NC STATE UNIVERSITY

Nuclear Reactor Program
Department of Nuclear Engineering
nrp.ne.ncsu.edu

Campus Box 7909
2500 Stinson Drive
Raleigh, NC 27695-7909
919.515.7294 (voice)
919.513.1276 (fax)

13 March 2023

US Nuclear Regulatory Commission
Document Control Desk
Washington, DC

Re: Regulatory Audit RE: License Amendment Request Regarding Fueled Experimetns for the PULSTAR Research Reactor (EPID L-2022-NFA-0004)
License No. R-120
Docket No. 50-297

Please find the updated documents and requested supplemental information for the regulatory audit of the license amendment request (LAR) for fueled experiments at the PULSTAR reactor attached.

If you have any questions regarding this amendment or require additional information, please contact Colby Fleming at 919-515-3347 or ncsorrel@ncsu.edu.

I declare under penalty of perjury that the forgoing is true and correct. Executed on 13 March 2023.

Sincerely,

Ayman I. Hawari, Ph.D.
Director, Nuclear Reactor Program
North Carolina State University

Enclosures:
Attachment 1: Technical Specification Amendment 19 Line Changes and Justification
Attachment 2: Technical Specifications Amendment 19 (with change bars)
Attachment 3: Technical Specifications Amendment 19 (clean pages)
Attachment 4: Supplemental Solutions and Corrections for Table 1 and 2 Calculations

ATTACHMENT 1:
Technical Specification Amendment 19 Line Changes and Justification

Technical Specification Amendment 19 Line Changes and Justification

13 March 2023

Changes to the Technical Specifications for the North Carolina State University PULSTAR Reactor are described below. Each change is noted along with justification of the change.

1. Document Page 1 – Amendment number and date updated.
   Amendment number was updated to reflect the new revision being submitted. Date for the last update to the TS documentation is changed to reflect the latest submission date.

2. Document Page 3 – Table of Contents updated.
   Table 3.8-1 and Figure 3.8-1 were removed from list of figures and tables.

3. Document Headers – all pages with changes
   Headers on all pages with changes were updated to reflect the current revision number and date.

4. TS Page 2 – Definition of Fueled Experiment

   e. **Fueled Experiment**: A fueled experiment is an experiment which ~~contains fissionable material.~~irradiates fissile material. Fueled experiments exclude the following:

      i. Fissile material not subjected to neutron fluence
      ii. Detectors containing fissile material
      iii. Sealed sources
      iv. PULSTAR reactor fuel used in operation of the reactor.

   The definition of fueled experiments was clarified to specify the irradiation of fissile materials and exclude common reactor applications of fissile materials such as detectors. This change clearly defines the fueled experiments as separate from reactor operation or monitoring using the NRC Glossary definition of fissile materials (last updated March 31, 2021).

   Detectors, here, are considered "off-the-shelf" and not fueled experiments themselves.

   "Sealed sources" would be limited to neutron sources used in reactor operations.

   Naturally occurring elements are assumed to not be fueled experiments.

   Clarity added to indicate "fuel used in operation of the reactor" is that of the PULSTAR reactor.

   List of points broken into individual bulleted elements for clarity.

5. TS Page 2 – Spacing Adjustments
   With the additional wording added to TS 1.2.9 e, spacing was adjusted between TS 1.2.7, 1.2.8, and 1.2.9.

6. TS 3.5: Radiation Monitoring

Specification

The reactor shall not be operated nor shall irradiated fuel or irradiated fueled experiments that are not contained in a properly sealed and approved shipping container be moved within the reactor building unless the radiation monitoring equipment listed below and in Table 3.5-1 is operable.(1)(2)(3)(7)

a. Three fixed area monitors operating in the Reactor Building with their setpoints as listed in Table 3.5-1.(1)(3)(4)

b. Stack pParticulate and stack gas building exhaust monitors continuously sampling air in the facility exhaust stack with their setpoints as listed in Table 3.5-1.(1)(3)(4)

c. The Radiation Rack Recorder.(5)

d. Vented fueled experiment exhaust gas radiation monitor continuously monitoring the experiment exhaust gas.(7)

c.e. Vented fueled experiment flow rate monitor continuously monitoring the experiment exhaust gas flow.(7)

Changes to TS 3.5 now include the movement of irradiated fuel and fueled experiments within not just the reactor pool but also the reactor building. This adds the requirement for radiation monitoring to be operable during such activities. The operability of such monitors ensures that during an accident scenario, confinement and other emergency actions will automatically occur. As an exception and for consistency with current standards, irradiated fuel within a sealed shipping container is excluded (see ANSI 15.1 standard).

The names of the gas and particulate monitors are updated to better correlate with Table 3.5-1. There is not intended change of the purpose.

Additional conditions for radiation monitoring for vented fueled experiments are added to specifically ensure the rate of release at the experiment is monitored at known conditions (flow rate) during the vented fueled experiments. The addition of these monitors will ensure the operational conditions are known and will isolate any potential experimental impact on the reactor settings.

7. Table 3.5-1: Required Radiation Area Monitors

Table 3.5-1: Required Radiation Area Monitors		
Monitor	Alert Setpoint	Alarm Setpoint
Control Room	≤ 2 mR/hr	≤ 5 mR/hr
Over-the-Pool	≤ 5 mR/hr	≤ 100 mR/hr
West Wall	≤ 5 mR/hr	≤ 100 mR/hr
Stack Gas	≤ 1000 Ar-41 AEC(6)	≤ 5,000 Ar-41AEC(6)
Stack Particulate	≤ 1000 Co-60 AEC(6)	≤ 5,000 Co-60 AEC(6)

The setpoints for the entire facility are not changed from the current TS and are based on the analysis of the dose to the public as performed in the facility Emergency Plan and the ANSI/ANS 15.16-2008 standard. The current analysis shows that our annual facility releases will be significantly below the 10 CFR 20 10 mrem annual dose constraint. Therefore, no change to the setpoints is made.

With the addition of fission gases from vented fueled experiments, the stack gas monitor is expected to see a combination of halogen and fission gas nuclides, not just Ar-41. However, Ar-41 and Co-60 still are applicable to current operations and are conservative even for fueled experiments. Fission product AEC values are higher than those for Ar-41 and Co-60. Therefore, using Ar-41 and Co-60 AEC for the setpoints is conservative.

8. TS 3.5: Radiation Monitoring – Footnotes

> (2) The Over-the-Pool Monitor may be bypassed for less than two minutes during return of a pneumatic capsule from the core to the unloading station or five minutes during removal of experiments from the reactor pool. Refer to SAR Section 5.

Footnote (2) moved from page 19 to page 20 for formatting purposes. Spaced adjusted on pages 19 and 20 between text lines to accommodate the additional wording.

9. TS 3.5: Radiation Monitoring - Footnotes

> (7) Monitors for vented fueled experiments are only required to be operating while the experiment is in operation.

