's approval prior to movement into the core area. Following the Control Room Operator's approval, place the fuel element in the core. The fuel element must be rotated 180° so that the bow of fuel points to center of pool.

8. When the element is seated, announce, "Element seated". Do not unlatch the fuel. Be prepared to immediately remove the fuel element from the core if instructed by the Control Room Operator.

9. With Control Room Operator approval, unlatch the element and move the tool clear of the core area. Announce, "Tool clear".

10. The Control Room Operator shall log the fuel movement in the permanent log.

11. Transfer the identification tag for the element from the fuel storage status board to the core status board.

12. To load additional fuel elements, repeat Steps 5 through 12 as instructed by the Control Room Operator.

13. When loading is complete, complete Steps 15, 16, and 17 of Section I of this procedure.

IV. Loading Control Rod Fuel Elements from the Fuel Storage Rack to the Core.

1. Complete a Pre-Startup Checklist to the extent possible. The 2 cps interlock may need to be bypassed by an SRO and other steps such as dropping rods may be omitted when no control rods are loaded in the core.

2. Load all of the control rod fuel elements in accordance with Steps 5 through 12 in Section III.

3. Insert control rods and reassemble the drive mechanisms.

4. Check the withdraw and insert control, observe the rod position indication, and ensure proper operation of the control rod drive system.

5. Perform Rod Drop Times (SOP 813) on all rod assemblies that have been moved or whose magnet assemblies have been removed and reinstalled.

6. If fuel loading is to continue go to section III of this procedure, otherwise complete Steps 15, 16, and 17 of Section I of this procedure.

TRANSFER ORDER FORM

Description of Fuel Movement ______________________________
Loading Number ______________________________

ELEMENT ID	FROM	TO	COMMENTS

Authorized by ________________ Accomplished by 1 ____________
(Reactor Manager or Director) 2 ____________

Date ________________ Date completed ____________

Rev

MSTR CORE AND RACK STORAGE FORM

DATE ________________ LOADING NUMBER ________

R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14	R15

RACK STORAGE FACILITY

R16	R17	R18	R19	R20	R21	R22	R23	R24	R25	R26	R27	R28	R29	R30

A									
B									
C									
D									
E									
F									
	1	2	3	4	5	6	7	8	9

Core Excess Reactivity ________________
Shut-Down Margin ____________________
Rod Worths
Rod 1: ________ Rod 3: _________
Rod 2: ________ Reg Rod: _______

MSTR CORE STATUS

Rev

Elem.	U-235 Mass	Elem.	U-235 Mass	Elem.	U-235 Mass

Total U-235 Mass (Grams) ___________

Review and Approval: ____

(Reactor Director or Manager)

A. PURPOSE

The purpose of this procedure is to provide guidance for calculating the radioactivity and reactivity.

B. PRECAUTIONS, PREREQUISITES, OR LIMITATIONS

1. SOP 702, "Request for Irradiation" specifies when this procedure is to be used.

2. Values obtained using these procedure are to be considered approximate.

C. PROCEDURE

1. Calculation of Activity

$$\text{Act}\left(\frac{\text{dis}}{\text{sec}}\right) = \frac{a\times m\times NA}{AW}\times\sigma_a\times\emptyset\times\left(1-e^{\frac{-0.639t}{T_{1/2}}}\right) \quad \text{(eq. 1)}$$

where

m = Mass of the element to be irradiated (grams)
a = Isotopic abundance of the element
NA = Avogadro's Number ($6.02\text{x}10^{23}$ atoms/mole)
AW = Isotopic weight (grams/mole)
σ_a = Isotopic activation cross-section (cm^2)
Φ = Neutron flux (n/cm^2 -sec)
$T_{1/2}$ = Half life of the produced radioisotope (min)
t = Irradiation time (min)

Sample Calculation:

A 0.0985 gm sample of Al^{27} is to be irradiated in a flux of $5\text{x}10^{10}$ n/cm^2-sec. What is the activity after 5 min. of irradiation? ($\sigma_a = 0.241b = 0.241\text{x}10^{-24}$ cm^2, $T_{1/2} = 2.24$ min, $3.7\text{x}10^7$ dis/sec = 1 mCi)

Revised by: William Bonzer

Approved By: William Bonzer

$$\text{Act} = \frac{1\times 0.0985\times 6.02\times 10^{23}}{27}(0.214\times 10^{-24})(5\times 10^{10})$$

$$1 - e^{\frac{-(0.693)(5)}{2.24}} = 2.08\times 10^{7}\, dis/sec = 0.56\text{ mCi}$$

2. Calculation of Reactivity Worth of a Sample

The reactivity worth of a sample ρ_s when placed in the neutron flux Φ_s can be calculated by comparing it to the reactivity worth ρ_a of a known absorber placed in the neutron flux Φ_a using the following formula

$$\rho_s = \rho_a \times \frac{\sigma_s}{\sigma_a} \times \frac{m_s}{m_a} \times \frac{AW_a}{AW_s} \times \left(\frac{\emptyset_s}{\emptyset_a}\right)^2 \qquad \text{(eq.2)}$$

where

σ = Microscopic absorption cross-section (barns)
m = Mass (grams)
AW = Isotopic weight (grams/mole)
Φ = Neutron thermal flux (n/cm^2-sec)

Subscripts "s" and "a" refer to the sample and known absorber respectively.

Using data from a reactivity experiment with a piece of indium absorber placed in the various positions of the row D at the reactor power of 20W the eq. (2) can be simplified to

$$\rho_s = 1.4\times 10^{-21} \times \frac{\sigma_s m_s}{AW_s} \times \emptyset_s^2 \times \text{abundance of Isotope} \qquad \text{(eq. 3)}$$

(Note: The value of the neutron flux Φ_s must correspond to the reactor power of 20 W.)

