



# Annual Report for the Research Reactor Infrastructure Program

December 2021

Douglas K. Morrell  
*RRI Project Manager*



*INL is a U.S. Department of Energy National Laboratory  
operated by Batelle Energy Alliance, LLC*

#### **DISCLAIMER**

This information was prepared as an account of work sponsored by an agency of the U.S. Government. Neither the U.S. Government nor any agency thereof, nor any of their employees, makes any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness, of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. References herein to any specific commercial product, process, or service by trade name, trade mark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the U.S. Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the U.S. Government or any agency thereof.

# **Annual Report for the Research Reactor Infrastructure Program**

**Douglas K. Morrell  
RRI Project Manager**

**December 2021**

**Idaho National Laboratory  
Idaho Falls, Idaho 83415**

**<http://www.inl.gov>**

**Prepared for the  
U.S. Department of Energy  
Office of Nuclear Energy  
Under DOE Idaho Operations Office  
Contract DE-AC07-05ID14517**

*Page intentionally left blank*

## SUMMARY

Idaho National Laboratory (INL) manages and provides project management, technical support, quality engineering, quality inspection and nuclear material support for the Department of Energy (DOE) Research Reactor Infrastructure (RRI) program. This program provides nuclear reactor fuel for United States domestic University Test and Research and Training Reactor programs. Currently, the RRI program supports 24 domestic universities that operate a total of 25 nuclear reactors at their on-campus reactor facilities. These on-campus reactors serve a vital national role in both educating and providing experience to nuclear engineers, nuclear scientists, and other professionals critical to our national laboratories, Department of Energy, Department of Defense, Nuclear Regulatory Commission, nuclear power, nuclear medicine, related industries, and Homeland Security. This Annual Report covers university reactor information, including the licensed power rating of the reactor facility, the fuel type of the reactor facility, and operational data. Data include energy generated in 2020, average hours per week that the reactor is operated, and grams of U-235 consumed in 2020 which is the most recent year that data are available.

During FY-21, the world continued to be impacted by a global pandemic, the Novel Coronavirus 2019 (COVID-19). The response to COVID-19 was different yet similar at each university reactor facility. This Annual Report includes a description of the impact that COVID-19 had on the reactor facilities during FY-21. Impact statements were provided by the reactor management teams at each facility.

The Annual Report also identifies RRI project accomplishments completed during FY-21. Accomplishments are discussed for fuel fabrication and delivery to university reactor facilities, spent fuel shipments from reactor facilities, project management and technical support provided by the RRI program, and issues and opportunities.

The mission of the RRI program was met for FY-21. Enough fuel elements were delivered to the university research reactors to maintain sustained operability of all supported reactor facilities. Spent fuel elements were returned to the DOE-owned receipt and storage facility at Savannah River Site, thus maintaining a minimal supply of Special Nuclear Material (SNM) at university facilities.

Regardless of pervasive funding constraints at each reactor facility, nuclear education and research programs continue to operate, and many are seeing expansion of their programs.

*Page intentionally left blank*

# CONTENTS

SUMMARY .....	iii
ACRONYMS .....	vii
1. PURPOSE OF THE PROGRAM.....	1
2. DESCRIPTION.....	1
2.1 Background and History .....	1
2.2 National Value of University Reactor Programs.....	1
2.2.1 Research.....	1
2.2.2 Education .....	2
2.2.3 Service.....	2
2.3 Mission.....	2
2.4 University Reactor Information .....	2
3. IMPACT OF COVID-19 ON THE UNIVERSITY REACTOR FACILITIES .....	6
3.1 University of Missouri–Columbia (MURR) .....	6
3.2 Massachusetts Institute of Technology (MIT) .....	6
3.3 University of California–Davis.....	7
3.4 Rhode Island Nuclear Science Center.....	7
3.5 Kansas State University .....	7
3.6 Oregon State University.....	7
3.7 University of Texas .....	7
3.8 North Carolina State University.....	7
3.9 Penn State University.....	7
3.10 Texas A&M.....	8
3.11 University of Massachusetts at Lowell .....	8
3.12 University of Wisconsin.....	8
3.13 Washington State University.....	8
3.14 Ohio State University.....	8
3.15 Reed College .....	8
3.16 University of California–Irvine.....	9
3.17 University of Maryland .....	9
3.18 University of Missouri S&T.....	9
3.19 University of Florida.....	9
3.20 University of Utah.....	9
3.21 Purdue University .....	9

3.22	Idaho State University.....	9
3.23	University of New Mexico.....	9
3.24	Rensselaer Polytechnic Institute .....	10
4.	RRI PROJECT ACCOMPLISHMENTS DURING FISCAL YEAR 2021 .....	10
4.1	Fuel Fabrication and Delivery to Universities .....	10
4.2	Spent Fuel Shipments.....	10
4.3	Project Management and Technical Support .....	10
4.4	Issues and Opportunities .....	11
4.5	Other Activities .....	11
5.	BUDGET SUMMARY .....	12
6.	CONCLUSIONS.....	12

## TABLES

Table 1.	Research reactor facility details. ....	2
Table 2.	Research reactor facility operational data (calendar year 2020).....	3
Table 3.	Research reactor facility usage data.....	5



## ACRONYMS

AGN	Aerojet General Nucleonics
BEA	Battelle Energy Alliance
BWXT	BWX Technologies, Inc.
COVID-19	coronavirus disease 2019
DHS CISA	Dept. of Homeland Security, Cybersecurity and Infrastructure Security Agency
DOD	Department of Defense
DOE	Department of Energy
DOE-ID	Department of Energy Idaho Operations Office
HEU	Highly Enriched Uranium
INL	Idaho National Laboratory
LEU	Low Enriched Uranium
MIT	Massachusetts Institute of Technology
MURR	University of Missouri Research Reactor (Columbia)
NRC	Nuclear Regulatory Commission
OLLI	Osher Lifelong Learning Institute
QSL	Qualified Suppliers List
RINSC	Rhode Island Nuclear Science Center
RO	Reactor Operator
RPI	Rensselaer Polytechnic Institute
RRI	Research Reactor Infrastructure
SNM	Special Nuclear Material
S&T	Science & Technology
TI	TRIGA International
TRIGA	Training, Research, Isotope production, General Atomics
TRTR	Test, Research and Training Reactors
UCI	University of California—Irvine

*Page intentionally left blank*

# **Annual Report for the Research Reactor Infrastructure Program**

## **1. PURPOSE OF THE PROGRAM**

Idaho National Laboratory (INL) manages and provides project management, technical support, quality engineering, quality inspection and nuclear material support for the Department of Energy (DOE) Research Reactor Infrastructure program (RRI). This program provides nuclear reactor fuel for United States domestic University Test, Research and Training Reactor (TRTR) programs. The two fuel types fabricated for the program, plate fuel and Training, Research, Isotope Production, General Atomics (TRIGA) fuel are obtained through subcontracts with two fuel fabricators, BWX Technologies, Inc. (BWXT) and TRIGA International (TI). Respectively, these subcontractors fabricate high and low enriched uranium aluminide, silicide and TRIGA fuel on a recurring basis. The program is also responsible for funding, coordinating, and scheduling the return of the DOE-owned, irradiated nuclear fuel over the life of the program.

## **2. DESCRIPTION**

### **2.1 Background and History**

The background and history of the RRI program is contained in Appendix A.

### **2.2 National Value of University Reactor Programs**

In 1980, there were 63 nuclear research and test reactors, which provided critical hands-on experience and enabled multidisciplinary research. Currently, the RRI program supports 24 domestic universities that operate a total of 25 nuclear reactors at their on-campus reactor facilities. On-site reactors, clearly, enhance the educational and research missions of a university. Properly equipped and managed on-campus reactors offer unique advantages in terms of hands-on education and research experience in running small scale experiments which would not be practical at larger off-campus reactors. These on-campus reactors serve a vital national role in both educating and providing experience to nuclear engineers, nuclear scientists, and other professionals critical to our national laboratories, DOE, Department of Defense (DOD), Nuclear Regulatory Commission (NRC), nuclear power, nuclear medicine, related industries, and Homeland Security. Additionally, the reactor facilities offer tours and information about the reactor facilities and the uses of nuclear energy. In a report from the University Research Reactor Task Force to the DOE Nuclear Energy Research Advisory Committee published in April 2001, the finding was that on-campus reactors have “become a valuable asset as an educational outreach tool for promoting and educating the public about nuclear technologies. These on-campus research reactors contribute to academic values through research, and education and through service to off-campus user constituencies.”

#### **2.2.1 Research**

University research reactors are the focus of multidisciplinary research with contributions to physics, chemistry, biology, medicine, epidemiology, environmental sciences, material sciences, fluid mechanics, geology, archaeology, paleontology, forensic sciences, and other fields in addition to nuclear engineering research and reactor physics. The three principal reactor research techniques are neutron activation analysis, neutron scattering, and neutron radiography. The latter two are largely confined to reactors of one megawatt and higher power. Research reactors in the United States constitute unique and essential research tools in several aspects: structural determinations of materials including superconductors and biologicals, ultra-sensitive analysis for traces of elements, radiological display of physical phenomena, and introduction of radioisotopes for medical diagnostics and research.

## 2.2.2 Education

On-campus reactors have been a traditional focus of educational programs for nuclear engineers. Educational uses are made of even the smallest fractional watt on-campus reactors. Beneficiaries include graduate and undergraduate students, as well as nuclear power plant operators, secondary schools and the general public through outreach programs.

## 2.2.3 Service

University reactors, particularly those of one megawatt and larger, serve a range of off-campus constituencies: the medical community, industrial organizations, and government agencies. These clients use irradiated materials, materials analysis, trace element detection, and radiographic analysis of objects and processes. By providing such services, managers of university research reactors establish beneficial links to off-campus users, expose faculty and students to commercial applications of the nuclear sciences, and earn revenue to help support reactor programs.

## 2.3 Mission

The mission of the RRI program is to provide nuclear reactor fuel to domestic universities at no, or low, cost to the university. The title of the fuel remains with the U.S. government and, when universities are finished with the fuel, the fuel is returned to the U.S. government. The authority for this program is established under Section 31, Atomic Energy Act of 1954, as amended, 42 U.S.C. 2051.

## 2.4 University Reactor Information

The RRI program requested input from all supported facilities to quantify the capabilities at each facility. Many variations of reactor technology exist within the university operated reactor facilities. The RRI program subcontracts with 24 university facilities to supply government owned nuclear fuel for operations. Facilities include 12 TRIGA facilities, eight plate fuel facilities, three Aerojet General Nucleonics (AGN) facilities, one Pulsar fueled facility, and one critical facility.

Two types of plate fuel are fabricated and used at the reactor facilities, aluminide, and silicide. All but two reactors have been converted from highly enriched uranium (HEU) to low enriched uranium (LEU) to conform to the objective of the Global Threat Reduction Initiative.

Reactors are licensed and operate at a wide range of powers. The reactor operating at the highest power level and supported by the RRI program is the University of Missouri–Columbia research reactor (MURR), which is licensed to operate at 10 mega-watts. New York’s Rensselaer Polytechnic Institute (RPI) operates the reactor with the lowest power level at 1 watt. A wide variety of capabilities exists within the university reactor community.

Table 1 contains information for university reactor facilities that are supported by the RRI program. Information contained in the table includes the licensed power rating of the reactor facility, the fuel type of the reactor facility, and whether the reactor fuel type is HEU or LEU.

Table 1. Research reactor facility details.

University	Reactor Licensed Power Level	Fuel Type	Fuel Details
University of Missouri–Columbia (MURR)	10 MW	Aluminide Plate Fuel	HEU
Massachusetts Institute of Technology (MIT)	4.9 MW	Aluminide Plate Fuel	HEU
Univ. of California–Davis	2 MW	TRIGA	LEU
Rhode Island Nuclear Science Center	2 MW	Silicide Plate Fuel	LEU

University	Reactor Licensed Power Level	Fuel Type	Fuel Details
Kansas State	1.25 MW	TRIGA	LEU
Oregon State University	1 MW	TRIGA	LEU
University of Texas at Austin	1 MW	TRIGA	LEU
North Carolina State University	1 MW	PULSTAR	LEU
Penn State University	1 MW	TRIGA	LEU
Texas A&M University	1 MW	TRIGA & AGN	LEU
University of Massachusetts at Lowell	1 MW	Silicide Plate Fuel	LEU
University of Wisconsin	1 MW	TRIGA	LEU
Washington State University	1 MW	TRIGA	LEU
Ohio State University	500 KW	Silicide Plate Fuel	LEU
Reed College	250 KW	TRIGA	LEU
University of California at Irvine	250 KW	TRIGA	LEU
University of Maryland	250 KW	TRIGA	LEU
University of Missouri S&T	200 KW	Silicide Plate Fuel	LEU
University of Florida	100 KW	Silicide Plate Fuel	LEU
University of Utah	100 KW	TRIGA	LEU
Purdue University	10 KW	Aluminide Plate Fuel	LEU
Idaho State University	5 W	AGN	LEU
University of New Mexico	5 W	AGN	LEU
Rensselaer Polytechnic Institute	1 W	Critical Facility	LEU

The primary mission of each university reactor facility is to educate and perform university research. Depending on the capabilities, experimentation activities, and additional missions of each reactor facility, operations may be performed around the clock or only a couple hours per week.

Table 2 contains operational data for each of the reactor facilities for calendar year 2020 (most recent year end data available). Data include energy generated in 2020, average hours per week that the reactor is operated, and grams of U-235 consumed in 2020.

Table 2. Research reactor facility operational data (calendar year 2020).

University	Energy Generated	Average Hours Per Week	U-235 Consumed
University of Missouri–Columbia (MURR)	79,000 MWH	151.86	4.15 kg
Massachusetts Institute of Technology (MIT)	17,059 MWH	60	0.903 kg
University of California–Davis	1,539 MWH	29.6	73 g
Rhode Island Nuclear Science Center	195.61 MWH	3.76	10.19 g
Kansas State	11.54 MWH	2.19	0.60 g

University	Energy Generated	Average Hours Per Week	U-235 Consumed
Oregon State University	1,193 MWH	25.1	69 g
University of Texas at Austin	339.6 MWH	6.53	14.86 g
North Carolina State University	1,269.3 MWH	27.6	61.66 g
Penn State University	207.7 MWH	11.6	10.6 g
Texas A&M University	539.8 MWH	13.4	24.12 g
University of Massachusetts at Lowell	121 MWH	6.5	6.32 g
University of Wisconsin	195.89 MWH	4.0	10.2 g
Washington State University	836 MWH	29	44 g
Ohio State University	55.47 MWH	7.0	2.9 g
Reed College	12.63 MWH	1	1 g
University of California at Irvine	11.2 MWH	2.20	0.58 g
University of Maryland	6.1 MWH	3	0.27 g
University of Missouri S&T	5.5 MWH	1.44	0.282 g
University of Florida	4.056 MWH	4.32	0.219 g
University of Utah	3.65 MWH	1.5	0.123 g
Purdue University	27.89 kWH	0.527	1.22 g
Idaho State University	0.0451 kWH	1	1.98 micrograms
*University of New Mexico	0.244 kWH	2.7	10.7 micrograms
Rensselaer Polytechnic	0.02683 kWH	<1	1.18 micrograms

\* Data provided by the University of New Mexico was for 2019. The University did not provide information for 2020 in time to include in the report.

