October 19, 2022

ATTN: Document Control Desk
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

Subject: Docket Number 50-184 license amendment request

Dear Sirs/Madams:

In our October 1, 2021, letter (Accession Number ML21288A555), we requested NRC permission to restart the reactor upon completion of listed corrective actions and recovery efforts. As part of that recovery effort, some debris from the February 3, 2021 fuel failure event was removed from the reactor primary coolant system, but some remains. Accordingly, we are requesting a license amendment to make specified changes to the NBSR Safety Analysis Report and allow reactor operation with the remaining debris in the primary system. Attached please find 1) Proposed SAR changes, 2) Finding of No Significant Hazards analysis, 3) Engineering Change Notice for operation with debris, including 50.59 analysis, and 4) supplemental analysis and discussion of remaining debris, accident analysis, and fission product release analysis.

As the reactor will be unable to resume operations without this amendment, we are also requesting expedition of this amendment request and a finding of exigent circumstances under 10CFR50.91(a)(6).

Sincerely,

ROBERT DIMEO

Digitally signed by ROBERT DIMEO
Date: 2022.10.19 07:31:54 -04'00'

Robert Dimeo, Director
NIST Center for Neutron Research

I declare under penalty of perjury that the following is true and correct.

Executed on October 19, 2022

By: ROBERT DIMEO

Digitally signed by ROBERT DIMEO
Date: 2022.10.19 07:32:14 -04'00'

10 CFR 50.59 EVALUATION

10 CFR 50.59 EVALUATION			ECR No.:	1251
ECR/Experiment Title:	Operating the NBSR with small amounts of unclad fuel in primary system			
System:	**Primary Cooling/Moderator**		Date:	**10/13/2022**

Does the proposed ECN:	YES	NO
A. **Require** a change to the Technical Specifications (Enter justification below).	☐	☒

The objective of running the NBSR is and remains to operate a clean reactor. However, the presence of debris from the February 3, 2021 event required evaluation of the technical specifications. This evaluation concluded that there is no change needed in the technical specifications to run the reactor safely under these conditions. The NBSR Emergency Plan requires the NBSR to be automatically shut down (via major SCRAM) when the effluent monitor count rate is 50,000 CPM or more. The 50,000 CPM level is based on the maximum dose allowed at the (400 m) site boundary per ANSI/ANS 15.16.

Does the proposed ECN:	YES	NO
B. Result in more than a minimal increase in the ***frequency*** of occurrence of an accident previously evaluated in the updated FSAR (Enter justification below).	☐	☒

None of the accidents analyzed in the FSAR are affected by the presence of unclad fuel particles in the primary system, as a) the mass of fuel material is insignificant to cause any reactivity effects in the reactor, cause flow blockage effects in the system, or limit mechanical devices (i.e. shim arms) if it were to be dislodged and b) the presence of this material does not affect normal operating parameters. See the attached evaluation of accidents. There are no accidents as analyzed in the updated FSAR that could be initiated by the existence of unclad fuel particles. Therefore, the frequency of occurrence of any accident is not changed.

Does the proposed ECN:	YES	NO
C. Result in more than a minimal increase in the ***likelihood*** of occurrence of a malfunction of a structure, system, or component important to safety previously evaluated in the updated FSAR (Enter justification below).	☐	☒

Several months of running all primary system pumps have shown no adverse effects on any SSC present in the primary system. All SSCs important to safety have been tested and continue to function normally. There are no credible means by which the material would suddenly come loose and render a safety component inoperable. Therefore, there is no increase in the likelihood of the occurrence of a malfunction of SSC important to safety.

Does the proposed ECN:	YES	NO
D. Result in more than a minimal increase in the ***consequences*** of an accident previously evaluated in the updated FSAR (Enter justification below).	☐	☒

Only two accidents analyzed in Chapter 13 of the FSAR show results of the release of radioactivity: the loss of coolant accident (LOCA) and the maximum hypothetical accident (MHA). NEI 21-06 section 4.3.3 in part mentions "An increase in consequences from a proposed activity is defined to be no more than minimal if the increase is less than or equal to 10 percent of the difference between the current calculated dose value in the UFSAR and the regulatory guideline value".

The MHA considers the melting of an entire 8-cycle fuel element. The dose at the 400 m boundary for the MHA is a total of 6.8 mrem, and 3.5 mrem within the first day (Table 13.4 Dose to an Individual at the Edge of the 400-meter Exclusion Zone After the Maximum Hypothetical Accident). The other accident that could be affected is the "Loss of Primary Coolant" (updated FSAR 13.2.3) LOCA event, where a major rupture in the cold leg of the primary system is assumed, which leads to draining the reactor core. In this case, if the entire inventory were to leak out in this manner, a person at the site boundary would receive less than 6.5 mrem and doses to personnel from the debris would be insignificant compared with tritium doses.

Both the MHA and LOCA accidents result in a total dose of less than 6.5 mrem at the site boundary on the first day. By contrast, it is estimated that the presence of remaining fuel material would result in a site boundary dose being at most **0.13 mrem** (assuming a full day of operation while releasing through the stack, see "Fission Product Release Updated - Addendum.docx"), which conservatively assumes the reactor continues to operate. This is a change of only 2% from the MHA and LOCA. The maximum permissible annual dose limit to the public is 10 mrem accepted in the updated FSAR (10 CFR 20.1101(d) limits the offsite dose to 10 mrem/year). The ten percent of the difference between the regulatory guideline value of 10 mrem and the newly calculated dose value for the MHA and LOCA is **0.32 mrem** and **0.35 mrem**, respectively. As stated before, the additional dose due to the existence of unclad fuel material products in the primary coolant is **0.13 mrem**, which is less than ten percent of the difference between the calculated dose value in the UFSAR and the regulator guideline value for both scenarios MHA and LOCA. Therefore, the consequences for MHA and LOCA from the proposed change are no more than minimal.

None of the other accidents analyzed in the FSAR are more than minimally affected by the presence of fuel particles in the primary system, as a) the mass and size of fuel material are too insignificant to cause any reactivity effects in the reactor, cause flow blockage effects in the system, or limit mechanical devices (i.e. shim arms) if it were to be dislodged and b) the presence of this material does not affect normal operating parameters. See the attached evaluation of accidents.

Therefore, there is no more than a minimal increase in the consequences of an accident previously analyzed in the updated FSAR.

Does the proposed ECN:	YES	NO
E. Result in more than a minimal increase in the ***consequences*** of a malfunction of a structure, system, or component important to safety previously evaluated in the updated FSAR (Enter justification below).	☐	☒

Several months of running all primary system pumps (without fuel in the core) have shown no adverse effects on any SSC present in the primary system. All SSCs important to safety have been tested and continue to function normally. There are no credible means by which the material would suddenly come loose and render a safety component inoperable. Should material be released into the core, effluent radiation monitors would detect this and perform its safety function as designed. Therefore, there is no more than a minimal increase in the consequences of a malfunction of an SSC important to safety. This conclusion has been arrived at based on a path that is clearly experimental, in that it requires reactor operations to confirm. It was not possible to predict that there could be no consequences to any SSC based on what could be known about the changes that are the basis of this ECN (i.e. the introduction of potentially friable fuel in the primary coolant). Again, note that the consequences of the use of SSCs that are being studied in this experimental approach are not safety significant if there is only a very minimal amount of unclad fuel present in the reactor, as is the case.

Does the proposed ECN:	YES	NO
F. Create a possibility for an accident of a different type than any previously evaluated in the updated FSAR (Enter justification below).	☐	☒

There is no credible scenario whereby the release of material present in the primary system would cause significant flow blockage, mechanical interference, or reactivity effects. Any introduction of a small amount of material into the core would fall into the realm of (and be easily bounded by) the maximum hypothetical accident, which assumes the melting of an entire fuel element. Thus, there is no possibility of an accident of a different type.

Does the proposed ECN:	YES	NO
G. Create a possibility for a malfunction of a structure, system, or component important to safety with a different result than any previously evaluated in the updated FSAR (Enter justification below).	☐	☒

Several months of running all primary system pumps (without fuel in the core) have shown no adverse effects on any SSC present in the primary system. All SSCs important to safety have been tested and continue to function normally. There are no credible means by which the material would suddenly come loose and render a safety component inoperable. Should material be released into the core, effluent radiation monitors would detect this and perform its safety function as designed. Therefore, there is no possibility of a malfunction of an SSC important to safety that has a different result from that evaluated in the FSAR. This conclusion has been arrived at based on a path that is clearly experimental, in that it requires reactor operations to confirm. It was not possible to predict that there could be no malfunction with a different result to any SSC based on what could be known about the changes that are the basis of this ECN (i.e. the introduction of potentially friable fuel in the primary coolant). Again, note that the SSCs and their possible malfunctions that are being studied in this experimental approach are not safety significant if there is only a very minimal amount of unclad fuel present in the reactor, as is the case. During normal reactor operation, the water is constantly filtered through resin and filters, and in case some of the debris that might have been present in the primary system, it would be caught in the filters or ion exchange resin.

Does the proposed ECN:	YES	NO
H. Result in ***exceeding or altering*** a design basis limit for a fission product barrier as described in the updated FSAR (Enter justification below).	☒	☐

This ECN addresses the change from a reactor system where the primary fission product barrier (i.e. the fuel cladding) is no longer present for a small portion of the reactor fuel, which is mostly immobilized (very) far away from the reactor core, so does not typically participate in the nuclear reaction if the reactor is running. Considering that a maximum of 66 grams of the damaged fuel element disappeared into the primary system and that most of the remaining material appears to be non-friable (immobilized) based on video survalience and cleaning operations, an estimate for the largest piece of unclad fuel present in the primary system is 0.14 gram (See "Potential Release of Fission Products from the NBSR Reactor During Startup Operations" by Steve Dewey). Beyond this, the amount of friable unclad fuel that can reach the reactor core (and can thus produce fission products) has been minimized by the following operations. 1) Operating the primary pumps with thirty 20-micron filters in the fuel positions. 2) Ultrasound vibration of the plumbing in strategic positions while the primary pumps are running. 3) Full drainage of the reactor into the storage tank followed by refilling through a 5-micron filter. 4) Sparging with Carbon Dioxide, followed by sparging with helium of the entire primary water inventory. At the end of all these operations, we must expect there to be some friable particulate matter, sized 5-micron or less, to remain present in the heavy water coolant/moderator. Hence, a license amendment application is completed with this ECN to evaluate the change.

Does the proposed ECN:	YES	NO
I. Result in a departure from a method of evaluation described in the updated FSAR used in establishing the design bases or in the safety analysis (Enter justification below).	☐	☒

The analysis methods employed for the quantifications of dose rates and radionuclide production are the same as those completed in the updated FSAR. The Dose calculations at the boundary are performed using the same applications, namely Origen 2 code and HOTSPOT 3.2. Updated versions with inputs modified to represent the reactor close to its state as described in the updated FSAR were used in the calculations as per NEI Section 3.7. NEI 3.7 " for purposes of implementation of 10 CFR 50.59, the FSAR (as updated) is considered to include FSAR changes resulting from evaluations of changes made since the FSAR update." Therefore, the analysis methods do not depart from updated FSAR evaluations.

10 CFR 50.59 EVALUATION			ECR No.:	1251
ECR/Experiment Title:	Operating the NBSR with small amounts of unclad fuel in primary system			
System:	**Primary Cooling/Moderator**		**Date:**	**10/13/2022**

Conclusion (Check one)	
☐	Based on the evaluation conducted in the above table, it is concluded that the proposed action ***does not meet*** any of the 10 CFR 50.59 criteria; therefore, the activity **does not require** a license amendment or prior NRC approval to perform the proposed action.
☒	Based on the evaluation conducted on the above table, it is concluded that the proposed action ***does meet one or more*** of the 10 CFR 50.59 criteria; therefore, the activity **does require** a license amendment to be obtained from the NRC under 10 CFR 50.90 to perform the proposed action.

X

50.59 Evaluator

NOTE
Consistent with the intent of 10 CFR 50.59, the justifications should be complete in the sense that another knowledgeable reviewer could draw the same conclusion. Restatement of the criteria in a negative sense or making simple statements of conclusion is **NOT** sufficient and should be avoided. The basis and logic used for engineering judgment and the determination should be documented to the extent practicable and to a degree commensurate with the safety significance and complexity of the activity.

ENGINEERING CHANGE NOTICE (ECN)			ECR No.:	1251
ECR Title:	Operating the NBSR with small amounts of unclad fuel in primary system			
System:	Primary Cooling System		Date:	9/29/2022

Design Description

The NIST Center for Neutron Research is requesting an Amendment to the TR-5 License that would allow it to run cycle 655 of the NBSR in accordance with the NBSR restart plan.