Sample Calculation:

A 2.0 gm sample of A1-27 (σ_s = 0.241 barns) is to be irradiated in a flux of 2.6x10^{10} n/cm^2 sec. at 2 kW. What is the expected reactivity worth?

Revised by: William Bonzer

William Bonzer

Approved By: William Bonzer

William Bonzer

$$\rho = 1.4 \times 10^{-21} \times \frac{0.241 \times 2.0}{27} \times \left(2.6 \times 10^{10} \times \frac{20}{2000}\right)^2$$

$= 1.7 \times 10^{-6}\ \Delta k/k$

3. Calculation of Reactivity Worth of a Void

When a void is placed in or near the reactor core a change in reactivity can be expected. This is due to the void coefficient of reactivity. A void itself will add negative reactivity to the reactor, but the greatest concern is the removal or collapse of a void which will add positive reactivity.

The void coefficient measured at the core periphery is $-10^{-6}\ \Delta k/k/cm^3$.

Sample Calculation:

A sample will be placed next to the core in an empty 250 ml bottle. What is change in reactivity due to the void?

$\rho = 250\ cm^3\ (10^{-6}\ \Delta k/k/cm^3) = 2.5 \times 10^{-4}\ \Delta k/k.$

Revised by: William Bonzer

William Bonzer

Approved By: William Bonzer

William Bonzer

A. PURPOSE

The purpose of this SOP is to ensure that power is restored to equipment in a safe and efficient manner following a trip of unregulated and/or regulated power and to prevent damage to the equipment.

B. PRECAUTIONS, PREREQUISITES, OR LIMITATIONS

1. Personnel restoring unregulated and/or regulated power should be familiar with the operation of the equipment affected.

2. A weekly check should be performed before operating the reactor at a power higher than 20 kW following a loss and restoration of power.

3. Any malfunctions or abnormality of equipment should be immediately reported to the SRO on Duty. | Rev

C. PROCEDURES

1. Reset the unregulated and regulated power supplies, which are located in the equipment room behind the console panel.

2. All annunciator lights and buzzer may be on. | Rev

3. Push the annunciator acknowledge button to silence the buzzer.

4. Reset the Linear power supply located in the control room. (Note: The power supply must warm up for several minutes before it will reset. | Rev

5. Press the annunciator panel reset button. The annunciator should now indicate a normal situation. (Note: A normal situation is indicated by all lights being extinguished, except Manual Scram, Recorder Off and Manual Operation.) | Rev

Written By: William Bonzer
William Bonzer

Approved By: William Bonzer
William Bonzer

6. Notify the SRO on Duty of the power outage or tag the console to assure a weekly check is completed prior to reactor runs exceeding 20 kW.

7. Start the demineralizer pump by pushing its "Start" button. (Note: The start button is located on the intermediate level, on the wall behind the pump. Rev

Written By: William Bonzer

William Bonzer

Approved By: William Bonzer

William Bonzer

A. REACTIVITY REQUIREMENTS

Any individual experiment involving a worth of more than 0.4% reactivity will be installed in the partially unloaded core and the reactor brought to power by a critical experiment. No single independent experiment worth more than 0.7% will be installed in the reactor.

B. PROCEDURE

When a new configuration of fuel elements for a new core position is to be used in the reactor, source multiplication in the core will be measured after each element is added. The data obtained will be plotted (as it is obtained) to allow prediction of the point at which the reactor will go critical. In the case where a large sample or experiment is to be positioned in or near the core, the reactor will be unloaded, the sample or experiment positioned, and the same procedure used to approach criticality. The steps in the procedure are as follows:

1. A calculation of the critical mass of the projected loading will be made.

2. The control rod fuel elements and rod drives will be installed in the desired positions.

3. The reactor checkout procedure will be carried out, as for a reactor start-up. Note that during the initial stages of the experiment, it will be necessary to bypass the 2 cps interlock. This will be under direct supervision of the SRO in charge of the critical experiment.

4. The rods and reg rod will be raised to the Shim Range.

5. A neutron source will be installed and approximately 50% of the critical mass calculated in step (1) will be loaded, with constant surveillance of the count rate. Whenever fuel elements are loaded or unloaded, fuel element numbers and positions will be carefully recorded both in the log book and on the loading chart. At this point, the count rate in the fission chamber channel will be determined using the scaler, to give a measure of the source multiplication.

William Bonzer William Bonzer

6. The rods then will be fully withdrawn and another count made. Then the rods will be driven back to Shim Range.

7. One additional fuel element will be loaded, and the measurements of steps (5) and (6) repeated. This data will be plotted to give the "Subcritical Multiplication Curve" as soon as it is obtained, before any further loading is done. The curve obtained from plotting the data taken with the rods fully withdrawn gives an indication of when it will be possible to make the reactor critical by withdrawing rods. The data taken with the rods at Shim Range gives a curve which indicates the possibility of going critical during the actual loading operation.

8. Step (7) will be repeated until the reactor goes critical at which point rod positions will be recorded. If the reactor goes critical without sufficient excess reactivity for operational use, the loading will be continued in half-element increments using the Shim Range Subcritical Multiplication Curve to ensure the criticality is not reached during loading of an element. This completes the critical experiment and at this point, a new core configuration will be designated. At the completion of the experiment, fuel handling tools will be locked and the plots of the data obtained and the loading chart will be attached to a page in the log book of core loadings. The person loading fuel will maintain a position which will allow instant reversal of motion of the fuel element if the operator at the console orders it. The loader will maintain positive control over the fuel element until the operator specifically gives permission to release it.

C. PLOTTING DATA

1. Select loading chart as illustrated in Figure 1 and record data on loading chart and in log book as critical experiment progresses.

2. Prepare graph as illustrated in Figure 2.

3. In step B-5 of this procedure, the initial 50% loading and rod position count will be at the base count rate C_0.

4. Beyond this point the various counts at Shim Range and fully withdrawn rod positions when loading elements will be designated as C_t.