Although the major focus of all university reactor facilities is to educate and perform university research, many also provide commercial services such as isotope production for medical and industrial use. All missions are executed concurrently, and no reactor facilities are operated solely to perform commercial work. Most on-site university research reactors offset operating costs by charging industrial users and commercial industry for neutrons and products provided. All funding derived from these sources are used to subsidize and maintain operability of the reactor facilities and, if these additional funding sources were not available to the reactor facilities, the reactor directors indicated that the reactors face a high risk of being shut down due to lack of operational funding provided by their respective universities.

Table 3 contains reactor usage data for each of the reactor facilities for calendar year 2020 (most recent year end data available). Data include percentage of fuel usage for five categories of operations. These include instruction and training, university research, academic and industrial research for facilities other than the sponsoring university, calibration and maintenance activities, and isotope or other products generated and sold to outside industry.

Table 3. Research reactor facility usage data.

University	Instruction and Training	University Research	Academic and Industrial Research	Calibration and Maintenance	Commercial Industry
University of Missouri–Columbia (MURR)*	36%	89%	89%	15%	89%
Massachusetts Institute of Technology (MIT)	10%	40%	15%	20%	15%
Univ. of California–Davis	0%	50%	50%	0%	0%
Rhode Island Nuclear Science Center	40%	30%	30%	5%	0%
Kansas State	34%	43%	0%	23%	0%
Oregon State University	2%	18%	51%	19%	10%
University of Texas at Austin	25%	55%	20%	0%	0%
North Carolina State University	56%	<2%	40%	2%	0%
Penn State University	18%	20%	44%	18%	0%
Texas A&M University	27%	15%	15%	5%	38%
University of Massachusetts at Lowell	37%	44%	16%	3%	0%
University of Wisconsin	90%	2%	3%	5%	0%
Washington State University	50%	25%	10%	10%	5%
Ohio State University	20%	35%	43%	3%	0%
Reed College	60%	30%	0%	10%	0%
University of California at Irvine	27%	54%	11%	8%	0%
University of Maryland	20%	70%	0%	10%	0%
University of Missouri S&T	95%	5%	0%	0%	0%
University of Florida	100%	0%	0%	0%	0%
University of Utah	60%	30%	0%	10%	0%
Purdue University	83%	17%	0%	0%	0%
Idaho State University	90%	10%	0%	0%	0%
University of New Mexico	100%	0%	0%	0%	0%
Rensselaer Polytechnic	80%	0%	0%	20%	0%

\* MURR reactor usage is impossible to subdivide into the five categories as all categories are performed simultaneously.

Appendix B contains information provided by the universities affiliated with the RRI program. Each university overview contains a brief history of the reactor facility, the mission of the reactor, products provided, and customers supported by the reactor facility, and any special capabilities that make the facility unique or different from the other university reactor facilities.

### **3. IMPACT OF COVID-19 ON THE UNIVERSITY REACTOR FACILITIES**

During FY-21, the world continued to be impacted by a global pandemic, the Novel Coronavirus 2019 (COVID-19). The response to COVID-19 was different, yet similar at each university reactor facility. Below is a description of the impact that COVID-19 had on the reactor facilities in 2021. Impact statements were provided by the reactor management teams at each facility.

#### **3.1 University of Missouri–Columbia (MURR)**

The University of Missouri-Columbia Research Reactor (MURR®) continued to operate during the COVID-19 pandemic; there were no disruptions to (1) the reactor operating schedule, and (2) producing and shipping MURR's life-saving isotopes, which patients rely on each week. This aligned with the U.S. President's guidance statement: *"If you work in a critical infrastructure industry, as defined by the Department of Homeland Security, such as healthcare services and pharmaceutical and food supply, you have a special responsibility to maintain your normal work schedule."* MURR continued to adhere to all the current University of Missouri COVID-19 policies such as social distancing, wearing masks, constant cleaning/sanitization, etc. Additionally, all MURR staff have returned to the facility – remote teleworking has stopped – and all research and education activities have resumed.

Some construction projects have had material availability/delivery delays that have caused schedules to slip; however, these are facility improvement/enhancement projects that do not affect reactor operations or isotope production/shipment.

#### **3.2 Massachusetts Institute of Technology (MIT)**

In mid-June 2020, the Massachusetts Institute of Technology (MIT) reopened after a 3-month closure caused by the COVID-19 public health emergency. Research activity was then ramped up in phases. By September 2020, all such activities at the MIT research reactor had resumed normal levels and have remained there since that time. Some research and administrative staff have been allowed to perform all or part of their work remotely as circumstances permit. However, educational activities continued to be restricted throughout spring and summer 2021, with no in-person classes or meetings except for lab classes that required in-person instruction. In autumn 2021, all in-person classes were restarted. Reactor tour activities have also restarted but are restricted to MIT groups and small groups of researchers. Large outside groups, such as high school students and teachers, are not yet permitted.

In early 2021, MIT's group of five student reactor operator (RO) trainees had their NRC licensing exam postponed (for the second time) by the pandemic; all of them were able to take it at the end of August 2021 and received their licenses at the end of October. MIT strongly encouraged, and eventually required, most employees to be vaccinated against COVID-19. By autumn 2021, the MIT Nuclear Reactor Lab / MIT overall achieved a 98% vaccination rate.



### **3.3 University of California–Davis**

The University of California–Davis reactor facility has had minimal impact due to COVID-19. Their work for the DOD required that they continue to operate in person. The only impact was that they had significantly less student tours.

### **3.4 Rhode Island Nuclear Science Center**

Although Rhode Island Nuclear Science Center (RINSC) resumed giving tours in the fall of 2020, many schools that historically made use of the facility on an annual basis, did not visit in 2021. Additionally, some tours and classes were held virtually. The research and irradiation services did not rebound to previous levels in 2021.

### **3.5 Kansas State University**

The Kansas State University reactor outreach activities (tours, workshops, demonstrations) were limited at the beginning of 2021. Currently the reactor has resumed typical tour activities. Additionally, new operator training was delayed until late spring. However, training and exams were completed in 2021.

### **3.6 Oregon State University**

The Oregon State University reactor was affected directly and indirectly by COVID-19 in 2021. It directly affected the reactor staff as twice they had to shut down the reactor for a period of 5 days due to low staffing availability caused by potential COVID-19 exposures. Indirectly, they saw a dramatic drop (about a third of normal) in the number of samples irradiated.

### **3.7 University of Texas**

The University of Texas reactor facility has had a very active year, although total energy generation was reduced. The UT reactor was declared an essential facility based on support for national nuclear security units, and technical staff continued work at the facility. Some administrative staff performed work from home and continues a mix of work from home and work at the facility. Some staff members were exposed to or infected by COVID-19, and appropriate quarantine measures were taken according to University of Texas policy developed in response to COVID-19.

### **3.8 North Carolina State University**

The North Carolina State University reactor has seen minimal impact due to the COVID-19 pandemic in 2021. To date, no reactor staff or student operators have reported becoming infected or ill with COVID-19. The ability of a few users to travel on site has been affected, but user project deliverables and schedule continue to be met.

### **3.9 Penn State University**

In normal years, the Penn State Reactor facility hosts approximately 3000 visitors, with many of these in the form of tour groups. The most significant impact of COVID-19 has been to reduce the number of visitors to the facility to approximately 200 (excluding PSU visitors) since March 2020. Penn State strove to support as many of their outreach projects as possible through virtual tours. This virtual outreach program included tours for the Osher Lifelong Learning Institute (OLLI), Nuclear Science Week, the University of Pittsburgh, and World Nuclear Energy Day.

The student operator training program has also been affected due to the lack of facility access for in-person training during 2020. Due to the limited time available to train and license undergraduate students between the time of their recruitment and graduation, a significant negative impact has been created on

the student operator program which continued into 2021. Currently, there is only one licensed student operator at the reactor facility, where there are normally 4-5.

Research and service work were mostly unaffected. This is especially true to for work deemed to support critical infrastructure per the DHS CISA guidance. Critical infrastructure work included neutron transmission testing of spent fuel pool absorber coupons and fast neutron irradiation of electronics for defense-related components. The reactor never fully shut down during the pandemic due to the need to support critical infrastructure work and license-required surveillance. In all, the operations hours of the facility were reduced from 895.4 hours in 2018 and 755.7 hours in 2019 to 604.5 hours in 2020. Total hours for 2021 are currently unknown.

### **3.10 Texas A&M**

The COVID-19 pandemic had limited impact on facility operations at Texas A&M, with standard operating weeks resuming in December of 2020. Non-operational staff were able to work from home as needed.

### **3.11 University of Massachusetts at Lowell**

The University of Massachusetts at Lowell reactor started 2021 with one-half of the staff on-site at any given time, making operations difficult, but manageable. As of September 1, 2021, all staff have returned to full-time on-site.

### **3.12 University of Wisconsin**

COVID-19 has had limited impact on the University of Wisconsin's effort to pivot to more research utilization of the reactor facility. All operations returned to normal in June 2020, and the facility has remained operational for research, industrial and educational utilization. Currently, the only impact is due to supply chain issues. Some spare parts are taking longer to become available (four weeks lead time instead of less than one week). However, equipment and parts are still available for now.

### **3.13 Washington State University**

The Washington State Nuclear Science Center saw major impacts due to COVID-19 in 2020. However, the rebound during 2021 has been substantial. They are on track to increase irradiation, isotope production, and other activities to above pre-pandemic levels. Operator training has increased as they have brought Zoom teaching online, thereby allowing students the flexibility of learning reactor theory wherever they choose, and then the students come to the reactor facility for hands-on training. This has proven to be an efficient use of both staff and student time in training.

### **3.14 Ohio State University**

The Ohio State University research reactor was impacted by the COVID-19 pandemic for the first half of 2021. During this period all tours were cancelled, and the number of visitors allowed in the building continued to be restricted. The number of students allowed in any given student lab section was limited, so the number of sections for hands-on student laboratories had to be increased to accommodate all the students.

### **3.15 Reed College**

The largest impact to Reed College in 2021 is that physical distancing requirements has greatly reduced their ability to support in-person training programs and decreased the availability of licensed operators to staff the reactor to support college research. High vaccination rates among Reed students (99%) and staff (>95%) allowed them to return to normal operations beginning in September 2021.

### **3.16 University of California–Irvine**

At the University of California, Irvine (UCI) most of the direct impact of COVID-19 was in calendar year 2020 when full closure occurred for a few months and only minimal surveillance was carried out. Full operations were resumed before the end of 2020. However, the university campus remained closed to most students and much research during 2021 until October 2021 when full occupancy (with masking and vaccinations required) was authorized. No in-person laboratory classes were taught between March 2020 and October 2021. Operator training on a one-on-one basis was permitted.

### **3.17 University of Maryland**

Unfortunately, the University of Maryland lost one of their ROs due to COVID-19. The University of Maryland has a small reactor staff, so the loss of even one RO results in a large impact on operations. It also disrupted the training program for new ROs which resulted in no new operators licensed in 2021.

### **3.18 University of Missouri S&T**

The ongoing pandemic has increasingly held back hiring searches for new employees at the University of Missouri S&T reactor facility. Medical examinations for student operators (including initial licensing) have been greatly impacted due to repeat COVID-19 exposures within the Student Wellness organization. Quarantine protocols within the facility have canceled or rescheduled some operations due to student, trainee, and operator exposure.

### **3.19 University of Florida**

The University of Florida identified impacts on staff training and Emergency Plan training. This increased the burden on staff to get the training completed in a timely manner. Most researchers were able to get grant extensions due to COVID-19.

### **3.20 University of Utah**

COVID-19 has added operational overhead and delay for the University of Utah due to testing requirements, mask requirements on campus, and general uncertainty regarding staff availability, and operations. It has also added fatigue/mental exhaustion of having to constantly “keep up” with moving policies and guidance.

### **3.21 Purdue University**

The COVID-19 Pandemic has led to fewer reactor tours at Purdue University. It has also increased the delay of research from industry due to travel restrictions and quarantines.

### **3.22 Idaho State University**

Impacts from COVID-19 at Idaho State University have included restrictions on the number of students allowed in the reactor bay at a time. Continued monthly operator requalification training had replaced quarterly operating hours through the first half of 2021. Finally, there has been limited access to conduct class laboratories, research, and non-mandatory maintenance to the facility.

### **3.23 University of New Mexico**

The following impacts were for 2020. The University did not provide information for 2020 in time to include in the annual report.

COVID-19 pandemic controls adopted by the University of New Mexico in the second quarter of 2020 impacted the use of the reactor; during the period of 3/19/20–6/7/20, no operation occurred. In typical years, the reactor logs extensive teaching laboratory use during this period. Student RO candidates studying for RO licensure in the fall of 2019 had been expected to sit for NRC examinations in the spring of 2020, but this was postponed. Although reactor use was impacted by the COVID-19 pandemic, reactor staffing, security, and surveillances were unaffected, as well as licensed staff-maintained currency in operating hours during the reporting period. Two RO candidates completed their NRC exams in the fall of 2020 after the spring postponement. Had the exams occurred in the spring, it is likely that the candidates would be licensed ROs assisting with the use of the reactor at this point, and it is likely that an additional 1-2 trainees would have felt comfortable sitting for the exam.

### **3.24 Rensselaer Polytechnic Institute**

The RPI research reactor in New York has seen no major impacts other than practicing social distancing and masking protocols of the operations staff. They have still been able to meet as needed for training and routine operations.

## **4. RRI PROJECT ACCOMPLISHMENTS DURING FISCAL YEAR 2021**

This section of the report identifies project accomplishments completed during FY-21. These accomplishments are divided into the following sub-sections:

1. Fuel fabrication and delivery to universities
2. Spent fuel shipments
3. Project management and technical support
4. Issues and opportunities
5. Other activities.

### **4.1 Fuel Fabrication and Delivery to Universities**

The following fresh fuel fabrication activities and deliveries were made to universities during FY-21.

- Twenty-four fresh fuel elements were delivered to the MURR facility. All planned shipments for the fiscal year were completed on schedule.
- Nine fresh fuel elements were delivered to the MIT facility. All planned shipments for the fiscal year were completed on schedule.