Assume:

1) Yearly dose allowance at Site Boundary: 10 mR/year
2) Somewhat dependent on isotope mix, this allowance will be spent in one(1) day with the NBSR stack monitor (RM 4-1) producing a reading of 50,000 CPM

Hence, with NBSR stack monitor reading 5000 CPM, it will take 10 days to spend the yearly dose allowance at the Site Boundary.

Note that it will be abundantly clear to the NBSR Operating and Health Physics staff that the stack monitor will be reaching 5000 CPM well before that level is reached. Exceeding that level will be prevented by reactor operators controlling power, as per the NBSR restart plan. The total dose allowance at the Site Boundary can obviously also be controlled by cycle duration.

At the end of cycle 655 the NBSR will report its findings to NRC along these lines. At the same time a path forward will be presented in concert with the core loading analysis for cycle 656.

Safety Considerations, Identification, and/or Analysis

The safety analysis for this ECN has two components. 1) the effects of friable unclad fuel present in the reactor plumbing, that might potentially affect the dose at the Site Boundary because of the potential for the production in and the release of fission products from it and 2) the potential effects of friable unclad fuel in a mechanical sense, in that it might create an obstruction to an SSC that is important to the safe operation of the NBSR.

The first part of this Safety Analysis has been presented in the 10 CFR 50.59 documentation that is accompanying this ECN and which refers to [1].

The second part, goes as follows:

The NBSR primary system, in addition to the reactor, vessel, and internals, consists of primary piping, pumps, heat exchangers, valves, and instruments. The effect of debris on each of these is discussed below. The damaged element was weighed, and we determined that the maximum amount of fuel debris that could have escaped the element into the primary system is 66 g. Note that there is considerable uncertainty in the measurement because the element was not weighed before the event, so the debris mass could be substantially smaller.

Pumps: All of the pumps in the primary system have been run frequently since insertion of the filter elements in April of 2022. The main primary pumps have been started and run more than one hundred times in various combinations without incident. Should any of the four main primary pumps fail during reactor operation for any reason, including interference from large debris, the reactor will automatically SCRAM from any of three redundant flow sensors. Other pumps in the primary system (redundant shutdown pumps, storage tank pumps, and experimental cooling pumps) perform no safety function. Thus, there is no identified safety issue regarding debris affecting pump operation.

Valves: Although there are many valves in the primary system, only a few perform safety functions. The emergency core cooling system valves would be closed in the event of a loss of coolant accident. These valves are tested quarterly and have shown no signs of malfunction. It should be noted that it would require a very large piece of debris to obstruct any of these valves and no such piece of debris currently exists in the primary system. In addition, the moderator dump valve, also a large valve, is used as a backup shutdown mechanism and is tested annually and prior to each startup. The only other valve that performs a safety function is the primary coolant system relief valve which is tested annually. Because of its location and function, there is no credible means by which a piece of debris from the February 2021 event could obstruct its ability to relieve primary pressure.

Heat Exchangers: The two main primary heat exchangers are plate-and-frame type heat exchangers. Radiation surveys have indicated the presence of some debris in these heat exchangers, but a number of attempts (as detailed in the vessel analysis and restart plan) have been unable to completely dislodge this debris. The presence of a quantity of debris sufficient to affect heat exchange would be essentially no different than other types of fouling and presents no safety issue. The inability to keep temperatures in an acceptable range during full power operation would necessitate reduction of power to avoid a reactor rundown from high outlet temperature.

Primary Piping: It is not credible for a sufficient amount of debris to exist to significantly affect flow in main primary piping, but if it did, the reactor would SCRAM on low flow, as described above.

Instruments: All of the instruments in the primary system that perform a safety function (mostly flow sensors) are separate and redundant. It is not credible that debris could simultaneously adversely affect all of them and prevent a safety action from taking place. These are all tested at least quarterly and have shown no signs of degradation, even during intense efforts of system debris removal over the past few months.

As discussed in the vessel report, it should be noted that there have been several attempts to dislodge debris over the last few months, including full primary flow, ultrasonics, and two-phase flow with CO_2 and helium. There have been no observed anomalies either in flow, pressure, vibrations, or other indications throughout the entire process.

SAR Revisions: The NBSR SAR has been reviewed and it was concluded that the following sections require additions, in accordance with the discussion presented above: 5.2.2.4 (new section on debris in the primary), 11.1.1.2.3 (Fission Products), 11.1.1.3.1 (Reactor Primary Coolant), 11.1.1.4.3.1 (new section on debris consequences). See proposed SAR changes, attached.

References:

1) Potential Release of Fission Products from the NCNR Reactor During Startup Operations, Dr. Steven Dewey, Chief NCNR Health Physics, 21 July, 2022.
2) Plan for Restart of the NBSR, 15 August, 2022.

Required Tests, Retests, Surveillances, or Measurements

The purpose of this ECN is to define a test for operations with debris present in the primary system. Permission for the performance of this test is sought by seeking approval for the License Amendment Request that is the "design" presented in this ECN.

ENGINEERING CHANGE NOTICE (ECN)			ECR No.:	1251
ECR Title:	Operating the NBSR with small amounts of unclad fuel in primary system			
System:	Primary Cooling System		Date:	9/29/2022

Safety Evaluation and Conclusion

The design presented in this ECN outlines an operational envelope for startup of core #655. If the operation of the NBSR is performed within this envelope with special attention being paid to the stack monitor not exceeding 5000 CPM there is no possibility that the total dose at the site boundary exceeds the regulatory limit of 10 mR/Year.

The mechanical effects of the presence of debris are inconsequential as long as a normal testing schedule for all SSC's is maintained (as defined in the TR-5 Technical Specifications).

SAR Chapter 13 evaluation

The presence of debris in the primary system prompted an evaluation of the accidents evaluated in the SAR and the effect of that debris on the accident scenarios.

13.1.1 Maximum Hypothetical Accident

The MHA considers the melting of an entire 8-cycle fuel element. The addition of – at most – a few grams of fuel that make it into the core would be insignificant in comparison. Cleaning of the reactor vessel removed particles greater than 1/16". After the effort to clean the reactor vessel, the vessel was inspected showing no material greater than a 1/16". 20-micron filter elements were used for further cleanup of the primary water. The MHA is calculated to result in a total dose of 3.5 mrem at the site boundary on the first day, and 6.8 mrem in 30 days. By contrast, it is estimated that the presence of the largest piece of remaining fuel material would result in a site boundary dose being at most 0.13 mrem, which conservatively assumes the piece makes it into the core and the reactor continues to operate.

The maximum permissible annual dose limit to the public is 10 mrem accepted in the updated FSAR (10 CFR 20.1101(d) limits the offsite dose to 10 mrem/year). The newly calculated dose rate for the MHA is then 6.93 mrem. The ten percent of the difference between the regulatory guideline value of 10 mrem and the current calculated dose value for the MHA is **0.32 mrem**. As stated before, the additional dose rate due to the existence of unclad fuel material products in the primary coolant is **0.13 mrem (assuming a full day of operation)**, which is less than ten percent of the difference between the calculated dose value in the UFSAR and the regulator guideline value.

13.1.2 Insertion of Excess Reactivity (step, ramp, and startup accident)

Debris removal efforts over much of 2022 have reached the point where there is no significant chance of large pieces of material being released into the core. Calculations using Stokes' Law have shown that any piece larger than about 3/32" (<0.02 g) would not be able to make it into the core due to the low flow velocity in the inlet plena. Thus, the ability of a piece large enough to make it into the core and have any significant reactivity effect is not credible. Thus, all reactivity insertion accidents are unchanged due to the presence of material in the primary system.

13.1.3 Loss of Primary Coolant

Dose at the site boundary under the worst-case conditions for the LOCA would not exceed 6.5 mrem. Additional doses due to the presence of material in the primary system are 0.13 mrem, even if the largest piece of material made it into the core.

The maximum permissible annual dose limit to the public is 10 mrem accepted in the updated FSAR (10 CFR 20.1101(d) limits the offsite dose to 10 mrem/year). The newly calculated dose rate for the LOCA is then 6.63 mrem. The ten percent of the difference between the regulatory guideline value of 10 mrem and the current calculated dose value for the LOCA is **0.35 mrem**. As stated before, the additional dose due to the existence of unclad fuel material products in the primary coolant is **0.13 mrem (assuming a full day of operation)**, which is less than ten percent of the difference between the calculated dose value in the UFSAR and the regulator guideline value.

Also, once a LOCA occurs it makes no significant difference if the fission products are laid out on the floor of the process room (submerged in the heavily tritiated primary water) or held in the plumbing.

The dose effects of the fission products are insignificant compared to the personnel dose effects of the heavy water that is exposed via the LOCA.

13.4.1 Loss of Primary Coolant Flow

A loss of primary coolant flow does not result in fuel damage. The presence of debris in the primary system would have no effect on coolant in the core, as there are no credible means by which additional particles would have any significant heating effects, either on the fuel element, or the particle itself.

All the listed scenarios are not impacted by the presence of debris. Nor does the presence of debris increase the likelihood of occurrence for any of the listed scenarios. The mechanism of failure for each scenario remains unchanged.

13.1.5 Mishandling or Malfunction of Fuel

The presence of debris has no impact on the movement or function of fuel elements and thus no effect on the analysis of a fuel mishandling accident.

13.1.6 Experiment Malfunction

As explained in the reactivity insertion accident above, there are no credible means by which a particle would have any significant reactivity effects on the malfunction of an experiment.

13.1.7 Loss of Normal Power

The loss of power has no effect on any debris in the system and thus is still bounded by the loss of flow accident.

13.1.8 External Events

The presence of debris in the primary system has no effect on support structures, and thus the external events analysis is unchanged.

Addendum to the Potential Release of Fission Products from the NCNR Reactor During Startup Operations

Dr. Steven Dewey
Chief, NCNR Health Physics
Chief, NCNR Occupational Safety and Health

10/13/2022

Purpose

The purpose of this document is an addendum to the report “Potential Release of Fission Products from the NCNR Reactor During Startup Operations”, 21 July 2022. This addendum includes additional analysis including the potential offsite fission product releases in the event the reactor is operated with the fission product monitor SCRAM set point at 50,000 cpm. This is the set point under normal operating conditions. It also makes one correction to the table. The dose rate at 1 foot from a piece that would result in 5000 cpm in the stack should be 0.7 R/h and not 0.1 R/h. This was a typo in the original table.

Assumptions and Calculations

The original assumptions and calculation methods were used to add an additional row to Table 4 from the original report. The table is show below.

Table 1: Release Scenarios for Various Quantities of Fuel in the Highest Flux in the Vessel. Values Calculated Using Tables 1 and 2 Above.

Criteria	Dose Rate (mrem/day)	Stack Reading (cpm)	Fuel Present in Vessel (g)	Number of Operating Days at 20 MW to Exceed 10 mrem annual limit 10CFR20.1101(d)[1]	Exposure Rate from a Fuel Piece of this Size at 1 ft (R/hr)[2]
Normal Operation	0.004	700	0	312	NA
1 g of Unclad Fuel Material	0.94	20.5k	1	10.6	2.8
20% NOUE Limit	3	65k	3.2	3.33	8.9
NOUE	15	328k	16	0.7	44.3
Unclad Fuel Piece Found in Process Room	0.08	1645	0.08	133	0.2
Estimated Largest Piece in Process Room based on measured dose rate	0.13	2902	0.14	43.8	0.4
5000 cpm Stack Monitor Reading	**0.22**	**5000**	**0.24**	**75.4**	**0.7**
50,000 cpm Stack Monitor Reading	**2.2**	**50,000**	**2.4**	**7.5**	**7**

Conclusions

- The normal operating limit of 50,000 cpm limit on the reactor stack would result in only a small dose to the public of 2.2 mrem/day dose to the public. Thus, this limit is very conservative will be protective of any release scenario. The condition would be immediately identified.

[1] The numbers here greater than 1 day are extremely conservative. They assume constant windspeed, direction and weather over the entire operating period. Varying windspeed and direction would significantly dilute any release and reduce the dose at any one point at the EPZ boundary.

[2] This is based upon measurement of a piece of damaged fuel found in the process room.

- To meet or exceed the 50,000 cpm SCRAM limit would require a piece of fuel of 2.4 grams. This is significantly larger than would be transportable by hydraulic flow in the primary system thus there is no feasible method for such a large piece to be mobile in the primary system

- This estimate is conservative and should be considered an upper bound estimate.

References

1. The Potential Release of Fission Products from the NCNR Reactor During Startup Operations, 21 July 2022

No Significant Hazard Consideration Determination

In a license amendment request dated October 19, 2022, the NIST Center for Neutron Research (NCNR) requested an amendment to the facility license involving an SAR change for operation following the fuel failure event of February 3, 2021. As required by 10 CFR 50.91(a), the following revised analysis is presented to show the proposed amendment does not create a significant hazard using the criteria of 10 CFR 50.92(c).