5. At each element addition (when Shim Range and fully withdrawn count is made) the subcritical multiplication M will be:

$$M = \frac{C_t}{C_0} \qquad \frac{1}{M} = \frac{C_o}{C_t}$$

where C_0 remains constant and C_t will vary for each counting condition.

6. The value of 1/M shall then be plotted on the curve vs. the number of elements added for Shim Range (Δ) and fully withdrawn rod positioned (0).

D. <u>LOADING NUMBERING SYSTEM</u>

The system for designating a loading will be as follows:

1. Each new core configuration will be designated by a number which will be the successive number following the last loading.

2. A loading diagram will be made out and stapled in the log book of core loadings for each loading.

Transfer Order Form

Sheet _________ of ________ No. ______________

Loading No. ______________

Move Elem. No.	From	To	Remarks

Authorized by __________________________ Accomplished by 1 _______________

Date __________________________ 2 _______________

Date, time completed _______________

Figure 1 _______________

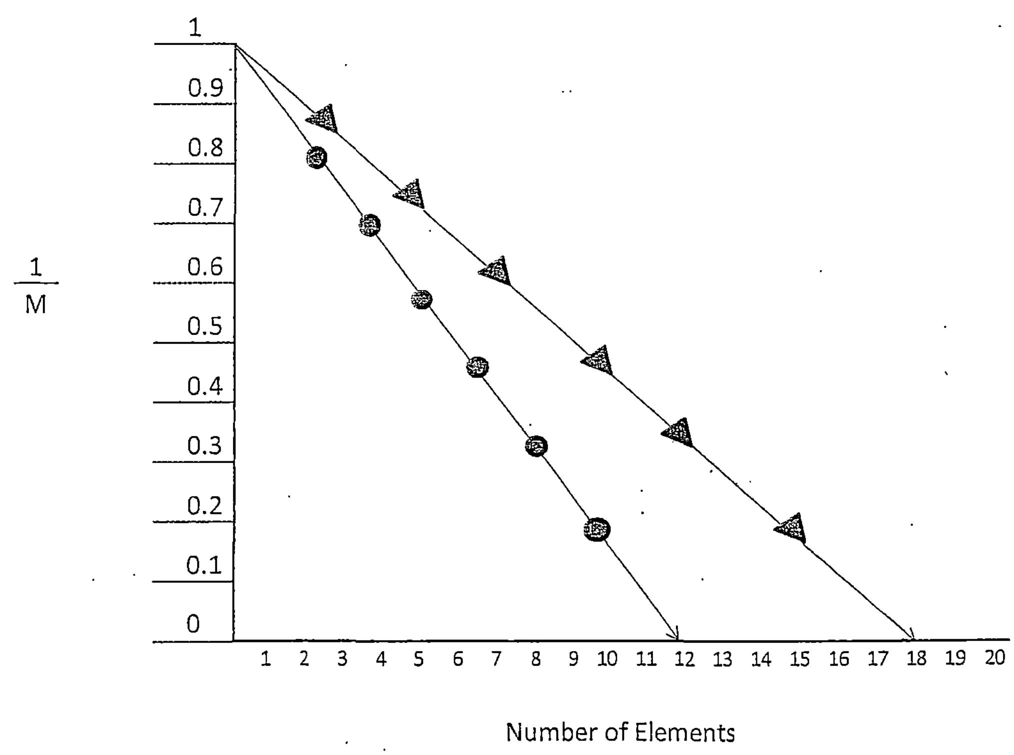
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1/M
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Number of Elements

Figure 2

Rev

MISSOURI S&T EMERGENCY PHONE LIST

Reactor Staff	CELL	HOME	WORK
William Bonzer, Manager, SRO	578-9463	368-0318	341-4384
Craig Reisner, Senior Reactor Operator	573-247-7557	573-729-7277	341-4291
Anthony Alchin, Electronics Technician III	816-274-1771		341-6617
Maureen Henry, Office Support Ast. III	201-7275		341-6016

Rev

University Administrative Staff			
Michelle Bresnahan, EHS Director, Radiation Safety Officer	314-239-7751		341-4305
Raymon Bogart Interim,Director Missouri S&T Police	201-5885	426-5815	341-4300
Dr.Cheryl B. Schrader, Chancellor	201-7392	341-7141	341-4116
Walter Branson, VC Chancellor Finance & Adm.	260-402-0317		341-4122
James Packard, Director Physical Facilities		578-8167	341-4252
Dr. Goodman DO, Director Student Health Services			341-4284
Dr.Hyoung Lee,Chair of Nuclear Eng, Reactor Director	573-202-4665		341-4585
Dr.Ralph Flori Jr, Interim Chair of Mining and Nuclear	578 -3130		341-7583
Fadha Ahmed, Health Physicist EHS-Missouri S&T	314-960-9211	636-223-2054	341-7014

Rev

Local	
Missouri S&T Police	341-4300
Rolla City Police	**911**
Rolla Fire Department	**911**
Phelps County Hospital	**911**
Rolla Emergency Management Agency	**911**

State Agencies		
Missouri Highway Patrol		**(573) 368-2345**
Missouri State Emergency Mgt. (24 hr.)		**(573) 751-2748**
Missouri Dept. of Natural Resources (24 hr.)		**(573) 634-2436**
Missouri Bureau of Environmental Epidemiology	**(573) 751-6160**	**(573) 751-4674 (24hrs)**

Federal Agencies	
NRC, Operations Center	**(301) 951-0550**
NRC Duty Officer (24 hr.)	**(301) 816-5100**

Other		
American Nuclear Insurers		**(860) 682-1301**
Radiation Emergency Assistance Center	**(865) 576-3131**	**(865) 576-1005 (24hrs)**

Revised By: Maureen Henry

Maureen Henry

Approved: William Bonzer

William Bonzer

A. PURPOSE

To ensure the integrity and encapsulation of sealed sources and to guard against contamination of personnel.

