MIT NUCLEAR REACTOR LABORATORY

AN MIT INTERDEPARTMENTAL CENTER

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U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

Attn.: Document Control Desk

Subject: Annual Report, Docket No. 50-20, License R-37, Technical Specification 7.7.1

Gentlemen:

Forwarded herewith is the Annual Report for the MIT Research Reactor for the period from January 1, 2018, to December 31, 2018, in compliance with paragraph 7.7.1 of the Technical Specifications issued November 1, 2010, for Facility Operating License R-37.

Sincerely,

Sarah Don
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EL/st

Enclosure: As stated

cc: USNRC – Senior Project Manager
Research and Test Reactors Licensing Branch
Division of Policy and Rulemaking
Office of Nuclear Reactor Regulation

USNRC – Senior Reactor Inspector
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Office of Nuclear Reactor Regulation

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MIT RESEARCH REACTOR
NUCLEAR REACTOR LABORATORY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

ANNUAL REPORT

to

United States Nuclear Regulatory Commission

for

the Period January 1, 2018 – December 31, 2018

by

REACTOR STAFF

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MIT RESEARCH REACTOR

ANNUAL REPORT TO

U. S. NUCLEAR REGULATORY COMMISSION

FOR THE PERIOD JANUARY 1, 2018 – DECEMBER 31, 2018

INTRODUCTION

This report has been prepared by the staff of the Massachusetts Institute of Technology Research Reactor for submission to the United States Nuclear Regulatory Commission, in compliance with the requirements of the Technical Specifications to Facility Operating License No. R-37 (Docket No. 50-20), Paragraph 7.7.1, which requires an annual report that summarizes licensed activities from the 1st of January to the 31st of December of each year.

The MIT Research Reactor (MITR), as originally constructed and designated as MITR-I, consisted of a core of MTR-type fuel, enriched in uranium-235, cooled and moderated by heavy water in a four-foot diameter core tank that was surrounded by a graphite reflector. After initial criticality on July 21, 1958, the first year was devoted to startup experiments, calibration, and a gradual rise to one megawatt, the initially licensed maximum power. Routine three-shift operation (Monday-Friday) commenced in July 1959. The authorized power level for MITR-I was increased to two megawatts in 1962 and to five megawatts (the design power level) in 1965.

Studies of an improved design were first undertaken in 1967. The concept which was finally adopted consisted of a more compact core, cooled by light water, and surrounded laterally and at the bottom by a heavy water reflector. It is under-moderated for the purpose of maximizing the peak of thermal neutrons in the heavy water at the ends of the beam port re-entrant thimbles and for enhancement of the neutron flux, particularly the fast component, at in-core irradiation facilities. The core is hexagonal in shape, 15 inches across, and utilizes fuel elements which are rhomboidal in cross section and which contain UAl_x intermetallic fuel in the form of plates clad in aluminum and enriched to 93% in uranium-235. The improved design was designated MITR-II. However, it retained much of the original facility, e.g., graphite reflector, thermal shield, biological shield, secondary cooling systems, containment, etc.

After Construction Permit No. CPRR-118 was issued by the former U.S. Atomic Energy Commission in April 1973, major components for the modified reactor were procured and the MITR-I completed its mission on May 24, 1974, having logged 250,445 megawatt-hours during nearly 16 years of operation.

The old core tank, associated piping, top shielding, control rods and drives, and some experimental facilities were disassembled, removed, and subsequently replaced with new equipment. After pre-operational tests were conducted on all systems, the U.S. Nuclear Regulatory Commission issued Amendment No. 10 to Facility Operating License No. R-37 on July 23, 1975. After initial criticality for MITR-II on August 14, 1975, and several months of startup testing, power was raised to 2.5 MW in December 1975. Routine 5-MW operation was achieved in December 1976. Three shift operation, Monday through Friday, was continued through 1995 when a gradual transition to continuous operation (24 hours per day, 7 days per week with a shutdown for maintenance every 4-5 weeks) was initiated.

In December 2000, a fission converter medical facility was commissioned. This facility generated the highest quality epithermal beam in the world for use in the treatment of certain types of cancer, and could again be made available.

From mid-April through mid-September 2010, all major piping in the primary and secondary coolant systems was replaced and upgraded. This included a titanium heat exchanger (replacing the three previous primary heat exchangers) and the major instrumentation sensors that monitor system flows, temperatures, and pressures.

On November 1, 2010, NRC approved the relicensing of the reactor for 6-MW operation through November 1, 2030. Reactor power was increased in small increments from 5 MW for observations and data collection, and reached 5.8 MW on April 23, 2011. Routine 5.8 MW operation began on May 25, 2011.

The current operating mode is generally continuous operation just under 6 MW when needed, with a maintenance shutdown scheduled every calendar quarter.

This is the forty-fourth annual report required by the Technical Specifications, and it covers the period from January 1, 2018, through December 31, 2018. Previous reports, along with the "MITR-II Startup Report" (Report No. MITNE-198, February 14, 1977) have covered the startup testing period and the transition to routine reactor operation. This report covers the forty-second full year of routine reactor operation, now at the 6-MW power level. It was another year in which the safety and reliability of reactor operation met and exceeded requirements and expectations.

A summary of operating experience and other activities and related statistical data are provided in Sections A through I of this report.

A. SUMMARY OF OPERATING EXPERIENCE

1. General

The MIT Research Reactor, MITR-II, is operated to facilitate experiments and research including in-core irradiations and experiments, neutron activation analyses, and materials science and engineering studies such as neutron imaging. It is also used for student laboratory exercises and student operator training, and education and outreach programs. Additionally, the reactor has been used for industrial production applications and other irradiation services. When operating, the reactor is normally maintained at slightly below 6 MW. For this reporting period, the nominal full power was 5.7 MW, with an operating cycle of about eleven weeks at a time, followed by a scheduled outage lasting about two weeks for reactor and experiment maintenance, protective system surveillance tests, and other necessary outage activities. The reactor would then be re-started to full power and maintained there for another eleven weeks.