The specifications of monitoring of vented experiments is limited to when the experiment is in operation. These conditions allow reactor operation without vented experiment monitoring when such experiments are not operating and not installed.

10. TS 3.5: Radiation Monitoring - Bases

> **Bases**
>
> A continued evaluation of the radiation levels within the Reactor Building will be made to assure the safety of personnel. This is accomplished by the area monitoring system of the type described in Section 5 of the Safety Analysis Report (SAR).
>
> Evaluation of the continued discharge air to the environment will be made using the information recorded from the stack particulate and stack gas monitors.
>
> When the radiation levels reach the alarm setpoint on any single area, or stack exhaust monitor, the building will be automatically placed in confinement as described in SAR Section 5.
>
> To prevent unnecessary initiation of the evacuation confinement system during the return of a pneumatic capsule from the core to the unloading station or during removal of experiments from the reactor pool, the Over-the-Pool Monitor may be bypassed during the specified time interval. Refer to SAR Section 5.
>
> Stack gas and stack particulate setpoints are based on the Notification of Unusual Event Emergency Action Level (EAL) for potential released nuclides including Ar-41, Co-60, and fission products. Fission product AEC values are higher than those for Ar-41 and Co-60. Therefore, using Ar-41 and Co-60 AEC for the setpoints is conservative.

The bases for TS 3.5 were updated to reflect the wording and description in the actual TS. As such the abbreviation of the Safety Analysis Report is defined and the particulate and gas monitors are described as stack particulate and stack gas monitors in keeping with the language in the TS.

Additional description of the setpoints in Table 3.5-1 is given. The levels used to define the Alert points is founded in the site Emergency Plan Section 5.1 and the definitions of a notification of unusual event for the site. Justification for the continued use of the Ar-41 and Co-60 AEC values as the standard is given.

11. TS 3.6: Confinement and Main HVAC Systems

Specification

The reactor shall not be operated~~,~~ nor shall irradiated fuel or irradiated fueled experiments that are not contained in a properly sealed and approved shipping container be moved within the ~~pool area,~~ reactor building unless the following equipment is operable, and conditions met:

Additional conditions for the operability of the confinement and HVAC systems were included to cover fueled experiment movement and also broaden the scope from the pool area to the reactor building as a whole. Additional wording to update the TS wording in compliance with the ANSI 15.1 standard providing an exception for sealed material in a shipping container.

Additionally, a blank line following this paragraph was removed to improve the layout on the page.

12. TS 3.6: Confinement and Main HVAC Systems – Footnotes

(7) When the radiation levels reach the alarm setpoint on any single area, or stack exhaust monitor, listed in Table 3.~~6~~5-1, the building will be automatically placed in confinement as described in SAR Section 5.

A historical typo which incorrectly references the wrong table is corrected to reference Table 3.5-1 which contains the radiation monitoring equipment.

13. TS 3.8: Operations with Fueled Experiments

a. The ~~mass,~~ fission rate for fueled experiments is limited to 2×10^9 fission/sec.~~and power are limited as indicated in Figure 3.8-1 and Table 3.8-1.~~

The wording was updated to provide a single limit for all fueled experiments. By defining a fission rate, samples with higher mass must be irradiated in lower fluxes. Samples with lower masses may be irradiated at higher fluxes. As a result of simplifying to a single fission rate, Table 3.8-1 and Figure 3.8-1 are no longer needed and are removed.

14. TS 3.8: Operations with Fueled Experiments

~~b. The reactor shall not be operated with a fueled experiment unless the ventilation system is operated in the confinement mode.~~

The requirement to operate in confinement during a fueled experiments is not needed to ensure public dose requirements are within reason. Restrictions are in place based on TS 3.8 d which require the site total released public dose to be less than 10 mrem. Further, the practice of standard operation with confinement running reduces the number of emergency systems in place if an accident were to occur. Based on the analysis of the proposed fueled experiments, the release will remain well within the 10 CFR 20 administrative limit and do not require confinement to be operating.

Confinement and radiation monitoring must be operable according to TS 3.5 and 3.6, and to avoid repetition, the redundant wording was removed.

15. TS 3.8: Operations with Fueled Experiments

c. Specification 3.2 pertaining to reactivity shall be met.

TS 3.2 provides the maximum experiment worths, and to avoid repetition, the redundant wording was removed.

16. TS 3.8: Operations with Fueled Experiments

d.b. Specification 3.7 pertaining to reactor experiments shall be met with the exception that encapsulation is not required for vented fueled experiments, and vented fueled experiments may allow for the release of airborne activity. Vented fueled experiments shall be designed to prevent interaction with reactor components or pool water.

Based on the analysis of both encapsulated and vented experiments, all potential releases produce doses well within the 10 CFR 20 annual dose constraint. As a result, previous restrictions which required encapsulation of all experiments is broadened here to allow for vented fueled experiments while still maintaining all other requirements for experiments at the reactor. Vented experiments are restricted to only allow for gaseous airborne activity and not particulate releases, further ensuring doses are kept minimal.

The intention from TS 3.7 of avoiding interaction with the reactor components or pool water was added to provide clarity that even without encapsulation, vented fueled experiments must still ensure reactor component and pool water safety. Wording of the vented experiments was also updated to consistently reference "vented fueled experiments."

17. TS 3.8: Operations with Fueled Experiments

e. Specification 6.5 pertaining to the review of experiments shall be met.

Review of experiments is required using both procedures currently in place within TS 6.2.3 and 6.5, and to avoid repetition, the redundant wording was removed.

c. Each type of fueled experiment shall meet the following items:

Each type of fueled experiment shall be classified as a new (untried) experiment with a documented review. The documented review shall includemeet the following items:

Based on the analysis for the fueled experiments completed for this LAR, the impact from fueled experiments is bounded by the fission rate in these proposed TS and potential releases are minimal. As such, each experiment may be reviewed under the standard procedures.

Additionally, the formatting of this point was improved to provide clarity to readers.

i. Meeting license requirements for the receipt, use, and storage of fissionable fissile material.

Terminology was updated to reflect the definition of fueled experiments given in the TS.

~~i.~~ii. Physical form shall be solid or liquid.

Fueled experiments will be further restricted from the currently approved TS to not included gaseous fuel materials.

~~ii.~~iii. Limiting the thermal power generated from the fissile material for experiments within the pool water to ensure that the surface temperature of the experiment does not exceed the saturation temperature of the reactor pool water.

The bases for this requirement is that the pool water must not boil. For fueled experiments which are outside the pool water, the temperature of the experiment will not impact potential boiling of the pool water.

~~iii.~~iv. Radiation monitoring for detection of released fission products~~.~~ at the exhaust of vented fueled experiments.

The radiation monitoring in place and required by TS 3.5 provide coverage of potential releases for encapsulated experiments. For vented fueled experiments, additional monitoring of the exhaust is required to provide notification of any unusual event at the experiment location.