B. PRECAUTIONS, PREREQUISITES, OR LIMITATIONS

1. This procedure is to be performed by Health Physics staff personnel.

2. The following sources located at the reactor facility are to be leak tested semi-annually: PuBe S/N M-1092 (Reactor Startup Source), PuBe S/N M-169 (RAM Calibration Source), Cs-137 S/N 74-156 (RAM Calibration Source). The Cs 137 source is located in the JL Shepherd Shield SN5409. Rev

3. Leak test requirements are listed in item 14 (A through F) of NRC Materials License number 24-00513-40.

C. PROCEDURE

1. The leak test should be performed with filter-paper discs or with cotton-tipped applicators depending upon the source activity, configuration, and containment.

2. The source, source holder, and immediately surrounding area should be rubbed firmly with the swipes held with tongs or forceps or with cotton-tipped applicators in order to remove any surface contamination that may be present. If access to the sealed source is prevented by the construction of the device, the swipes should be taken as near the source as possible.

3. Each swipe or applicator should be placed in a separate envelope appropriately labeled for identification.

4. Frisk the swipes with an open window G-M probe. If any detectable activity is observed above background, contact the Reactor Health Physicist for appropriate approvals before removing the swipe from the facility. If no detectable activity is identified, the swipes may be removed from the facility for counting at the Health Physics office.

Revised By: William Bonzer Approved By: William Bonzer

William Bonzer William Bonzer

5. Evaluation of swipes taken from sealed sources containing a beta-gamma emitter should be made with shielded, end-window, Geiger-Mueller counter or equivalent. Evaluation of swipes taken from sealed sources containing an alpha emitter should be made with a gas-flow proportional counter or equivalent.

6. If the results of the test indicate a removable contamination in excess of 0.005 microcuries, the following steps shall be taken:

   a. The source is to be taken from service immediately and held in secured storage until it can be decontaminated.

   b. Notify the Reactor Manager.

   c. File a report with the NRC that contains the information required by section 14.E of the Materials License.

Revised By: William Bonzer
William Bonzer

Approved By: William Bonzer
William Bonzer

A. PURPOSE

To provide for the thorough Reactor Staff review of all experiments to be irradiated by neutrons from the MSTR. The review evaluates potential 1) reactivity effects, 2) dose hazards to the experimenter, and 3) hazards to the reactor. Rev

B. PRECAUTIONS, PREREQUISITES OR LIMITATIONS

1. All sample irradiations must be performed under an approved Irradiation Request Form (IRF) with two approval signatures.

2. All materials to be irradiated are to either be corrosion resistant or encapsulated in corrosion resistant containers.

3. Approved IRFs remain valid for future irradiations.

4. IRFs will be numbered sequentially following the last two digits of the current year (e.g. 95-1, 95-2, etc.).

5. Radiation Safety Committee approval is required for

    a. experiments worth more than 0.4% Δk/k,
    b. explosive materials,
    c. fueled experiments, or
    d. untried experiments.

6. The total reactivity worth of all experiments is limited to 1.2% Δk/k.

7. Experiments having moving parts shall not have an insertion rate greater than 0.05% Δk/k per second.

8. Cooling is to be provided as needed to prevent the surface temperature of an experiment being irradiated from exceeding the boiling point of the pool.

C. PROCEDURE - IRRADIATION REQUEST FORM

The IRF should be completed according to the following steps:

1. **IRRADIATION REQUEST** - This section of the IRF should be completed by the experimenter.

   a. **Sample Description** - Describe the sample material to be irradiated (e.g. dried tobacco leaves, powdered milk, gold foil, etc.)

   b. **Physical Form** - Specify the physical form of the sample material (e.g, powder, ash, liquid, etc).

   c. **Encapsulation** - Check the box marked "Poly-vial" or check "other" and describe.

   d. **Irradiation Location** - Specify the irradiation facility to be used. More than one facility may be authorized on a single IRF. If "Other" is specified, describe the irradiation location (for example: "wire stringer in Grid Position C-3").

   e. **Irradiation Limits** - Specify the irradiation limits as follows:

      1) **Power** - Specify the maximum reactor power for irradiation. Samples may **NOT** be irradiated at powers higher than specified.

      2) **Time** - Specify the irradiation time for the sample(s) at the maximum power. Samples may be irradiated at lower powers for times longer than the specified irradiation time as long as the total fluence (i.e. kW-hrs) does not exceed the product of the specified maximum power and irradiation time.

      3) **Mass** - Specify the maximum sample mass (grams) to be irradiated in any single irradiation.
      Handwritten revisions to the limits are allowed based on the measure dose rate from the initial irradiation(s).

Assume dose rate is a linear function of power, irradiation time, and sample mass. Revised irradiation limits require the review and approval of either the SRO on Duty, Reactor Manager, or Reactor Director as signified by their initials with dates.

f. **Expected Dose Rate** - Specify the expected 1 foot dose rate when the sample comes out of the reactor based on one of the categories below:

Experience - The expected dose rate may be based on measurements made during previous similar irradiations. In such instances, record the IRF number of the previous similar irradiation.

Calculations - The expected dose rate may be calculated using the DR=6CE rule (or other appropriate method) where DR is the 1 foot dose rate in mrem/hr, C is the expected activity in mCi, and E is the gamma energy in MeV. The expected activity can be calculated using $A = N\sigma\phi(1 - e^{-\lambda t_{irr}})$ where N is the number of target atoms, σ is the cross section, φ is the neutron flux, λ is the decay constant and t_{irr} is the irradiation time.