### **4.2 Spent Fuel Shipments**

The following spent fuel shipment activities were completed during FY-21.

- Sixteen spent fuel elements were shipped from MURR to the DOE Receipt Facility located at the Savannah River Site. One shipment scheduled to be completed in September was delayed until November per MURR's request.
- Sixteen spent fuel elements were shipped from MIT to the DOE Receipt Facility located at the Savannah River Site.

### **4.3 Project Management and Technical Support**

The following project management and technical support activities were completed during FY-21.

- The RRI project manager updated the comprehensive fuel tracking system to support fuel acquisition and dispositioning planning. The tracking system includes all domestic university reactors and is updated and maintained on a regular basis. Additional information gathered included fresh fuel and spent fuel anticipated needs for the next five years. This information is important to DOE and the RRI program as it will be used to prioritize fresh fuel procurement activities and spent fuel shipment support.
- INL maintained current and updated fuel support contracts with the 24 domestic universities that operate reactor facilities. These contracts document government ownership of reactor fuel, usage, and reporting requirements. Maintenance of these contracts is important to DOE and the RRI program as these are the contractual agreements that implement the Atomic Energy Act Sections 31 and 53 for the receipt and use of DOE-owned reactor fuel.
- MURR was invoiced for 20 fresh fuel elements delivered during FY-20 in accordance with a contractual agreement between the Department of Energy Idaho Operations Office (DOE-ID) and the University of Missouri, (Contract # DE-SC07-78D01723). This subcontract was put in place to address potential perceptions of government assistance to a university competing with commercial industry in the production and distribution of medical isotopes. INL invoices MURR on an annual basis for the fuel elements delivered and accepted during the previous fiscal year. These funds are then used to support program activities as agreed upon between the RRI program and DOE, either through fiscal year planning activities or implementation of the baseline change proposal process. During FY-15, the cost share agreement was renegotiated with MURR. The cost share amount was increased to \$10,000 for all fuel elements delivered after July 2017.

#### **4.4 Issues and Opportunities**

The following Issues and Opportunities for project improvements were addressed during FY-21.

- Penn State, the University of Texas, and UC Davis have all requested to return spent TRIGA fuel elements to DOE. TRIGA spent fuel is returned for long term storage to INL. Due to issues associated with the 1995 Idaho Settlement Agreement, INL is unable to receive spent fuel from locations outside of Idaho. Until these issues are resolved, and spent reactor fuel can once again be received, the universities have retained the spent fuel at the reactor facilities. This has the potential to impact reactor operations. Routine maintenance can be impacted due to the spent fuel increases radiation levels in the reactor pools, causing increased exposure to maintenance personnel and ROs. In addition, the NRC sets limits for how much fuel may be possessed at a reactor facility. If spent fuel is not returned to the DOE receipt facilities, there is a risk that the reactor facilities will be impacted since they will not be able to receive new fuel without exceeding the established possession limits. This is becoming an issue for Penn State. Discussions with the reactor management team have been held to plan for options until the spent fuel can be returned. Options that are being implemented include: 1) Penn State will prepare and submit a license amendment to the NRC requesting an increase to the possession limit, and 2) the RRI program will identify a location where fresh fuel that is not currently being used by Penn State can be stored for future use. This is important to DOE and the RRI program because without being able to return spent TRIGA fuel to the INL may impact operations at university reactor facilities.

#### **4.5 Other Activities**

The following other activities are project management tasks completed to support the RRI program and ensure success in meeting the mission of the program.

- The TRIGA fuel fabrication line in Romans, France is currently scheduled to restart operations in the end of calendar year 2021. The Battelle Energy Alliance (BEA) and TI are currently working on the award of Release 1 for the fabrication of the initial 55 fuel elements. To procure reactor fuel, TI must

be placed on the Qualified Suppliers List (QSL) at the INL. A quality audit was performed and both TI and Framatome have been added to the QSL. This is important to DOE and the RRI program because TI is currently the only international source for new TRIGA fuel fabrication. The twelve university-operated TRIGA reactor facilities have estimated a need of approximately 801 additional fuel elements for the lifetime of their respective reactor cores. Of these, approximately 668 will be fabricated by TI. The remainder will come from the inventory of lightly irradiated fuel elements currently stored at INL.

- The RRI project manager presented the Program Status Report at the annual TRTR Conference. Due to the COVID-19 pandemic, the annual conference was held virtually. Attendees included representatives from the university reactor facilities, national laboratories, DOE, and the NRC. Attendance and presentation at the annual TRTR conference is important to DOE and the RRI program as this is an opportunity to meet with reactor facilities representatives to address concerns and to update the reactor community on the status and future plans for the RRI program.

## **5. BUDGET SUMMARY**

The INL RRI program budgeted cost of work scheduled for FY-21 was \$6,048,097. At year-end, the budgeted cost of work performed was \$5,543,610; the actual cost of work performed was \$5,480,929. This resulted in a schedule variance of \$504,487 (8.3%), and a cost variance of \$62,681 (1.13%).

## **6. CONCLUSIONS**

The mission of the RRI program was met for FY-21. Enough fuel elements were delivered to the university research reactors to maintain sustained operability of all supported reactor facilities. Spent fuel elements were returned to the DOE-owned receipt and storage facility at Savannah River Site, thus maintaining a minimal supply of Special Nuclear Material (SNM) at university facilities.

Regardless of pervasive funding constraints at each reactor facility, nuclear education and research programs continue to operate, and many are seeing expansion of their programs.

*Page intentionally left blank*

## **Appendix A**

### **Research Reactor Infrastructure Program History**



*Page intentionally left blank*

The Atomic Energy Commission (AEC) initiated the Research Reactor Infrastructure program (formerly known as the University Reactor Fuel Assistance Program) by issuing grants to universities to assist in the procurement of reactor fuel. Because the federal government funds this program and owns the uranium, title of the fuel is retained by the government. Beginning in 1974, increased physical security requirements for safeguarding SNM required fuel manufacturing licensees to upgrade their facilities at significant costs, which caused many fuel manufacturers to discontinue operations.

On October 11, 1974, in wake of the 1973 oil crisis, the AEC was split as part of the Energy Reorganization Act of 1974. Two new agencies were formed: the NRC which would regulate the commercial nuclear power industry, while the Energy Research and Development Administration (ERDA) would manage the energy research and development, nuclear weapons, and naval reactors programs. The ERDA agency became active on January 19, 1975.

Because possible foreign fuel suppliers were not allowed to possess U.S. government-owned HEU needed to fabricate the fuel in the mid-1970s only Texas Instruments and Atomics International were manufacturing plate-type fuel for ERDA (Texas Instruments was manufacturing oxide fuel, and Atomics International was manufacturing aluminide fuel). Both Texas Instruments and Atomics International were only accepting cost plus fixed fee contracts, which were very difficult for universities to handle and manage. Seven plate-type reactors had to sharply reduce reactor operations and faced the inability to operate because of lack of fuel. In 1977, an organized university consortium requested ERDA assistance in providing plate-type fuel through use of existing government subcontracts using government owned equipment at Atomics International, where ERDA had a contract to manufacture aluminide plate-fuel.

In 1977, the ERDA Idaho Operations Office was assigned responsibility for the fuel assistance program which was managed by EG&G Idaho, Idaho National Engineering Laboratory's prime subcontractor. In late 1977, the ERDA became the DOE. Fuel deliveries under this program began in 1978.

In 1985, the aluminide plate-type fuel subcontract was transferred from Atomics International to BWXT located in Lynchburg, Virginia. Currently, all plate fuel for the RRI program is fabricated by BWXT.

In 1958, General Atomics in San Diego, California started manufacturing TRIGA fuel which was used to operate their newly designed TRIGA reactors. In 1996, General Atomics entered a joint venture with CERCA in France to form TI, and the fabrication line was moved from California to Romans, France.

**Appendix B**

**University Reactor Information**

*Page intentionally left blank*

## University of Missouri – Columbia (MURR)

The University of Missouri Research Reactor (MURR) is a multi-disciplinary research, development and education center operated by the University of Missouri-Columbia (MU). With its first start-up on October 13, 1966, the reactor has been in operation for more than 40 years. A 100% power upgrade from 5 to 10 MW was performed in 1974 and a more than 50% increase in operating hours in 1977 allow the reactor to



maintain a 150+ hours per week schedule. The 10 MW light water moderated and cooled reactor is versatile and compact in design, with a peak unperturbed thermal neutron flux of  $6E14$  n/cm<sup>2</sup>-s and a peak fast flux of  $1E14$  n/cm<sup>2</sup>-s in the flux trap, and its enviable operating record allows multiple irradiations and experiments virtually around the clock. Safety at the MURR holds the highest operational priority, and its solid record of safe operation is owing to a combination of meeting stringent NRC-directed safety regulations, employing a high-quality technical and operations staff, and endorsing a philosophy of proactive, corrective and preventive maintenance. The MURR is recognized worldwide as the single most productive university-operated research reactor, in large part because of its reliable operating schedule, concise reactor design and wide-ranging, interdisciplinary research, education and development programs.

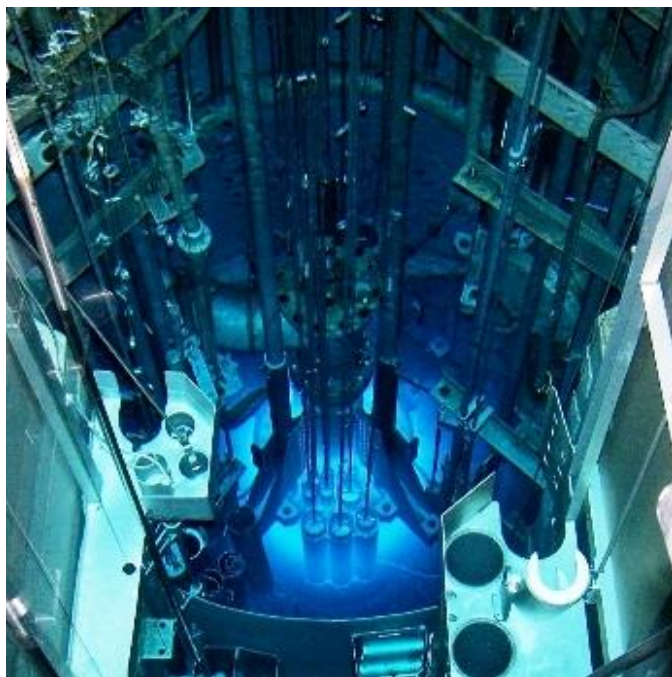
This is in keeping with the MURR's three-fold mission of research, education and service. Of particular importance are interdisciplinary Research & Development programs with partnering MU departments, other universities, federal and industrial labs—programs that could not be conducted without the unique MURR facilities and personnel. The MURR provides leverage for the expertise and talents resident in other departments and institutions, and a keen focus is on collaborative research programs in the life sciences with potential to lead to breakthroughs in healthcare.

The University and private collaborators have developed, patented and commercialized three FDA-approved radiopharmaceuticals: **Ceretec**<sup>™</sup>, the first radiopharmaceutical to image the brain effectively to diagnose and assess stroke victims and now also used to locate infection; **TheraSphere**<sup>™</sup> to treat liver cancer; and **Quadramet**<sup>®</sup>, which relieves the debilitating pain associated with metastatic bone cancer. With its unique collection of resources—the MURR; School of Medicine and its Ellis Fischel Cancer Hospital; College of Veterinary Medicine; and College of Agriculture, Food and Natural Resources; and neighboring Harry S Truman Veterans Administration Hospital—MU is actively developing new medical technologies through translational and comparative research. A sampling of other R&D programs involve nanotechnologies, materials analyses, nuclear battery development, semiconductors, biomembranes, environmental analyses, epidemiology, boron neutron capture therapy and international databases with applications in archaeology, anthropology and geology.

The MURR provides rich research and training opportunities for an international population of undergraduate, graduate and postdoctoral students in such disciplines as

anthropology, archaeology, chemistry, engineering (chemical, electrical, mechanical and nuclear), geology, materials science, medical and life sciences (including cancer diagnostics, treatment and prevention), nutrition, physics and veterinary medicine, and is active in producing technicians in the nuclear medicine and power industries.

Over the past several years MURR staff worked systematically through its Renewal and Relicensing Program (R&R), completing tasks fundamental to its license renewal for an additional 20 years of safe and productive operation, submitted in 2006. The R&R program involved modernizing key equipment and structures and upgrading to meet revised health and safety codes. Federal endorsement of the R&R efforts is evident in significant funding received from the Department of Energy to support key aspects.

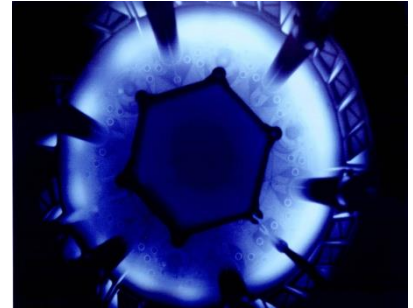


With its reliable operating schedule, custom facilities and instrumentation and expertise in processing and regulatory compliance, the MURR routinely provides research and commercial isotopes to a global community, in some cases is the nation's sole provider of products and services that directly result in treatments to cancer patients. In recent years MURR built from scratch an FDA-compliant cGMP (current Good Manufacturing Practices) program encompassing quality systems, infrastructure, staff and expertise to bring pharmaceutical grade radiochemicals, drug products and analyses to its roster of products and services. The 16 MeV cyclotron housed at MURR (owned and operated by Essential Isotopes, LLC)

produces a complementary set of positron-emitting isotopes for regional research and patient applications.

## Massachusetts Institute of Technology

The MIT Nuclear Reactor Laboratory (NRL), is an interdepartmental center that operates a 5 MW research reactor in support of MIT's educational and research initiatives and goals. The reactor, which is designated as the MITR-II, is the second of two research reactors that have been operated by the NRL. The original reactor (the MITR-I) achieved criticality in 1958. In 1973, the MITR-I was shut down to allow conversion to the MITR-II, which offered a higher neutron flux level. On 8 July 1999, a formal application was submitted to the U.S. Nuclear Regulatory Commission (NRC) to relicense the reactor for an additional twenty years and to upgrade the power level to 6 MW. The reactor design has the capability of running at 10 MW.



The NRL's mission is to provide faculty and students from MIT as well as the national scientific and engineering community with both a state-of-the-art reactor facility and the infrastructure to enable and support its use for research and other societal objectives. Highest priority is placed on operating the research reactor in a highly professional manner that is safe to MIT and NRL staff, researchers, the public, as well as the environment. The NRL is also committed to educating the general public by promoting education and training in nuclear sciences and technologies.