Throughout CY2018, the reactor averaged 90 operating hours per week, compared to 108 hours per week for CY2017, 112 hours per week for CY2016, 73 hours per week for CY2015, and 102 hours per week for CY2014. The lower average for CY2015 was the result of operating the reactor only as needed, when at times there were no in-core experiments or other irradiations that called for continuous operation.

The reactor was operated throughout the year with 24 fuel elements in the core. The remaining three positions were occupied by either solid aluminum dummies or in-core experiments. During CY2018, compensation for reactivity lost due to burnup was provided by four refuelings. These followed standard MITR practice which is to introduce fresh fuel to the inner portion of the core (the A- and B-Rings) where peaking is least and to place partially spent fuel into the outer portion of the core (the C-Ring). In addition, fuel elements were inverted and rotated so as to achieve more uniform burnup gradients in them. With the four refuelings, six new fuel elements were introduced into the reactor core and nine spent fuel elements were discharged from the core during CY2018.

The MITR-II fuel management program remains quite successful. During the period of CY2018, 16 discharged or spent fuel elements were returned to an off-site DOE facility.

As in previous years, the reactor was operated throughout the period without the fixed hafnium absorbers.

2. Experiments and Utilization

The MITR-II was used for experiments and irradiations in support of research, training and education programs at MIT and elsewhere. Irradiations and experiments conducted in CY2018 include:

a) The second irradiation campaign for Phase 2 of a major ATF program by Westinghouse Electric Company (WEC), supported by DOE, was irradiated from February to July 2018. A variety of SiC composite materials, some with end plugs and experimental coatings and coated Zircaloy tubing and plates made up the sample matrix. Several samples were previously irradiated in the Phase 1 program. This run also included coated Zircaloy samples from NSED Professor Michael Short to evaluate their corrosion and crud resistance. A second prototype test unit for an in-core wireless fuel temperature sensor under development by WEC, and additive manufactured Zircaloys for advanced fuel spacer grids were also included in the irradiation. Following irradiation the samples and sensor were moved to the hot cells for examination.

b) The second in-core sensor irradiation in the ICSA – ULTRA2 – was irradiated for the first cycle, February to April 2018, completing four cycles of irradiation for this experiment. As in the first ULTRA irradiation, the behavior of ultrasonic sensors provided by INL is being investigated. ULTRA2 also included a number of fiber optic temperature sensors from the University of Pittsburgh and the French Commissariat à l'énergie atomique (CEA). All of these sensors were interrogated in real time through cables and fibers fed through the ICSA top flange and the reactor core tank wall and connected to data acquisition systems on the reactor floor. In addition to the sensors under test, a set of glass samples for radiation resistant optical fibers was irradiated and will be evaluated by post-irradiation examination. Following irradiation the samples and sensors were moved to the hot cells for extraction for shipping.

c) The second phase of irradiations from the previous year, a week-long instrumentation test in support of the TREAT transient test reactor at INL was carried out in January 2018. A test capsule with neutron detectors and thermocouples was placed in two in-core locations and operated at low reactor power (<100 kW) with the reactor lid off and no forced primary coolant flow. Response of the neutron detectors to positive and negative power transients initiated by reactor control blade movements were tested. Neutron and gamma flux detectors were provided by Kansas State University, INL, and the CEA. In addition, various activation materials for spectral flux unfolding were simultaneously irradiated in-core and in the pneumatic irradiation system. Following this successful set of experiments, the facility was packaged and shipped to TREAT for additional in-core irradiation.

d) The fourth fluoride salt irradiation (FS-4) was carried out in the 3GV6 graphite reflector position for one week in January 2018. This test, in which an electrically-heated triple-encapsulated liquid fluoride salt crucible is irradiated in the core-equivalent thermal neutron and gamma flux, required operation at reduced power in order to manage tritium production. The steady-state stream of tritiated gas produced during this irradiation was used in high-temperature diffusion and barrier coating testing at the reactor top in support of the Fluoride Salt-Cooled High-Temperature Reactor (FHR) Integrated Research Project (IRP). This test marks the establishment of a new capability for high-temperature lead-out irradiation in the 3GV positions.

e) The irradiation of coated Zircaloy specimens under pressurized water reactor conditions took place in the in-core water loop during the fourth cycle. This test primarily contained samples from NSED Professor Michael Short as part of his Exelon-funded research project. It also included metallic specimens from NSED Professors Ju Li and Koroush Shirvan. These materials are of interest for accident-tolerant cladding development as well as for the reduction of crud deposition on in-core surfaces.

f) Extraction and post-irradiation examination (PIE) of samples from the first three fluoride salt irradiations continued during 2018. The major activities were microstructure examination of the samples at MIT and INL, and measurement of trapped tritium and tritium-trapping mechanisms in graphite from the irradiations.

g) Experiments were performed at the 4DH1 radial beam port facility by MIT undergraduate, graduate, and executive education students (course 22.09/90 "Principles of Nuclear Radiation Measurement and Protection", and MIT NSE "Reactor Technology Course for Utility Executives" sponsored by the Institute for Nuclear Power Operations), including: 1) measurements of leakage neutron energy spectrum to determine reactor temperature; 2) measurement of neutron wavelength and time-of-flight; 3) measurement of attenuation coefficients for a variety of shielding materials; and 4) Bragg diffraction of neutrons in a copper single crystal. Note that repairs to the 4DH1 port collimator undertaken in July 2018 dramatically restored and increased the thermal neutron flux at the beam port and thereby greatly improved data quality, reduced data acquisition times, and permitted experiments on the diffracted beam.

h) Measurements at the 4DH4 Neutron Diffractometer were conducted in support of a DOE National Science User Facilities (NSUF) Rapid Turnaround Experiments (RTE) project towards characterizing the microstructure of unirradiated nuclear fuel by neutron diffraction. This project is in collaboration with Idaho National Laboratory (INL).

i) NRL Seed Program: Measurements were conducted at the 4DH4 Neutron Diffractometer: measuring the void fraction in transient boiling heat transfer by neutron radiography in collaboration with Professor Matteo Bucci (MIT NSE); neutron computed tomography scanning of cave deposits for fluid inclusions in collaboration with Professor David McGee (MIT MSE); and neutron-based mapping of hydrogen diffusion during plasticity in collaboration with graduate student Haoxue Yan (MIT MSE).