Completely Unknown - A trial irradiation is required if the expected dose rate is completely unknown. The irradiation limits for a trial irradiation are normally reactor power $\leq$ 2 kW, irradiation time $\leq$ 1 minute, and sample mass $\leq$ 1 gram. The reviewers may approve different trial irradiation limits at their discretion. Dose rates for higher powers, masses and times can then be linearly extrapolated based on the measured dose rate resulting from the trial irradiation.

g. **Reactivity Worth** - Estimate the reactivity worth of the sample based on one of the categories below:

Default - A default reactivity worth of <0.05% $\Delta k/k$ may be used for the rabbit facilities if the sample mass is less than 7 grams. A default reactivity worth for core periphery stringers of <0.1% $\Delta k/k$ may be used for holders with a volume of 35 cm^3 or less and a sample mass of 7 grams or less. (Note: The default mass and location values are based on a report by Wagner, 1992.) Beamport and thermal column irradiations have a default reactivity of 0.0%.

Experience - The estimated reactivity worth based on previous "experience" may be specified along with the applicable IRF number. If no previous experience exists, estimate the reactivity worth using SOP 306. | Rev

Completely Unknown - If reactivity worth is completely unknown and not easily calculated, it must be experimentally determined.

h. **Comments** - Provide additional comments, if any.

i. **Request Completed By** - The person completing items **a** through **h** above should sign their name in the blank provided.

2. **REVIEW AND APPROVAL** - This portion of the IRF is to be completed by one of the reviewers and approved by both of the reviewers.

a. **Analysis of Potential Hazards** - Reviewers shall analyze potential hazards associated with the experiment with regard to following:

1. **Reactivity** - Review the expected reactivity worth information. Assure that the Technical Specification Section 3.7 requirements are met. Check the box marked "None" or "Other" as appropriate. If "Other" is specified, explain.

2. **Dose Rate** - Review the expected dose rate information and assess potential dose rate hazards. Check the box marked "None" or "Other" as appropriate. If "Other" is specified, explain.

3. **Reactor Equipment** - Verify that no corrosion problems exist. Verify that no explosive materials or fueled experiments are to be irradiated without Radiation Safety Committee approval. Verify that proper provisions for cooling have been made. Evaluate the experiment with respect to potential hazards to the reactor or reactor operations (for example, detector "shadowing"). Check the box marked "None" or "Other" as appropriate. If "Other" is specified, explain.

4. **Other** - Evaluate the experiment for any other types of conceivable hazards to personnel or equipment.

b. **Additional Restrictions/Requirements** - The reviewers are to specify any additional restrictions or requirements deemed appropriate.

c. **Approvals** - Reviewers shall signify approval of the experiment by signing and dating in the appropriate blank. Two signatures are required from either the Director, Manager, SROs, or the Health Physicist.

D. PROCEDURE - SAMPLE IRRADIATION LOG

A Sample Irradiation Log will accompany each IRF to document sample irradiation information. An entry shall be made on the Sample Irradiation Log for each sample irradiated.

1. **Date** - Specify the date of the sample irradiation.

2. **Sample ID** - Specify the sample identification number or name.

3. **Experimenter's Name** - Provide the name of the experimenter responsible for the sample.

4. **Location** - Specify the irradiation location.

5. **Power** - Specify the power level at which the irradiation is performed.

6. **Time In** - Specify the console time at which the irradiation began.

7. **Time Out** - Specify the console time at which the irradiation ended.

8. **Total Time** - Specify the total time of the irradiation.

9. **Dose Rate @ 1 foot** - Record the 1 foot dose rate from the sample at the time of initial sample handling.

10. **Decay Time** - Specify the approximate decay time between the end of the irradiation and the time of the dose rate measurement.

11. **Initials** - Either the console operator (licensed operator, student, or trainee) or the experimenter will provide their initials signifying that sample irradiation information is complete.

IRRADIATION REQUEST FORM

IRF # ______

1. IRRADIATION REQUEST

a. Sample Description: ____
____

b. Physical Form: ______________ c. Encapsulation () Poly-Vial () Other ______________

d. Irradiation Location: () Bare Rabbit () Cad Rabbit () Beam Port () Thermal Column
() Other ______________

e. Irradiation Limits: 1) Power: __________ 2) Time: __________ 3) Mass: __________ gm

f. Expected 1 Foot Dose Rate: __________ mrem/hr Based on: () experience (IRF# ________)
() calculations (attached)
() completely unknown

g. Expected Reactivity Worth: ________ % k/k Based on: () default
() experience (IRF# ________)
() SOP 306 calculations (attached)
() completely unknown

h. Comments: ____
____

i. Request Completed By: ______________________________

2. REVIEW AND APPROVAL

a. Analysis of Potential Hazards:

1. Reactivity () None () Other ______________
2. Dose Rate () None () Other ______________
3. Reactor Equipment () None () Other ______________
4. Other () None () Other ______________

b. Additional Restrictions/Requirements ______________________________
____
____
____

c. Irradiation Request Reviewed and Approved (two signatures required):

Director ______________ Date ________, Manager ______________ Date ________
SRO ______________ Date ________, SRO ______________ Date ________
Health Physicist ______________ Date ________

SAMPLE IRRADIATION LOG

Page #_______

Date	Sample ID	Experimenter's Name	Irradiation Information					Dose Rate @ 1 ft (mR/hR)	Decay Time (Approx.)	Initials
			Location	Power	Time In	Time Out	Total Time			

A. PURPOSE

To provide a consistent method for checking the calibration of the Log and Linear drawer which includes Log N, Period, and Power Range.