1. **Does the proposed amendment involve a significant increase in the probability or consequences of an accident previously evaluated?**

None of the accidents analyzed in the FSAR would be more than minimally affected by the presence of fuel particles in the primary system, as a) the mass and size of fuel material is too insignificant to cause any reactivity effects in the reactor, cause flow blockage effects in the system, or limit mechanical devices (i.e. shim arms) if it were to be dislodged and b) the presence of this material has no effect on normal operating parameters. Only two accidents analyzed in Chapter 13 of the FSAR show results of release of radioactivity: the loss of coolant accident (LOCA) and the maximum hypothetical accident (MHA). The presence of fission products in the primary system has no effect on the consequences of any of the other accidents analyzed.

The MHA considers melting of an entire 8-cycle fuel element. The addition of – at most – a few grams of fuel would be insignificant in comparison. Both the MHA and LOCA accidents result in a total dose of less than 6.5 mrem at the site boundary. By contrast, it is estimated that the presence of the largest piece of remaining fuel material being lodged in the core (which is too large to be carried into the core by normal primary flow velocities) would result in a site boundary dose being at most 0.13 mrem/day, which also conservatively assumes the reactor continues to operate. Thus, there is no more than a minimal increase in the consequences of accidents previously analyzed.

Also, once a LOCA occurs it makes no significant difference if the fission products are laid out on the floor of the process room (submerged in the heavily tritiated primary water) or held in the plumbing. The dose effects of the fission products are insignificant compared to the dose effects of the heavy water that is exposed via the LOCA. Calculations have shown that debris larger than 0.093" will not be transported into the core with the liquid velocity range present in the NBSR inlet and outlet plena leading to the core. Smaller particles have been largely removed by filtration. Thus, remaining debris in the primary system is unlikely to be dislodged into the core.

Therefore, the proposed FSAR amendment allowing operation with debris in the primary system will not involve a significant increase in the probability or consequences of an accident previously evaluated.

2. **Does the proposed amendment create the possibility of a new or different kind of accident from any accident previously evaluated?**

Because of the limited amount and size of material present in the primary system and the limited primary flow velocity, there is no credible scenario whereby the release of material present in the primary system would cause significant flow blockage, mechanical interference, heating, or reactivity effects. Any introduction of the small amount of material into the core would fall into the realm of (and be easily bounded by) the maximum hypothetical accident, which assumes melting of an entire fuel element. No other changes to reactor parameters or operations are being proposed. The proposed amendment to the SAR will not change the operations, process variables or reactor structures, systems, or components. Therefore, the proposed amendment for operation with small amounts of debris from the February 3, 2021 event will not create the possibility of a new or different kind of accident from any accident previously evaluated.

3. **Does the proposed amendment involve a significant reduction in a margin of safety?**

The proposed license amendment is to modify the NBSR SAR to allow operations with a small amount of debris from the February 3, 2021 incident in the primary system. Calculations have shown that debris larger than 0.093" will not be transported into the core with the liquid velocity range present in the NBSR inlet and outlet plena leading to the core. Smaller particles have been largely removed by filtration. Thus, because of the limited amount and size of material present in the primary system and the limited primary flow velocity, there is no credible scenario whereby the release of material present in the primary system would cause significant flow blockage, mechanical interference, heating, or reactivity effects, and is insufficient to cause a significant reduction in any margin of safety. Therefore, the proposed amendment of the SAR in allowing this operation does not involve a significant reduction in a margin of safety.

Conclusion

Based on the above determinations, the NCNR concludes that the proposed amendment to the NBSR SAR does not involve a significant hazards consideration under the standards set forth in 10CFR50.92(c) and accordingly, a finding of no significant hazards is justified.

Primary system debris supplement

On June 29, 2022, NCNR submitted an analysis of the effect of debris on the vessel and internals. This is a supplement to that analysis, focusing on debris in the primary piping.

The NBSR primary system, in addition to the reactor, vessel, and internals, consists of primary piping, pumps, heat exchangers, valves, and instruments. The effect of debris on each of these is discussed below. The damaged element was weighed, and we determined that the maximum amount of fuel debris that could have escaped the element into the primary system is 66 g. Note that there is considerable uncertainty in the measurement because the element was not weighed before the event, so the debris mass could be substantially smaller.

Pumps: All of the pumps in the primary system have been run frequently since insertion of the filter elements in April of 2022. The main primary pumps have been started and run more than one hundred times in various combinations without incident. Should any of the four main primary pumps fail during future reactor operation for any reason, including interference from large debris, the reactor will automatically SCRAM from lack of sufficient flow in any of three redundant flow sensors (i.e. total flow, inner plenum flow and outer plenum flow). Other pumps in the primary system (redundant shutdown pumps, storage tank pumps, and experimental cooling pumps) perform no safety function. Thus, there is no remaining safety issue regarding debris affecting pump operation.

All pumps that comprise the design basis of the primary system are centrifugal pumps, which are very forgiving to minor amounts of solids passing through them, particularly if the solids are made up of small particulate matter. The estimated amount of 66 grams of small mass/small volume particulate matter is insignificant compared to a heavy water inventory that exceeds 10,000 gallons. The primary pumps consist of a set of four installed pumps. Only three are needed for proper/safe reactor operation. The unused pump serves as an installed spare.

At this point one primary pump suffers from an as-yet undiagnosed issue: the pump appears to be noisy. NCNR has contracted for pump repair services to inspect the pump and replace and/or repair as appropriate. This is not a safety issue. If one of the three pumps that currently remains operable ceases to operate, the flow meters will detect that, and a low flow response (scram) will automatically shut down the reactor in the same way it would if there would be a discontinuity in the electrical supply to the building.

Table 1. Primary pumps

Pumps (Functional description)	**Test Specification (OI, TS, or N/A)**
Primary Pumps	N/A (Flow SCRAM upon failure)
Shutdown Pumps	N/A
#4 Sump Emergency Pump	TSP 4.3.2(2) Performed annually. Last 8/30/2022
Storage Tank Pumps	N/A (Startup up prohibit with <5 gpm overflow)

Valves: Although there are many valves in the primary system, none perform safety functions beyond "defense in depth". The reactor is analyzed (SAR Chapter 13) to remain in a safe condition even if all the coolant is lost from the vessel. Regardless, in the event of a Loss of Coolant Accident (LOCA), the active emergency core cooling system valves (LOCA valves) would be closed. These valves are opened and closed on a regular basis (daily when the building is opened and closed daily). It should be noted that it would require a very large piece of debris to obstruct any of these valves and no such piece of debris currently exists in the primary system. If the LOCA valves malfunction (i.e. not close when closure is initiated), such can be observed on the outside of the valve where it is fitted with a passive mechanical indicator).

Control valves in the Emergency Core Cooling System (ECCS) are exercised quarterly and have shown no sign of malfunction. As these valves are connected to the emergency tank, the possibility of debris making this circuitous route is unlikely, as the debris would have to be collected by the reactor overflow, make it out of the storage tank, and be pushed via the storage tank pumps up about 100 feet to the emergency tank, then drain to the valves. Only very small pieces of debris would be able to make this path, as particle transport is governed by Stoke's law (under a flow of about 35 gpm in a three-inch line) and would thus be too small to create interference in these valves, which are, at a minimum 1.5 inches in diameter.

We also have primary pump exit check valves for the event a LOCA takes place. In essence, these check valves are tested every time a pump is started by verifying that the – just started – pump develops the (system) flow that it is expected to develop and not less, which would be indicative of bypass through an incompletely closed check valve and the associated pump (that is not running, or more worrisome: running backwards).

The moderator dump valve, also a large valve, is used to initiate a backup shutdown mechanism (i.e. dumping the moderator). It is tested annually and prior to each reactor startup. Testing has continued in accordance with the Technical Specifications after the February 2021 incident.

The last valve that performs a safety function is the primary coolant system relief valve which is tested annually (and which has continued to be tested after the February 2021 event) . The stem of this valve is designed to lift at a vessel pressure of 50 psi. Since the vessel loop seal is emptied out at approximately 6 inches of water, thereby effectively depressurizing the vessel, the only way the relief valve can be made to lift is during yearly testing for which it is isolated from the vessel. Considering the February 2021 incident, the worst thing that can happen to this valve is that during a test, debris enters the valve and prevents it from fully seating after completion of the test, at which time there is a minor bypass leak from the primary loop directly to the storage tank (through the relief valve). The magnitude of such leak would be entirely negligible considering the particle size distribution of the debris that entered the primary system.

There are many additional valves in the primary system that do not perform a safety function. If the function of any of these valves is compromised by the presence of unclad fuel, such can be easily detected, both by radiation detection and functional deterioration. When this happens, regular maintenance scheduled under our developing Aging Reactor Management Program will address the issue. An example that has been recently dealt with was the gathering of fissionable debris in a 1" drain valve (a ball valve). Removing and replacing that valve removed a considerable amount of radioactivity from the primary system.

Table 2. Primary system valves

Valve (Functional Description)	Test Procedure	Test Dates	Test Result
ECCS valves exercised quarterly Primary Pump Check Valves	TSP 4.3.2(1) N/A (every pump start)	08/01/2022	PASS
		04/07/2022	PASS
		07/22/2021	PASS
		04/21/2021	PASS
Moderator Dump cycled annually	TSP 4.3.3 (May be accomplished with OI 1.1.0)	07/06/2022	PASS
		04/07/2022	PASS
		06/01/2021	PASS
Primary Coolant Relief Valve tested annually	TSP 4.3.1(1)	06/27/2022	PASS
		08/11/2020	PASS

Heat Exchangers: The two main primary heat exchangers are plate-and-frame type heat exchangers. The primary sides of the heat exchangers are contained in welded cassettes, where the only elastomer interface are O-rings surrounding the inlet and outlet ports between every cassette. Radiation surveys have indicated the presence of some debris in these heat exchangers, but our attempts (as detailed in the vessel analysis and restart plan) have been unable to completely dislodge this debris. The presence of a quantity of debris sufficient to adversely affect the efficiency of the heat exchangers would be no different than other types of fouling and presents no safety issue. We do not expect the available debris (maximally 66 grams) to significantly (measurably) affect the effective surface area of the heat exchangers, but this cannot be proven until the reactor is operating and actual (significant) heat is being exchanged.

If the temperature of the water entering the heat exchanger exceeds 130 ^{o}F, a reactor rundown is triggered (without operator involvement, although the operators are expected to see this coming and act accordingly, i.e. reduce the power). If along this way it would become clear that the efficiency of the heat exchangers is significantly reduced, this will be solved by a reduction of power to avoid a reactor rundown from high outlet temperature.

Heat exchanger efficiency can be monitored by observing the operating parameters of the heat exchangers (pressure drop, flow, temperature drop/rise depending on the side: primary or secondary). The NBSR heat exchangers are fully instrumented and provide continuous logging of the relevant operating parameters. These can be compared to data from before the February 2021 event. They can also be compared to the original specification of the heat exchangers.

Primary Piping: The primary piping system, which is comprised of several vessels and the plumbing holds about 10000 gallons of heavy water. During the February 2021 incident less than 66 grams of debris was distributed in this volume. As we were starting to clean out the primary, first by "vacuuming" the upper and lower grid plates and later by operating the primary pumps and pumping water through filters (that replaced fuel elements), and even later by first applying ultrasound and then sparging various gasses through the system, it was noticed that the radioactive spots in the primary system were not moved around very much. This suggests that a significant part of the 66 grams is not friable even with the pumps running. We can say, however, that the portion of the material that was friable was caught in the filters, which were later removed from the core and placed in the storage pool.

As the level of contamination in the process room remained largely the same during our efforts, we conclude that the material that remains friable is only a very small portion of the total 66 gram inventory and only defined by the fact that when the pumps work water through fuel elements, the flow is just a bit higher than when they work water through filter elements. This design condition is an artefact of the impossibility to design filters with a higher flow coefficient than the fuel elements (which obviously should not surprise anyone).

The plumbing size of the primary plumbing that carries flow is minimally ½" and maximally 18 inch, where the flow velocity in the higher diameters typically exceeds the flow in the small diameters. One additional class of lines concerns instrument lines, which have no flow (pressure transducers). These can be as small as ¼" in diameter.

In an environment where the debris neither moves, nor oxidizes, the debris is not expected to be able to obstruct an instrument line (if it is even capable of getting in there). If such were to happen anyway, calibration procedures would catch that. Also, it can be (and has been) calculated that debris of ¼" is not friable in the liquid velocity range present in the NBSR (for example the friability limit as defined in terms of what can pass the inner and outer plenums is conservatively calculated to be about 0.093": anything larger than that will not move into the fuel element nozzles). Note that this is smaller than the minimum coolant gap in the fuel (side channel) of 0.106".