j) Elemental analyses were performed using neutron activation analysis (NAA) on samples of the in-core components to be used in the WATF-2b irradiation experiment described below. Neutron activation studies using a variety of metal foils were continued in order to better characterize the neutron flux and spectrum of the reactor's out-of-core neutron irradiation facilities.

k) Activation in Thermal Neutron Beam (TNB) facility of HEU targets and fission chambers to support fission product yield measurements in collaboration with Los Alamos National Laboratories and Duke University.

l) Activation of uranium foils for detector calibration at the Los Alamos National Laboratories and Ciambrone Laboratory at Patrick AFB.

m) Elemental analyses were performed using NAA on the flux wire samples used in the TREAT irradiation experiment described above.

n) Several activations of aluminum, stainless steel, and Teflon samples for a neutron damage study for the MIT Nuclear Science and Engineering Department.

o) Activation of SiC samples for further NAA studies for University of Alabama.

p) Activation and NAA of various samples in support of course 22.01 "Introduction to Nuclear Engineering and Ionizing Radiation".

q) Activations of Europium source for use in MIT Junior Physics Lab.

r) Activation of gold-198 seeds for brachytherapy.

s) Other use of the reactor for training MIT student reactor operators and for MIT nuclear engineering and executive education classes (course 22.01 "Introduction to Nuclear Engineering and Ionizing Radiation", course 22.011 "Seminar in Nuclear Science and Engineering", and MIT NSE "Reactor Technology Course for Utility Executives"). Additionally a group from Intercontinental Nuclear Institute (INI) in conjunction with University of Massachusetts Lowell conducted various experiments, power manipulations, and a tour of the reactor facility.

An ongoing initiative is the partnership with the Department of Energy's Nuclear Science User Facilities (NSUF) for advanced materials, high temperature sensors, and fuel irradiation. The MITR became the first university research reactor to be a partner facility with the NSUF in 2008. MIT-NRL staff also worked with INL staff to jointly develop advanced reactor instrumentation, and reviewed NSUF's user proposals.

3. Changes to Facility Design

Except as reported in Section E, no changes in the facility design were made during this calendar year. The nominal uranium loading of MITR-II fuel is 34 grams of U-235 per plate and 510 grams per element (manufactured by BWXT). Performance of these fuel elements has been excellent. The loading results in 41.2 w/o U in the fuel meat, based on 7% voids, and corresponds to the maximum loading in Advanced Test Reactor (ATR) fuel. Two hundred twenty-two elements fabricated by BWXT have been received, forty-two of which remain in use. One has been removed because of suspected excess out-gassing, another because it was dropped, and one hundred seventy-eight have been discharged because they have attained the fission density limit.

The MITR is actively involved in studies for future use of low enrichment uranium (LEU) in the MITR, partially supported by the Reduced Enrichment for Research and Test Reactors (RERTR) Program at DOE. These studies principally focus on the use of monolithic U-Mo fuels with uranium densities in excess of 15 g/cm^3 (compared with 1.5 g/cm^3 for UAl_x fuel), currently under development by the RERTR Program. Although initial studies show that the use of these fuels is feasible, conversion of the MITR-II to lower enrichment must await the final successful qualification of these high-density fuels. In December CY2017, a report entitled "LEU Conversion Preliminary Safety Analysis Report for the MITR" was docketed with NRC to support a future application for licensing to convert from High Enriched Uranium (HEU) to LEU fuel. This PSAR provides analysis determining that a power increase from 6 MW with the current HEU core to 7 MW when using the LEU core is required in order to maintain core neutronic flux performance.

4. Changes in Performance Characteristics

Performance characteristics of the MITR-II were reported in the "MITR-II Startup Report." Minor changes have been described in previous reports. Performance characteristics of the Fission Converter Facility were reported in the "Fission Converter Facility Startup Report", and in the FY2006 report which described a 20% improvement in the intensity of the unfiltered epithermal neutron beam. In CY2012, fuel was removed from the fission converter tank. It will remain unfueled pending resumption of epithermal beam research. In CY2013, the D_2O coolant was removed from the fission converter and replaced with demineralized light water. The D_2O was put into on-site storage for future use.

5. Changes in Operating Procedures

With respect to operating procedures subject only to MITR internal review and approval, a summary is given below of changes implemented during CY2018.

a) AOP 5.2.6 "Low Level Core Tank Warning" was updated to correct an error in the valve alignment to be checked, and to reflect that flow meters MF-2 and BF-2 are now readable only inside the equipment room. (SR #2016-4)

b) PM 7.1.5 "Damper Accumulators Charging and Actuator Inspection Procedure. Main Damper – Auxiliary Damper Interlock" was updated to adjust nominal hydraulic pressure ranges to reflect current practices and equipment, and was split into two sections (intake damper and exhaust damper) for clarity. (SR #2016-18)

c) PM 6.5.6.2 "System Pressure Gauge Calibration – PSI Range" was revised to denote which gauges are oil-filled, and to add steps to vent them. There were no changes to human-machine interfaces and no cyber security issues. (SR#2017-7)

d) PM 1.1.1 "MIT Administration and Committees", PM 1.1.2 "Nuclear Reactor Laboratory", and PM 1.10.1 "Experimental Review and Approval" received a variety of administrative updates to staff lists, titles, and organization chart. Description was added regarding the use and duties of a Task Supervisor for experiment installation and removal procedures. (SR #2017-13)

e) PM 6.3.3 "Waste Tank System Alarms and Interlocks" was updated to highlight safety considerations and to make clarifications. Pre-notice to Reactor Radiation Protection was added, in case contamination is identified. (SR #2017-24)

f) PM 6.4.25 "Calibration of Waste Tank Level Indications" was established to provide a uniform method for testing and calibrating the local and control room indications of the waste tank levels. Performance of the procedure does not involve radiological work. (SR #2017-25)

g) PM 6.5.16.1A "Regulating Rod Calibration by Period Measurement" and PM 6.5.16.2 "Shim Blade Calibration Procedure" were updated to reflect current practices such as use of an electronic spreadsheet, and to raise the power limit from 1 kW to 10 kW. The heating and xenon added at 10 kW vs. 1 kW is negligible, and the hot channel power is still several orders of magnitude below the hot channel safety limit, even with natural circulation. Technical Specification 3.2.4.2 permits absorber worth measurements at power up to100 kW. (SR #2017-56)