B. PRECAUTIONS, PREREQUISITES AND LIMITATIONS

1. This procedure is to be performed annually. | Rev
2. A second knowledgeable person shall check all cable connections that have been broken and reconnected.
3. Refer to Section 1, "Log and Linear Drawer Calibration" of the Annual Checklist (SOP 800) for forms to document this procedure. | Rev

C. PROCEDURES

a. Open the housings of both the Log and Linear drawer and the Log/Period recorders and clean as necessary. Pay particular attention to assure air vents are clear.

b. 80% High Voltage Rundown

1. Obtain the magnet key from the SRO on duty and have a Licensed Operator raise shim rods 3 inches.
2. Adjust A4R4, on the high voltage card A4, to the lower voltage that will cause the Low CIC Voltage Rundown trip to occur.
3. Record the voltage at A4TP1 where the trip had occurred. (200 times the voltage at A4TP1 equals the desired HV)
4. Verify receipt of the visual and audible alarms for Low CIC Voltage. Verify that a rod rundown is initiated.
5. Adjust A4R4 to 540V. (200 times the voltage at A4TPT equals the desired HV)
6. Reset the annunciator panel.
7. Remove the magnet key from the console and return it to the SRO on Duty.

Revised By: William Bonzer

William Bonzer

Approved By: William Bonzer

William Bonzer

c. 120% Full Power Rundown

1. Disconnect the 3 detector cables (signal, HV, and CV) at the drawer.
2. Connect the Keithley 263 pico-amp source to J5 of the Log and Linear drawer. Adjust current to 100% full power. | Rev
3. Reset annunciator panel.
4. Obtain the magnet key from the SRO on Duty and have a Licensed Operator raise shim rods 3 inches.
5. Slowly increase current to obtain a reading of 120%.
6. Observe from the Linear Power Range digital display when the 120% rundown occurs. | Rev
7. Observe the 120% Full Power rundown and annunciator. Record values.
8. Reset the annunciator panel.
9. Remove the magnet key from the console and return it to the SRO on Duty.

d. **Log and Linear Detector/Cable Check** - Discharge each cable through a multimeter by connecting the meter probes to the outer shield and center conductor. Use the highest voltage scale and observe the voltage decline to 0 volts. Measure the resistance of the detector cable with an electrometer at 1000 VDC. Record the results. The cables should read about 10^{10} ohms. Again discharge the cables with the multimeter.

e. **Drawer Alignment** - Perform the steps in Section 4.3.1, "Low Voltage Power Supplies" from the Log and Linear drawer equipment manual.

High Voltage/Compensating Voltage Check

1. Measure HV at J6.
2. Adjust A4R4 as needed to measure 540 VDC.
3. Adjust A4R4 to a lower voltage until the non-operate LED turns on and the Low CIC Annunciator panel alarms.
4. Record the HV at J6 that the trip occurred at.
5. Record the voltage measured from A4TP10-A4TP1.
6. Verify that the keypad non-operate switch LED illuminates. Record the results.
7. Adjust A4R4 to measure 540 VDC at J6.
8. Reset annunciator panel.
9. Verify and record the non-operate keypad switch LED goes off.
10. Record the HV at J6. The high voltage at J6 should be 540 VDC ± 1 V.

11. Record the voltage measured from A4TP10-A4TP1.
12. If the Low CIC Voltage trip point needs to be adjusted follow the Log and Linear equipment manual steps 4.3.2.1 and 4.3.2.2.
13. Measure compensating voltage at J7. Adjust A5R4 to 5.8 V as needed.
14. Record compensating voltage level at J7. The compensating voltage should be 5.8 VDC ± 1 V.
15. Record voltage at A5TP10-A5TP1.

Log Amplifier Alignment

1. Connect the Keithley 263 pico-amp source to J5 of the Long and Linear drawer. Use the readings from the Keithley 263 pico-amp source for the current settings. Rev
2. Complete in the Log Displays Table of SOP 800 for the listed current levels.
3. If alignment is necessary follow steps 4.3.3.1-9 of the Log and Linear equipment manual. Repeat Step 3 following any adjustment in alignment.

Period Alignment

1. Perform Section 4.3.4, "Period Amplifier" in the Log and Linear drawer equipment manual. These adjustments determine the accuracy of the period. When performing these steps, the following guidance should be used.
   a. Set the oscilloscope to read 50 mV/cm (DC mode) and 0.2 sec/cm.
   b. Use the single sweep display mode with internal triggering.
   c. Save the ramp using the "save mode". After the ramp has been saved, use the cursor feature to automatically read the voltage change for a time span of about 1 second. (Note: The cursor feature provides a more accurate measurement than manually reading the scope.)
2. Complete the Period Displays Table on the Annual Checklist.

Linear Amplifier Alignment

1. Use the Keithley 263 pico-amp source connected to the Log and Linear drawer at J5. | Rev
2. Connect the voltage meter to ATP10-ATP1.
3. Apply the currents listed in the Linear Displays Table of SOP 800 and record the displayed readings.
4. If the Linear Amplifier circuit needs aligned, follow steps 4.3.5.1-3 of the Log and Linear equipment manual.

f. Isolated Outputs - Adjust the zero and span on each isolator, as necessary, for equal inputs and outputs.

g. Keypad Switches - Fill out the Keypad Switch Table by depressing the indicated switch and recording the associated readings.

h. Discharge the detector cables at the connectors and the corresponding jacks at the drawer. Reconnect the detector HV, CV, and signal cables. Have an independent knowledgeable person verify cables are properly connected.

i. The person that performed this calibration procedure shall initial and date that the calibration has been properly completed.

 Re

A. **PURPOSE**

To ensure that the fire and smoke alarm system is operable during annual calibrations. Re

B. **PROCEDURE**

1. Inform Missouri S&T Police of fire alarm system test.

2. Test emergency power by turning circuit breaker No. 32 in the power panel off.

3. If alarm sounds, replace power supply batteries in the battery box and repeat test.

4. Check at least one (1) sensor, such as pull station in front office, to insure the system will operate.

5. Turn circuit breaker No. 32 on.

6. Using a heat and smoke source, check each smoke detector by placing the source close to each detector. Acknowledge alarm condition at master station for all detectors. Re

7. Remove cover of each pull station by turning the top screw and pull the inside lever of each of the two (2) pull stations. Acknowledge alarm condition at master station.