As discussed in SAR section 6.1.1, the loss of water during a LOCA results in draining of water from the Inner Reserve Tank (IRT) to the distribution pan above the fuel. The nozzles leading from the IRT to the distribution pan are 0.72" in diameter. Holes in the distribution pan have a nominal diameter of 0.316". Both the IRT nozzles and the distribution pan holes are significantly larger than that in which a piece of fuel debris can cause flow blockage.

Instruments: All of the instruments in the primary system that perform a safety function (mostly flow sensors driven by differential pressure transducers) are separate and redundant. As a result, there is no single point failure that would obscure our (and the safety system's) ability to know primary flow: the debris will not simultaneously adversely affect all sensors and prevent a safety action from taking place. These are all tested at least quarterly and have shown no signs of degradation, even during intense efforts of system debris removal over the past few months. Temperature transducers, because of their construction are insensitive to debris: they are typically placed in a dry well. Pressure and level transducers that are designed to read pressure (instead of deducting flow) are – by definition – attached to non-flowing lines.

Instruments that do not perform a direct safety function are part of regularly scheduled calibrations. Any anomalies are expected to be easily detectable and will lead to exhaustive investigation. An important role will be played by members of the radiation protection professionals (Health Physics), who will be able to detect abnormalities in the plumbing that are caused by shifting internal contamination. Again, none of that is expected to happen, but the Quality Assurance function exists.

Note: the required quarterly channel checks associated with instruments in Table 3 continue to be performed, but would not indicate whether debris might be present.

Table 3. Primary System Instruments

Instrument	Test Procedure	*Date	Result
Total Primary Flow Calibrated Annually	ICP 3.1.3 - Annual TS 4.1.1(2) - Annual TS 4.2.2 – Annual	07/27/2022	PASS
Inner Plenum Flow Calibrated Annually	ICP 3.1.1 - Annual TS 4.1.1(2) - Annual TS 4.2.2 – Annual	07/27/2022	PASS
Outer Plenum Flow Calibrated Annually	ICP 3.1.2 - Annual TS 4.1.1(2) - Annual TS 4.2.2 – Annual	07/27/2022	PASS
Vessel Level Indication Calibrated Annually	ICP 4.1 - Annual TS 4.1.1(2) - Annual TS 4.2.2 – Annual	06/13/2022	PASS

*Dates for annual calibrations only

Potential Release of Fission Products from the NCNR Reactor During Startup Operations

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Summary

- The 5000 cpm limit on the reactor stack count rate would result in only an insignificant dose to the public of 0.2 mrem/day dose to the public. Thus, this limit is very conservative and protective to both the public and the environment.

- Based on dose rate measurements, the largest piece of unclad fuel in the process room would not result in a NOUE if the fuel was transported into the vessel. The largest piece would only result in a release that is <10% of NOUE limits

Purpose

The purpose of this document is to assess the potential consequences from the release of fission products from the NCNR Reactor during startup operations. This assessment is intended to be conservative and thus realistic worst-case assumptions are made when assessing a release. This analysis is intended to provide a bounding estimate of the potential releases during reactor startup.

As a result of the February 2021 reactor incident, there is a potential for unclad fuel in the reactor vessel. Although extensive cleaning operations have been performed, there still exists the possibility that a piece of fuel may be transported into the vessel during operation or that a piece of unclad fuel is still present in the vessel. The presence of unclad fuel in the vessel could result a measurable release of fission products. The intent of this document is to assess the potential offsite dose after reactor restart and to ensure that if elevated levels of fission products are detected from the reactor stack, they will be quickly identified and responded to, and there will be no offsite dose consequences to the public.

Assumptions

- Fission product release rates are linear with reactor power

- Fission product release rates are linear with the mass of U235 in the vessel

- Any U235 that is in the reactor vessel is in the highest neutron flux in the vessel (this is a worst-case assumption)

- The reactor will be SCRAMMED at a stack monitor reading greater than 5000 cpm. Note that all three effluent monitors (normal air, irradiated air, and stack) will have their setpoints reduced to 5000 cpm for the startup. The fission product monitor will also give an early indication of the presence of fission products.

- The fuel piece collected in the process room is representative of other unclad fuel in the primary coolant system

Limiting Factors

- Fission product release rates should remain well below the Emergency Plan limit for a NOUE which is 15 mrem averaged over a day. A limit of 20% of a NOUE is assumed for this analysis, 3 mrem.
- 10 CFR 20.1101(d) limits the offsite dose to 10 mrem/year[1]

Release Estimates

The release rate of a fission product can be estimated using the following equation

$$RR_i = FPR_i * m_{U235} * \frac{RP}{20\ MW}$$

Where:

RR_i – The fission product release rate of isotope i in uCi/day

FPR_i- The fission product production rate from 1 g of U235 in the vessel at full power in uCi/day*g

RP – Reactor power in MW

This assumes that the quantity of fission products generated is linearly related to the mass of U235 in the vessel and the power level of the reactor. These are both reasonable assumptions. FPR for each isotope was calculated by using the ORIGEN-2 code. These release rates are the total production for the day and include a decay factor for the time it would take the isotope to travel to the stack. Only volatile fission products are of concern. All other isotopes would remain in the primary system. There is not enough heat present in the reactor to volatize these isotopes. The isotopes that would be potentially released include noble gas isotope of Xe and Kr and iodine isotopes. These would be in addition to the normal release of argon-41 and tritium that are released during normal operations. Although a large fraction of the iodine will remain in the vessel based on the SAR and based upon the analysis of the Feb 2021 event, iodine is included in this analysis as a conservative assumption. The Safety Analysis Report, Chapter 13 states that only 3% of the iodine isotopes produced would be in the volatile I_2 form. The rest would remain in the primary system. This is consistent with the releases measured during the Feb 2021 event.

The release rate of these isotopes will vary with time. For this reason, the assumption is made that the material stays in the vessel for at least 6 days and thus the release rate at 6 days is used (conservative). After approximately 6 days the release rate of fission products begins to gradually decline as a result of U-235 burn up. This timing varies slightly for each isotope, but the variation between isotopes is less than a few percent and thus has no significant impact on this assessment. Refer to reference 1 for additional details. The release rates for 1 gram of material are listed in Table 1 below. It should be noted that these release rates are conservatively high. Any released gases would be captured in the helium

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[1] Although this is an ALARA limit and in theory can be exceeded it requires a report to the NRC and a plan to prevent reoccurrence. However, for practical purposes we should consider this a limit that cannot be exceeded.

sweep and would be slowly released from there to the stack and thus the shorter-lived isotopes would undergo additional decay before release.

Table 1: Volatile fission products released per day calculated using ORIGEN-2 code

Isotope	FPR (Ci/day*g)
Kr-83m	1.58E+00
Kr-85	1.33E-04
Kr-85m	3.42E+00
Kr-87	7.91E+00
Kr-88	1.01E+01
Xe-131m	4.50E-04
Xe-133	1.14E+00
Xe-133m	6.96E-02
Xe-135	1.27E+00
Xe-135m	2.93E+00
Xe-137	2.03E+01
Xe-138	2.07E+01
I-130	5.99E-04
I-130m	4.38E-04
I-131	7.48E-01
I-132	9.47E+00
I-133	9.73E+00
I-133m	1.55E+00
I-134	2.48E+01
I-134m	1.18E+00
I-135	1.51E+01

At a given moment, there is 1 gram of fuel within the core region, 0.117 grams of U-235, 0.00867 grams of U-238, 0.0227 grams of O and 0.852 grams of Al. The ORIGEN module in SCALE 6.2.3 is used to calculate time dependent actinide mass and gaseous fission product activity.

The dose rate at the Emergency Planning Zone Boundary can be calculated using HOTSPOT for each isotope of concern. HOTSPOT with conservative weather conditions[2] was used to determine the dose rate at the 400-meter EPZ boundary. A MATLAB version of HOTSPOT created by the author was also used to calculate the boundary dose for some of the isotopes. Assuming 1 gram of material and the release rate listed in Table 1 above, HOTSPOT 3.2 was used to estimate the dose rate at the boundary per day.

[2] Weather was wind at 1 m/s with class F conditions. This is most conservative weather condition resulting in the maximum dose outside the EPZ. HOTSPOT assumes that the wind blows in the same direction at the same speed for the entire day. This is a very conservative assumption as changes in wind speed and direction would further dilute any material released.

Table 2: Releases and Dose Rates from Noble Gases for a 1 g Piece of Unclad Fuel at the Highest Flux in the Vessel for a Day. Values Calculated Using HOTSPOT 3.2

Isotope[3]	Activity Released (Ci/day)	Dose (rem/day)[4]
Kr-83m	1.58E+00	7.30E-10
Kr-85	1.33E-04	5.10E-12
Kr-85m	3.42E+00	8.10E-06
Kr-87	7.91E+00	9.90E-05
Kr-88	1.01E+01	3.20E-04
Xe-131m	4.50E-04	5.60E-11
Xe-133	1.14E+00	5.70E-07
Xe-133m	6.96E-02	3.10E-08
Xe-135	1.27E+00	4.80E-06
Xe-135m	2.93E+00	1.40E-05
Xe-137	2.03E+01	1.90E-05
Xe-138	2.07E+01	2.80E-04
Total Dose:		7.40E-04

Table 3: Releases and Dose Rates from Iodine Isotopes for a 1 g Piece of Unclad Fuel at the Highest Flux in the Vessel for a Day. Values Calculated Using HOTSPOT 3.2

Isotope	Activity Released (Ci/day)[5]	Dose (rem/day)[4,6]
I-130	5.99E-04	4.20E-09
I-130m	4.38E-04	1.30E-11
I-131	7.48E-01	2.30E-05
I-132	9.47E+00	1.70E-05
I-133	9.73E+00	6.80E-05
I-133m	1.55E+00	0.0
I-134	2.48E+01	3.80E-05
I-134m	1.18E+00	4.20E-08
I-135	1.51E+01	4.90E-05
Total Dose		2.0E-4

[3] HOTSPOT does not include decay progeny in its calculations. Shorter lived isotopes will decay during transport; however, previous calculations have demonstrated that these progeny make no significant contribution to public dose.
[4] These dose rates are calculated using the values in Federal Guidance Report 12, "External Exposure to Radionuclides in Air, Water and Soil".
[5] Only 3% of the iodine isotopes produced would exit the vessel. This based on analysis in the SAR.
[6] Standard breathing rates were used for HOTSPOT as stated in 10 CFR 20 Appendix B.

Thus for 1 gram of fuel material (0.117 g U-235), the dose rate at the EPZ boundary would be 0.94 mrem/day, 0.74 mrem from noble gases and 0.20 mrem from iodine isotopes. To remain within the limitations set above at full operating power (20 MW), no more than 20% of the NOUE limit, there could be no more than 3.19 g of fuel material in the vessel. To remain below the NOUE limit, there could be no more than 16.0 g of fuel material. It should be noted though this estimate is based on conservative assumptions, and it is likely additional material would have to be in the vessel for these limits to be exceeded. It should be noted that a dose rate of 1 mrem/day would not be acceptable for continued operation as the public ALARA limit of 10 mrem/year would be quickly exceeded. These calculations demonstrate that it would take a significant quantity of fuel in the vessel to exceed emergency limits and that this condition would be quickly recognized by an increase in the stack count rate.

The intent of this document is not to perform an engineering analysis of the flow paths and flow rates that would result in a piece of unclad fuel would be transferred from the process room to the vessel. It is known that unclad fuel is present in the primary piping in the process room. This can be ascertained by the exposure rate measurements in the process room. Elevated dose rates were identified in the heat exchangers and in locations where flow is not continues, i.e., dead ends such as the HE-1C flange. There exists the possibility that these unclad fuel pieces could be transported through the primary system into the vessel. This is considered extremely unlikely for several reasons. The primary coolant pumps have been run in a variety of configurations to move the material. Ultrasonic transducers were connected to various pipe locations where unclad fuel was identified. This was performed by a contract with worldwide expertise in performing this work. This resulted in only minimal movement of pieces in the primary. The entire primary system was drained and refilled with the intent of causing turbulent flow in the system to move the pieces. This again only resulted in minimal movement. Lastly, carbon dioxide was injected into the primary system to move the pieces. The intent was to allow the CO2 to lift the pieces into the flow path. This resulted in only minimal movement of material. Thus, multiple methodologies have been employed to move the unclad material in the primary with only minimal success. This leads to the conclusion that the material present in the primary is very unlikely to move under normal operations and even more unlikely to move all the way to the reactor vessel. The only other viable potential concern is the presence of unclad material already present in the vessel. This is possible but unlikely. The vessel has been thoroughly inspected using cameras and any visible pieces of debris were collected and removed.