The MITR-II is the major experimental facility of the NRL. It is a heavy-water reflected, light-water cooled and moderated nuclear reactor that utilizes flat, plate-type, finned, aluminum-clad fuel elements. The average core power density is about 70 kW per liter. The maximum fast and thermal neutron flux available to experimenters are  $1 \times 10^{14}$  and  $5 \times 10^{13}$  neutrons/cm<sup>2</sup>-s, respectively. Experimental facilities available at the MITR include two medical irradiation rooms, beam ports, automatic transfer facilities (pneumatic tubes), and graphite-reflector irradiation facilities. In addition, several in-core sample assemblies (ICSAs) are available. It generally operates 24/7, except for planned outages for maintenance. The MITR-II encompasses a number of inherent (i.e., passive) safety features including negative reactivity temperature coefficients of both the fuel and moderator; a negative void coefficient of reactivity; the location of the core within two concentric tanks; the use of anti-siphon valves to isolate the core from the effect of breaks in the coolant piping; a core-tank design that promotes natural circulation in the event of a loss-of-flow accident; and the presence of a full containment. These features make it an exceptionally safe facility.

The NRL has a long history of providing faculty and students with a high-quality neutron source complemented with an extensive infrastructure to facilitate its use. Its organizational structure is composed of four groups that work to sustain the NRL's long-standing record of safe operation, to continuously maintain and improve upon the state-of-the-art reactor and its experimental facilities, and to provide an environment of support and excellence for researchers and students. These groups are: Reactor Operations; Research, Development, and Utilization; Engineering; and Administration. The Laboratory's primary objective is in support of educational training and research in the areas of nuclear fission engineering, radiation effects in





biology and medicine, material studies, neutron physics, geochemistry, and environmental studies. Through the years, MIT undergraduate and graduate students have benefited tremendously from the hands-on experience they have gained at the NRL. This is a result of students being able to conduct research that has resulted in their successful completion of more than two hundred MS and PhD theses or through the more than 300 students that have participated in the NRL's Reactor Operator Training Program. During this time period, cutting edge research has also been conducted by MIT faculty as well as faculty and scientists from other institutions. Current research and service areas supported and provided by MITR-II include: Providing researchers with a service-based infrastructure that supports the US initiative for designing and building the next generation of nuclear reactors as a means of reducing the country's reliance on fossil fuels. Supporting research in the area of advanced materials and fuel research. Providing researchers with a service-based infrastructure that utilizes the MITR-II for trace element analysis, isotope production, and irradiation services.

The production of neutron transmutation doping of silicon. Supporting an outreach program to the educational community to encourage understanding of nuclear energy and its applications. Supporting MIT's educational missions by providing Independent Activities Period lectures; hosting Undergraduate Research Opportunities Program students; and offering lab courses for professionals, undergraduates, and advanced secondary school students. Expanding the user base for underutilized experimental facilities Support of web-enabled time-of-flight experimental facility. Support of neutron scattering facility.

An exceptional feature of the MITR-II is its in-core loop capabilities. As a result, the NRL has a strong materials and in-core loop program that supports research in the areas of advanced materials and advanced fuels that are necessary for both existing and advanced power reactors. The MITR-II offers a unique technical capability that involves the design and use of in-core loops that replicate pressurized water reactor (PWR)/boiling water reactor (BWR) conditions to study the behavior of advanced materials and to perform scoping studies of advanced nuclear fuel. With rekindled national interest on the part of DOE and the nuclear industry in next-generation nuclear power systems, many using novel materials and advanced forms of fuels, facilities are needed to test material and fuel behavior in a variety of radiation environments. MITR is arguably the best-suited university reactor for carrying out such basic studies because of its relatively high-power density (similar to a light water reactor), the capability to control chemistry and thermal conditions to reflect prototypic conditions, its easy-access geometric configuration, and space for up to three independent irradiation tests.

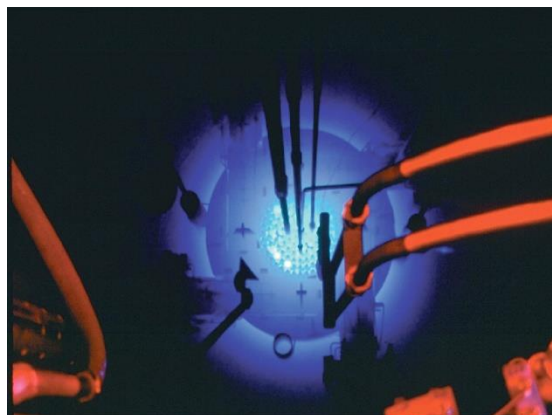
A major goal of the MIT Research Reactor (MITR) is to maintain its partnership with the DOE-Idaho National Laboratory's Advanced Test Reactor National Scientific User Facility (ATR-NSUF) which is charged with performing fuel and advanced materials irradiation experiments crucial to future-generation reactors. High temperature and radiation-resistant materials are needed for proposed designs that would exhibit high thermal efficiency as well as for hydrogen-production reactors. A related and equally important goal is to identify advanced fuels and materials that will enable both life-extension and improved economic performance of the existing LWR fleet. This collaboration, the first in an expected series of national partnerships designed to enhance the NSUF infrastructure and capabilities, is designed to increase user access to national reactor irradiations and testing capabilities. The NSUF test space at both reactors is made available at no cost to external users whose projects are selected via a peer review process. The MITR will offer a portion of its test capability to the NSUF experimenters.



The NRL also seeks to support other key societal benefits of our reactor, such as the production of medical isotopes, with particular attention to the challenge posed by the extremely important Mo-99 isotope. This critical isotope is currently only produced in foreign reactors using HEU as the starting material. The MITR-II operating at 6 MW will be a very useful facility for domestic production using molybdenum metal as the starting material, thereby eliminating the proliferation risk associated with international shipment of HEU.

## University of California - Davis

The McClellan Nuclear Research Center (MNRC) is a facility built around a 2 MW TRIGA research reactor. The reactor became operational in 1990 making it the newest research reactor in the US. This facility was built by the US Air Force for the nondestructive inspection of aircraft structures for early warning signs of corrosion using neutron radiography. The University of California, Davis (UCD) took ownership of the reactor in 2000, following the closure of the McClellan Air Force Base. UCD has transformed the MNRC from an inspection facility for military aircraft into a center for university research. During this transformation tomography, neutron activation analysis, radiation effects testing, research scale isotope production, and silicon doping capabilities were established and developed. As such, the MNRC is one of the three largest university research reactors in the nation. The reactor is located adjacent to a large airstrip (of the former Air Force Base). The airstrip is beneficial in that relatively short half-life radioactive materials can be flown in and out of the facility quickly. The reactor is located only 40 km (25 miles) from the UC Davis campus providing researchers easy access to the facility.



The MNRC has four bays to perform neutron imaging. Two bays are large enclosures that can accommodate large samples using robotic manipulators. The Center has the largest radiography capability in the US and can image samples as large as 10.00 m long, 3.65 m high, and weighing up to 2,270 kg. The other two bays are laboratory-size rooms where smaller samples can be inspected using both radiography and tomography. The maximum usable neutron beam size is 22- 50 cm in diameter with intensities of approximately  $1 \times 10^5$  n/cm<sup>2</sup>·s to  $1 \times 10^7$  n/cm<sup>2</sup>·s, depending on the bay used. The highly collimated (L/D of 50 - 400) and thermalized neutron beams provide high spatial resolution and quality. Dynamic radiography can be taken at 30 frames/second; the film neutron radiography system can produce images with spatial resolutions of 50 micrometers; and MNRC's neutron tomography system has an overall spatial resolution of approximately 200 micrometers. The MNRC has multiple facilities to perform neutron irradiation. These include in-core areas, out-of-core areas and the four bays, accommodating a wide variety of sample shapes and sizes. These facilities enable the MNRC to also provide Neutron Activation Analysis (NAA), Radiation Hardness Testing, Isotope production and silicon doping.

Substantial work has been done on the tomography of geological materials. Neutron radiography is ideal for imaging the distribution of hydrated and organic phases within the minerals. Among the most recent efforts at MNRC is the imaging of fuel cell systems; NAA is used to detect low level Gadolinium contamination in human tissue; and Arabidopsis seeds are irradiated for mutagenesis. Numerous industrial applications are also done on a fee-for-service basis. Examples include radiography of precision cast parts (Boeing and Lockheed Martin), carbon build-up in jet engine fuel nozzles (Goodrich), and fire retardant tanks (US Forest Service). Numerous companies use the neutron beam to evaluate radiation effects on electronics

(Cisco, Altera, Structural Integrity, Aerospace Corp., SAVEinc, and International Rectifier). In an agricultural application, NRT Growers are doing gamma irradiation of rice seeds.

The facility was originally built for neutron radiography, it is still among the leading neutron imaging facilities in the US. New detector techniques and new neutron optics are currently developed and tested worldwide. MNRC is in permanent contact with other facilities to keep its imaging facilities at the state of the art. This includes collaborations with National Laboratories such as Oak Ridge, Los Alamos and Lawrence Livermore as well as the NIST reactor. An effort to establish a high-pressure apparatus for neutron tomography is made in collaboration with Argonne and Los Alamos National Laboratories and the University of Edinburgh, Scotland. To better serve the NAA community upgrades of the detector systems are planned in collaborations with Lawrence Livermore and Lawrence Berkeley National Laboratories. These planned upgrades include detectors that are tailored to detect a particular isotope by using only a small energy range. To take full advantage of the reactors abilities to produce radioisotopes, a proposal has been submitted to become part of a consortium of university reactors to provide radiopharmaceuticals in response to a critical shortage in North America.

## Rhode Island Nuclear Science Center

The Rhode Island Nuclear Science Center is located on the Bay Campus of the University of Rhode Island. As enacted in the Rhode Island General Law, it was created for the purpose of research, experimentation, training personnel, testing of materials and techniques, and any other purposes that are deemed to be necessary for the health, welfare, and economy of the people of the state. By law, the use of the reactor is required to be made available to the colleges, universities, and industries of the state. Thus, rather than having one flagship university construct a reactor, the state of Rhode Island constructed a reactor for use by all of the colleges and universities within the state.

In November 1958, the people of the state of RI approved a bond issue for the construction of the Rhode Island Nuclear Science Center (RINSC). In July 1962, the Atomic Energy Commission (AEC) issued a construction permit, and ground was broken in August that year. The AEC granted the initial facility license for operation up to 1 MW in July 1964. At the end of that month the reactor was taken critical for the first time. In September 1968, the facility license was amended to allow operation up to 2 MW. In March 1993, an order was issued to convert the fuel from high enriched uranium (HEU), to low enriched uranium (LEU). In August that year, the fuel was converted and the initial LEU core was taken critical. In May 2004, a re-licensing application was submitted to the NRC. The facility is currently in the process of re-licensing.

The mission of the facility is to serve as a tool for education, research, and service work related to the nuclear industry and technology. The long term vision for the facility is for it to become an integral part of the national infrastructure that educates future scientists and engineers about nuclear technology and the nuclear industry, is used for research that utilizes nuclear technology and helps test materials for the next generation of nuclear reactors, and provides technical expertise and technology for industrial purposes.

The facility recently used federal grants and state funds to build a classroom and a student counting laboratory for use as part of the education mission.



The counting laboratory is equipped with high purity GeLi detectors which allow students to learn about neutron activation analysis.

The facility also recently upgraded the control rod drive system to a digital system. It is currently in the process of converting the cooling system instrumentation and control to a digital system. The short term plan is to upgrade the facility IT system so that control rod position information, and cooling system parameters could be sent via the internet as real time information for use in university classrooms.

Funding has been received for the purpose of setting up an additional counting laboratory that will have a variety of different kinds of radiation detectors for use as part of a nuclear measurements course.

In the future, the facility will pursue a power upgrade to 5 MW in order to make it more valuable as a tool for testing next generation nuclear reactor materials, and for producing medical isotopes.

RINSC has a wide variety of educational users, from a wide variety of education levels. The facility routinely hosts tours for the general public, specific groups such as the Boy Scouts, middle schools, and high schools. The facility provides laboratory support for chemistry, physics, and nuclear engineering programs at the community college, undergraduate, and graduate levels of education from many of the local institutions of higher education.

Over the years, RINSC has engaged in numerous research projects involving atmospheric chemistry, archeology, neutron capture therapy, etc. More than one hundred graduate degrees have been granted to students that utilized the facility for their research projects.

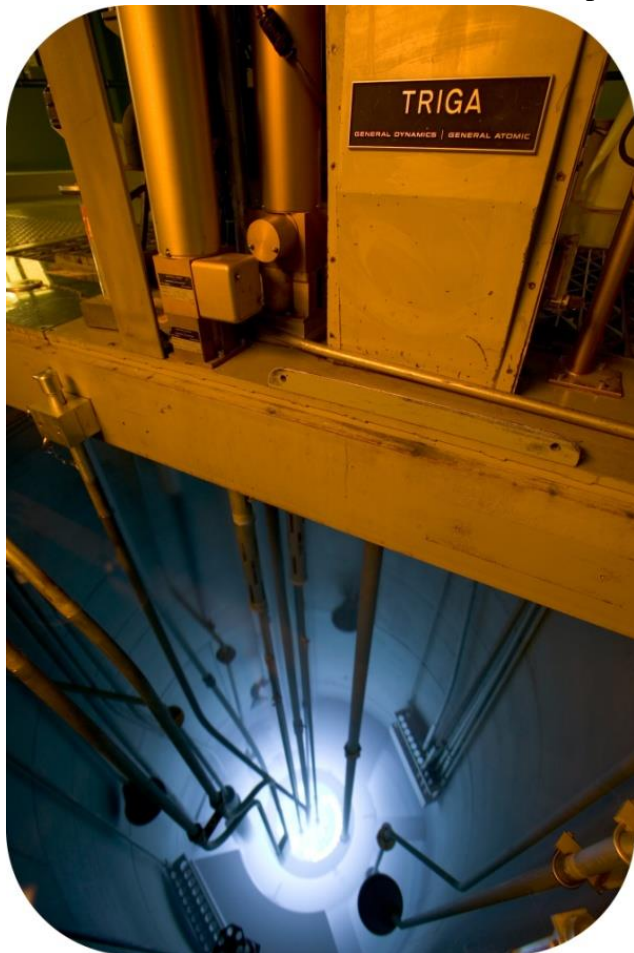
RINSC has a couple of consistent industry users, including Bio Physics Assay Laboratory (BioPAL) and Infoscitex. BioPAL has pioneered the use of neutron activation analysis (NAA) to provide an alternative technique for in vivo cell tracking and quantifying studies. They make use of their technique for a variety of treatment and research purposes including the area of stem cell research. Their customers are world wide. Infoscitex is currently working on developing radiation resistant glass and glass adhesives for use in solar cells. Irradiated reactor fuel is used as a gamma radiation source for their tests.