~~Design criteria related to meeting conditions given in Specifications 3.2 and 3.7.~~

Experiment requirements are in TS 3.2 and 3.7, and to avoid repetition, the redundant wording was removed.

~~f.~~d. Credible failure of any fueled experiment shall not result in releases or exposures in excess of 10 percent of the annual limits established in 10 CFR Part 20.

The limit on dose release including credible fueled experiment accidents is set at the 10 CFR 20 annual dose constraint of 10 mrem in keeping with ALARA principles.

18. TS 3.8: Operations with Fueled Experiments

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Table 3.8-1 and Figure 3.8-1 were removed as the data was simplified to the description in TS 3.8 a.

Pages 27 and 28 were intentionally left blank after the figure and table were removed to maintain the formatting of the TS document.

19. TS 3.8: Operations with Fueled Experiments - Bases

Specification 3.8.e ensures that each type of fFueled experiments isare reviewed, approved, and documented as required by Specifications 6.2.3 and 6.5. This includes (1) meeting applicable limitations on experiments given in Specifications 3.2 and 3.7license requirements for the receipt, use, and storage of fissile material,

(2) limiting the amount of fissile material to ensure that experimental reactivity conditions are met and that radiation doses are well within 10 CFR Part 20 radiation dose limits following maximum fission product release from a failed experiment or vented release, and (3) limiting the thermal power generated from the fissile material to ensure that the surface temperature of the experiment does not exceed the saturation temperature of the reactor pool water.

The bases of TS 3.8 are kept the same as the logic applied is consistent with the currently approved TS. The change in reference to the sections required for the approval and review of fueled experiments is updated to reflect the change in the TS 3.8.

20. TS 4.4: Radiation Monitoring Equipment

4.4 Radiation Monitoring Equipment

Applicability

This specification applies to the surveillance requirements for the area and stack effluent radiation monitoring and vented fueled experiment exhaust gas radiation and flow monitoring equipment.

Objective

The objective is to assure that the radiation monitoring equipment is operable.

Specification

a. TChannel calibration of the area and stack monitoring systems shall be calibrated performed annually but at intervals not to exceed fifteen (15) months.

b. The setpoints of the area and stack monitoring systems shall be verified weekly, but at intervals not to exceed ten
b. (10) days.

c. Channel calibration of the vented fueled experiment exhaust gas radiation and flow monitors shall be performed prior to initial operation of the experiment and annually, not to exceed fifteen (15) months, thereafter while the experiment is installed in the reactor.

d. The setpoints of the vented fueled exhaust gas radiation and flow monitors shall be verified weekly, but at intervals not to exceed ten (10) days if the vented fueled experiment is installed in the reactor.

e. Channel checks shall be performed for the following:
   i. Area and stack radiation monitors prior to first start of reactor operation of the day.
   ii. Vented fueled experiment exhaust gas radiation monitor prior to first start of operation of the experiment of the day.
   iii. Vented fueled experiment flow rate monitor prior to first start of operation of the experiment of the day.

f. Channel tests shall be performed monthly, but at intervals not to exceed six (6) weeks, for the following:
   i. Area and stack radiation monitors.
   ii. Vented fueled experiment exhaust gas radiation monitor if the vented fueled experiment is installed in the reactor.
   iii. Vented fueled experiment flow rate monitor if the vented fueled experiment is installed in the reactor.

Bases

These systems provide continuous radiation monitoring of the Reactor Building with a check of readings performed prior to and during reactor operations. Therefore, the wWeekly verification of the setpoints in conjunction with the annual calibrationchannel checks, monthly channel tests, and annual calibration is adequate to identify long term variations in the system operating characteristics. Vented fueled experiments shall be considered installed in the reactor when they are placed in the experiment location and operable.

Applicability updated to include the new conditions for the vented fueled experiment exhaust gas radiation and flow monitoring equipment when the experiment is installed in the reactor.

The calibration of the area and stack monitoring systems was changed to be a channel calibration to clearly stipulate that the whole of the channel should be calibrated.

If changes/replacement is made to a channel, the channel is altered or new must be calibrated. This is understood for all channels. To be consistent with the rest of TS, a specific statement regarding such requirements is not made here since it is not explicitly stated elsewhere for other channels in the TS.

Clarification wording added to address specifically the setpoints of the area and stack monitoring systems.

Channel calibration of the required channels for the vented fueled experiment (i.e. radiation monitoring and flow monitoring) are required prior to initial operation of the experiment to ensure operability and then annually in accordance with other similar surveillances of similar systems.

Setpoints for the vented fueled experiment exhaust gas radiation and flow monitoring required to be checked.

Channel checks of the radiation and flow monitors for vented fueled experiments shall be completed prior to use of the experiment. If the experiment is not going to be operated, then these checks are not required.

Channel check and test requirements were added to reflect the recommendations in NUREG 1537 Appendix 14.1 and ANSI 15.1-4.7.1 standards. Channel tests are made to be monthly in agreement with NUREG 1537 for radiation monitoring systems.

Bases were updated to reflect the additions to the TS. Vented fueled experiments were defined to be installed in the reactor when they are both in place and able to be used to provide clarity for the applicability of the respective TS.

Font size of TS 4.4 were updated to allow for cleaner formatting.

ATTACHMENT 2:
Technical Specifications Amendment 19
(with change bars)

Appendix A

Technical Specifications for the

North Carolina State University

PULSTAR Reactor

Facility License No. R-120

Docket No. 50-297

Amendment No. 19

Date: February 23, 2023

FIGURES

TABLES

1.2.7 **Control Rod**: A control rod is a neutron absorbing blade having an in-line drive which is magnetically coupled and has SCRAM capability.

1.2.8 **Excess Reactivity**: Excess reactivity is that amount of reactivity that would exist if all control rods (and Shim Rod) were fully withdrawn from the point where the reactor is exactly critical (k_{eff}=1).

1.2.9 **Experiment**: Any operation, hardware, or target (excluding devices such as detectors, foils, etc.) that is designed to investigate non-routine reactor characteristics or that is intended for irradiation within the pool, on or in a beam tube or irradiation facility, and that is not rigidly secured to a core or shield structure so as to be a part of their design. Specific categories of experiments include:

a. **Tried Experiment**: Tried experiments are those experiments that have been previously performed in this reactor. Specifically, a tried experiment has similar size, shape, composition and location of an experiment previously approved and performed in the reactor.

b. **Secured Experiment**: A secured experiment is any experiment, experimental facility, or component of an experiment that is held in a stationary position relative to the reactor by mechanical means. The restraining forces must be substantially greater than those to which the experiment might be subjected by hydraulic, pneumatic, buoyant, or other forces which are normal to the operating environment of the experiment, or by forces which can arise as a result of credible malfunctions.

c. **Non-Secured Experiment**: A non-secured experiment is an experiment that does not meet the criteria for being a "secured" experiment.

d. **Movable Experiment**: A movable experiment is one where it is intended that all or part of the experiment may be moved in or near the core or into and out of the reactor while the reactor is operating.

e. **Fueled Experiment**: A fueled experiment is an experiment which irradiates fissile material. Fueled experiments exclude the following:

i. Fissile material not subjected to neutron fluence
ii. Detectors containing fissile material
iii. Sealed sources
iv. PULSTAR reactor fuel used in operation of the reactor.