Stack Rate Monitor Assessment

The stack monitor is roughly linear with offsite dose. The typical stack monitor reads approximately 700 cpm. Using the stack calibration factor this equates to a release of approximately 4.3 Ci/day of Ar-41. Using HOTSPOT and the same parameters used results in a dose at the EPZ boundary of 0.032 mrem/day. A proposed limit on the stack reading of 5000 cpm will be used during startup. This would result in a dose rate of 0.2 mrem/day at the EPZ boundary and will preclude reaching any emergency action level *regardless of the release scenario*. The impact to the fission product monitor count rate was not assessed.

Potential Release Scenarios

The following Table 4 summarizes the estimated releases from various quantities of unclad fuel in the vessel. These values are for the reactor at full power. At reduced power these values should be scaled linearly. For example, if the reactor was operating at 10 MW there could be up to 32.0 g of unclad fuel in the vessel before a NOUE would be exceeded. Note that estimates were made of the mass of fuel lost from element 1175 and it was concluded that a total mass of around 44.8 g (+/- 22 g) of fuel was lost from the element. This does not include fuel pieces retrieved from the vessel during cleanup, which may account for the majority of this material.

A piece of unclad fuel was discovered in the process room. The piece weighed 0.08 grams and the on-contact dose rate of the piece was 17 R/h and 0.2 are at 30 cm. The dose rate from this piece can be used to estimate the largest piece of fuel in the process room based on the dose rates measured there. This is a very rough estimate as the measured dose rates are impacted by other sources in the area, shielding from other materials present, and imprecise locations of the sources. The current highest on contact dose rate in the process room is 30 R/h, scaling this to the piece found, this represents approximately a 0.14 g piece of fuel. This would represent a dose rate of 0.13 mrem per day at the EPZ boundary. This would be easily detectable with the stack count rate monitor and no release limit would be exceeded and the dose to the public would be negligible.

It should also be noted that the presence of 0.14 g of unclad fuel in the core would produce negligible heat (< 7 W in the worst possible position with full flow) and negligible reactivity (<$0.001).

Table 4: Release Scenarios for Various Quantities of Fuel in the Highest Flux in the Vessel. Values Calculated Using Tables 1 and 2 Above.

Criteria	**Dose Rate (mrem/day)**	**Stack Reading (cpm)**	**Fuel Present in Vessel (g)**	**Number of Operating Days at 20 MW to Exceed 10 mrem annual limit 10CFR20.1101(d)**[7]	**Exposure Rate from a Fuel Piece of this Size at 1 ft (R/hr)**[8]
Normal Operation	0.004	700	0	312	NA
1 g of Unclad Fuel Material	0.94	20.5k	1	10.6	2.8
20% NOUE Limit	3	65k	3.2	3.33	8.9
NOUE	15	328k	16	0.7	44.3
Unclad Fuel Piece Found in Process Room	0.08	1645	0.08	133	0.2
Estimated Largest Piece in Process Room based on measured dose rate	0.13	2902	0.14	43.8	0.4
5000 cpm Stack Monitor Reading	**0.22**	**5000**	**0.24**	**75.4**	**0.1**

Conclusions

- The 5000 cpm limit on the reactor stack would result in only an insignificant dose to the public of 0.2 mrem/day dose to the public. Thus, this limit is very conservative will be protective of any release scenario.
- Based on dose rate measurements, the largest piece of unclad fuel in the process room would not result in a NOUE if the fuel was transported into the vessel. The largest piece would only result in a release that is <10% of NOUE limits and have no significant heating or reactivity effects.

[7] The numbers here greater than 1 day are extremely conservative. They assume constant windspeed, direction and weather over the entire operating period. Varying windspeed and direction would significantly dilute any release and reduce the dose at any one point at the EPZ boundary.
[8] This is based upon measurement of a piece of damaged fuel found in the process room.

- This estimate is conservative and should be considered an upper bound estimate.

References

1. Gaseous Fission Product Release, Dagistan Sahin, August 01, 2022
2. 10 Code of Federal Regulations 20, “Standards for Protection Against Radiation”
3. ANS/ANSI 15.16-2015, “Emergency Planning for Research Reactors”.
4. HOTSPOT Health Physics Code Version 2.07.1 User’s Guide, 2010
5. NBSR Emergency Plan, As Amended July 01, 2017
6. An Assessment of the Determination of Emergency Classes at the NBSR Reactor for Increased Airborne Releases of Radioactive Materials, January 13, 2022

Attachments

1. Summary of Calculations
2. Iodine Isotope HOTSPOT Results
3. Ar-41 HOTSPOT Results
4. Brookhaven National Lab Review Comments and Response

ATTACHMENT 1

Fuel in Vessel Asseement

Criteria	Dose Rate (mrem/day)	Stack Reading (cpm)	Fuel Present in Vessel (g)	10CFR20.1101(d) Number of Days to Exceed 10 mrem annual limit	Exposure Rate at 30 cm (R/hr)	On Contact Dose Rate (R/h)
Normal Operation	0.032	700	0	312.5	NA	
1 g	0.94	20562.5	1	10.6	2.8	
20% NOUE Limit	3	65625	3.191489362	3.3	8.9	
NOUE	15	328125	15.95744681	0.7	44.3	
Piece Found in Process Room	0.0752	1645	0.08	133.0	0.2	17
Stack Limit of 5000 cpm	0.228571429	5000	0.243	43.8	0.7	
Piece of Fuel in Process Room	0.132705882	2902.941176	0.141176471	75.4	0.4	30

Isotope Release Rates	uCi/day	3% Fractions (uCi/day)	TEDE (rem/day)	TEDE(mrem)
Kr-83m	1.35E+01			
Kr-85	1.14E-03			
Kr-85m	2.92E+01			
Kr-87	6.76E+01			
Kr-88	8.63E+01			
Xe-131m	3.85E-03			
Xe-133	9.74E+00			
Xe-133m	5.95E-01			
Xe-135	1.09E+01			
Xe-135m	2.50E+01			
Xe-137	1.74E+02			
Xe-138	1.77E+02			
I-130	5.99E-04	1.80E-05	4.20E-09	4.20E-06
I-130m	4.38E-04	1.31E-05	1.30E-11	1.30E-08
I-131	7.48E-01	2.24E-02	2.30E-05	2.30E-02
I-132	9.47E+00	2.84E-01	1.70E-05	1.70E-02
I-133	9.73E+00	2.92E-01	6.80E-05	6.80E-02
I-133m	1.55E+00	4.65E-02	0	0.00E+00
I-134	2.48E+01	7.44E-01	3.80E-05	3.80E-02
I-134m	1.18E+00	3.54E-02	4.20E-08	4.20E-05
I-135	1.51E+01	4.53E-01	4.90E-05	4.90E-02
Total Dose/Day			1.95E-04	rem
			0.195046213	mrem

Normal Ar-41 Release Rates

Cal Factor Stack Mon	1.20E+08	cpm*m^3/Ci
Stack Flow Rate	18000	cfm
Stack Flow Rate	30582	m^3/hr
Daily Flow Rate	733968	m^3/day
Typical Stack Count Rate	700	cpm
Typical Stack Concentration	5.83E-06	Ci/m^3
Cureis Released Per Day	4.28E+00	Ci
Dose Rate	3.20E-05	rem
	0.032	mrem

ATTACHMENT 2

HotSpot Version 3.1.2 General Plume
Jul 5, 2022 1:37:51 PM

```
Source Material            : I-130   D   12.36h
Material-at-Risk   (MAR)   : 1.8000E-05 Ci
Damage Ratio        (DR)   : 1.00
Airborne Fraction  (ARF)   : 1.000
Respirable Fraction (RF)   : 1.000
Leakpath Factor    (LPF)   : 1.000
Respirable Source Term     : 1.80E-05 Ci
Non-respirable Source Term : 0.00E+00 Ci
Effective Release Height   : 30 m
Wind Speed (h=30 m)        : 1.00 m/s
Wind Speed (h=H-eff)       : 1.00 m/s
Stability Class            : B
Respirable Dep. Vel.       : 0.30 cm/s
Non-respirable Dep. Vel.   : 8.00 cm/s
Receptor Height            : 1.5 m
Inversion Layer Height     : None
Sample Time                : 10.000 min
Breathing Rate             : 3.33E-04 m3/sec
Distance Coordinates       : All distances are on the Plume Centerline

Maximum Dose Distance      : 0.18 km
MAXIMUM TEDE               : 9.70E-09 rem
Inner  Contour Dose        : 0.100 rem
Middle Contour Dose        : 0.080 rem
Outer  Contour Dose        : 0.050 rem
Exceeds Inner  Dose Out To : Not Exceeded
Exceeds Middle Dose Out To : Not Exceeded
Exceeds Outer  Dose Out To : Not Exceeded
```

FGR-11 Dose Conversion Data - Total Effective Dose Equivalent (TEDE)

Include Plume Passage Inhalation and Submersion
Include Ground Shine (Weathering Correction Factor : None)
Exposure Window:(Start: 0.00 days; Duration: 4.00 days) [100% stay time].
Initial Deposition and Dose Rate shown
Ground Roughness Correction Factor: 1.000

DISTANCE km	T E D E (rem)	RESPIRABLE TIME-INTEGRATED AIR CONCENTRATION (Ci-sec)/m3	GROUND SURFACE DEPOSITION (uCi/m2)	GROUND SHINE DOSE RATE (rem/hr)	ARRIVAL TIME (hour:min)
0.030	0.0E+00	4.1E-21	0.0E+00	0.0E+00	

<00:01

0.100	3.7E-09	1.4E-09	3.9E-06	1.1E-10	00:01
0.200	9.4E-09	3.4E-09	1.0E-05	2.9E-10	00:03
0.300	6.5E-09	2.3E-09	7.0E-06	2.0E-10	00:05
0.400	4.2E-09	1.5E-09	4.6E-06	1.3E-10	00:06
0.500	2.9E-09	1.1E-09	3.2E-06	8.8E-11	00:08
0.600	2.1E-09	7.6E-10	2.3E-06	6.4E-11	00:10
0.700	1.6E-09	5.7E-10	1.7E-06	4.8E-11	00:11
0.800	1.2E-09	4.4E-10	1.3E-06	3.7E-11	00:13
0.900	9.8E-10	3.6E-10	1.1E-06	3.0E-11	00:15
1.000	8.0E-10	2.9E-10	8.7E-07	2.4E-11	00:16
2.000	2.1E-10	7.5E-11	2.3E-07	6.3E-12	00:33
4.000	5.4E-11	2.0E-11	5.9E-08	1.6E-12	01:06
6.000	2.5E-11	8.9E-12	2.7E-08	7.5E-13	01:40
8.000	1.4E-11	5.1E-12	1.5E-08	4.3E-13	02:13
10.000	9.2E-12	3.4E-12	1.0E-08	2.8E-13	02:46
20.000	2.4E-12	8.7E-13	2.6E-09	7.3E-14	05:33
40.000	5.6E-13	2.0E-13	6.1E-10	1.7E-14	11:06
60.000	2.1E-13	7.7E-14	2.3E-10	6.5E-15	16:40
80.000	9.9E-14	3.6E-14	1.1E-10	3.0E-15	22:13

HotSpot Version 3.1.2 General Plume
Jul 5, 2022 1:39:39 PM

```
Source Material             : I-130m  8.8400E+00 m
Material-at-Risk   (MAR)    : 1.3100E-05 Ci
Damage Ratio        (DR)    : 1.00
Airborne Fraction  (ARF)    : 1.000
Respirable Fraction (RF)    : 1.000
Leakpath Factor    (LPF)    : 1.000
Respirable Source Term      : 1.31E-05 Ci
Non-respirable Source Term  : 0.00E+00 Ci
Effective Release Height    : 30 m
Wind Speed (h=30 m)         : 1.00 m/s
Wind Speed (h=H-eff)        : 1.00 m/s
Stability Class             : B
Respirable Dep. Vel.        : 0.30 cm/s
Non-respirable Dep. Vel.    : 8.00 cm/s
Receptor Height             : 1.5 m
Inversion Layer Height      : None
Sample Time                 : 10.000 min
Breathing Rate              : 3.33E-04 m3/sec
Distance Coordinates        : All distances are on the Plume Centerline

Maximum Dose Distance       : 0.17 km
MAXIMUM TEDE                : 4.13E-11 rem
Inner  Contour Dose         : 0.100 rem
Middle Contour Dose         : 0.080 rem
Outer  Contour Dose         : 0.050 rem
Exceeds Inner  Dose Out To  : Not Exceeded
Exceeds Middle Dose Out To  : Not Exceeded
Exceeds Outer  Dose Out To  : Not Exceeded
```

FGR-11 Dose Conversion Data - Total Effective Dose Equivalent (TEDE)