RINSC has two rabbit systems, four incore facilities, a central irradiation facility, six beam ports, a through port, a thermal column, dry tubes, and an irradiator room.

The L2 beam port has a wide angle scattering diffractometer on it, and the R2 beam port has a small angle diffractometer on it. The small angle diffractometer uses a state of the art plane neutron detector that a RINSC staff member helped develop in collaboration with Oak Ridge National Laboratory.

## Oregon State University

The Oregon State University TRIGA Reactor (OSTR) is a flexible research tool which supports international research and teaching activities across multiple disciplines. The TRIGA Mark II reactor achieved initial criticality using 20% enriched uranium fuel on March 10, 1967. Steady state power was limited to 250 KW, although reactor power could be briefly pulsed to several thousand MW. In 1969, maximum license steady state power was increased to 1 MW. In 1976, the OSTR was refueled with 70% enriched “FLIP” fuel. In 2008 the highly enriched fuel was replaced with 20% low enrichment fuel. The newest fuel maintains the performance characteristics of the FLIP fuel and has an expected lifetime of several decades.



and medical isotopes is also anticipated.

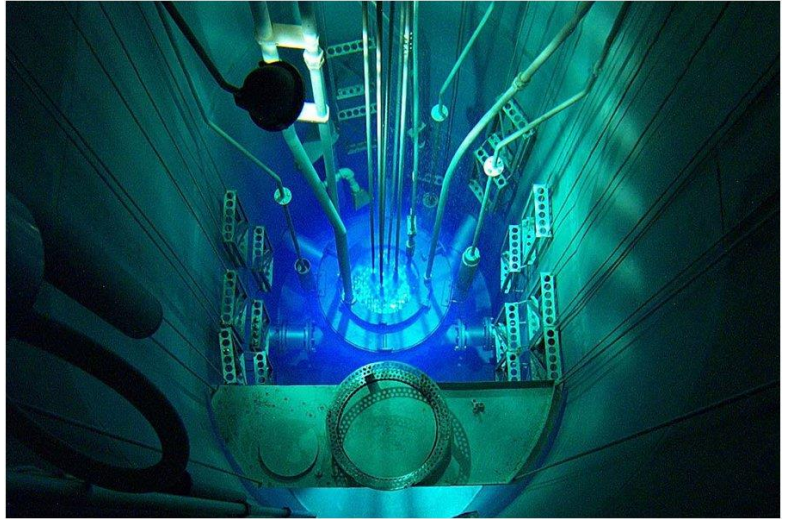
The OSTR operates a suite of experimental facilities in support of teaching and research. During the July 2008 - June 2009 reporting period the reactor supported 61 different academic courses. The number of samples irradiated in the reactor during this period was 997. The Radiation Center provided service to 64 different organizations, 39% of which were from other states and 22% of which were from outside the U. S. and Canada. Users of the facility published or submitted 114 articles during this period. Teaching and research conducted at the OSTR spans fields such as chemistry, physics, geology, archaeology and of course nuclear engineering and radiation health physics. Experimental facilities can be operated simultaneously in support of multiple research projects.

The staff of the OSTR looks forward to many years of productive operation. Plans include enhancement of existing facilities and addition of new facilities to allow neutron diffraction and crystallography studies. Upgrades of secondary cooling systems are in progress. Additional production of industrial



## University of Texas at Austin

The University of Texas at Austin has operated two different TRIGA reactors with the first located main campus beginning in 1969. The current TRIGA II reactor was licensed in 1993 for 1.1 MW operations, with pulsing to 2.2%  $\Delta k/k$ , in the Nuclear Engineering Teaching laboratory (NETL) located on the Pickle research Center campus 8 miles north of main campus. The NETL TRIGA (the newest U.S. university reactor) is scheduled for license renewal in 2011, and will include a request for increased power level.



The NETL is a multifunction laboratory supporting education, research & development, and nuclear-based testing. The reactor is a focal point for laboratory exercises and facility tours in the Nuclear and Radiation Engineering program of the Department of Mechanical Engineering. The reactor serves academic programs at other universities through the Big-12 Engineering Consortium, programs supporting historically black colleges and universities, and other special opportunities. The facility provides training and education for professional development programs with the USNRC and IAEA. The facility supports primary & secondary education and various other organizational programs with tours and demonstrations. The facility supports research for undergraduate and graduate programs, other universities, industry, and government laboratories.

The NETL facilities include capabilities unusual or unique to most university reactors, including a cold source, 6-meter neutron guide tube, and a capillary focusing device



The University of Texas at Austin has operated two different TRIGA reactors with the first located main campus beginning in 1969. The current TRIGA II reactor was licensed in 1993 for 1.1 MW operations, with pulsing to 2.2%  $\Delta k/k$ , in the Nuclear Engineering Teaching laboratory (NETL) located on the Pickle research Center campus 8 miles north of main campus. The NETL TRIGA (the newest U.S. university reactor) is scheduled for license renewal in 2011, and will include a request for increased power

level.

## North Carolina State University

The NCSU PULSTAR is a 1 MW pool type nuclear research reactor which is administered by the Nuclear Reactor Program and located in Burlington Laboratory on the N.C. State north campus. The NC State reactor is one of two PULSTAR reactors built, and the only one still in operation. The other reactor was a 2 MW reactor at the University of Buffalo, which went critical in 1964 and was decommissioned in 1994.

The PULSTAR fuel is 4% enriched, pin type fuel consisting of uranium dioxide pellets in zircaloy cladding. This fuel gives the PULSTAR Reactor response characteristics that are very similar to commercial light water power reactors. These characteristics allow teaching experiments to measure moderator temperature and power reactivity coefficients including Doppler feedback.

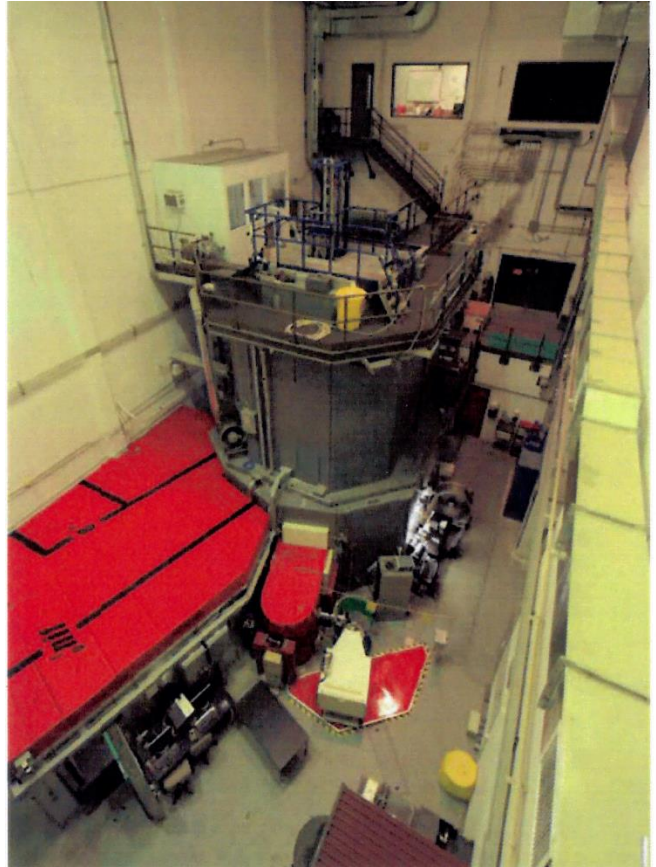
The heavy fuel load in the PULSTAR, combined with a relatively high fuel-to-moderator ratio, results in high fast neutron leakage at the core boundary. This causes a large thermal neutron “reflector hump” at the core periphery yielding high thermal neutron fluxes at the sample irradiation facilities and beamports. Currently the PULSTAR Reactor is undergoing a power upgrade to 2 MW.

Internet Reactor Laboratories are available to external academic institutions who wish to utilize the PULSTAR in demonstrating nuclear reactor operations and kinetics for their students. This capability enriches academic programs at universities without research reactors of their own, and may be used to expand the educational opportunities for nuclear engineering students throughout the United States and internationally.

Distance learning laboratory participants are able to interact with PULSTAR reactor facility personnel through direct video and audio communication links, and have the ability to direct remote control cameras in the reactor control room. An online data acquisition system is utilized to provide real time visualization of the reactor operating parameters, and for collecting experimental data.

The PULSTAR Reactor has four “User Facilities” which are available for use by research groups internal and external to the UNC system. Each of these four facilities harness the intense radiation fields emanating from the reactor beamports to create unique research and non-destructive diagnostic instruments.

At the NC State University PULSTAR Reactor laboratory, an intense positron source has been developed to supply a high rate positron beam to two different positron/positonium lifetime spectrometers. The positron source is comprised of a Tungsten moderator assembly surrounded by a Cadmium shroud located adjacent to the PULSTAR core in beamport #6. Positrons are

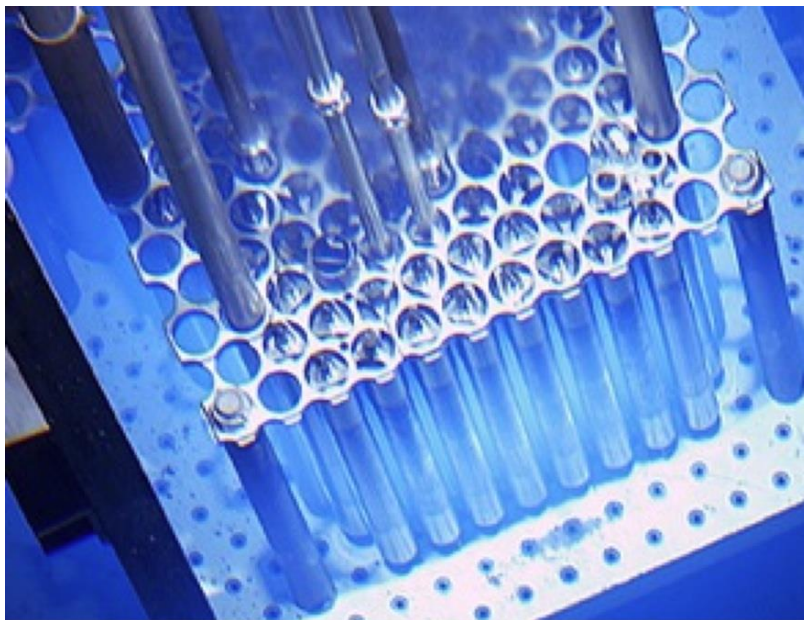




created when gamma rays emanating from the reactor, and from neutron capture in the Cadmium shroud, interact via pair production with the Tungsten.

## Penn State University

The Radiation Science and Engineering Center (RSEC) facilities include the Penn State Breazeale Reactor (PSBR), gamma irradiation facilities (In-pool Irradiator, Dry Irradiator, and Hot Cells), and various radiation detection and measurement laboratories. The PSBR, which first went critical in 1955, is the nation's longest continuously operating university research reactor. The PSBR is a 1 MW, TRIGA with moveable core in a large pool and with pulsing capabilities. The core is located in a 24 ft deep pool with ~71,000 gallons of demineralized water.



A picture of the reactor core is shown above. A variety of dry tubes and fixtures are available in or near core irradiations for Neutron Activation Analysis and other applications. A pneumatic transfer system is also available for irradiation of samples for Neutron Activation Analysis. When the reactor core is placed next to a D<sub>2</sub>O tank and graphite reflector assembly near the beam port locations, thermal neutron beams become available for neutron transmission and neutron radiography measurement from two of the seven existing beam ports. In steady-state operation at 1 MW, the thermal neutron flux is  $1 \times 10^{13}$  n/cm<sup>2</sup>sec at the edge of the core and  $3 \times 10^{13}$  n/cm<sup>2</sup>sec at the central thimble. The PSBR can also pulse with the peak flux for maximum pulse  $\sim 6 \times 10^{16}$  n/cm<sup>2</sup>sec with pulse half width of  $\sim 10$  msec.

The improvements for some existing RSEC facilities are currently underway or just completed. New core-moderator and beam port arrangement are planned with an expansion of the existing beam laboratory. The research areas envisioned for RSEC's new beam port/beam hall design primarily will be in cutting-edge nuclear science and materials science. Examples include the following: a Neutron Depth Profiling facility for depth vs. concentration measurements in materials; a Neutron Imaging facility that includes a neutron computed tomography capabilities for imaging of fuel cells and other technologically important components; a Cold Neutron Source and Cold Neutron Prompt Gamma Activation Analysis for neutron focusing research and determination of impurities in historically or technologically important material; and a Neutron Powder Diffractometer for structural determination of materials.

## Texas A&M University

The Texas A&M University Nuclear Science Center (NSC) is a multi-disciplinary research and education center supporting basic and applied research in nuclear related fields of science and technology as well as providing educational opportunities for students in these fields as a service to the Texas A&M University System and the state of Texas.

The NSC reactor, an 1-MW pool-type TRIGA reactor, is at the heart of the NSC facilities which includes a 2-MW micro-beam accelerator, a  $^{60}\text{Co}$  gamma calibration range, a real-time neutron radiography facility, hot cells and manipulators, radiation measurement laboratories, radiochemical laboratories, many HPGe gamma spectroscopy systems, and a variety of instruments for radiation detection and measurement.

The NSC reactor is designed for easy load and unload of various types of samples and is being actively used to produce various kinds of radioisotopes for industry, hospitals, and academic users. The NSC is also nationally recognized for its neutron activation analysis (NAA) services to many research and academic institutions in the western part of the United States. The NSC reactor actively supports the Nuclear Engineering Department on campus, one of the largest nuclear engineering programs in the United States. The NSC reactor is serving approximately 50 nuclear engineering students annually through its teaching and research activities. The NSC reactor has been also successfully used to attract students to nuclear engineering programs by providing introductory tours and part-time jobs. The NSC reactor has become one of the major attractions on campus. Through offering tours, the NSC is emphasizing the importance of nuclear energy in the United States.

With the strong support from the University, the NSC is continuously increasing the diversity of its facilities and services.



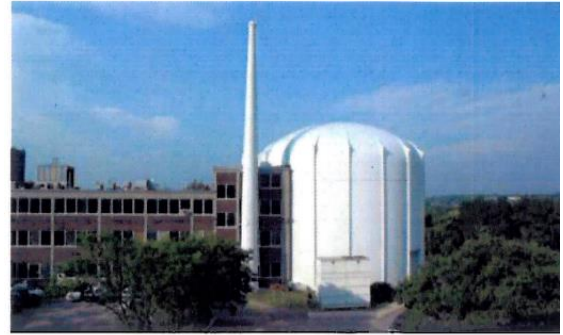
## University of Massachusetts at Lowell

The University of Massachusetts-Lowell Research Reactor (UMLRR) is an LEU fueled, one-megawatt, steady-state, pool-type reactor. It is one of three facilities within the University of Massachusetts-Lowell Radiation Laboratory, which includes various Co-60 gamma irradiators and a 5.5 MV Van de Graff accelerator. The principal purpose of the UMLRR is to provide a multidisciplinary facility for use in nuclear-related education and research.