1.2.10 **Experimental Facilities**: Experimental facilities are facilities used to perform experiments. They include beam tubes, thermal columns, void tanks, pneumatic transfer systems, in-core facilities at single-assembly positions, out-of-core irradiation facilities, and the bulk irradiation facility.

3.5 Radiation Monitoring Equipment

Applicability

This specification applies to the availability of radiation monitoring equipment which must be operable during reactor operation.

Objective

To assure that radiation monitoring equipment is available for evaluation of radiation conditions in restricted and unrestricted areas.

Specification

The reactor shall not be operated nor shall irradiated fuel or irradiated fueled experiments that are not contained in a properly sealed and approved shipping container be moved within the reactor building unless the radiation monitoring equipment listed below and in Table 3.5-1 is operable.(1)(2)(3)(7)

a. Three fixed area monitors operating in the Reactor Building with their setpoints as listed in Table 3.5-1.(1)(3)(4)

b. Stack particulate and stack gas building exhaust monitors continuously sampling air in the facility exhaust stack with their setpoints as listed in Table 3.5-1.(1)(3)(4)

c. The Radiation Rack Recorder.(5)

d. Vented fueled experiment exhaust gas radiation monitor continuously monitoring the experiment exhaust gas.(7)

e. Vented fueled experiment flow rate monitor continuously monitoring the experiment exhaust gas flow.(7)

Table 3.5-1: Required Radiation Area Monitors

Monitor	Alert Setpoint	Alarm Setpoint
Control Room	≤ 2 mR/hr	≤ 5 mR/hr
Over-the-Pool	≤ 5 mR/hr	≤ 100 mR/hr
West Wall	≤ 5 mR/hr	≤ 100 mR/hr
Stack Gas	≤ 1000 Ar-41 AEC(6)	≤ 5,000 Ar-41AEC(6)
Stack Particulate	≤ 1000 Co-60 AEC(6)	≤ 5,000 Co-60 AEC(6)

(1) For periods of time, not to exceed ninety days, for maintenance to the radiation monitoring channel, the intent of this specification will be satisfied if one of the installed channels is replaced with a gamma-sensitive instrument which has its own alarm audible or observable in the control room. Refer to SAR Section 5.

(2) The Over-the-Pool Monitor may be bypassed for less than two minutes during return of a pneumatic capsule from the core to the unloading station or five minutes during removal of experiments from the reactor pool. Refer to SAR Section 5.

(3) Stack Gas and Particulate are based on the AEC quantities present in the ventilation flow stream as it exits the stack. Refer to SAR Section 10 for setpoint bases for the radiation monitoring equipment.

(4) May be bypassed for less than one minute immediately after starting the pneumatic blower system.

(5) During repair and/or maintenance of the recorder not to exceed 90 days, the specified area and effluent monitor readings shall be recorded manually at a nominal interval of 30 minutes when the reactor is not shutdown. Refer to SAR Section 5.

(6) Airborne Effluent Concentrations (AEC) values from 10 CFR Part 20 Appendix B, Table 2

(7) Monitors for vented fueled experiments are only required to be operating while the experiment is in operation.

Bases

A continued evaluation of the radiation levels within the Reactor Building will be made to assure the safety of personnel. This is accomplished by the area monitoring system of the type described in Section 5 of the Safety Analysis Report (SAR).

Evaluation of the continued discharge air to the environment will be made using the information recorded from the stack particulate and stack gas monitors.

When the radiation levels reach the alarm setpoint on any single area, or stack exhaust monitor, the building will be automatically placed in confinement as described in SAR Section 5.

To prevent unnecessary initiation of the evacuation confinement system during the return of a pneumatic capsule from the core to the unloading station or during removal of experiments from the reactor pool, the Over-the-Pool Monitor may be bypassed during the specified time interval. Refer to SAR Section 5.

Stack gas and stack particulate setpoints are based on the Notification of Unusual Event Emergency Action Level (EAL) for potential released nuclides including Ar-41, Co-60, and fission products. Fission product AEC values are higher than those for Ar-41 and Co-60. Therefore, using Ar-41 and Co-60 AEC for the setpoints is conservative.

3.6 Confinement and Main HVAC Systems

Applicability

This specification applies to the operation of the Reactor Building confinement and main HVAC systems.

Objective

The objective is to assure that the confinement system is in operation to mitigate the consequences of possible release of radioactive materials resulting from reactor operation.

Specification

The reactor shall not be operated nor shall irradiated fuel or irradiated fueled experiments that are not contained in a properly sealed and approved shipping container be moved within the reactor building unless the following equipment is operable, and conditions met:

Table 3.6-1: Required Main HVAC and Confinement Conditions

	Equipment/Condition	Function
a.	All doors, except the Control Room, and basement corridor entrance: self-latching, self-closing, closed and locked.	To maintain reactor building negative differential pressure (dp).(1)
b.	Control room and basement corridor entrance door: self-latching, self-closing and closed.	To maintain reactor building negative differential pressure.(2)
c.	Reactor Building under a negative differential pressure of not less than 0.2" H_2O with the normal ventilation system or 0.1" H_2O with one confinement fan operating.	To maintain reactor building negative differential pressure with reference to outside ambient.(3)
d.	Confinement system	Operable(4)(5)(7)
e.	Evacuation system	Operable(6)

(1) Doors may be opened by authorized personnel for less than five minutes for personnel and equipment transport provided audible and visual indications are available for the reactor operator to verify door status. Refer to SAR Section 5.

(2) Doors may be opened for periods of less than five minutes for personnel and equipment transport between corridor area and Reactor Building. Refer to SAR Section 5.

[3] During an interval not to exceed 30 minutes after a loss of dp is identified with Main HVAC operating, reactor operation may continue while the loss of dp is investigated and corrected. Refer to SAR Section 5.

[4] Operability also demonstrated with an auxiliary power source.

[5] One filter train may be out of service for the purpose of maintenance, repair, and/or surveillance for a period of time not to exceed 45 days. During the period of time in which one filter train is out of service, the standby filter train shall be verified to be operable every 24 hours if the reactor is operating with the Reactor Building in normal ventilation.

[6] The public address system can serve temporarily for the Reactor Building evacuation system during short periods of maintenance.

[7] When the radiation levels reach the alarm setpoint on any single area, or stack exhaust monitor, listed in Table 3.5-1, the building will be automatically placed in confinement as described in SAR Section 5.