h) PM 6.1.3.7A/B "Calibration of Core Tank Level Indications ML-3A, ML-3B, and Verification of Low Level Scram Point" was updated to reflect current equipment and best practices, and for clarity. This included splitting it into two separate procedures, for using the air pressure regulator assembly versus the Transmation Model 190 Calibrator. (SR #2018-3)

i) PM 3.2.1 "Shutdown from Operation at Power" was updated to reflect current practices and equipment. There were no changes to human-machine interfaces and no cyber security issues. (SR #2018-14)

j) PM 3.3.4.1 "Fuel Shipping Supervisory Checklist", PM 3.3.4.1.1 "Receipt of BRR Cask and Removal from Transport Vehicle", PM 3.3.4.4 "BRR Cask Vacuum Drying and Helium Leak Test", and PM 3.3.4.5 "Placement on Transport Vehicle and Shipment of BRR Cask" were updated with new and expanded steps to increase certain levels of detail such as confirming checklists status, equipment availability, and MIT Police notifications, along with inspections and verifications by the DOE shipping support contractor. Accuracy and clarity of the procedures was maintained, as was verbatim compliance with the cask's Safety Analysis Report. (SR #2018-15)

k) PM 7.4.3.2 "HE-01 Chemical Cleaning" was rewritten to align with the current heat exchanger and piping systems. The chemical used for cleaning was changed to enhance safety for both equipment and personnel. (SR #2018-18)

6. Surveillance Tests and Inspections

There are many written procedures in use for surveillance tests and inspections required by the Technical Specifications. These procedures provide a detailed method for conducting each test or inspection and specify an acceptance criterion which must be met in order for the equipment or system to comply with the requirements of the Technical Specifications. Thirty such tests and inspections are scheduled throughout the year with a frequency at least equal to that required by the Technical Specifications. Together with those not required by Technical Specifications, over 100 tests and calibrations are conducted on an annual, semi-annual, or quarterly basis.

Other surveillance tests are done each time before startup of the reactor if shut down for more than 24 hours, before startup if a channel has been repaired or de-energized, and at least quarterly; a few are on different schedules. Procedures for such surveillance are incorporated into daily or quarterly startup, shutdown, or other checklists.

During this reporting period, surveillance frequencies have been at least equal to those required by the Technical Specifications, and the results of tests and inspections were satisfactory throughout the year for Facility Operating License No. R-37.

7. Status of Spent Fuel Shipment

In CY2018, there were two shipments made, reducing the inventory of spent fuel at MIT. These shipments are made using the BEA Research Reactor (BRR) package. The U.S. Department of Energy has indicated that further shipments may be feasible in CY2019 for future fuel discharges.

B. REACTOR OPERATION

Information on energy generated and on reactor operating hours is tabulated below:

	Calendar Quarter 1	Calendar Quarter 2	Calendar Quarter 3	Calendar Quarter 4	Total
1. Energy Generated (MWD):					
a) MITR-II (MIT CY2018) (normally at 5.7 MW)	245.7	361.9	155.0	293.2	1,055.8
b) MITR-II (MIT FY1976-CY2017)					38,477.0
c) MITR-I (MIT FY1959-FY1974)					10,435.2
d) Cumulative, MITR-I & MITR-II					49,968.0
2. MITR-II Operation (hours): (MIT CY2018)					
a) At Power (≥ 0.5-MW) for Research	1,069	1,571	692	1,332	4,664
b) Low Power (< 0.5-MW) for Training[1] and Test	8	16	0	10	34
c) Total Critical	1,077	1,587	692	1,342	4,698

(1) These hours do not include reactor operator and other training conducted while the reactor is at or above 0.5 MW. Such hours are included in the previous line (row 2a of the table).

C. SHUTDOWNS AND SCRAMS

During this reporting period, there was one inadvertent scram and eight unscheduled shutdowns.

The term "scram" refers to shutting down of the reactor through protective system automatic action when the reactor is at power or at least critical, while the term "shutdown" refers to an unscheduled power reduction to subcritical by the reactor operator in response to an abnormal condition indication. Control blade drops and electric power loss without protective system action are included in unscheduled shutdowns.

The following summary of scrams and shutdowns is provided in approximately the same format as for previous years in order to facilitate a comparison.

		Total
1.	Nuclear Safety System Scrams	
	a) Trip on Low Voltage Chamber Power Supply at the Channel #5 ion chamber while it was being used to supply signal to Channel #7.	1
	Subtotal	1
2.	Process System Scrams	
	a) None.	0
	Subtotal	0

3. Unscheduled Shutdowns

a)	Shutdown due to loss of off-site electrical power.	1
b)	Minor scram initiated by operator upon observing or suspecting only one operable period channel on line during startup.	2
c)	Minor scram initiated by operator after Shim Blade #4 dropped from its magnet while the blade was being moved.	2
d)	Shutdown to correct loss of D_2O helium recombiner flow because of broken drive belt at the recombiner blower.	1
e)	Shutdown because of loss of ventilation when main exhaust damper hydraulic pump tripped off.	1
f)	Shutdown because of ventilation trip on low air temperature when campus steam heating supply was lost while NW12 boiler was inoperable.	1
	Subtotal	8
	Total	**9**

4. Experience during recent years has been as follows:

Calendar Year	Nuclear Safety and Process System Scrams
2018	1
2017	1
2016	4
2015	8
2014	13
2013	4
2012	6
2011	9
2010	20
Fiscal Year	
2010	6
2009	2

D. MAJOR MAINTENANCE

Major reactor maintenance projects performed during CY2018 are described in this Section. These were planned and performed to improve safety, reliability and efficiency of operation of the MIT Research Reactor, and hence improve the reliability of the reactor operating schedule and the availability of the reactor for experiments, research and training purposes. Additionally, Reactor Operations staff performed safety reviews for all reactor experiments and their operating procedures. The staff also provided support for installations and removals of reactor experiments, and monitored key performance data from the experiments during reactor operations.