Various experimental facilities within the UMLRR produce thermal neutrons for radioactivation purposes and fast (fission spectrum) neutrons for radiation effects research.

The reactor license also provides for a substantial Co-60 inventory. A number of high dose and low dose gamma irradiation facilities have been established to meet the needs of the aerospace and nuclear industries. The gamma facilities have a quality assurance program meeting 10CFR 50 Appendix-B requirements. The fast neutron and gamma facilities have been included in a lab suitability determination by the Defense Logistics Agency.

The major uses of the reactor include instrumental neutron activation analysis, neutron radiography, neutron and gamma irradiation of biological media, neutron irradiation of borated polymers, the production of short-lived isotopes for educational and research purposes, educational coursework, and personnel training. UMass Lowell was selected as part of a \$1.5M consortium awarded by the Department of Energy to study the scattering properties of neutrons. Part of the research work is expected to use the research reactor as a neutron source for various experiments. Over 30 organized groups are typically provided tours of the facilities each year.



The UMLRR is one of only three URRs in the US that has a full containment building. Despite the current license level of 1MW, the facility is designed for power levels up to 5MW. The current license is to be renewed in 2015. With adequate funding for cooling system improvements and a comprehensive safety analysis, the UMLRR could be licensed up to 5MW, which would provide substantially higher neutron fluences and subsequent research capabilities.



## University of Wisconsin

The University of Wisconsin Nuclear Reactor is a 1 MW, open pool-type reactor, fueled with TRIGA-LEU fuel with pulsing capabilities. The reactor first went critical in 1961 as a 10kW reactor utilizing GE-MTR fuel. It underwent a power up rate to 250kW in 1964 until 1967 at which time it was refueled with GA-TRIGA standard 8.5w/o, 20% enriched fuel and increased power to 1 MW. From 1973 to 1979 the facility commenced a refueling to an all TRIGA-FLIP core (8.5w/o, 70% enriched HEU). It operated with the all HEU core until 2009 at which time a complete refueling to TRIGA 30w/o, 20% enriched LEU fuel was initiated.

The UW Nuclear Reactor serves a vital role in the nuclear engineering curriculum and supporting research within the UW College of Engineering as well as other UW departments and other universities throughout the country. The UW Nuclear Reactor is an integral part of the nuclear engineering program; several core nuclear engineering courses directly use the reactor. The facility also provides significant educational outreach to the local community through the use of internet based remote distance education tools as well as traditional tours and demonstrations. The UWNr has



partnered with local technical colleges and power reactor operators to provide tailored educational programs in support of the nuclear industry's work force development.

Research is supported through services provided by the neutron activation analysis program as well as basic research conducted in the areas of neutron radiography and neutron radiolysis. Irradiation facilities are provided to permit use of radiation from the reactor for experiments. These facilities include three hydraulic irradiation facilities, four beam ports, one thermal column, and a pneumatic transfer system. The maximum fast and thermal neutron fluxes at 1 MW are  $3.0 \times 10^{13}$  n/cm<sup>2</sup>-s and  $3.2 \times 10^{13}$  n/cm<sup>2</sup>-s, respectively. As mentioned earlier, the reactor is capable of pulsed operations with a peak power of approximately 1000 MW and a pulse duration, measured by a full width at half maximum, of approximately 3 ms. The maximum fast and thermal neutron fluxes at 1000 MW are  $3.0 \times 10^{16}$  n/cm<sup>2</sup>-s and  $3.2 \times 10^{16}$  n/cm<sup>2</sup>-s, respectively.

The neutron activation analysis program at the facility utilizes two high purity germanium



spectrometers with integrated automatic sample transfer system for high throughput, rapid, irradiation and analysis. This capability is being enhanced with the development of a complementary prompt gamma neutron activation analysis system.

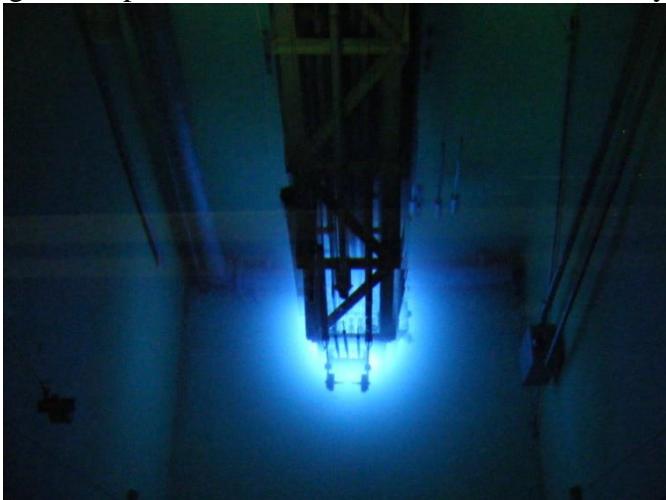
Future enhancements to the facility will be directed towards materials studies including development of new capabilities such as neutron depth profiling and neutron diffraction as well as enhancement of existing facilities such as refurbishment of the facility's hot cell and the current neutron imaging facility.

## Washington State University

The WSU Nuclear Radiation Center (WSUNRC) is an independent unit within the Office of Research at Washington State University. The WSUNRC operates as a campus-wide research facility, and provides research support, irradiation services, radioisotope production and laboratory space to faculty and students throughout the university. The WSUNRC operates the WSU nuclear reactor, which is a 1000 kW open-pool TRIGA-fueled reactor. Criticality was first reached in March, 1961 as a General Electric design using MTR-fuel, with a licensed power level of 100 kW. The reactor was converted to use TRIGA fuel in 1967, with an accompanying license modification allowing operation up to 1000 kW. The reactor was fueled with 8.5 weight percent, 20% enriched standard TRIGA fuel until 1976, at which time it was converted to operate with HEU fuel provided through the Fuel Life Improvement Program (FLIP). The WSU reactor was operated with a mixture of standard 8.5/20 and FLIP HEU-fuels until 2008, when the reactor was converted to an entirely LEU fueled core.



WSU maintains close ties with the Pacific Northwest National Laboratory (PNNL). The WSUNRC performs irradiation services, radioisotope production and analytical services on a frequent basis for researchers at PNNL. The WSU reactor is also used to produce radionuclides for research use in the radiochemistry program at WSU. The proximity to a source of radioactive materials and specialized radiochemistry laboratory space provides WSU faculty and students an unusual opportunity to carry out research that is not possible at most other educational institutions. Neutron activation analysis is carried out at the WSUNRC as a research and analytical service that is provided to graduate students and faculty members at the university. There are 14 irradiation positions adjacent to the reactor core, including a cadmium lined irradiation position that is used to provide epithermal and fast neutron irradiation. The WSUNRC also features a full suite of nuclear analytical equipment such as liquid scintillation counting, automatic gamma counting, alpha-spectroscopy and eight high purity germanium gamma spectrometers. The WSUNRC has recently received a grant to purchase a single crystal



x-ray diffractometer, which will be used for investigation of solid-state structure of radioactive materials, including molecules that incorporate radioisotopes that will be produced in the WSU reactor.

WSU does not have a nuclear engineering major, but does offer courses in nuclear engineering for undergraduate and graduate students through the College of Engineering. A course in Nuclear Reactor Operations is offered by the WSUNRC through the WSU Department of Chemistry. The course is designed to

give students a basic understanding of the principles of nuclear reactor operation and provides a foundation for continued study to prepare students to take the U.S. Nuclear Regulatory Commission (NRC) Reactor Operator licensing examination.

The WSUNRC produces radioisotopes for national laboratory and business clients who use the materials for research and commercial purposes. The income that is generated through radionuclide production and irradiation services is reinvested by supporting students and staff members who provide these services in addition to supporting R&D by staff and students. The WSU reactor has pulsing capability, with pulses reaching as much as 1000 MW. The pulsing of the reactor is regularly used in cooperation with staff scientists at PNNL for research projects such as the determination of short-lived fission product yields. The reactor facility features ten beam ports, including a well-characterized epithermal neutron beam port that was designed for research in boron neutron capture therapy.

Plans for the future include an anticipated application in 2011 to the U.S. NRC for a license modification allowing a power uprate to 1300 kW. WSU also intends to install reactor upgrades such as a pneumatic transfer system for small samples to improve capability for analysis of short lived fission and neutron activation products and an enhanced cooling system for the reactor. Long-term strategic plans include continuing to develop a customer base for irradiation and analytical services to provide a stable funding mechanism for support of the research and education mission of the WSUNRC.



## Ohio State University

The Ohio State University Research Reactor (OSURR), in operation since 1961, is an open pool-type reactor that is utilized for a variety of instructional, research, and service activities. It is licensed for steady state operation (no pulsing) up to a maximum of 500 kW thermal power. At full power, it has a maximum thermal flux in the center of the core of  $1.5 \times 10^{13}$  n/cm<sup>2</sup>/s and a total flux of  $3 \times 10^{13}$  n/cm<sup>2</sup>/s. The reactor is fueled with MTR-type LEU fuel and is immersed in a pool of light water that provides moderation and cooling by natural convective flow. From 1961 until 1988 it operated with HEU fuel, and in 1988 it was one of the first few research reactors to convert to LEU and the first to convert to uranium-silicide fuel. Analysis for a power uprate was part of the conversion process, and in 1990 the OSURR was granted a power increase to 500 kW.



A number of experimental facilities converge at the reactor core, allowing simultaneous performance of multiple experiments. These facilities include two beam ports, a pneumatic transfer system, a graphite thermal column, a central irradiation facility that extends into a water-filled flux trap, two auxiliary in-core dry tube irradiation facilities, and multiple movable dry tubes that can be positioned next to the core.

The OSURR is used for a wide range of research endeavors, including neutron activation analysis (NAA), radiation-damage evaluation for electronic components and for other materials, evaluation of neutron and radiation sensitive detectors, isotope production, and biomedical experiments. The OSURR provides a variety of instructional services, including facility tours, student laboratory sessions, and research projects structured to student and faculty interests. It is not constrained by a fixed duty-cycle, allowing great flexibility in scheduling research and education and performing demonstrations and laboratories that include power changes. Many student laboratories include start-ups and shut-downs, allowing students to observe the reactor dynamics associated with these. NAA research utilizes a professional gamma-ray spectroscopy system consisting of three shielded high purity germanium spectrometers and a computer-based data collection and analysis system.

Some exciting developments are on the horizon for the OSURR. An external neutron beam facility is being designed and constructed at Beam Port #2, which will provide a small-sized clean neutron beam for *real-time* testing of neutron detectors and *in-situ* characterization of nuclear materials with nuclear analytical technologies (e.g. neutron imaging and neutron depth profiling). In addition, a low-activation high-temperature irradiation facility for optical fiber testing is being developed as a part of a Department of Energy (DOE) NEUP research project, and a cryogenic irradiation facility will soon be created using funding from a DOE NEUP Minor Reactor Upgrade grant. The same Minor Reactor Upgrade grant is also funding installation of an upgrade to the cooling system that will enable full-power operation for prolonged irradiations during the hottest summer days, which is a capability that could not be guaranteed prior to the upgrade.

## Kansas State University

The Kansas State University TRIGA Mk-II reactor is a pulsing research reactor operated by the KSU Department of Mechanical and Nuclear Engineering in Manhattan, Kansas. It was constructed beginning in 1958, with initial criticality achieved in 1962, and has served a vital role in the United States' first accredited nuclear engineering program. The KSU TRIGA is presently licensed to operate at up to 1.25 MW thermal power, although power is currently limited to 550 kW by thermal feedback. The core was originally designed to use 19.5%-enriched, 8% uranium by weight, aluminum clad fuel. The current core uses 8.5% weight percent uranium stainless-steel fuel, with plans to incorporate 12% loaded fuel in the near future to allow operation at higher power.

The experimental facilities at the reactor include: irradiation volumes such as the central thimble and reflector well; four beam ports, with different energy spectra and fluxes; a pyrolytic graphite monochromator; and a counting laboratory featuring high-purity germanium gamma spectroscopy detectors.

The reactor has four primary roles: research support; education; training; and outreach. The research support mission is partly fulfilled through providing neutron beams for prototype neutron detector testing. This is an especially vital role, as SMART Lab, a premier semiconductor neutron detector development center, is located at KSU and frequently makes use of the reactor for device testing. Another significant area of research support is neutron activation analysis, for such customers as the Indoor Environmental Research (IER) lab, entomologists, and geologists.

The reactor hosts two nuclear reactor operations laboratory courses, and provides tours and sample irradiations for numerous other courses throughout the University.

The KSU TRIGA is staffed entirely by undergraduate students, with the exception of the Reactor Manager. Therefore an important mission of the reactor is to continuously train new operators to staff the reactor as experienced personnel graduate. This gives many KSU students the opportunity to graduate as NRC-licensed Reactor Operators and Senior Reactor Operators.

Numerous tour groups visit the KSU reactor, including hundreds of visitors in a single event, Engineering Open House. Other visitors and outreach groups include the Boy Scouts, Girl Scouts, local high schools and grade schools, classes from nearby universities, and outreach programs hosted by the University.

Planned improvements at the reactor include upgraded research infrastructure, including a new neutron radiography system, and a power increase pending approval to incorporate higher-load fuel into the core.



## Reed College

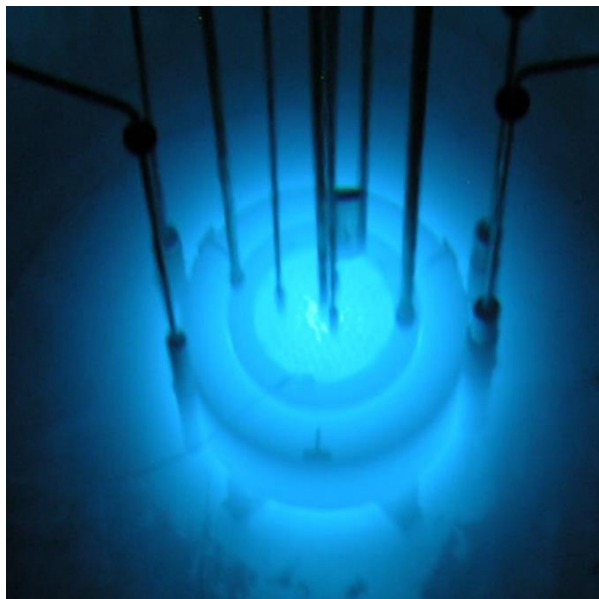
The Reed Research Reactor is a 250 kW TRIGA<sup>®</sup> Mark I water-cooled reactor. It uses standard 8.5w/o, 20% enriched TRIGA<sup>®</sup> fuel in a circular grid array. Most reactor components are clad with aluminum. The reactor sits at the bottom of a 10-foot by 15-foot tank, 25-feet deep. The Reed Research Reactor has been used for research and educational projects in the Portland area since its establishment in 1968. A power upgrade to 500 kW is planned for 2011.