Bases

In the event of a fission product release, the confinement initiation system will secure the normal ventilation fans and close the normal inlet and exhaust dampers. In confinement mode, a confinement system fan will: maintain a negative pressure in the Reactor Building and insure in-leakage only; purge the air from the building at a greatly reduced and controlled flow through charcoal and absolute filters; and control the discharge of all air through a 100 foot stack onsite. Section 5 of the SAR describes the confinement system sequence of operation.

The allowance for operation under a temporary loss of dp when in normal ventilation is based on the requirement of having the confinement system operable and therefore ready to respond in the unlikely event of an airborne release.

3.8 Operations with Fueled Experiments

Applicability

This specification applies to the operation of the reactor with any fueled experiment.

Objective

The objective is to prevent damage to the reactor or excessive release of radioactive materials in the event of an experiment failure.

Specifications

Fueled experiments may be performed in experimental facilities of the reactor with the following conditions and limitations:

a. The fission rate for fueled experiments is limited to 2×10^9 fission/sec.

b. Specification 3.7 pertaining to reactor experiments shall be met with the exception that encapsulation is not required for vented fueled experiments, and vented fueled experiments may allow for the release of airborne activity. Vented fueled experiments shall be designed to prevent interaction with reactor components or pool water.

c. Each type of fueled experiment shall meet the following items:

   i. Meeting license requirements for the receipt, use, and storage of fissile material.

   ii. Physical form shall be solid or liquid.

   iii. Limiting the thermal power generated from the fissile material for experiments within the pool water to ensure that the surface temperature of the experiment does not exceed the saturation temperature of the reactor pool water.

   iv. Radiation monitoring for detection of released fission products at the exhaust of vented fueled experiments.

d. Credible failure of any fueled experiment shall not result in releases or exposures in excess of 10 percent of the annual limits established in 10 CFR Part 20.

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Bases

NUREG 1537 provides guidelines for the format and content of non-power reactor licensing. Guidelines on operating conditions and accident analysis for fueled experiments are given in NUREG 1537. These guidelines include (1) actuation of engineered safety features (ESF) to prevent or mitigate the consequences of damage to fission product barriers caused by overpower or loss of cooling events, (2) use of ESF to control of radioactive material released by accidents, (3) radiation monitoring of fission product effluent and accident releases, (4) accidental analysis for loss of cooling or other experimental malfunction resulting in liquefaction or volatilization of fissile materials, (5) accident analysis for catastrophic failure of the experiment in the reactor pool or air, (6) accident analysis for insertion of excess reactivity leading to fuel melting, and (7) emergency plan activation and classification.

The limitations given in Specification 3.8 ensure that (1) fueled experiments performed in experimental facilities at the reactor prevent damage to the reactor or excessive release of radioactive materials in the event of an experiment failure, (2) radiation doses to occupational personnel and the public and radioactive material releases are ALARA, (3) adequate radiation monitoring is in place, and (4) in the event of failure of a fueled experiment with the subsequent release of radioactive material, the resulting dose to personnel and the public at any location are well within limits set in 10 CFR Part 20.

Fueled experiments are reviewed, approved, and documented as required by Specifications 6.2.3 and 6.5. This includes (1) meeting license requirements for the receipt, use, and storage of fissile material, (2) limiting the amount of fissile material to ensure that experimental reactivity conditions are met and that radiation doses are well within 10 CFR Part 20 radiation dose limits following maximum fission product release from a failed experiment or vented release, and (3) limiting the thermal power generated from the fissile material to ensure that the surface temperature of the experiment does not exceed the saturation temperature of the reactor pool water.

4.4 Radiation Monitoring Equipment

Applicability

This specification applies to the surveillance requirements for the area and stack effluent radiation monitoring and vented fueled experiment exhaust gas radiation and flow monitoring equipment.

Objective

The objective is to assure that the radiation monitoring equipment is operable.

Specification

a. Channel calibration of the area and stack monitoring systems shall be performed annually but at intervals not to exceed fifteen (15) months.

b. The setpoints of the area and stack monitoring systems shall be verified weekly, but at intervals not to exceed ten (10) days.

c. Channel calibration of the vented fueled experiment exhaust gas radiation and flow monitors shall be performed prior to initial operation of the experiment and annually, not to exceed fifteen (15) months, thereafter while the experiment is installed in the reactor.

d. The setpoints of the vented fueled exhaust gas radiation and flow monitors shall be verified weekly, but at intervals not to exceed ten (10) days if the vented fueled experiment is installed in the reactor.

e. Channel checks shall be performed for the following:
   i. Area and stack radiation monitors prior to first start of reactor operation of the day.
   ii. Vented fueled experiment exhaust gas radiation monitor prior to first start of operation of the experiment of the day.
   iii. Vented fueled experiment flow rate monitor prior to first start of operation of the experiment of the day.

f. Channel tests shall be performed monthly, but at intervals not to exceed six (6) weeks, for the following:
   i. Area and stack radiation monitors.
   ii. Vented fueled experiment exhaust gas radiation monitor if the vented fueled experiment is installed in the reactor.
   iii. Vented fueled experiment flow rate monitor if the vented fueled experiment is installed in the reactor.

Bases

These systems provide continuous radiation monitoring of the Reactor Building with a check of readings performed prior to and during reactor operations. Weekly verification of the setpoints in conjunction with the channel checks, monthly channel tests, and annual calibration is adequate to identify long term variations in the system operating characteristics. Vented fueled experiments shall be considered installed in the reactor when they are placed in the experiment location and operable.

ATTACHMENT 3:
Technical Specifications Amendment 19
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Appendix A

Technical Specifications for the

North Carolina State University

PULSTAR Reactor

Facility License No. R-120

Docket No. 50-297

Amendment No. 19

Date: February 23, 2023

FIGURES

TABLES

1.2.7 Control Rod: A control rod is a neutron absorbing blade having an in-line drive which is magnetically coupled and has SCRAM capability.

1.2.8 Excess Reactivity: Excess reactivity is that amount of reactivity that would exist if all control rods (and Shim Rod) were fully withdrawn from the point where the reactor is exactly critical (k_{eff}=1).