Include Plume Passage Inhalation and Submersion
Include Ground Shine (Weathering Correction Factor : None)
Exposure Window:(Start: 0.00 days; Duration: 4.00 days) [100% stay time].
Initial Deposition and Dose Rate shown
Ground Roughness Correction Factor: 1.000

DISTANCE km	T E D E (rem)	RESPIRABLE TIME-INTEGRATED AIR CONCENTRATION (Ci-sec)/m3	GROUND SURFACE DEPOSITION (uCi/m2)	GROUND SHINE DOSE RATE (rem/hr)	ARRIVAL TIME (hour:min)
0.030	0.0E+00	2.9E-21	0.0E+00	0.0E+00	

<00:01

0.100	1.8E-11	8.8E-10	2.5E-06	3.7E-12	00:01
0.200	3.9E-11	1.9E-09	5.8E-06	8.5E-12	00:03
0.300	2.3E-11	1.2E-09	3.5E-06	5.1E-12	00:05
0.400	1.3E-11	6.6E-10	2.0E-06	3.0E-12	00:06
0.500	8.1E-12	4.0E-10	1.2E-06	1.8E-12	00:08
0.600	5.1E-12	2.5E-10	7.6E-07	1.1E-12	00:10
0.700	3.4E-12	1.7E-10	5.0E-07	7.5E-13	00:11
0.800	2.3E-12	1.2E-10	3.5E-07	5.1E-13	00:13
0.900	1.6E-12	8.1E-11	2.4E-07	3.6E-13	00:15
1.000	1.2E-12	5.8E-11	1.7E-07	2.6E-13	00:16
2.000	8.3E-14	4.1E-12	1.2E-08	1.8E-14	00:33
4.000	1.6E-15	8.1E-14	2.4E-10	3.6E-16	01:06
6.000	5.6E-17	2.8E-15	8.4E-12	1.2E-17	01:40
8.000	2.4E-18	1.2E-16	3.6E-13	0.0E+00	02:13
10.000	0.0E+00	5.9E-18	1.8E-14	0.0E+00	02:46
20.000	0.0E+00	3.7E-24	0.0E+00	0.0E+00	05:33
40.000	0.0E+00	0.0E+00	0.0E+00	0.0E+00	11:06
60.000	0.0E+00	0.0E+00	0.0E+00	0.0E+00	16:40
80.000	0.0E+00	0.0E+00	0.0E+00	0.0E+00	22:13

HotSpot Version 3.1.2 General Plume
Jul 5, 2022 1:40:57 PM

```
Source Material             : I-131   D    8.04d
Material-at-Risk   (MAR)    : 2.2400E-02 Ci
Damage Ratio        (DR)    : 1.00
Airborne Fraction  (ARF)    : 1.000
Respirable Fraction (RF)    : 1.000
Leakpath Factor    (LPF)    : 1.000
Respirable Source Term      : 2.24E-02 Ci
Non-respirable Source Term  : 0.00E+00 Ci
Effective Release Height    : 30 m
Wind Speed (h=30 m)         : 1.00 m/s
Wind Speed (h=H-eff)        : 1.00 m/s
Stability Class             : B
Respirable Dep. Vel.        : 0.30 cm/s
Non-respirable Dep. Vel.    : 8.00 cm/s
Receptor Height             : 1.5 m
Inversion Layer Height      : None
Sample Time                 : 10.000 min
Breathing Rate              : 3.33E-04 m3/sec
Distance Coordinates        : All distances are on the Plume Centerline

Maximum Dose Distance       : 0.18 km
MAXIMUM TEDE                : 5.38E-05 rem
Inner  Contour Dose         : 0.100 rem
Middle Contour Dose         : 0.080 rem
Outer  Contour Dose         : 0.050 rem
Exceeds Inner  Dose Out To  : Not Exceeded
Exceeds Middle Dose Out To  : Not Exceeded
Exceeds Outer  Dose Out To  : Not Exceeded
```

FGR-11 Dose Conversion Data - Total Effective Dose Equivalent (TEDE)

Include Plume Passage Inhalation and Submersion
Include Ground Shine (Weathering Correction Factor : None)
Exposure Window:(Start: 0.00 days; Duration: 4.00 days) [100% stay time].
Initial Deposition and Dose Rate shown
Ground Roughness Correction Factor: 1.000

DISTANCE km	T E D E (rem)	RESPIRABLE TIME-INTEGRATED AIR CONCENTRATION (Ci-sec)/m3	GROUND SURFACE DEPOSITION (uCi/m2)	GROUND SHINE DOSE RATE (rem/hr)	ARRIVAL TIME (hour:min)
0.030	5.6E-17	5.1E-18	1.0E-15	0.0E+00	

<00:01

0.100	2.1E-05	1.7E-06	4.9E-03	2.5E-08	00:01
0.200	5.2E-05	4.3E-06	1.3E-02	6.4E-08	00:03
0.300	3.6E-05	2.9E-06	8.8E-03	4.4E-08	00:05
0.400	2.3E-05	1.9E-06	5.8E-03	2.9E-08	00:06
0.500	1.6E-05	1.3E-06	4.0E-03	2.0E-08	00:08
0.600	1.2E-05	9.5E-07	2.9E-03	1.4E-08	00:10
0.700	8.8E-06	7.2E-07	2.2E-03	1.1E-08	00:11
0.800	6.9E-06	5.6E-07	1.7E-03	8.4E-09	00:13
0.900	5.5E-06	4.5E-07	1.3E-03	6.7E-09	00:15
1.000	4.5E-06	3.7E-07	1.1E-03	5.5E-09	00:16
2.000	1.2E-06	9.6E-08	2.9E-04	1.4E-09	00:33
4.000	3.2E-07	2.6E-08	7.7E-05	3.9E-10	01:06
6.000	1.5E-07	1.2E-08	3.6E-05	1.8E-10	01:40
8.000	8.8E-08	7.2E-09	2.2E-05	1.1E-10	02:13
10.000	5.9E-08	4.8E-09	1.4E-05	7.2E-11	02:46
20.000	1.8E-08	1.4E-09	4.3E-06	2.2E-11	05:33
40.000	5.5E-09	4.5E-10	1.4E-06	6.8E-12	11:06
60.000	2.8E-09	2.3E-10	6.9E-07	3.5E-12	16:40
80.000	1.8E-09	1.4E-10	4.3E-07	2.1E-12	22:13

HotSpot Version 3.1.2 General Plume
Jul 5, 2022 1:41:57 PM

```
Source Material            : I-132   D    2.30h
Material-at-Risk   (MAR)   : 2.4800E-01 Ci
Damage Ratio        (DR)   : 1.00
Airborne Fraction  (ARF)   : 1.000
Respirable Fraction (RF)   : 1.000
Leakpath Factor    (LPF)   : 1.000
Respirable Source Term     : 2.48E-01 Ci
Non-respirable Source Term : 0.00E+00 Ci
Effective Release Height   : 30 m
Wind Speed (h=30 m)        : 1.00 m/s
Wind Speed (h=H-eff)       : 1.00 m/s
Stability Class            : B
Respirable Dep. Vel.       : 0.30 cm/s
Non-respirable Dep. Vel.   : 8.00 cm/s
Receptor Height            : 1.5 m
Inversion Layer Height     : None
Sample Time                : 10.000 min
Breathing Rate             : 3.33E-04 m3/sec
Distance Coordinates       : All distances are on the Plume Centerline

Maximum Dose Distance      : 0.18 km
MAXIMUM TEDE               : 4.00E-05 rem
Inner  Contour Dose        : 0.100 rem
Middle Contour Dose        : 0.080 rem
Outer  Contour Dose        : 0.050 rem
Exceeds Inner  Dose Out To : Not Exceeded
Exceeds Middle Dose Out To : Not Exceeded
Exceeds Outer  Dose Out To : Not Exceeded
```

FGR-11 Dose Conversion Data - Total Effective Dose Equivalent (TEDE)

Include Plume Passage Inhalation and Submersion
Include Ground Shine (Weathering Correction Factor : None)
Exposure Window:(Start: 0.00 days; Duration: 4.00 days) [100% stay time].
Initial Deposition and Dose Rate shown
Ground Roughness Correction Factor: 1.000

DISTANCE km	T E D E (rem)	RESPIRABLE TIME-INTEGRATED AIR CONCENTRATION (Ci-sec)/m3	GROUND SURFACE DEPOSITION (uCi/m2)	GROUND SHINE DOSE RATE (rem/hr)	ARRIVAL TIME (hour:min)
0.030	3.2E-17	5.6E-17	1.1E-14	0.0E+00	

					<00:01
0.100	1.5E-05	1.9E-05	5.4E-02	1.6E-06	00:01
0.200	3.9E-05	4.7E-05	1.4E-01	4.1E-06	00:03
0.300	2.6E-05	3.2E-05	9.5E-02	2.8E-06	00:05
0.400	1.7E-05	2.1E-05	6.2E-02	1.8E-06	00:06
0.500	1.2E-05	1.4E-05	4.2E-02	1.2E-06	00:08
0.600	8.4E-06	1.0E-05	3.0E-02	8.9E-07	00:10
0.700	6.3E-06	7.5E-06	2.3E-02	6.6E-07	00:11
0.800	4.8E-06	5.8E-06	1.7E-02	5.1E-07	00:13
0.900	3.8E-06	4.6E-06	1.4E-02	4.1E-07	00:15
1.000	3.1E-06	3.7E-06	1.1E-02	3.3E-07	00:16
2.000	7.6E-07	9.0E-07	2.7E-03	8.0E-08	00:33
4.000	1.7E-07	2.0E-07	6.1E-04	1.8E-08	01:06
6.000	6.8E-08	8.2E-08	2.5E-04	7.2E-09	01:40
8.000	3.4E-08	4.1E-08	1.2E-04	3.6E-09	02:13
10.000	1.9E-08	2.3E-08	7.0E-05	2.1E-09	02:46
20.000	2.5E-09	3.1E-09	9.2E-06	2.7E-10	05:33
40.000	1.5E-10	1.8E-10	5.5E-07	1.6E-11	11:06
60.000	1.5E-11	1.8E-11	5.3E-08	1.6E-12	16:40
80.000	1.8E-12	2.1E-12	6.3E-09	1.9E-13	22:13

HotSpot Version 3.1.2 General Plume
Jul 5, 2022 1:43:03 PM

```
Source Material            : I-133   D    20.8h
Material-at-Risk   (MAR)   : 2.9200E-01 Ci
Damage Ratio        (DR)   : 1.00
Airborne Fraction  (ARF)   : 1.000
Respirable Fraction (RF)   : 1.000
Leakpath Factor    (LPF)   : 1.000
Respirable Source Term     : 2.92E-01 Ci
Non-respirable Source Term : 0.00E+00 Ci
Effective Release Height   : 30 m
Wind Speed (h=30 m)        : 1.00 m/s
Wind Speed (h=H-eff)       : 1.00 m/s
Stability Class            : B
Respirable Dep. Vel.       : 0.30 cm/s
Non-respirable Dep. Vel.   : 8.00 cm/s
Receptor Height            : 1.5 m
Inversion Layer Height     : None
Sample Time                : 10.000 min
Breathing Rate             : 3.33E-04 m3/sec
Distance Coordinates       : All distances are on the Plume Centerline

Maximum Dose Distance      : 0.18 km
MAXIMUM TEDE               : 1.57E-04 rem
Inner  Contour Dose        : 0.100 rem
Middle Contour Dose        : 0.080 rem
Outer  Contour Dose        : 0.050 rem
Exceeds Inner  Dose Out To : Not Exceeded
Exceeds Middle Dose Out To : Not Exceeded
Exceeds Outer  Dose Out To : Not Exceeded
```

FGR-11 Dose Conversion Data - Total Effective Dose Equivalent (TEDE)

Include Plume Passage Inhalation and Submersion
Include Ground Shine (Weathering Correction Factor : None)
Exposure Window:(Start: 0.00 days; Duration: 4.00 days) [100% stay time].
Initial Deposition and Dose Rate shown
Ground Roughness Correction Factor: 1.000

DISTANCE km	T E D E (rem)	RESPIRABLE TIME-INTEGRATED AIR CONCENTRATION (Ci-sec)/m3	GROUND SURFACE DEPOSITION (uCi/m2)	GROUND SHINE DOSE RATE (rem/hr)	ARRIVAL TIME (hour:min)
0.030	1.4E-16	6.6E-17	1.3E-14	0.0E+00	