For continuous support of neutron transmutation doping of silicon, reactor staff performed routine irradiation and shipping activities. There is an annual external audit to review the program for maintaining the ISO 9001 Certification. Preventive maintenance on conveyor machinery, such as alignment of conveyor carriages, was performed during major outages.

Major maintenance items performed in CY2018 are summarized as follows:

1. Reactor staff replaced the auxiliary intake damper control system and power supply during the week of 1/8.

2. Reactor staff repacked and replaced process system ion columns several times during the year. The primary system ion column was done in January, April, July, and October. Its inlet and outlet filters were also replaced in January, April, and November. The D_2O reflector system ion column was replaced in July.

3. The digital auto-controller for nuclear instrumentation channel #9 was replaced.

4. The GTRI-RMS security systems were replaced with Sentry-RMS units in March and April, with testing and commissioning completed in June.

5. Reactor staff performed preventive maintenance on the silicon load and unload cell equipment during the first week of April.

6. The power switches and flow switches for the plenum blowers (#1 and #2) were replaced by reactor staff on 4/4.

7. During the week of 4/9, reactor staff completed reactivity worth measurements for the regulating rod and all six shim blades.

8. During the week of 4/10 reactor staff established a new containment penetration to the Utility Room in NW12 for the planned NW12 fire alarm and protection system upgrade.

9. 4/12-13 reactor staff worked with MIT Facilities to replace the containment ventilation intake fan bearing.

10. On 4/13 reactor engineers replaced aging electrical cabling on the main airlock.

11. On 5/1 reactor staff replaced the motor for shim blade #3.

12. On 5/14 and 8/20 reactor staff coordinated with MIT Facilities to install four new high-bay LED dome lighting fixtures inside the containment building.

13. On 7/18 reactor staff completed the annual efficiency test for the charcoal filters in the containment building's pressure relief system.

14. 7/19-20 shim blades #1 and #4 were replaced and their reactivity worth measurements were completed the following week.

15. On 8/2 reactor staff completed the annual gain determination for nuclear safety channels #5 and #6 low-range amplifiers.

16. During the weeks of 9/3, 9/10, and 9/17 reactor staff worked continuously to remove all the plastic fill from the cooling towers, knock out the built-up mineral deposits, and reinstall them, replacing deteriorated fill with new pieces.

17. On 9/4 main primary-secondary heat exchanger HE-1 was cleaned with phosphoric acid to regain its heat transfer efficiency.

18. On 9/7 a new pressure switch was installed in the D_2O reflector system's helium line to the D_2O recombiner in order to provide for control room indication of a low flow condition.

19. During the weeks of 9/10 and 9/17 extensive heat removal capability characterization was performed on the cooling towers with assistance from TowerTech personnel.

20. A remotely-operable shutter system was installed on the 4DH1 spectrometer beam during the week of 9/10.

21. During the week of 10/1 reactor staff replaced the DL-6 reflector tank level conductivity probe with an ultrasonic sensor.

22. On 10/3 reactor staff replaced the drive and electromagnet for shim blade #1.

23. During the month of November reactor staff completed the annual inventory of heavy water.

Many other routine maintenance and preventive maintenance items were also scheduled and completed throughout the calendar year.

E. SECTION 50.59 CHANGES, TESTS, AND EXPERIMENTS

This section contains a description of each change to the reactor facility and associated procedures, and of the conduct of tests and experiments carried out under the conditions of Section 50.59 of 10 CFR 50, together with a summary of the safety evaluation in each case.

Changes that affect only the operating procedures and that are subject only to MITR internal review and approval, including those that were carried out under the provisions of 10 CFR 50.59, are similarly discussed in Section A.5 of this report.

The review and approval of changes in the facility and in the procedures as described in the SAR are documented in the MITR records by means of "Safety Review Forms". These have been paraphrased for this report and are identified on the following pages for ready reference if further information should be required with regard to any item. Pertinent pages in the SAR have been or are being revised to reflect these changes, and they either have or will be forwarded to the NRC Document Control Desk.

The conduct of tests and experiments on the reactor are normally documented in the experiments and irradiation files. For experiments carried out under the provisions of 10 CFR 50.59, the review and approval is documented by means of the Safety Review Form. This includes all in-core experiments, which are additionally reviewed and approved by the MIT Reactor Safeguards Committee (MITRSC) prior to installation in the reactor core. All experiments not carried out under the provisions of 10 CFR Part 50.59 have been done in accordance with the descriptions provided in Section 10 of the SAR, "Experimental Facilities".

Advance Cladding Irradiation Facility (ACI) \ Water Loop
SR #0-06-4 (04/03/2006), SR #0-06-6 (05/18/2006), SR #2015-8 (05/22/2015),
SR #2015-9 (05/22/2015)

An in-core experiment loop was installed on May 22, 2006, to investigate the effects at various stages of irradiation on specimens of silicon carbide intended for use in advanced fuel cladding designs. Its envelope of operating conditions is very similar to that of previous in-core experiments such as the Zircaloy Corrosion Loop and the Electro-Chemical Potential Loop. No new safety issues were raised. Operation continued until October 2007. A second advanced cladding loop, designated ACI-2, operated in core from March 2009 through mid-December 2009, March to April 2010, December 2010 through June 2011, from October 2011 to July 2012, and from August through October 2013. A later version of this loop, designated the Westinghouse Accident-Tolerant Fuel (WATF) experiment, was installed in 2014 and operated until May 2015, and again from December 2015 until July 2016. The latter run featured a stepped thimble to minimize neutron streaming to the reactor top. Additionally, from May 2015 to August 2015, the facility was used to test an In-Core Crack Growth Measurement (ICCGM) system. In 2017, from January to June, the ACI facility was used for the COATI irradiation ("CTP and ORNL Accident Tolerant Irradiation") of a variety of silicon carbide composite materials. From August 2017 through December 2018, it was used for WATF Phase 2 and Exelon experiments.

