**TECHNICAL REVIEW OF RRD-RED-930373 CRITICALITY
SAFETY EVALUATION FOR L AREA DISASSEMBLY BASIN
CLEANUP (U)**

by
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SAVANNAH RIVER TECHNOLOGY CENTER
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SRT-CMA-930065

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TECHNICAL REVIEW OF RRD-RED-930373
CRITICALITY SAFETY EVALUATION
FOR L AREA DISASSEMBLY BASIN CLEANUP (U)

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INTRODUCTION

The study documented in RRD-RED-930373 (Reference 1) performed an evaluation of the criticality potential associated with sludge removal from the Disassembly Basin to the Monitor Basin of L Area Disassembly. The concern was that sufficient fissionable material has been released into the basin (and is now intermixed in the sludge) that the process of removing the sludge can cause the fissionable material to be formed into a critical configuration. The evaluation employed results of analytical measurements of the sludge composition to estimate the total amount of fissile material in the basin and provided comparisons of those fissile masses with accepted standard safe subcritical mass limits for each fissile component to demonstrate that the fissionable material isotopic composition of the sludge can not be formed into a critical configuration.

The analysis demonstrated that the fissile material content of the L Disassembly Basin is insufficient to form a critical mass, even with optimum geometry and concentration.

RRD-RED-930373 used the same methodology and arguments as previously reviewed in RRD-RED-930306 (References 2 and 3). The review was performed per QAP II-14 of 1Q34 (References 4 and 5).

DISCUSSION

This review emphasized the adequacy of the approaches and approximations used for the study and verification of agreement between the analytical data used in the fissile mass estimate process and the reported analytical data. The analytical data used for the estimates were also reviewed for internal consistency and reasonableness.

The review was performed before the analytical results had been formally reported in a documented analysis, but the analytical results were informally transmitted from the analyst to Rosser to expedite Rosser's work. No changes are expected in the results during that documentation process. If changes occur, Rosser will provide needed adjustments before issuing his report, with additional review, as needed, by APG personnel, before APG signature approval is granted.

The review consisted of

- a careful reading of the draft document, reference documents, and the author's notebook in which the calculations converting the analytical sludge material compositions to total masses in the basins were recorded,
- examination of consistency of numerical values reported in the draft document with data provided in reference documents,
- examination of the relative data values of the analytical results to verify the composition data are reasonable and consistent, and
- discussion with the author of minor editorial comments.

Separate, independent calculations were not performed since all calculations were essentially repetitive conversions of the analytical data reported by SRTC-ADS from isotopic wt % values in sludge to grams fissile material (each isotope) in the basins and comparisons by Rule of Fractions as provided in ANSI/ANS-8.15-1981) to safe subcritical limits specified in the ANS standards. The conversions and comparisons were reviewed (with numerous spot recalculations) and determined to be accurate. The volume-to-mass conversions for the sludge volumes and masses in each basin were reviewed, including explicit dimensional verifications from the referenced drawings. The estimated volumes stated were cross-checked against a value for the overall Disassembly Basin dimensions. No computer code calculations were employed by the author or reviewer.

No technical comments were noted. None were expected since the methodology duplicates that in a similar previously reviewed study (References 2 and 3). Only fissile isotopes were considered in the evaluation since the sludge material is in a very aqueous state. Several editorial comments were verbally discussed with the author. Those comments recommended that embedded tables in the text be placed in a column format for easier reading and suggested minor wording improvements.

It was suggested to the author that the hand calculations be placed on a spreadsheet since several such more analyses will be required during different phases of the sludge removal from all areas. A spreadsheet calculation can also be readily updated if transcribing errors or inaccurate values are noted. Verifications of such hand calculations can also be easily done since all numbers inputted are part of the spreadsheet and can be printed and saved in logbooks for record purposes.

SUMMARY AND CONCLUSIONS

The study presents a good evaluation of the criticality potential associated with the sludge removal process in L Disassembly Basin. Even with a large degree of conservatism employed in the evaluation, the analysis shows that the total fissile mass in the basin is less than a critical mass. The conservative factors have been well-delineated and the degree of conservatism has been assessed. Appropriate conservative actions are recommended and should be implemented:

- Verification of NIM operability prior to and during the sludge removal operation,
- Prohibition of fissile component movement during the sludge removal operation, and
- Measurement of sludge composition after the sludge transfer to the monitor basin.