The Reed Reactor Facility is primarily used for instruction, research, and analysis for Reed College faculty and students. The reactor and associated facilities are used in chemistry, biology, and physics courses, as well as the senior thesis required of all Reed students. In addition to providing student research opportunities, the reactor works to educate the surrounding community on the principles of nuclear energy and fission-reactor operation.

Between 40 and 80 students attend the reactor seminar that meets twice a week through the school year. This is out of a freshman class that averages 300. A maximum of 15 students are allowed to apply for NRC licenses each year, and the competition is tough. The students are primarily physics, chemistry, biology, and mathematics majors, but students with majors in studio arts, art history, literature, philosophy, economics, sociology, political science, classics, and religion have recently obtained licenses. The number of students who use the reactor for thesis research varies from a just a few to over a dozen each year. Each year a few students from other colleges and universities use the reactor for their research.

The full time staff consists of the reactor director and assistant director. The reactor is operated almost entirely by licensed undergraduate students working as part-time employees. There are approximately 25 student reactor operators and 15 student senior reactor operators, evenly divided between women and men. Reed is the only liberal arts college in the world with a nuclear reactor.

Irradiation Facilities include a pneumatic transfer system (rabbit), a rotating specimen rack (lazy susan) with 40 locations each of which can hold 2 samples, a central thimble (one sample), a vertical beam facility, an irradiation chamber in dummy fuel element, and foil-insertion holes. Near core, in-pool irradiation facilities can be arranged for larger samples.



## University of California at Irvine

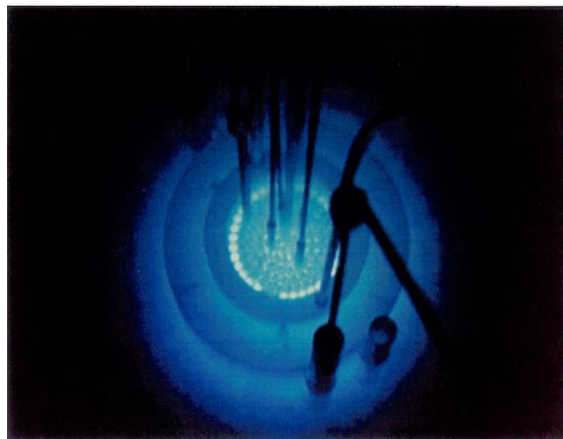
The UCI Nuclear Reactor is operated by the Department of Chemistry for use in radiochemistry applications. The reactor is a 250 kilowatt steady-state power Mark I TRIGA reactor built by General Atomics. Pulsing is possible to about 1000 megawatts if needed. TRIGA reactors are water and zirconium hydride moderated to be especially safe for training and research purposes. The reactor first became critical in November 1969 and has been in continuous use in teaching and research since then. The facility specializes in neutron activation analysis (NAA) using thermal and epi-thermal neutrons. Past work has included measurements on the JFK assassination bullet

lead, mercury levels in ancient specimens of swordfish and tuna, sculptures in the Getty Museum in Los Angeles, ancient bone, samples of mosaics from St Vitus Cathedral in Prague, and tracing manganese pollutants. Work is also being done to test systems and detectors for homeland security screening applications. The facility has provided short-lived radioactive isotopes on multiple occasions for tracer/tracking studies in industry and medical research.

Current research in the Department of Chemistry continues with improvement of methods for neutron activation analysis and provision of tracer radionuclides. Support for research at other universities is aiding studies in art and archeology and geo- and astro-chemistry. A new program in the department of Chemical Engineering and Material Science focuses on improving solvent extraction separations of actinides and lanthanides in association with spent fuel reprocessing and uses both tracers and neutron activation analysis in that work. This program is also using the reactor, along with other techniques, to study the radiolytic chemistry of materials used in those extractions. The combination of controlled radiolysis using the TRIGA reactor, and NMR analysis of the product distribution using modern 2D NMR techniques, has improved the understanding of these liquid extraction systems.

A primary function of the reactor is to support the educational programs at UCI. Courses in Radioisotope Techniques, Nuclear and Radiochemistry, and Nuclear Reactor Fundamentals are offered in the chemistry department's elective curriculum. Facilities for research as well as for tours and demonstrations are available to the many surrounding colleges and universities in the entire Southern California region. In addition a Nuclear Science Outreach early education program takes radioactivity equipment and measurements to high school classrooms and encourages visits to the facility to encourage students to learn about and consider careers in nuclear science. The reactor is also used for training reactor operators.

The maximum steady thermal neutron flux is about  $5 \times 10^{12}$  neutrons/sec.cm<sup>2</sup>. Large numbers of samples can be simultaneously irradiated at a flux of about  $1 \times 10^{12}$ . In-core pneumatic transfer systems are installed to return samples in 2 seconds, or 1/2 second respectively. For the fast system a thermal or epithermal flux (Cd lined) terminus is available in core. Samples can be returned to either a manual unload port or to automated systems including a gamma ray spectrometer station or a neutron counting station (for delayed neutron counting). Pulses can be made to provide the equivalent of a one hundred second irradiation, but with the flux peaking near  $10^{16}$ n/sec.cm<sup>2</sup>.



Two gamma-ray spectrometer systems are available, each with an HPGe detector, digital MCA's and modern software systems. One is a 30% detector, one a 60% detector. A Compton suppression set-up enables measurement of low energy gamma rays and an automatic sample changer. The larger detector can be used with a 300 sample automatic sample changer for long sequenced counting.. Sodium iodide gamma detectors, proportional beta counters, helium-3 neutron counters, and a liquid scintillation system are also available. Chemistry laboratories are available within the facility and elsewhere for radiochemistry applications. Also available is a gamma irradiator with a large chamber for gamma radiation exposure studies.

Future goals include upgrade of instrumentation to provide education and operator training in modern digital control systems, raising the power level to enable a greater variety of experiments, and introduction of new educational experiences for students such as courses in nuclear instrumentation, nuclear regulation issues, advanced radiochemistry and combining these and existing courses into a nuclear science minor and a nuclear science concentration. Reactor operator training will be offered more widely to undergraduates as well as graduate students, and to students from other colleges and universities. In addition we are actively seeking industry collaboration in support of workforce development for the Southern California region, which includes nuclear utility operations as well as several companies with products and services in nuclear instrumentation and other nuclear science fields.



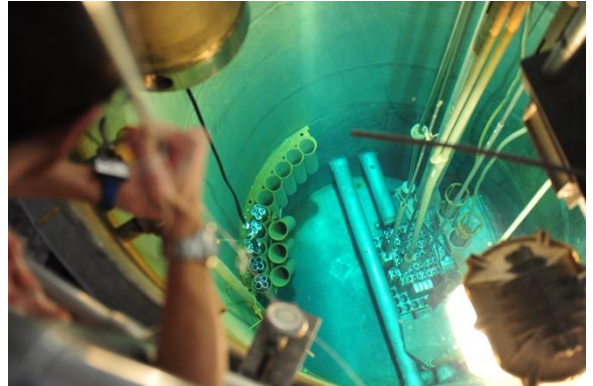
## University of Maryland

The University of Maryland Training Reactor is located in College Park, Maryland. This TRIGA reactor is licensed to operate at 250 kW. The reactor initially went critical on June 13, 1974 and initiated operation at full power in May 1976. This reactor is operated as needed (daily if needed) to support the educational and experimental programs of the university.

The reactor structure at the University of Maryland (UMD) was originally installed as a 10 kW materials testing reactor in 1960. In 1970, the concrete tank was converted to house a very early model 250 kW TRIGA reactor. The open-pool Maryland University Training Reactor (MUTR) first went critical on June 18, 1974. The MUTR completed the timely license renewal process in 2016 which included an increase in our possession limit of U-235. A shipment of 19 lightly-irradiated fuel elements removed from storage at Idaho National Laboratory were delivered in March 2017. Currently, the elements are in storage awaiting the completion of a license amendment request for use in our core.

The MUTR supports undergraduate and graduate education, research and development and radiation-based testing. The reactor offers five experimental facilities: a graphite filled thermal column for neutron imaging, 2 beam ports and 1 through-tube for the placement of samples adjacent to the core, and in-core irradiations of small sample size can be performed using the pneumatic transfer system. The facility maintains an active outreach program for primary and secondary educational institutions and other community organizations with tours and demonstrations. In addition to the MUTR, the radiation facilities at UMD are comprised of a 6 MeV electron linear accelerator, an intense Co-60 source, and an educational cyclotron.

Currently, the MUTR supports a neutron imaging research program in the Materials Science and Engineering department at UMD.

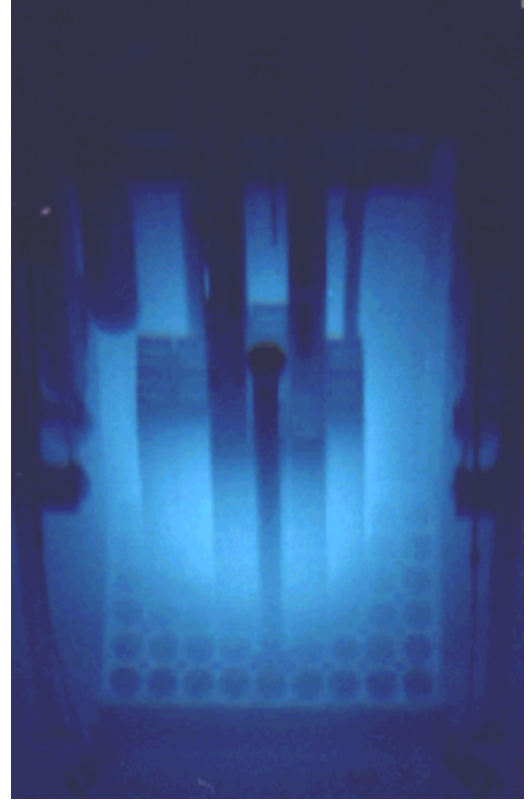


## University of Missouri S&T

The University of Missouri Research Reactor (UMRR) was the first operating nuclear reactor in the state of Missouri. The initial licensed power was 10 kW. The licensed power was upgraded to 200 kW in 1966. During the summer of 1992, the reactor fuel was converted from high-enriched uranium fuel to low-enriched uranium. The facility is equipped with several experimental facilities and a counting laboratory that has gamma and alpha spectroscopy capabilities. The gamma spectroscopy system includes germanium and sodium-iodide detectors, associated electronics, and state-of-the-art data acquisitions and spectrum analysis software. The alpha spectroscopy system consists of a surface barrier detector and data acquisition equipment. The beam-port experimental area is equipped with NE-213 and time-of-flight neutron spectroscopy systems.

An average of more than 900 students from 40 different institutions participate in the Reactor Sharing Program at UMR. Ours is a model program that directly meets DOE objectives of strengthening nuclear science and engineering instruction, as well as providing research opportunities for faculty and students from non-reactor owning universities. Typical Reactor Sharing session topics include: Radioisotope decay and Half-Life Determination, Neutron Activation Analysis, Reactor Systems and Operations, Radiation Shielding and Reactor Experiments. The UMRR also provides one-on-one individual science project research. Several high school students perform individual science fair projects every year at the UMRR facility.

Nuclear Engineering students have performed graduate level research on genetic algorithm unfolding, thermal power calibration, neutron spectroscopy and safety analyses of the UMR Reactor within the last two years. Nuclear Engineering (NE) utilizes the facility for full time courses in the undergraduate program. Other departments using the UMRR include Physics, Chemistry, Chemical Engineering, Mechanical Engineering, Life Science, Civil Engineering, Basic Engineering and Engineering Management. The University of Missouri-Columbia has training for reactor theory and reactor operations with a graduate class at the UMR Reactor Facility annually. This training is a condensed version of one of the UMR NE classes. The UMRR Facility provides training for power plant reactor operators from within the state of Missouri.



## **University of Florida**

The University of Florida Training Reactor (UFTR), first licensed in 1959, was one of the first nuclear reactors on a university campus. The reactor operates at a maximum thermal power level of 100 kilowatts in a loop-type design versus the more familiar pool-type non-power reactor.

The UFTR is used within the Nuclear and Radiological Engineering Department at the University of Florida to train students to operate reactors, for laboratory courses for a variety of departments including Physics, Chemistry, Geology, Mechanical Engineering, Anthropology, and Environmental Engineering Sciences, among others, and as a radiation source for various research programs and experiments such as trace element analysis of ocean sediments, river sediments, foods, plants and many other materials. Recent trace element analysis projects utilizing neutron activation analysis include measurements of mercury and arsenic levels in fresh fish, silver in zeolites and contact lens as well as copper, chromium and arsenic in treated wood and wood ash. The facility also has a neutron radiography capability using film cassette technology. The facilities are also available to other schools at no cost for non-externally funded programs through the Department of Energy Reactor Sharing Program (DOERSP). Under DOERSP, the UFTR has been used to train technologists in medical physics and radiation protection and conduct numerous educational and research activities. External users over the past seven years include more than forty schools located around Florida and the Southeast including Florida State University, Stetson University, Florida Institute of Technology, University of South Florida (Tampa), University of Central Florida, Savannah State University, St. Petersburg and six other community colleges, as well as Crystal River High School, St. Augustine High School, and many other high schools, professional and civic groups. Indeed, we have had more than a dozen regional science fair winners perform research at our analytical laboratory in the last six years, some on projects suggested by teachers, others suggested at the UFTR.

More recently the mission vision for the UFTR has expanded to make it a more accessible and useful tool for industry, including nuclear utilities. The facility is undergoing a complete mechanical renovation and upgrade to a fully digital control system. Because the UFTR is a relatively low power reactor (100 kW) the irradiation capabilities, and in-core flux limits the scope of applications of which it is capable compared to many other research reactors. In view of this a research, development and modernization program was initiated to focus on the design and installation of the first fully digital control system for a nuclear reactor within the United States. The modernization procedure over the past 4 years has, or will, include a modernization of essentially the entire UFTR facility. This includes the complete replacement of the fuel with new low-enriched fuel, the fabrication and refueling processes funded by the US Department of Energy. The DOE's NNSA has also initiated the installation of a updated security system. Subsequently in 2009-10 the reactor was disassembled to replace all of the major mechanical components of the facility, including water piping, fuel boxes, clutch couplings, etc. These upgrades were funded through a combination of federal, state, and industry financial support which also contribute to the upgrade of the original control system, to a fully digital control system that interfaces with a digital safety system. The digital control upgrade will incorporate a new control room, is scheduled to be completed in October 2011 and will serve as a demonstration and training resource for the integration of state-of-the-art digital control system integration with nuclear reactors.