Heated In-Core Sample Assembly Experiment (ICSA)
SR #0-04-19 (12/01/2004), SR #M-04-2 (12/30/2004), SR #0-05-11 (07/22/2005),
SR #M-09-1 (07/30/2009), SR #M-09-2 (12/11/2009), SR #0-10-2 (03/28/2010),
SR #0-12-17 (06/04/2012), SR #0-12-19 (07/09/2012), SR #2017-6A (05/03/2017)

High-temperature sample capsules were used with the redesigned titanium 2" ICSA tube to provide a heated irradiation environment for the specimens within. These capsules include gamma-heating susceptors similar in principal to the High Temperature Irradiation Facility. No new safety issues were raised. An alternate 16" plug was designed and installed in the reactor top shield lid to allow simultaneous use of the ICSA and the ACI-2 in-core experiments. The ICSA operated in core from December 2009 through April 2010, from August 2010 to January 2012, from April to July 2012, and from mid-September through October 2013 for various sample irradiations using heated and unheated capsules. The MIT Reactor Safeguards Committee (MITRSC) approved two ICSA Safety Evaluation Report amendments in early 2013 to allow the 2013 irradiation of molten fluoride salt in-core using a nickel capsule inside the ICSA. The ICSA facility remained in regular use in CY2018 for in-core experiments and irradiations. – See section A.2 (Experiments and Utilization), item (b).

High Temperature Irradiation Facility (HTIF) FS-2 and FS-3
SR #2014-12 (06/11/2014), SR #2016-31 (11/04/2016)

The MITRSC In-Core Experiments Subcommittee approved the HTIF FS-2 test rig by mail ballot between 6/07/2014 and 6/11/2014. The experiment then operated successfully in core from July 2014 to August 2014. Its successor, the HTIF FS-3, operated in core from November 2016 to December 2016. There were no HTIF irradiations in 2018.

DWK 250 Wide Range Monitors and Mirion Fission Chamber Detectors
SR #O-12-21 (10/19/2012), SR #O-13-22 (07/11/2013), SR #O-13-27 (11/08/2013)
SR #2017-52 (10/04/2017)

All four DWK 250 Wide Range Monitors and their associated fission chamber detectors have been installed in the control room and the reactor respectively, along with their corresponding TKV23 pre-amplifiers. Reactor staff completed fabrication and bench testing of all downstream supporting modules. These include the Signal Distribution Module, Scram Logic Card Modules, LED Scram Display, <100 kW Key-Switch Module, the PLC module, the DWK 250 "Test" Condition Bypass Assembly, and the magnet power supply and rundown relay module. Additionally, reactor staff completed modification and testing of the Withdraw Permit Circuit Bypass Panel in preparation for future installation of the new Nuclear Safety System. Reactor staff assembled all of the modules into a single instrumentation rack in the control room. Written procedures were developed to perform pre-operational global testing of the system. The integrated system is operating in parallel in the control room, but is not connected to the existing reactor scram circuits. Throughout CY2018, reactor staff recorded crucial parameters from the system as part of the hourly logs whenever the reactor was at power, and performed routine calibration procedures about once a month.

In CY2018, reactor staff docketed three rounds of responses (4/20, 5/3, and 11/7/2018) to NRC Requests for Additional Information (RAI). Any response that involved revising a proposed Technical Specification was reviewed and approved by the MITRSC Standing Subcommittee prior to docketing. Response to the initial RAI, which was based on an NRC Onsite Regulatory Audit visit in July 2017, had been docketed on 12/14/2017. Reactor staff also met with NRC by conference call in a formal Public Meeting on 4/19/2018 regarding the grounds for modifying one of the relevant Technical Specifications.

Procedures Governing Shipment of Spent Fuel
SR #O-12-22 (03/21/2013), SR #O-13-2 (03/28/2013), SR #O-13-12 (06/28/2014), SR #O-13-12A (07/03/2014), SR #O-13-12B (07/22/2015), SR #2015-22 (08/26/2015), SR #2017-29 (08/30/2017), SR #2018-15 (07/25/2018)

The reactor's Standard Operating Plan was modified to allow designated omission of the inverse multiplication measurements, as approved by the MITRSC in 2012. The PM 3.3.4 Spent Fuel Shipping Procedures were updated to expand and improve oversight and coordination of the spent fuel shipment process, and for verbatim compliance with the shipping cask's Safety Analysis Report Chapters 7 and 8. These updates were inspected by NRC during an actual shipment in 2014 and deemed satisfactory. The procedures, with further updates, were also used satisfactorily in September 2015 and May 2016. Prior to the 2016 shipment, the NRL reached an agreement with DOE to fund on-site inspection of the BRR cask for each shipment by an independent contractor, prior to loading and again after loading. Reactor staff and the independent contractor developed written procedures for these inspections to document the condition of the cask and to ensure compliance with the cask SAR. In 2017, all the procedures were revised to maintain verbatim agreement with the BRR cask's Safety Analysis Report (Revision 10). In 2018, the Supervisory Checklist was overhauled to ensure better preparation prior to a shipment, and to improve clarity for transportation compliance. Many other spent fuel shipping procedures were also reviewed and revised to improve clarity. – See Section A.5 (Changes in Operating Procedures), item (j).

Physical Security Plan Revision
SR #O-13-16 (05/12/2014), SR #O-13-30 (12/24/2013), SR #2014-19 (11/07/2014), SR #2014-23 (02/18/2015), SR #2015-5 (01/23/2015), SR #2017-5 (2/14/2017)

MITRSC approval for revised Plan was granted per the Security Subcommittee meeting of 6/6/2013. It was then submitted to NRC as a License Amendment Request, for which approval was received on 5/12/2014. The PM 3.2.4 "Response to Weekend Alarms" procedures were then revised accordingly, along with those under PM 3.7.3, "Normal Containment Entry/Exit". In 2015, a security alarm coincidence monitoring system was installed to provide local and remote notification should the weekend alarm or an intrusion alarm become deactivated during periods of unattended shutdown. Procedures were revised to incorporate use of this monitoring system. In 2017, the Plan was revised in response to an NRC Request for Additional Information (RAI) regarding incorporation of material from NRL's responses to NRC Compensatory Action Letters. The revision and response to NRC were approved by the MITRSC Special Subcommittee for Security. In 2018, further modifications to the Plan were proposed as a followup to the RAI, and were reviewed and approved by the MITRSC in October 2018. These proposed modifications were discussed with NRC during a routine inspection in December 2018.