1.2.9 Experiment: Any operation, hardware, or target (excluding devices such as detectors, foils, etc.) that is designed to investigate non-routine reactor characteristics or that is intended for irradiation within the pool, on or in a beam tube or irradiation facility, and that is not rigidly secured to a core or shield structure so as to be a part of their design. Specific categories of experiments include:

a. **Tried Experiment**: Tried experiments are those experiments that have been previously performed in this reactor. Specifically, a tried experiment has similar size, shape, composition and location of an experiment previously approved and performed in the reactor.

b. **Secured Experiment**: A secured experiment is any experiment, experimental facility, or component of an experiment that is held in a stationary position relative to the reactor by mechanical means. The restraining forces must be substantially greater than those to which the experiment might be subjected by hydraulic, pneumatic, buoyant, or other forces which are normal to the operating environment of the experiment, or by forces which can arise as a result of credible malfunctions.

c. **Non-Secured Experiment**: A non-secured experiment is an experiment that does not meet the criteria for being a "secured" experiment.

d. **Movable Experiment**: A movable experiment is one where it is intended that all or part of the experiment may be moved in or near the core or into and out of the reactor while the reactor is operating.

e. **Fueled Experiment**: A fueled experiment is an experiment which irradiates fissile material. Fueled experiments exclude the following:

i. Fissile material not subjected to neutron fluence
ii. Detectors containing fissile material
iii. Sealed sources
iv. PULSTAR reactor fuel used in operation of the reactor.

1.2.10 Experimental Facilities: Experimental facilities are facilities used to perform experiments. They include beam tubes, thermal columns, void tanks, pneumatic transfer systems, in-core facilities at single-assembly positions, out-of-core irradiation facilities, and the bulk irradiation facility.

3.5 Radiation Monitoring Equipment

Applicability

This specification applies to the availability of radiation monitoring equipment which must be operable during reactor operation.

Objective

To assure that radiation monitoring equipment is available for evaluation of radiation conditions in restricted and unrestricted areas.

Specification

The reactor shall not be operated nor shall irradiated fuel or irradiated fueled experiments that are not contained in a properly sealed and approved shipping container be moved within the reactor building unless the radiation monitoring equipment listed below and in Table 3.5-1 is operable.(1)(2)(3)(7)

a. Three fixed area monitors operating in the Reactor Building with their setpoints as listed in Table 3.5-1.(1)(3)(4)

b. Stack particulate and stack gas building exhaust monitors continuously sampling air in the facility exhaust stack with their setpoints as listed in Table 3.5-1.(1)(3)(4)

c. The Radiation Rack Recorder.(5)

d. Vented fueled experiment exhaust gas radiation monitor continuously monitoring the experiment exhaust gas.(7)

e. Vented fueled experiment flow rate monitor continuously monitoring the experiment exhaust gas flow.(7)

Table 3.5-1: Required Radiation Area Monitors

Monitor	Alert Setpoint	Alarm Setpoint
Control Room	≤ 2 mR/hr	≤ 5 mR/hr
Over-the-Pool	≤ 5 mR/hr	≤ 100 mR/hr
West Wall	≤ 5 mR/hr	≤ 100 mR/hr
Stack Gas	≤ 1000 Ar-41 AEC(6)	≤ 5,000 Ar-41AEC(6)
Stack Particulate	≤ 1000 Co-60 AEC(6)	≤ 5,000 Co-60 AEC(6)

(1) For periods of time, not to exceed ninety days, for maintenance to the radiation monitoring channel, the intent of this specification will be satisfied if one of the installed channels is replaced with a gamma-sensitive instrument which has its own alarm audible or observable in the control room. Refer to SAR Section 5.

(2) The Over-the-Pool Monitor may be bypassed for less than two minutes during return of a pneumatic capsule from the core to the unloading station or five minutes during removal of experiments from the reactor pool. Refer to SAR Section 5.

(3) Stack Gas and Particulate are based on the AEC quantities present in the ventilation flow stream as it exits the stack. Refer to SAR Section 10 for setpoint bases for the radiation monitoring equipment.

(4) May be bypassed for less than one minute immediately after starting the pneumatic blower system.

(5) During repair and/or maintenance of the recorder not to exceed 90 days, the specified area and effluent monitor readings shall be recorded manually at a nominal interval of 30 minutes when the reactor is not shutdown. Refer to SAR Section 5.

(6) Airborne Effluent Concentrations (AEC) values from 10 CFR Part 20 Appendix B, Table 2

(7) Monitors for vented fueled experiments are only required to be operating while the experiment is in operation.

Bases

A continued evaluation of the radiation levels within the Reactor Building will be made to assure the safety of personnel. This is accomplished by the area monitoring system of the type described in Section 5 of the Safety Analysis Report (SAR).

Evaluation of the continued discharge air to the environment will be made using the information recorded from the stack particulate and stack gas monitors.

When the radiation levels reach the alarm setpoint on any single area, or stack exhaust monitor, the building will be automatically placed in confinement as described in SAR Section 5.

To prevent unnecessary initiation of the evacuation confinement system during the return of a pneumatic capsule from the core to the unloading station or during removal of experiments from the reactor pool, the Over-the-Pool Monitor may be bypassed during the specified time interval. Refer to SAR Section 5.

Stack gas and stack particulate setpoints are based on the Notification of Unusual Event Emergency Action Level (EAL) for potential released nuclides including Ar-41, Co-60, and fission products. Fission product AEC values are higher than those for Ar-41 and Co-60. Therefore, using Ar-41 and Co-60 AEC for the setpoints is conservative.

3.6 Confinement and Main HVAC Systems

Applicability

This specification applies to the operation of the Reactor Building confinement and main HVAC systems.

Objective

The objective is to assure that the confinement system is in operation to mitigate the consequences of possible release of radioactive materials resulting from reactor operation.

Specification

The reactor shall not be operated nor shall irradiated fuel or irradiated fueled experiments that are not contained in a properly sealed and approved shipping container be moved within the reactor building unless the following equipment is operable, and conditions met:

Table 3.6-1: Required Main HVAC and Confinement Conditions

	Equipment/Condition	Function
a.	All doors, except the Control Room, and basement corridor entrance: self-latching, self-closing, closed and locked.	To maintain reactor building negative differential pressure (dp).(1)
b.	Control room and basement corridor entrance door: self-latching, self-closing and closed.	To maintain reactor building negative differential pressure.(2)
c.	Reactor Building under a negative differential pressure of not less than 0.2" H_2O with the normal ventilation system or 0.1" H_2O with one confinement fan operating.	To maintain reactor building negative differential pressure with reference to outside ambient.(3)
d.	Confinement system	Operable(4)(5)(7)
e.	Evacuation system	Operable(6)

(1) Doors may be opened by authorized personnel for less than five minutes for personnel and equipment transport provided audible and visual indications are available for the reactor operator to verify door status. Refer to SAR Section 5.

(2) Doors may be opened for periods of less than five minutes for personnel and equipment transport between corridor area and Reactor Building. Refer to SAR Section 5.

(3) During an interval not to exceed 30 minutes after a loss of dp is identified with Main HVAC operating, reactor operation may continue while the loss of dp is investigated and corrected. Refer to SAR Section 5.

(4) Operability also demonstrated with an auxiliary power source.

(5) One filter train may be out of service for the purpose of maintenance, repair, and/or surveillance for a period of time not to exceed 45 days. During the period of time in which one filter train is out of service, the standby filter train shall be verified to be operable every 24 hours if the reactor is operating with the Reactor Building in normal ventilation.