8. Use Test Filter 6424 Projected Beam Detector sheet in front of the Beam Detector. Acknowledge alarm condition at master station.

9. Ensure all alarm conditions are cleared.

Note: Acknowledgment of alarm will consist of verification of audible and visual alarms and resetting by pressing Signal Silence and Reset/Lamp Test buttons at master station.

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A. PURPOSE

To ensure that the power indicated on the linear and log channels is the power generated in the reactor.

B. PRECAUTIONS, PREREQUISITES, OR LIMITATIONS

1. In accordance with Technical Specification 4.2.2(3) all console instruments and safety system shall be calibrated once each year, not to exceed 15 months. Rev

2. The power generation in the Missouri S&T Reactor is limited by Technical Specifications to 200 kW. Rev It is, therefore, important that the reactor power is less or, in an ideal case, equal to the power indicated in the reactor control room. The calibration of the power instruments is performed by the calibration procedure described below. (For more details see the report MSTR/85-i.) Stable Rev atmospheric conditions are helpful for a successful calibration.

C. PROCEDURE

1. Turn on both nitrogen diffusers and the pool lights.

2. Set up pool level measuring equipment. It is recommended that two gauges be used in order to have redundant measurements. (Minimum recommended scale division is 0.001 inches.)

3. After the diffusers have been on for at least 30 minutes start to take level readings every 15 minutes. Continue for at least one hour prior to the reactor startup to determine the average pool level drop. Be sure to note accurately the time of each reading. Record also the temperature of the pool water inlet thermocouples. Rev

4. Take the reactor to some intermediate power level, e.g. 20, 30, or 40 kW. Note the time the reactor reaches that power level. After running the reactor at this power for a time t_p such that the reactor thermal output is between 30 and 50 kW hr. shut down the reactor and note the shutdown time. For example, it is recommended that the reactor power be chosen 40 kW and the operational time t_p 1 hr.

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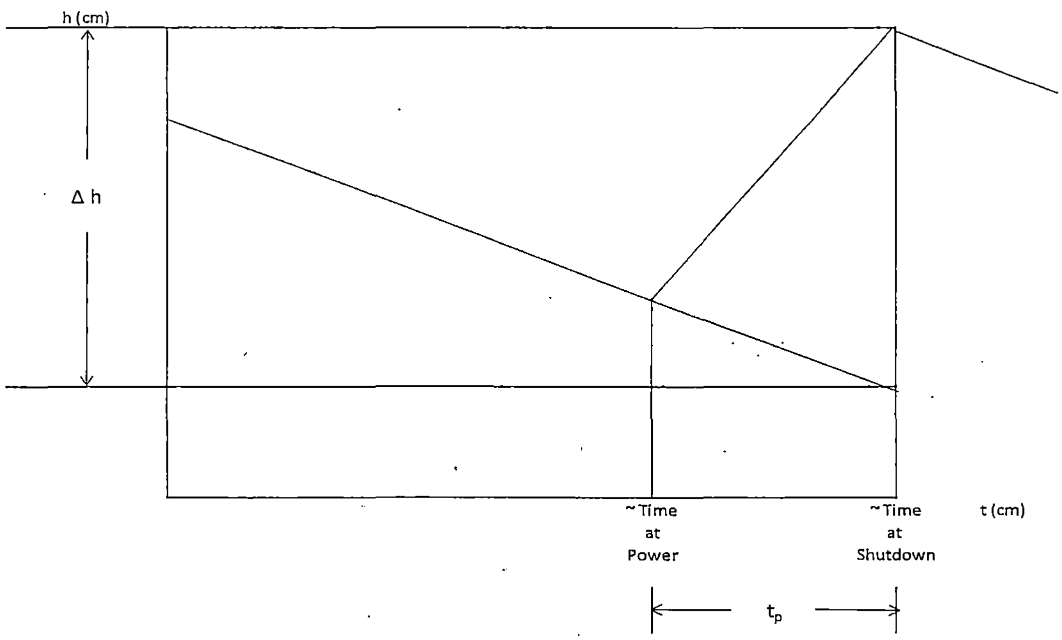
5. Once all control rods and magnets are fully inserted, note time and pool level every 15 minutes until level decreases equal the rate of decrease before the power run. During this time also continue to take temperature readings using all reactor thermocouples.

6. Plot the data measured with both relative height gauges such as to construct the time-dependent plot of h, i.e. the relative change in height of the pool water surface before, during, and after the power run. (Use units of cm for the plot of h.)

7. Determine Δ h as shown in the sketch below



8. Calculate the average pool water temperature T_W using the data taken immediately before the beginning of the power run and after the reactor shutdown. (Use only the inlet temperature readings.)

9. Using Figure 1 and data determined in step 7 and 8 determine the amount of heat Q generated in the reactor during the calibration run. (The fact that the coefficient

of the thermal volumetric expansion is to be taken at the temperature which is 1 K higher than the average pool temperature has already been taken into account while constructing the plot in Figure 1.)

10. Calculate the reactor power using the relationship

$$P\ [kW] = \frac{Q\ [kW\ hr]}{t_p\ [hr]}$$

11. It the power indicated on the linear and/or Log N recorder is equal to or greater than the calculated power P by not more than 5% no further action is needed. In any other case the position of the pertinent neutron detector needs to be adjusted so as to satisfy the above condition.