Stack Effluent & Water Monitor Project
SR #2015-30 (pending), SR #2015-30A (12/02/2015), SR #2015-30B (07/08/2016), SR #2015-30C (03/31/2016), SR #2015-30E (04/21/2017)

As part of a project to install new stack effluent monitors and secondary water monitors using detectors located outside the containment building, a new 1-1/4" diameter piping penetration was installed on the south side of the containment building, about four feet below ground. It was tested as satisfactory per existing procedures for pressure-testing new penetrations. Until such time as it is connected to the main system piping, the new piping will remain blank-flanged, or isolated and tagged out, in order to ensure containment integrity is maintained. A new climate-controlled shed, the "stack monitor shed", was constructed in the reactor's back yard in CY2016, with the two new stack monitor stations fully mounted within. In CY2018, this newly-installed system continued to operate in parallel with the existing stack effluent and water monitoring systems.

TREAT Core Instrumentation Low Power Experiment
SR #2017-19 (06/27/2017), SR #2017-19A (07/18/2017), SR #2017-19B (07/26/2017), SR #2017-19C (07/27/2017)

This week-long experiment was first carried out in July 2017. A test capsule with neutron detectors, flux wires, and thermocouples was placed in a designated in-core location. During the experiment, the reactor operated at <100 kW, with the reactor top shield lid off, and zero primary coolant flow. Along with the experiment itself, written procedures were reviewed and approved by the MITRSC Special Subcommittee for In-Core Experiments in meetings on 1/27/2017 and 7/5/2017, to be followed by the console operator for the performance of the experiment. Part of the planned tests were completed in 2017, and the remainder in early 2018.

4DH1 Spectrometer Improvements
SR #2017-27 (08/21/2017), SR #2017-27A (09/20/2018)

In July 2017, the 4DH1 student spectrometer beam port was opened to investigate the cause of the neutron beam diminishing over time. This required disassembly of the Silicon system's load-side cell shielding. Reactor staff cleaned off accumulated corrosion surrounding the beam path, and replaced the deformed cadmium neutron shield on the tip of the port plug with a new Boral "hat" inner neutron shield. This new inner shield is expected to be as effective as the cadmium in minimizing neutron activation of the port plug, while maintaining better rigidity than the cadmium, which had collapsed into the beam path. The result of the work was a much-improved neutron beam, restoring the beam port to its designed usability. In 2018, the spectrometer's local manual operation was upgraded to include remote shutter actuation from the control room, and position indication there.

4DH4 Diffractometer Beam Facility
SR #O-12-3 (07/09/2018)

After extensive design, construction, testing, and characterization, a neutron beam facility featuring a diffractometer was placed in service at the 4DH4 beam port. Procedures were established for operation in monochromatic and polychromatic modes, and an Abnormal Operating Procedure was introduced for response to alarm conditions and for emergency shutdown of the beam. The installation includes redundant beam status indicators, and multiple personnel warning alarms active whenever the beam is on. Shielding of the diffractometer drum and the beam has been optimized for reduction of radiation levels and for experiment accessibility.

Withdraw Permit Circuit Relay Replacement
SR #2017-50 (10/11/2017)

In October 2017, all 36 three-pole double-throw relays in the Withdraw Permit Circuit were replaced with equivalent units from a different manufacturer, which were then individually tested. The original model relay had gone out of production.

Technical Specification (TS) 7.5.2.1 Experiment Review and Approval
SR #2018-2 (06/12/2018), SR #2018-17 (09/17/2018)

In January 2018, the NRL submitted an amendment request for TS 7.5.2.1, modifying the procedure approval requirements for reactor experiments of a type not previously approved. While the MIT Reactor Safeguards Committee would continue to review and approve the design and safety evaluation of new experiments, review and approval of the written procedures for those experiments would shift to Reactor Operations. The amendment was approved by NRC in June 2018. A corresponding change was then made in PM 1.10.1, "Experiment Review and Approval".

Low Flow Recombiner Alarm
SR #2018-19 (09/05/2018), SR #2018-19A (12/05/2018)

A new pressure switch was installed in the D_2O helium recombiner flow system to notify the console operator if proper flow is lost. An associated Abnormal Operating Procedure was introduced, as was a procedure for testing and calibrating the alarm set point.

F. ENVIRONMENTAL SURVEYS

Environmental monitoring is performed using continuous radiation monitors and passive dosimetry devices (TLD). The radiation monitoring system consists of detectors and associated electronics at each remote site with data transmitted continuously to the Reactor Radiation Protection office and recorded electronically in a database. The environmental monitoring remote sites are located within a quarter mile radius of the facility. The calendar year totals per sector, due primarily to Ar-41, are presented below. The passive TLDs were in place at all times throughout the year and are exchanged quarterly.

Site	Exposure (01/01/18 – 12/31/18)
North	0.18 mrem
East	0.28 mrem
South	0.21 mrem
West	0.28 mrem
Green (east)	0.01 mrem

Calendar Year Average

2018	0.2 mrem
2017	0.4 mrem
2016	0.6 mrem
2015	0.4 mrem
2014	0.8 mrem
2013	0.2 mrem
2012	0.3 mrem

G. RADIATION EXPOSURES AND SURVEYS WITHIN THE FACILITY

A summary of radiation exposures received by facility personnel and experimenters is given below:

January 1, 2018 - December 31, 2018

Whole Body Exposure Range (rems)	Number of Personnel
No measurable	54
Measurable – < 0.1	46
0.1 – 0.25	5
0.25 – 0.50	1
0.50 – 0.75	0
0.75 – 1.00	0
1.00 – 1.25	0
1.25 – 1.50	0
1.50 – 1.75	0
1.75 – 2.00	0

Total Person Rem = 2.2 Total Number of Personnel = 106

From January 1, 2018, through December 31, 2018, the Reactor Radiation Protection program provided radiation protection services for the facility which included power and non-power operational surveillance (performed on daily, weekly, monthly, quarterly, and other frequencies as required), maintenance activities, and experimental project support. Specific examples of these activities included, but are not limited to, the following:

1. Collection and analysis of air samples taken within the containment building and in the exhaust/ventilation systems.
2. Collection and analysis of water samples taken from the secondary, D_2O, primary, shield coolant, liquid waste, and experimental systems, and fuel storage pool.
3. Performance of radiation and contamination surveys, radioactive waste collection and shipping, calibration of area radiation monitors, calibration of effluent and process radiation monitors, calibration of radiation protection/survey instrumentation, and establishing/posting radiological control areas.
4. Provision of radiation protection services during fuel movements, in-core experiments, sample irradiations, beam port use, ion column removal, diffractometer beam testing, etc.