					<00:01
0.100	6.0E-05	2.2E-05	6.4E-02	5.1E-07	00:01
0.200	1.5E-04	5.6E-05	1.7E-01	1.3E-06	00:03
0.300	1.0E-04	3.8E-05	1.1E-01	9.1E-07	00:05
0.400	6.8E-05	2.5E-05	7.5E-02	5.9E-07	00:06
0.500	4.7E-05	1.7E-05	5.1E-02	4.1E-07	00:08
0.600	3.4E-05	1.2E-05	3.7E-02	3.0E-07	00:10
0.700	2.6E-05	9.3E-06	2.8E-02	2.2E-07	00:11
0.800	2.0E-05	7.2E-06	2.2E-02	1.7E-07	00:13
0.900	1.6E-05	5.8E-06	1.7E-02	1.4E-07	00:15
1.000	1.3E-05	4.7E-06	1.4E-02	1.1E-07	00:16
2.000	3.4E-06	1.2E-06	3.7E-03	2.9E-08	00:33
4.000	8.9E-07	3.3E-07	9.8E-04	7.8E-09	01:06
6.000	4.1E-07	1.5E-07	4.5E-04	3.6E-09	01:40
8.000	2.4E-07	8.8E-08	2.6E-04	2.1E-09	02:13
10.000	1.6E-07	5.8E-08	1.7E-04	1.4E-09	02:46
20.000	4.4E-08	1.6E-08	4.8E-05	3.8E-10	05:33
40.000	1.2E-08	4.2E-09	1.3E-05	1.0E-10	11:06
60.000	5.0E-09	1.8E-09	5.5E-06	4.4E-11	16:40
80.000	2.6E-09	9.6E-10	2.9E-06	2.3E-11	22:13

HotSpot Version 3.1.2 General Plume
Jul 5, 2022 1:44:58 PM

```
Source Material             : I-134   D    52.6m
Material-at-Risk   (MAR)    : 7.4400E-01 Ci
Damage Ratio        (DR)    : 1.00
Airborne Fraction  (ARF)    : 1.000
Respirable Fraction (RF)    : 1.000
Leakpath Factor    (LPF)    : 1.000
Respirable Source Term      : 7.44E-01 Ci
Non-respirable Source Term  : 0.00E+00 Ci
Effective Release Height    : 30 m
Wind Speed (h=30 m)         : 1.00 m/s
Wind Speed (h=H-eff)        : 1.00 m/s
Stability Class             : B
Respirable Dep. Vel.        : 0.30 cm/s
Non-respirable Dep. Vel.    : 8.00 cm/s
Receptor Height             : 1.5 m
Inversion Layer Height      : None
Sample Time                 : 10.000 min
Breathing Rate              : 3.33E-04 m3/sec
Distance Coordinates        : All distances are on the Plume Centerline

Maximum Dose Distance       : 0.17 km
MAXIMUM TEDE                : 9.17E-05 rem
Inner  Contour Dose         : 0.100 rem
Middle Contour Dose         : 0.080 rem
Outer  Contour Dose         : 0.050 rem
Exceeds Inner  Dose Out To  : Not Exceeded
Exceeds Middle Dose Out To  : Not Exceeded
Exceeds Outer  Dose Out To  : Not Exceeded
```

FGR-11 Dose Conversion Data - Total Effective Dose Equivalent (TEDE)

Include Plume Passage Inhalation and Submersion
Include Ground Shine (Weathering Correction Factor : None)
Exposure Window:(Start: 0.00 days; Duration: 4.00 days) [100% stay time].
Initial Deposition and Dose Rate shown
Ground Roughness Correction Factor: 1.000

DISTANCE km	T E D E (rem)	RESPIRABLE TIME-INTEGRATED AIR CONCENTRATION (Ci-sec)/m3	GROUND SURFACE DEPOSITION (uCi/m2)	GROUND SHINE DOSE RATE (rem/hr)	ARRIVAL TIME (hour:min)
0.030	8.9E-17	1.7E-16	3.4E-14	1.1E-18	

<00:01					
	0.100	3.6E-05	5.5E-05	1.6E-01	5.4E-06
00:01					
	0.200	8.9E-05	1.4E-04	4.1E-01	1.4E-05
00:03					
	0.300	5.9E-05	9.1E-05	2.7E-01	9.2E-06
00:05					
	0.400	3.8E-05	5.8E-05	1.8E-01	5.9E-06
00:06					
	0.500	2.6E-05	3.9E-05	1.2E-01	4.0E-06
00:08					
	0.600	1.8E-05	2.8E-05	8.3E-02	2.8E-06
00:10					
	0.700	1.3E-05	2.0E-05	6.1E-02	2.1E-06
00:11					
	0.800	1.0E-05	1.6E-05	4.7E-02	1.6E-06
00:13					
	0.900	8.0E-06	1.2E-05	3.7E-02	1.2E-06
00:15					
	1.000	6.4E-06	9.8E-06	2.9E-02	9.9E-07
00:16					
	2.000	1.3E-06	2.1E-06	6.2E-03	2.1E-07
00:33					
	4.000	2.3E-07	3.6E-07	1.1E-03	3.6E-08
01:06					
	6.000	7.1E-08	1.1E-07	3.3E-04	1.1E-08
01:40					
	8.000	2.7E-08	4.1E-08	1.2E-04	4.2E-09
02:13					
	10.000	1.2E-08	1.8E-08	5.4E-05	1.8E-09
02:46					
	20.000	3.9E-10	6.0E-10	1.8E-06	6.1E-11
05:33					
	40.000	1.5E-12	2.4E-12	7.1E-09	2.4E-13
11:06					
	60.000	9.9E-15	1.5E-14	4.5E-11	1.5E-15
16:40					
	80.000	7.7E-17	1.2E-16	3.5E-13	1.2E-17
22:13					

HotSpot Version 3.1.2 General Plume
Jul 5, 2022 1:46:45 PM

Source Material : I-134m 3.6000E+00 m
Material-at-Risk   (MAR) : 3.5400E-02 Ci
Damage Ratio   (DR) : 1.00
Airborne Fraction (ARF) : 1.000
Respirable Fraction (RF) : 1.000
Leakpath Factor   (LPF) : 1.000
Respirable Source Term : 3.54E-02 Ci
Non-respirable Source Term : 0.00E+00 Ci
Effective Release Height : 30 m
Wind Speed (h=30 m) : 1.00 m/s
Wind Speed (h=H-eff) : 1.00 m/s
Stability Class : B
Respirable Dep. Vel. : 0.30 cm/s
Non-respirable Dep. Vel. : 8.00 cm/s
Receptor Height : 1.5 m
Inversion Layer Height : None
Sample Time : 10.000 min
Breathing Rate : 3.33E-04 m3/sec
Distance Coordinates : All distances are on the Plume Centerline

Maximum Dose Distance : 0.16 km
MAXIMUM TEDE : 2.02E-07 rem
Inner Contour Dose : 0.100 rem
Middle Contour Dose : 0.080 rem
Outer Contour Dose : 0.050 rem
Exceeds Inner Dose Out To : Not Exceeded
Exceeds Middle Dose Out To : Not Exceeded
Exceeds Outer Dose Out To : Not Exceeded

FGR-11 Dose Conversion Data - Total Effective Dose Equivalent (TEDE)

Include Plume Passage Inhalation and Submersion
Include Ground Shine (Weathering Correction Factor : None)
Exposure Window:(Start: 0.00 days; Duration: 4.00 days) [100% stay time].
Initial Deposition and Dose Rate shown
Ground Roughness Correction Factor: 1.000

DISTANCE km	T E D E (rem)	RESPIRABLE TIME-INTEGRATED AIR CONCENTRATION (Ci-sec)/m3	GROUND SURFACE DEPOSITION (uCi/m2)	GROUND SHINE DOSE RATE (rem/hr)	ARRIVAL TIME (hour:min)
0.030	0.0E+00	7.3E-18	1.5E-15	0.0E+00	

<00:01

0.100	9.7E-08	2.0E-06	5.6E-03	2.2E-08	00:01
0.200	1.8E-07	3.6E-06	1.1E-02	4.1E-08	00:03
0.300	8.7E-08	1.8E-06	5.3E-03	2.1E-08	00:05
0.400	4.2E-08	8.4E-07	2.5E-03	9.8E-09	00:06
0.500	2.1E-08	4.2E-07	1.3E-03	4.9E-09	00:08
0.600	1.1E-08	2.2E-07	6.6E-04	2.6E-09	00:10
0.700	5.9E-09	1.2E-07	3.6E-04	1.4E-09	00:11
0.800	3.4E-09	6.8E-08	2.0E-04	7.9E-10	00:13
0.900	1.9E-09	3.9E-08	1.2E-04	4.6E-10	00:15
1.000	1.2E-09	2.3E-08	7.0E-05	2.7E-10	00:16
2.000	1.2E-11	2.5E-10	7.4E-07	2.9E-12	00:33
4.000	5.3E-15	1.1E-13	3.2E-10	1.3E-15	01:06
6.000	4.1E-18	8.2E-17	2.5E-13	0.0E+00	01:40
8.000	0.0E+00	7.9E-20	2.4E-16	0.0E+00	02:13
10.000	0.0E+00	8.6E-23	0.0E+00	0.0E+00	02:46
20.000	0.0E+00	0.0E+00	0.0E+00	0.0E+00	05:33
40.000	0.0E+00	0.0E+00	0.0E+00	0.0E+00	11:06
60.000	0.0E+00	0.0E+00	0.0E+00	0.0E+00	16:40
80.000	0.0E+00	0.0E+00	0.0E+00	0.0E+00	22:13

HotSpot Version 3.1.2 General Plume
Jul 5, 2022 1:49:42 PM

```
Source Material             : I-135   D    6.61h
Material-at-Risk   (MAR)    : 4.5300E-01 Ci
Damage Ratio        (DR)    : 1.00
Airborne Fraction  (ARF)    : 1.000
Respirable Fraction (RF)    : 1.000
Leakpath Factor    (LPF)    : 1.000
Respirable Source Term      : 4.53E-01 Ci
Non-respirable Source Term  : 0.00E+00 Ci
Effective Release Height    : 30 m
Wind Speed (h=30 m)         : 1.00 m/s
Wind Speed (h=H-eff)        : 1.00 m/s
Stability Class             : B
Respirable Dep. Vel.        : 0.30 cm/s
Non-respirable Dep. Vel.    : 8.00 cm/s
Receptor Height             : 1.5 m
Inversion Layer Height      : None
Sample Time                 : 10.000 min
Breathing Rate              : 3.33E-04 m3/sec
Distance Coordinates        : All distances are on the Plume Centerline

Maximum Dose Distance       : 0.18 km
MAXIMUM TEDE                : 1.12E-04 rem
Inner  Contour Dose         : 0.100 rem
Middle Contour Dose         : 0.080 rem
Outer  Contour Dose         : 0.050 rem
Exceeds Inner  Dose Out To  : Not Exceeded
Exceeds Middle Dose Out To  : Not Exceeded
Exceeds Outer  Dose Out To  : Not Exceeded
```

FGR-11 Dose Conversion Data - Total Effective Dose Equivalent (TEDE)

Include Plume Passage Inhalation and Submersion
Include Ground Shine (Weathering Correction Factor : None)
Exposure Window:(Start: 0.00 days; Duration: 4.00 days) [100% stay time].
Initial Deposition and Dose Rate shown
Ground Roughness Correction Factor: 1.000

DISTANCE km	T E D E (rem)	RESPIRABLE TIME-INTEGRATED AIR CONCENTRATION (Ci-sec)/m3	GROUND SURFACE DEPOSITION (uCi/m2)	GROUND SHINE DOSE RATE (rem/hr)	ARRIVAL TIME (hour:min)
0.030	7.6E-17	1.0E-16	2.1E-14	0.0E+00	

<00:01

0.100	4.3E-05	3.4E-05	9.9E-02	1.9E-06	00:01
0.200	1.1E-04	8.6E-05	2.6E-01	5.0E-06	00:03
0.300	7.4E-05	5.9E-05	1.8E-01	3.5E-06	00:05
0.400	4.9E-05	3.8E-05	1.2E-01	2.3E-06	00:06
0.500	3.3E-05	2.6E-05	7.9E-02	1.5E-06	00:08
0.600	2.4E-05	1.9E-05	5.7E-02	1.1E-06	00:10
0.700	1.8E-05	1.4E-05	4.3E-02	8.4E-07	00:11
0.800	1.4E-05	1.1E-05	3.3E-02	6.5E-07	00:13
0.900	1.1E-05	8.8E-06	2.7E-02	5.2E-07	00:15
1.000	9.1E-06	7.2E-06	2.2E-02	4.2E-07	00:16
2.000	2.3E-06	1.8E-06	5.5E-03	1.1E-07	00:33
4.000	5.9E-07	4.7E-07	1.4E-03	2.7E-08	01:06
6.000	2.6E-07	2.1E-07	6.2E-04	1.2E-08	01:40
8.000	1.5E-07	1.2E-07	3.5E-04	6.8E-09	02:13
10.000	9.3E-08	7.4E-08	2.2E-04	4.3E-09	02:46
20.000	2.1E-08	1.7E-08	5.0E-05	9.8E-10	05:33
40.000	3.7E-09	3.0E-09	8.9E-06	1.7E-10	11:06
60.000	1.1E-09	8.6E-10	2.6E-06	5.0E-11	16:40
80.000	3.8E-10	3.0E-10	9.1E-07	1.8E-11	22:13