12. After both power channels (linear and log) have been properly adjusted take the reactor to 200 kW and adjust, if necessary, both safety channels so as to indicate the reactor power of 200 kW. Rev

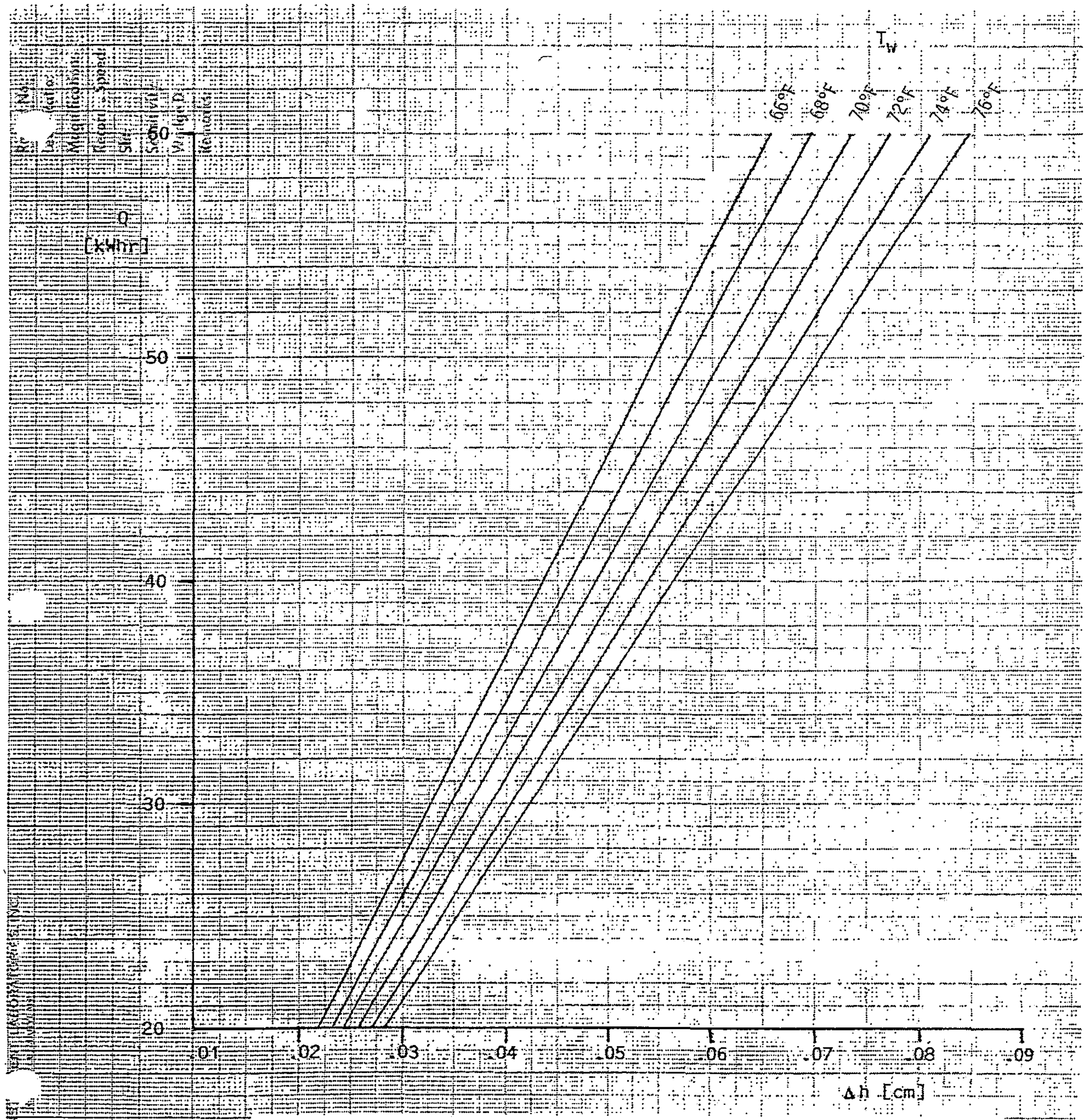


Figure 2. UMRR Thermal Output vs. Change in Pool Water Height

A. PURPOSE

In accordance with Technical Specification 4.2.2, all console instruments and safety systems will be calibrated once each year not to exceed 15 months.

B. PRECAUTIONS, PREREQUISITES, OR LIMITATIONS

After each item is completed, a second knowledgeable person will check connections (where connections have been broken and reconnected), to ensure that the equipment is connected and on line. This step is very important because failure to reconnect some of the equipment can cause violations of Technical Specifications if the reactor is operated.

C. PROCEDURE

A list of equipment in the form of a checklist on SOP 800 will be used to record the date that each system was checked or calibrated. Procedures listed in the Technical manuals have been reprinted in the form of SOP's. As each piece of equipment is checked or calibrated, it shall be checked off on the checklist to ensure that the list has been completed and to serve as a record of the date when the item was completed.

1. Contact Central Dispatch Inc. at 364-6686 and the Missouri S&T Police at extension 4300 to make them aware of the security testing taking place and for verification of each alarm. Also verify each alarm with the Reactor Managers email and cell phone.

2. Arm the alarm system. After the set delay time is up, release the switch for the security door (dead bolt switch).

3. After the alarm has been verified, continue to check all non-24 hour alarms.

4. Clear the alarms and verify that all were received.

5. Do not arm the security system. Check the 24 hour alarms and no alarms should sound.

6. After the alarm has been verified clear the security system.

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7. Do not arm the security system. Check the Duress Alarm.

8. After the alarm has been verified clear the security system.

9. Arm the security system. Remove the AC power cord from the building AC power plug-in. This steps checks the back-up battery and no alarms should sound.

10. Plug the AC cord back into the wall receptacle and unarm the security system.

11. Open the doors on the security system panels. After alarm has been verified, close and lock doors, and reset the alarm system.

12. Remove the front cover from the motion detector located at the entrance to the secure area.

13. After alarm has been verified, replace cover, and reset the alarm.

14. Repeat steps 12 and 13 on the remaining motion detectors.

15. After the alarm has been verified clear the security system.

16. Using either the intermediate or beam room RAM modules, cause a High Radiation alarm to sound.

17. After alarm has been verified, reset the annunciator panel.

18. Using the battery test switch, test the unit battery.

19. Check all the door tampers by removing covers or cover plates on doors.

20. Complete checklist in SOP 800, step 10.

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