The results of all surveys and surveillances conducted have been within the guidelines established for the facility.

H. RADIOACTIVE EFFLUENTS

This section summarizes the nature and amount of liquid, gaseous, and solid radioactive wastes released or discharged from the facility.

1. Liquid Waste

Liquid radioactive wastes generated at the facility are discharged only to the sanitary sewer serving the facility. The possible sources of such wastes during the year include cooling tower blowdown, the liquid waste storage tanks, and one controlled sink in the Restricted Area (Engineering Lab). All of the liquid volumes are measured, by far the largest being the 10,703,771 liters discharged during CY2018 from the cooling towers. (Other large quantities of non-radioactive waste water are discharged to the sanitary sewer system by other parts of MIT, but no credit for such dilution is taken because the volume is not routinely measured.)

Total activity less tritium in the liquid effluents (cooling tower blowdown, waste storage tank discharges, and engineering lab sink discharges) amounted to 1.84E-5 Ci for CY2018. The total tritium was 2.13E-1 Ci. The total effluent water volume was 10,711,497 liters, giving an average tritium concentration of 1.92E-5 μCi/ml.

The above liquid waste discharges are provided on a monthly basis in the following Table H-3.

All releases were in accordance with Technical Specification 3.8-1, including Part 20, Title 20, Code of Federal Regulations. All activities were substantially below the limits specified in 10 CFR 20.2003. Nevertheless, the monthly tritium releases are reported in Table H-3.

2. Gaseous Waste

Gaseous radioactivity is discharged to the atmosphere from the containment building exhaust stack. All gaseous releases likewise were in accordance with the Technical Specifications and 10 CFR 20.1302, and all nuclides were substantially below the limits, using the authorized dilution factor of 50,000 (changed from 3,000 starting with CY2011 per the renewed license's Technical Specifications). The only principal nuclide was Ar-41, which is reported in the following Table H-1. The 1627.29 Ci of Ar-41 was released at an average concentration of 2.49E-10 μCi/ml. This represents 2.49% of EC (Effluent Concentration (1E-08 μCi/ml)).

3. Solid Waste

One shipment of solid waste was made during the calendar year. The information pertaining to this shipment is provided in Table H-2.

TABLE H-1

ARGON-41 STACK RELEASES

CALENDAR YEAR 2018

	Ar-41 Discharged (Curies)	Average Concentration[1] (µCi/ml)
January 2018	15.28	3.20 E-11
February	291.99	4.89 E-10
March	105.80	1.77 E-10
April	23.80	4.99 E-11
May	263.66	4.41 E-10
June	233.72	4.89 E-10
July	203.80	4.26 E-10
August	92.29	1.54 E-10
September	89.96	1.88 E-10
October	152.69	2.56 E-10
November	66.79	1.40 E-10
December	87.46	1.46 E-10
Totals (12 Months)[2]	**1627.29**	**2.49 E-10**
EC (Table II, Column I)		1×10^{-8}
% EC		**2.49%**

(1) Average concentrations do not vary linearly with curies discharged because of differing monthly dilution volumes.

(2) Last decimal place may vary because of rounding.

TABLE H-2

SUMMARY OF MITR-II RADIOACTIVE SOLID WASTE SHIPMENTS

CALENDAR YEAR 2018

Description	
Volume	30 ft^3
Weight	998 lbs.
Activity	13 mCi
Date of shipment	May 24, 2018
Disposition to licensees for burial	Energy Solutions, Clive, UT, and Toxco Material Management Center, Oak Ridge, TN
Waste broker	Ecology Services Inc., Columbia, MD

TABLE H-3

LIQUID EFFLUENT DISCHARGES
CALENDAR YEAR 2018

	Total Activity Less Tritium	Total Tritium Activity	Volume of Effluent Water[1]	Average Tritium Concentration
	($x10^{-6}$ Ci)	(mCi)	(liters)	($x10^{-6}$ µCi/ml)
Jan. 2018	NDA[2]	.000318	91,939	3.46
Feb.	2.69	.0254	729,377	34.8
Mar.	NDA[2]	.000210	1,164,304	.181
Apr.	NDA[2]	.000888	69,623	12.7
May	NDA[2]	.00143	1,243,206	1.15
June	7.68	.0324	1,107,408	29.3
July	NDA[2]	.00242	686,206	3.52
Aug.	3.15	.0294	737,677	39.9
Sept.	2.45	.0210	952,468	22.0
Oct.	2.43	.0988	1,182,964	83.5
Nov.	NDA[2]	.000334	1,471,746	.227
Dec.	NDA[2]	.00000250	1,274,582	.00196
12 months	18.4	.213	10,711,497	19.2

(1) Volume of effluent from cooling towers, waste tanks, and NW12-139 Engineering Lab sink. Does not include other diluent from MIT estimated at $1.0x10^{7}$ liters/day.

(2) No Detectable Activity (NDA): less than $1.26x10^{-6}$ µCi/ml beta for each sample.

I. SUMMARY OF USE OF MEDICAL FACILITY FOR HUMAN THERAPY

The use of the medical therapy facility for human therapy is summarized here pursuant to Technical Specification No. 7.7.1.9.

1. Investigative Studies

Investigative studies remain as summarized in the annual report for FY2005.

2. Human Therapy

None.

3. Status of Clinical Trials

The Phase I glioblastoma and melanoma trials with BIDMC have been closed. A beam that is superior to the original epithermal beam in the basement Medical Therapy Room in both flux and quality could again be made available from the Fission Converter Facility. No use of that beam is anticipated in the near term because of a nationwide funding hiatus for work of this type.