## University of Utah

The University of Utah TRIGA Reactor (UUTR) is licensed at 100 kW thermal power; reactor is an open pool-type. Currently, the UUTR operates at the maximum power of 90 kW. The UUTR uses TRIGA standard 8.5 w/o, 20% enriched fuel and heavy water and graphite elements as reflectors. The reactor construction started in 1972; the UUTR went critical in October 1975.

The UUTR reactor is used for research, training of our students to operate the reactor, and education with hands-on experience for 35 years within the University of Utah. Main mission of the UUTR is that it represents an integral part of our nuclear engineering program, provides broad opportunities for academic research and services to industry, is used to train students for operating licenses and is used for educational outreach. Our vision is to establish the UUTR as a hub for hands-on learning of nuclear engineering principles in western states.



In 2009 we have established a new nuclear engineering curriculum inclusive of advanced graduate courses and a minor degree in nuclear engineering, centering on the hands-on experience using the UUTR in majority of our courses, as well as using UUTR in enhancing course work in radiochemistry, nuclear forensics, nuclear safeguards simulation & visualizations of reactor neutronics and other reactor phenomena. Recently we also provide courses remotely and accept students from other Universities for laboratory practices at the UUTR facility. The UUTR and the “*Utah Energy Playground*” Museum provide significant educational outreach to the local community through the traditional tours and demonstrations. Approximately 500 visitors mainly from elementary, junior high and high schools visit the UUTR and Museum every year. Besides serving the academic community of the University of Utah and local community, the UUTR serves also commercial and government entities, other Universities and National Laboratories in providing a variety of nuclear engineering services and educational and research opportunities. Research is supported through various grants and awards, as well as recently re-established services by the neutron activation analysis (NAA); our main service-based research is in a field of neutron hardness tests provided for the U.S. Air Force. Irradiation facilities at the UUTR include Fast Neutron Irradiation facility (FNIF), Thermal Neutron Irradiator (TI), Pneumatic Irradiator (PI), and Central Irradiator (CI). The maximum total neutron flux at 90 kW is  $3.6 \times 10^{12}$  neutrons/cm<sup>2</sup>-s in CI. The UUTR has a unique FNIF; that facility provides 1 MeV equivalent fast neutron beam with the maximum neutron flux of  $2.1 \times 10^{11}$  neutrons/cm<sup>2</sup>-sec. The TI provides well-thermalized neutron flux of  $3.69 \times 10^{11}$  neutrons/cm<sup>2</sup>-sec. The NAA program at the UUTR is redeveloped to increase the use of our reactor. The PI (Pneumatic Irradiator) that transfers a sample to the detector using a pressurized helium gas to minimize contamination and dose to operating staff is in the re-modeling process to maximize its capability.

In years to come we plan to increase the total power output of the UUTR; develop few benchmark examples for testing new computational efforts in accurately predicting reactor core performances; establish rather unique Boron Neutron Capture Therapy experiments tailored

toward new modes of targeted treatments for aggressive cancers; design and build neutron radiography using under-water removable beam ports, and improve NAA service lines.

## Purdue University

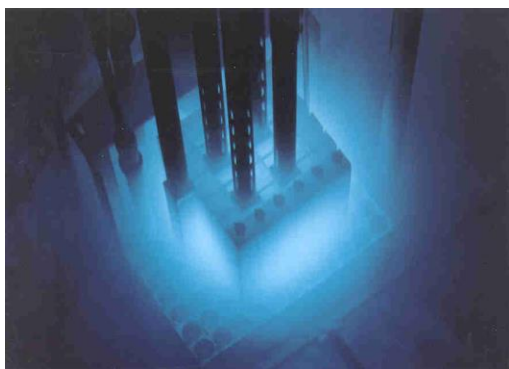
The Purdue University School of Nuclear Engineering operates the PUR-1 reactor. This reactor is the first and only operating reactor in the state of Indiana. It is used as an integral part of both the undergraduate and graduate programs in Nuclear Engineering, as well as having a highly visible role in public education about nuclear processes.

The PUR-1 reactor is a 1 kW pool type reactor that utilizes flat plate MTR type fuel. First critical on August 30<sup>th</sup> in 1962, the reactor was re-licensed in 1988 for an additional 20 years of operation. The reactor is operated as needed for classes, presentations, and research.

The primary mission of the reactor is education, not only of Purdue University students, but of area high school students and the general public as well. The reactor is also available for research projects by University users as well as outside groups.

There are two courses in Nuclear Engineering (one undergraduate and one graduate) that make direct use of the reactor. Specifically, the students operate the reactor and perform experiments to learn reactor physics principles. There is also a third course in the School of Health Science wherein the students calibrate some of the reactor instrumentation and irradiate samples for analysis in their lab course.

The PUR-1 reactor facility also runs a neutron activation analysis class for area high school students under a reactor sharing grant. These students spend the entire day in our lab learning how to use gamma spectrometers, in conjunction with the reactor to produce samples for them to identify. This program has operated for the last fifteen years and has an average of 6-7 high schools with 8-10 students each participating each year. This year, only two weeks after

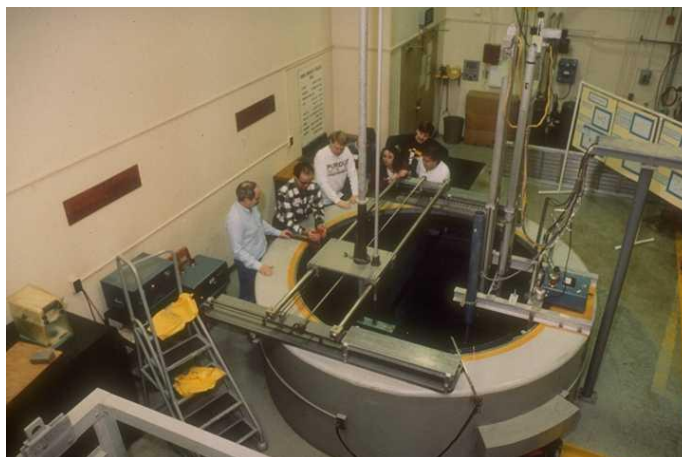


invitations were mailed to teachers, four groups involving fifty students have already responded.

The reactor is also assigned a prominent role in educating the public about nuclear processes.

Lecture/tour combinations are offered to student groups, Purdue classes, and the community. This emphasis was increased in the last three years and an average of 800-1000 people toured the facility each of those years. We are currently collaborating with Rush University Medical Center to perform preliminary work on a variation of the Boron Neutron Capture Therapy

(BNCT) method for treating malignant brain tumors.



## Idaho State University

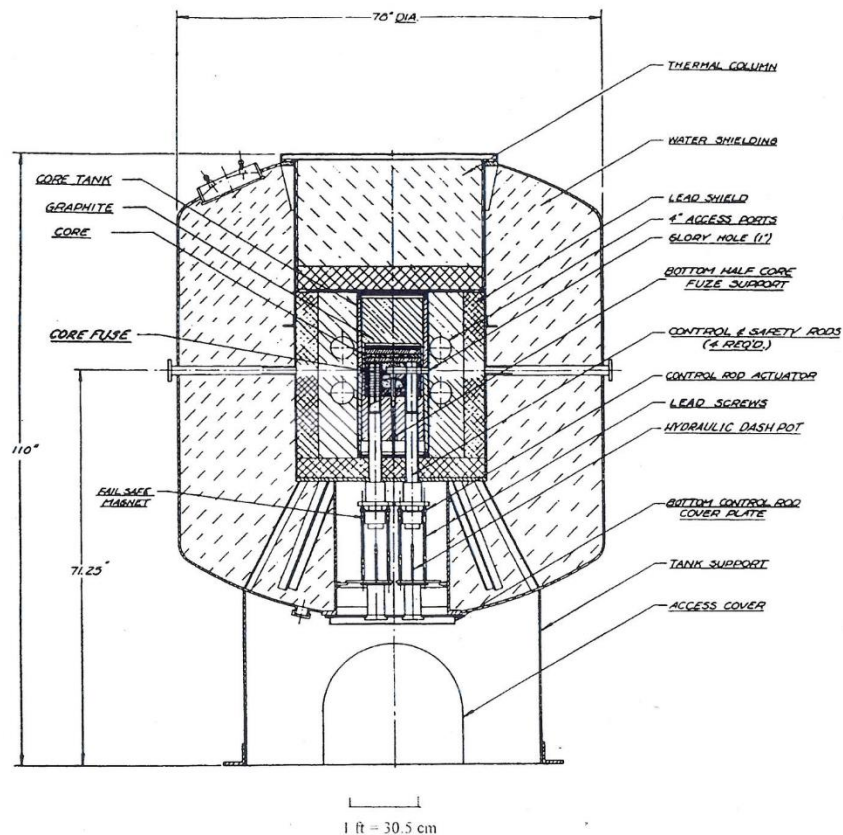
Idaho State University has an AGN-201 Training Reactor, designed and built in the 1950s by Aerjojet General Corporation, as an ultra safe training reactor. About 30 of these were built and distributed to various universities by the Atomic energy Commission. Idaho State University received it in 1967, and the unit is housed in the reactor room in the basement of the Lillibridge Engineering Building.

These are considered "training" reactors, not research reactors, though we have done a number of both MS theses and one PhD dissertation using the reactor as the base experimental device, though it is licensed for only 5 watts power.

This reactor type is very unique, probably the lowest critical mass of LEU (low enriched uranium, 19.9% U-235) of any device that has ever been built. It has about 672 grams of U-235 (2688 grams of U-238), and at 15 C has a k-excess of about 0.5% delta k.

This subcritical facility presents a significant contrast and challenge to the students, concerning reactor physics design and the optimum designs to achieve criticality. We have two NRC licenses, one for the Reactor, and one for the SNM in the Subcritical Facility.

Idaho State University has no external commercial customers. ISU has a number of research contracts in cooperation with the INL, and several of these use the AGN-201 as part of the research.



AGN-201 reactor unit.



## University of New Mexico

The University of New Mexico has operated its AGN-201M reactor at its Albuquerque campus since it arrived from the University of California at Berkeley in 1966. In 1986, the license for operation was renewed for another 20 years, expiring on March 20, 2007. License renewal has been filed with the NRC and another 20 year license is expected to be granted April 2010. Although many universities have decommissioned their reactors, UNM feels that an operating reactor is an invaluable teaching tool for our nuclear engineering program. With the license renewal application in 2007, we renewed our commitment to



maintaining and using this facility for the next 20 years. The AGN-201M reactor continues to be used extensively for teaching and for experiments as part of our undergraduate and graduate programs. Because of the low power level, the AGN fuel can be removed and handled by students providing hands-on opportunities to learn about handling radioactive materials and performing an approach to critical experiment. Other experiments include: reactor period and reactivity measurements, importance function measurements, neutron temperature measurements, reactor power and fluence measurements, control rod calibrations, sample activation, and void coefficient measurements. We also use the reactor in support of our faculty and student research efforts. It is regularly used in the Fall and Summer Semesters to provide demonstrations and support research. Its heaviest use occurs during the Spring semester when both seniors and graduate students are enrolled in the reactor laboratory classes. During this time, the reactor is used twice a week for an average of 10 hours of operational time per week.

The AGN reactor is a homogeneous thermal reactor, used for teaching and training. The reactor core is 25.6 cm diameter by 24 cm high and it consists of nine fuel discs that are separated at the mid-plane by a thin aluminum baffle. A 1-inch inside diameter glory hole passes through the center of the core in the radial direction. The AGN-201M reactor can provide neutrons with a flux of  $2.5 \times 10^8$  thermal neutrons /  $\text{cm}^2\text{-sec}$  at the centerline in a 2.3 cm diameter experiment port. The reactor is licensed by the US Nuclear Regulatory Commission. Operation must be done under the supervision of licensed Reactor Supervisors (Currently there are 3 licensed Reactor Supervisors on staff).

Two research projects have been carried out using the AGN-201M reactor over the past ten years. First, the reactor has been used to generate reference samples for a project which analyzes beam energy spectra from pulsed power facilities. Foils of different materials are activated in the reactor to determine their responses to thermal neutrons and to analyze content particularly with respect to impurities that may be present. The second project is a small sample reactivity measurement technique that is being applied to geologic samples to determine their thermal neutron cross sections and relative water content. This work has application in both the oil well core logging industry and in the waste disposal area where pulsed neutron logging techniques are widely used. Again the effort of the research is to create references which can be used to validate and interpret pulsed neutron data.

## Rensselaer Polytechnic Institute

The Rensselaer Polytechnic Institute Reactor Critical Facility (RCF) is a zero power, open pool-type reactor, fueled with SPERT F1-LEU fuel pins. The reactor first went critical in 1957 as a critical facility for the Army packaged-power reactor program utilizing high-enriched, plate fuel. RPI has operated the facility since 1963 as a research and teaching facility. It underwent a conversion from high-enriched plate fuel to low-enriched (4.81 w/o)  $\text{UO}_2$  pins in 1985-1986.

The RCF serves a vital role in the nuclear engineering curriculum at RPI. The Critical Reactor Laboratory class has been very popular and has recently been made a required class in the undergraduate nuclear engineering curriculum. In addition, many undergraduate research projects, Master's level theses and several Ph.D. theses have been performed utilizing the reactor.

The facility is also in the process of providing distance and blended learning opportunities. Several remotely controlled cameras provide the capability to tape class room lectures and experiments. RPI is working toward full videoconferencing capabilities to support remote teaching.

Since the RCF is uniquely configured to support critical benchmark experiments, most of the research activity has been in the area of critical benchmark measurements. This has included reactivity worth measurements of new poison materials and critical configurations using different metal reflector materials.

The facility possesses a gamma-spectroscopy capability using a NaI detector and MCA card in a PC-based system. The spectroscopy equipment is used for foil activation experiments and gamma scanning of activated fuel pins for power mapping experiments.



Future enhancements to the facility will be directed towards improving the distance and blended learning capabilities with full videoconferencing capabilities and expanding the role of the facility in the undergraduate nuclear engineering curriculum. Efforts to characterize the facility for performing high-quality critical benchmarks are also being pursued. Upgrading the gamma-ray spectroscopy experiment is also planned with a replacement of the NaI system with a more modern germanium detector system.