(6) The public address system can serve temporarily for the Reactor Building evacuation system during short periods of maintenance.

(7) When the radiation levels reach the alarm setpoint on any single area, or stack exhaust monitor, listed in Table 3.5-1, the building will be automatically placed in confinement as described in SAR Section 5.

Bases

In the event of a fission product release, the confinement initiation system will secure the normal ventilation fans and close the normal inlet and exhaust dampers. In confinement mode, a confinement system fan will: maintain a negative pressure in the Reactor Building and insure in-leakage only; purge the air from the building at a greatly reduced and controlled flow through charcoal and absolute filters; and control the discharge of all air through a 100 foot stack onsite. Section 5 of the SAR describes the confinement system sequence of operation.

The allowance for operation under a temporary loss of dp when in normal ventilation is based on the requirement of having the confinement system operable and therefore ready to respond in the unlikely event of an airborne release.

3.8 Operations with Fueled Experiments

Applicability

This specification applies to the operation of the reactor with any fueled experiment.

Objective

The objective is to prevent damage to the reactor or excessive release of radioactive materials in the event of an experiment failure.

Specifications

Fueled experiments may be performed in experimental facilities of the reactor with the following conditions and limitations:

a. The fission rate for fueled experiments is limited to 2×10^9 fission/sec.

b. Specification 3.7 pertaining to reactor experiments shall be met with the exception that encapsulation is not required for vented fueled experiments, and vented fueled experiments may allow for the release of airborne activity. Vented fueled experiments shall be designed to prevent interaction with reactor components or pool water.

c. Each type of fueled experiment shall meet the following items:

   i. Meeting license requirements for the receipt, use, and storage of fissile material.

   ii. Physical form shall be solid or liquid.

   iii. Limiting the thermal power generated from the fissile material for experiments within the pool water to ensure that the surface temperature of the experiment does not exceed the saturation temperature of the reactor pool water.

   iv. Radiation monitoring for detection of released fission products at the exhaust of vented fueled experiments.

d. Credible failure of any fueled experiment shall not result in releases or exposures in excess of 10 percent of the annual limits established in 10 CFR Part 20.

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Bases

NUREG 1537 provides guidelines for the format and content of non-power reactor licensing. Guidelines on operating conditions and accident analysis for fueled experiments are given in NUREG 1537. These guidelines include (1) actuation of engineered safety features (ESF) to prevent or mitigate the consequences of damage to fission product barriers caused by overpower or loss of cooling events, (2) use of ESF to control of radioactive material released by accidents, (3) radiation monitoring of fission product effluent and accident releases, (4) accidental analysis for loss of cooling or other experimental malfunction resulting in liquefaction or volatilization of fissile materials, (5) accident analysis for catastrophic failure of the experiment in the reactor pool or air, (6) accident analysis for insertion of excess reactivity leading to fuel melting, and (7) emergency plan activation and classification.

The limitations given in Specification 3.8 ensure that (1) fueled experiments performed in experimental facilities at the reactor prevent damage to the reactor or excessive release of radioactive materials in the event of an experiment failure, (2) radiation doses to occupational personnel and the public and radioactive material releases are ALARA, (3) adequate radiation monitoring is in place, and (4) in the event of failure of a fueled experiment with the subsequent release of radioactive material, the resulting dose to personnel and the public at any location are well within limits set in 10 CFR Part 20.

Fueled experiments are reviewed, approved, and documented as required by Specifications 6.2.3 and 6.5. This includes (1) meeting license requirements for the receipt, use, and storage of fissile material, (2) limiting the amount of fissile material to ensure that experimental reactivity conditions are met and that radiation doses are well within 10 CFR Part 20 radiation dose limits following maximum fission product release from a failed experiment or vented release, and (3) limiting the thermal power generated from the fissile material to ensure that the surface temperature of the experiment does not exceed the saturation temperature of the reactor pool water.

4.4 Radiation Monitoring Equipment

Applicability

This specification applies to the surveillance requirements for the area and stack effluent radiation monitoring and vented fueled experiment exhaust gas radiation and flow monitoring equipment.

Objective

The objective is to assure that the radiation monitoring equipment is operable.

Specification

a. Channel calibration of the area and stack monitoring systems shall be performed annually but at intervals not to exceed fifteen (15) months.

b. The setpoints of the area and stack monitoring systems shall be verified weekly, but at intervals not to exceed ten (10) days.

c. Channel calibration of the vented fueled experiment exhaust gas radiation and flow monitors shall be performed prior to initial operation of the experiment and annually, not to exceed fifteen (15) months, thereafter while the experiment is installed in the reactor.

d. The setpoints of the vented fueled exhaust gas radiation and flow monitors shall be verified weekly, but at intervals not to exceed ten (10) days if the vented fueled experiment is installed in the reactor.

e. Channel checks shall be performed for the following:
   i. Area and stack radiation monitors prior to first start of reactor operation of the day.
   ii. Vented fueled experiment exhaust gas radiation monitor prior to first start of operation of the experiment of the day.
   iii. Vented fueled experiment flow rate monitor prior to first start of operation of the experiment of the day.

f. Channel tests shall be performed monthly, but at intervals not to exceed six (6) weeks, for the following:
   i. Area and stack radiation monitors.
   ii. Vented fueled experiment exhaust gas radiation monitor if the vented fueled experiment is installed in the reactor.
   iii. Vented fueled experiment flow rate monitor if the vented fueled experiment is installed in the reactor.

Bases

These systems provide continuous radiation monitoring of the Reactor Building with a check of readings performed prior to and during reactor operations. Weekly verification of the setpoints in conjunction with the channel checks, monthly channel tests, and annual calibration is adequate to identify long term variations in the system operating characteristics. Vented fueled experiments shall be considered installed in the reactor when they are placed in the experiment location and operable.

ATTACHMENT 4:
Supplemental Solutions and Corrections for Table 1 and 2 Calculations

Solution Documentation to Values Provided in Tables 1 and 2

1) The irradiation of 1,000 micrograms (or less) of fissionable material at thermal neutron flux levels on the order of $1x10^{12}$ $n/cm^2 \cdot s$ for 500 hours (vented experiment).
2) The irradiation of 35 grams of fissionable material in the PULSTAR's neutron beams at thermal neutron flux levels on the order of $1x10^7$ $n/cm^2 \cdot s$ (encapsulated experiment).

Using a conservative assumption of saturated activity conditions, these experiments yield the dose rates below. This evaluation does not credit any holding time or filtration (experiment or confinement).