ATTACHMENT 3

HotSpot Version 3.1.2 General Plume
Aug 5, 2022 9:03:04 AM

Source Material : Ar-41 1.0961E+02 m
Material-at-Risk (MAR) : 4.2800E+00 Ci
Damage Ratio (DR) : 1.00
Airborne Fraction (ARF) : 1.000
Respirable Fraction (RF) : 1.000
Leakpath Factor (LPF) : 1.000
Respirable Source Term : 4.28E+00 Ci
Non-respirable Source Term : 0.00E+00 Ci
Effective Release Height : 30 m
Wind Speed (h=30 m) : 1.00 m/s
Wind Speed (h=H-eff) : 1.00 m/s
Stability Class : B
Respirable Dep. Vel. : 0.00 cm/s
Non-respirable Dep. Vel. : 8.00 cm/s
Receptor Height : 1.5 m
Inversion Layer Height : None
Sample Time : 1440.000 min
Breathing Rate : 3.33E-04 m3/sec
Distance Coordinates : All distances are on the Plume Centerline

Maximum Dose Distance : 0.18 km
MAXIMUM TEDE : 7.38E-05 rem
Inner Contour Dose : 0.100 rem
Middle Contour Dose : 0.080 rem
Outer Contour Dose : 0.050 rem
Exceeds Inner Dose Out To : Not Exceeded
Exceeds Middle Dose Out To : Not Exceeded
Exceeds Outer Dose Out To : Not Exceeded

FGR-11 Dose Conversion Data - Total Effective Dose Equivalent (TEDE)

Include Plume Passage Inhalation and Submersion
Include Ground Shine (Weathering Correction Factor : None)
Exposure Window:(Start: 0.00 days; Duration: 4.00 days) [100% stay time].
Initial Deposition and Dose Rate shown
Ground Roughness Correction Factor: 1.000

DISTANCE km	T E D E (rem)	RESPIRABLE TIME-INTEGRATED AIR CONCENTRATION (Ci-sec)/m3	ARRIVAL TIME (hour:min)
0.030	8.6E-17	3.6E-16	<00:01
0.100	2.9E-05	1.2E-04	00:01
0.200	7.2E-05	3.0E-04	00:03
0.300	4.9E-05	2.0E-04	00:05
0.400	3.2E-05	1.3E-04	00:06

0.500	2.2E-05	9.0E-05	00:08
0.600	1.6E-05	6.5E-05	00:10
0.700	1.2E-05	4.8E-05	00:11
0.800	9.0E-06	3.7E-05	00:13
0.900	7.1E-06	3.0E-05	00:15
1.000	5.8E-06	2.4E-05	00:16
2.000	1.4E-06	5.8E-06	00:33
4.000	3.1E-07	1.3E-06	01:06
6.000	1.2E-07	4.9E-07	01:40
8.000	5.7E-08	2.4E-07	02:13
10.000	3.1E-08	1.3E-07	02:46
20.000	3.3E-09	1.4E-08	05:33
40.000	1.3E-10	5.4E-10	11:06
60.000	8.3E-12	3.4E-11	16:40
80.000	6.4E-13	2.7E-12	22:13

ATTACHMENT 4

BNL Comments on NBSR Report:

(Response to comments are in blue italic text)

"Potential Release of Fission Products from the NCNR Reactor During Startup Operations"

1. General – well written and clear report.
2. *ORIGEN-2* – the radioactive isotope production assumes 6-days of operation at given power level (at maximum flux location); How would "relatively stable" compare with infinite period of operation, a bit more justification that 6 days is conservative.

   Modified text to describe the use of 6 days in more detail. The calculations performed in Reference #1 demonstrate that the release rate climbs to a maximum and then slowly begins to decline. This asymptote occurs at around 6 days and thus is a worst case.

3. *"helium sweep and would be slowly released"* – is the assumed decay time before stack release consistent with the SAR values; possibly refer back to the SAR?

   The SAR does not record this information. However, an engineering study was done that demonstrates that this is a reasonable and conservative assumption.

4. *HOTSPOT* - Possibly mention that release is assumed to be continuous and conservatively assumed that the wind blows in one direction throughout the day; moderately stable Class F could result in somewhat higher dose rate. Possibly mention that breathing rate is in accordance with Appendix B of Part 20; mention the vintage/year of the FGR-11/12 being used by the version of Hotspot.

   Added text to clarify the assumptions in HOTSPOT and how they are conservative. Also mentioned that HOTSPOT in most cases used FGR-11/12. Although in cases where dose conversion factors don't exist for some isotopes, FGR-15 was used. Although it is true that F class can lead to higher dose rates, it is not correct in this case. The dose in this case is dominated by shorter lived isotopes. For class F, the maximum occurs at a much farther distance and thus isotopes decay before reaching that point. Thus, for longer lived isotopes F is more conservative but for shorter lived isotopes B is more conservative. Below are two figures comparing the dose rate from noble gases from this postulated release for Class B stability and Class F stability.

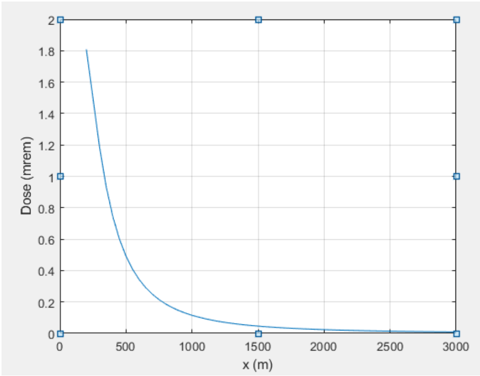

Figure 1: Dose vs Distance Class B Stability

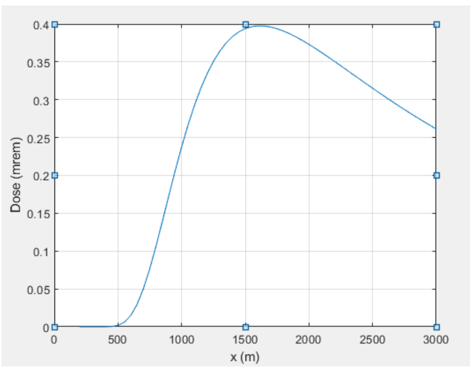

Figure 2: Dose versus Distance Class F Stability

5. *Stack monitor* – not clear how 700 cpm correlated with dose rate using COMPLY. Dose rate during normal operation is dominated by Ar-41 release. Would the COMPLY calculations indicate that the noble gas plus iodine release dose rate of ~1mrem/day correlate with the 5000 cpm? Do the COMPLY analysis assumes an average wind rose distribution over the year; may not be fully compatible with the HOTSPOT assumptions.

   Concur. I have modified the calculations to use the typical daily Ar-41 release rate (~4.3 Ci/day) to calculate the daily EPZ boundary dose. This is overly conservative for extended releases as it assumes constant weather conditions however it does provide an upper bound estimate. Actual doses are likely to be much lower. The is a more scientifically defensible methodology though.

Proposed Changes to the Safety Analysis Report for the NBSR

Introduction

As a small amount of debris from the February 3, 2021 fuel failure event remains in the primary system, a systematic review of the SAR and Technical Specifications was made to determine if changes were necessary. The presence of this small amount of debris has no effect on the siting (Chapters 1 and 2), structures, systems or components (Chapter 3, except for the primary system, discussed in Chapter 5 proposed changes), reactor design (Chapter 4), engineering safety features (Chapter 6), Instrumentation (Chapter 7), Electrical distribution (Chapter 8), Auxiliary systems (Chapter 9), experiments (Chapter 10), the reactor vessel (Chapter 16), and administrative issues (Chapters 12, 15, and 17). The accident analyses (Chapter 13) are discussed in the attached ECN and Technical Specifications (Chapter 14) are discussed below. There were changes proposed for Chapter 5 (Primary coolant system) and in Chapter 11 (Radiation Protection) as given below.

Technical Specifications: As there are no effects of the debris on the systems as discussed in the SAR, no changes in technical specifications are needed, including of those of reactivity control, instrumentation, and radiation and effluent monitors. There are also no additional required surveillances.

Proposed changes to SAR chapters 5 and 11:

5.2.2.4.4 Debris from February 3, 2021 Event

As a result of the fuel failure event of February 3, 2021, despite aggressive attempts to remove it, a small amount of fuel debris remains in the primary system. A conservative calculation, based on weighing the failed fuel element, shows that the maximum possible quantity of debris in the system was initially 66 grams. Some of this debris was removed via retrieval and filtering. The impact of the remaining debris is discussed below.

Pumps

All of the pumps in the primary system were run frequently after the event in various combinations without incident. Should any of the four main primary pumps fail during future reactor operation for any reason, including interference from large debris, the reactor will automatically scram from lack of sufficient flow in any of the redundant flow sensors discussed in 5.2.2.5.1. Other pumps in the primary system (redundant shutdown pumps, storage tank pumps, and experimental cooling pumps) perform no safety function. Thus, there is no remaining safety issue regarding debris affecting pump operation.

All pumps that comprise the design basis of the primary system are centrifugal pumps, which are very forgiving to minor amounts of solids passing through them, particularly if the solids are made up of small particulate matter. The maximum amount of 66 grams of small mass/small volume particulate matter is insignificant compared to a heavy water inventory that exceeds 10,000 gallons.

Valves

Although there are many valves in the primary system, none perform safety functions beyond “defense in depth”. The reactor is analyzed (13.2.3) to remain in a safe condition even if all the coolant is lost from the vessel. All valves listed in 5.2.2.4 are regularly tested and have shown no effects from debris. Large pieces of debris would be required to interfere with operation of these valves, and the possibility of such debris reaching these valves is remote.

Piping

The primary piping system, which is comprised of several vessels and the plumbing holds about 10,000 gallons of heavy water. During the February 2021 incident, less than 66 grams of debris was distributed in this volume. In 2022, a number of efforts were made to clean out the piping system and reached the point of where no discernable changes could be made. The remaining debris is likely not friable and thus unlikely to cause interference. Calculations have shown that debris larger than 0.093" will not be transported into the core with the liquid velocity range present in the NBSR inlet and outlet plena leading to the core.

Instrumentation

Instruments listed in 5.2.2.5 are separate and redundant. As a result, there is no single point failure that would obscure our (and the safety system's) ability to know primary flow: any debris will not simultaneously adversely affect all sensors and prevent a safety action from taking place. These are all tested at least quarterly and have shown no signs of degradation, even during intense efforts of system debris removal in 2022. Temperature transducers (RTDs or thermocouples), because of their construction are insensitive to debris: they are typically placed in a dry well. Pressure and level transducers that are designed to read pressure (instead of deducting flow) are by definition attached to non-flowing lines.

Heat Exchangers

Radiation surveys of the main heat exchangers (5.2.2.1) have indicated the presence of some debris. The presence of a quantity of debris sufficient to adversely affect the efficiency of the heat exchangers would be no different than other types of fouling and presents no safety issue.

11.1.1.2.3 Fission products

Add: The effect of fission products from the February 3, 2021 event is described in 11.1.1.4.3.1 below.

11.1.1.3.1 Reactor Primary Coolant

Add sentence to 2nd paragraph: Fission products from the February 3, 2021 event is described in 11.1.1.4.3.1. below.

11.1.1.4.3.1 Debris from February 3, 2021 fuel failure incident

The presence of debris from the February 3, 2021 fuel failure incident has the potential for the condition of small amounts of unclad fuel to exist in the reactor. Fission products from this unclad fuel would be easily detected by the fission product monitor (RM 3-2) and other effluent monitors (RM 3-4, RM 3-5, and RM 4-1). Based on radiation dose rate measurements on the primary piping, the largest single piece of material has a mass of no greater than 0.14 g. Were this piece to become lodged in the core and the reactor continued to operate, the total release of fission product noble gases would be about 10 Ci/day, which equates to a dose rate at the boundary of 0.13 mrem/day. This level is easily detectable by the effluent monitors, whereupon the reactor operator would take action to shut down the reactor. As an extra precaution, major scram setpoints for RM 3-4, RM 3-5, and RM 4-1 will be reduced to 5kcpm during startup of core #655, in accordance with the reactor restart plan.

Because of both decay and removal, dose rates due to debris in the primary system have reduced to the point where routine maintenance can be performed in the process room. The presence of any additional fission products generated from this material being lodged in the core during operations would have a negligible effect on personnel doses. As mentioned in 11.1.1.3.1, the process room is routinely surveyed, and the survey data is made available for any work performed in this area.