Table 1. Estimated Site Releases (Activity and TEDE)

1 Current release levels (maximum in 2018 – 2022)	2 Current release levels (average in 2018 – 2022)	3 Estimated release vented irradiation (scenario 1)	1+3 Predicted total annual release
7.29 Ci 1.230 mrem	5.13 Ci 0.860 mrem	0.03 Ci 0.003 mrem	7.32 Ci 1.233 mrem

For the vented experiment, a hypothetical break in the ventilation line resulting in a leak of fission gases into the reactor bay rather than exiting through the stack directly is analyzed. This accident is evaluated assuming an eight hour exposure with normal ventilation for all reactor personal as well as the general public.

For the encapsulated experiment accident, the encapsulation of the fuel is assumed to completely fail and release the saturated activity into the reactor building. The contents of the fuel experiment are assumed to be evacuated from the reactor building over the course of 24 hours of fumigation conditions with a time-averaged decay in the building assumed. Reactor personal are assumed to vacate the reactor building within six minutes.

Table 2. Potential Accident Releases (Activity and TEDE)

Accident release vented experiment OCCUPATIONAL (scenario 1)	Accident release vented experiment PUBLIC (scenario 1)	Accident release encapsulated experiment OCCUPATIONAL (scenario 2)	Accident release encapsulated experiment PUBLIC (scenario 2)
$7x10^{-7}$ Ci $7x10^{-4}$ mrem	$7x10^{-7}$ Ci $6x10^{-6}$ mrem	$1.7x10^{-3}$ Ci 1.7 mrem	0.01 Ci 0.09 mrem

Calculations for Table 1:

Column 1: Ci released taken from facility procedures and annual reports.

Annual dose = C * X/Q * F * DCF, where X/Q*F = 0.005 from procedures

mrem/y = (3.5×10^{-8} μCi/mL)(0.005)(100 mrem/y per 1.42×10^{-8} μCi/mL) = 1.23 mrem

Column 2: Ci released averaged from annual report.

Column 3: Scenario 1 conditions were used. Additional information used;

Assumed a non-thermal flux = 30% of thermal flux
Experiment flow rate = 100 mL / minute = p
Experiment exhaust volume = 3163 liters = w
Normal ventilation exhaust rate = 0.883 m^3/s = F
X/Q = 9.15E-5 s/m^3 for a sector averaged atmospheric dispersion
2.4E9 mL is the reactor building free air volume

$C_i = (C_{stack} \times T)\ F$

$[C_{stack}]$(500 h)(3600 s/h)(0.883 m^3/s)(1×10^6 mL/m^3)(1×10^{-6} Ci/μCi) = 0.034 Ci ~ 0.03 Ci

$C_{stack} = (A_{sat}/ w) \times p/(p+F)$ = [3.62E4 μCi / 3.16E6 mL] x [1.67E-6 m^3/s / (1.67E-6 +0.883) m^3/s] = 2.17×10^{-8} μCi/mL

Dose = C_{stack} (F)(X/Q)(500 h)(DCF in rem/h per μCi/mL)

e.g. Kr^{87}; 1.7E-5 mrem = (8.0E-10 μCi/mL)(0.883 m^3/s)(9.15E-5 s/m^3)(525.4 rem/h per μCi/mL)(500h)(1000 mrem/rem)

For all nuclides, the sum is 2.86E-3 mrem ~ 0.003 mrem

Calculations for Table 2:

Scenario 2 conditions were used. Additional conditions included non-thermal flux of 30% of the thermal flux.

Column 1: Vented experiment accident for 8h into the reactor building

$C_i = [A_{sat}$ / 2.4E9 mL](p / (p+F) T F x (1E6 mL/m^3 x 1 Ci / 1E6 μCi)(3600 s/h); where T = 8 h, F = 0.883 m^3/s

C_i = [3.62E4 μCi / 2.4E9 mL](1.67E-6 m^3/s / ((1.67E-6 +0.883) m^3/s)(500 h)(0.883 m^3/s)(3600 s/h) = 7.25E-7 Ci

TEDE = $[A_{sat}$ / 2.4E9 mL](p / (p+F) T x DCF

e.g. Kr^{87}; 4.44E-6 mrem = = (1.34E3 μCi / 2.4E9 mL)(1.67E-6m^3/s / [1.67E-6 +0.883] m^3/s)(8 h)(525.4 rem/h per μCi/mL)

TEDE for all nuclides = 7.45E-4 mrem ~ 7E-4 mrem

Column 2: Vented experiment accident for 8h into the reactor building

Activity is the same as Column 1

TEDE to public is adjusted from Column 1 for atmospheric dispersion and exhaust from the reactor building

TEDE = [A_{sat} / 2.4E9 mL] (p / (p+F)) T x DCF x (X/Q)(F); X/Q is for fumigation conditions

2.4E9 mL is the reactor building free air volume. Dose is adjust for dispersion.

TEDE = 7.45E-4 mrem (0.00854 s/m^3)(0.883 m^3/s) = 5.62E-6 mrem ~ 6E-6 mrem; NOTE Table 2 shows corrected value without exponent error.

Column 3: Encapsulated accident. Occupational exposure and release for 0.1 h

C_i = C(0) x 0.1h x F x 3600 s/h x 1E6 mL/m^3 x 1 Ci / 1E6 μCi

Where C(0) = A_{sat} / V(rb) and V(rb) = 2.4E9 mL, V(rb) is the reactor building free air volume

Ci = (5.29E-6 μCi/mL for all nuclides)(0.1 h)(3600 s/h)(0.883 m^3/s)(1E6 mL per m^3/1E6 μCi per Ci) =1.7E-3 Ci vs 1E-3 Ci

TEDE to occupational personnel = C(0) T DCF x 1000 mrem/rem

e.g. Kr^{87}; (468 μCi/2.4E9mL)(0.1 h)(525.4 rem/h per μCi/mL)(1000 mrem/rem) = 0.01 mrem

TEDE for all nuclides = 1.73 mrem ~ 1.7 mrem

Column 4: Accidental release of encapsulated experiment. Public dose in 24 h. X/Q is for fumigation conditions.

C_i = C(24h average) x F T; where F = 0.883 m^3/s and T = 24 h

C(24h average) = C(0) [1-Exp(-k x 24h)] / (k x 24h) and k = λ + v, v = ventilation removal rate constant

C_i = 1.15E-7 μCi/mL for all nuclides x (0.883 m^3/s)(24 h)(3600 s/h)(1 Ci/ 1E6 μCi) = 8.8E-3 Ci ~ 0.01 Ci vs 0.1 Ci

NOTE: Table 2 now correctly uses the C(24h avg) instead of the previous incorrect use of C(2h avg); 1.15E-7 μCi/mL (current) vs. 1.3E-6 μCi/mL (incorrect)

TEDE = C(24h average) x F X/Q x T x DCF

e.g. Kr^{87}; (4.35E-9 μCi/mL)(0.883 m^3/s)(0.00854 s/m^3)(24 h)(525.4 rem/h per μCi/mL)(1000 mrem/rem) =4.14 E-4 mrem

For all radionuclides; TEDE = 8.95E-2 mrem ~ 0.09 mrem