REFERENCES

1. M. A. Rosser, "CRITICALITY EVALUATION FOR L AREA DISASSEMBLY BASIN CLEANUP (U)", RRD-RED-930373, September 29, 1993 (DRAFT) (See Attachment 2)
2. M. A. Rosser, "CRITICALITY EVALUATION FOR K AREA DISASSEMBLY VTS CLEANUP (U)", RRD-RED-930306, August 18, 1993
3. R. L. Reed, "TECHNICAL REVIEW OF RRD-RED-930306 NUCLEAR CRITICALITY SAFETY EVALUATION FOR K AREA DISASSEMBLY VTS CLEANUP (U)", SRT-SMA-930049, August 17, 1993
4. MANUAL 1Q34, NRTSC QUALITY ASSURANCE MANUAL, January 1991
5. NRTSC QA Procedure QAP II-14, "TECHNICAL REVIEW", August, 1991

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NRTSC REVIEW SHEET

OSR 24-K7

TASK TITLE NCSE FOR L AREA DISASSEMBLY BASIN CLEANUP

TASK NUMBER N/A

ITEM REVIEWED RRD-RED-930373

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(Attach additional pages as necessary; marked-up pages are acceptable.)

1. Areas reviewed (*identify clearly each area reviewed*).

Logic of presentation

Clarity of presentation

Accuracy of presentation

Applicability of presentation

Consistency of data values referenced to reference values

2. Approaches used to perform the review.

Read the document carefully.

Read the references carefully and ensured data values were accurately repeated.

Checked the hand calculations reported and verified their accuracy.

Ensured the readability of the presentation and agreement of intent with material as presented.

Discussed minor editorial preferences with author

3. Questions, comments to be resolved.

Before issue of RRD-RED-930373, verify that analytical results used in RRD-RED-930373 are same as those in ADS analyst's final report.

☒ I agree with the technical content ☐ I disagree with the technical content.

☒ I accept the conclusions and recommendations

☐ I do not accept the conclusions and recommendations for the following reasons:

Reviewer Signature Raymond L Seed Date 10/1/93

DRAFT

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FROM: M. A. Rosser, 705-K

SRTC Technical Reviewer: _____

CRITICALITY SAFETY EVALUATION FOR L AREA DISASSEMBLY BASIN CLEANUP (U)

INTRODUCTION

Preparations are currently being made to remove sludge from the Disassembly Basin in all reactor areas. Because this sludge contains fissile isotopes (Reference 1), it is necessary to perform a criticality safety evaluation for the planned activities. Previous evaluations examined the criticality safety aspects of the sludge removal process for K and P Areas (References 2 and 3). This document addresses the criticality safety aspects of the L Area disassembly basin cleanup work.

The L Area disassembly basin cleanup will involve, as a first step, pumping the basin sludge into the Monitor Basin. From the Monitor Basin, the sludge will be pumped into other tanks or containers for permanent disposition. The criticality safety evaluation discussed in this document covers the transfer of the sludge to the Monitor Basin. Future transfers of the sludge will require additional material sample analyses and may require additional criticality safety evaluations.

SUMMARY

The total mass of fissile material that could be present in the Monitor Basin as a result of the transfer of sludge from the L Area

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disassembly basin is less than that required to attain a critical configuration. Thus, there are no criticality safety operating limits required for the L Area disassembly basin sludge removal process that transfers sludge to the Monitor Basin.

DISCUSSION

An accumulation of sludge is present on the floor of the L Area disassembly basin. In June 1993, samples were taken from the L Area basin to determine the composition of the sludge. The concentrations of isotopes that are of concern for criticality safety evaluations were determined from ICP/MS spectrometry (Reference 4). The isotopes of interest for this evaluation are those fissile isotopes (i.e., can support a slow neutron chain reaction) that are present in the sludge. The concentrations of interest, representing the most conservative basin concentrations for these isotopes, are given in Table 1 in units of grams/gram of sample (Reference 1). In addition, SRTC analysts estimate the sludge density as approximately 1.01 gram/cubic centimeter (Reference 10).

Determination of Isotope Masses

Having determined the concentrations of the isotopes of interest for this criticality safety evaluation, the next step is to determine the mass of each isotope. To do this, an estimate of the amount of sludge present is needed. From the dimensions provided in various disassembly basin drawings and assuming a best estimate sludge depth of 3 inches (Reference 5), the following values were determined for the assumed volume of sludge present in each area of the basin:

- VTS [includes D&E canal] (Drawings W132078, W132079, W132025 and W132054): $4.0 \times 10^7 \text{ cm}^3$
- Dry Cave Area (Drawing W132555): $2.9 \times 10^7 \text{ cm}^3$ - does dry cave have?
- Emergency Disassembly Area (Drawing W132548): $1.2 \times 10^7 \text{ cm}^3$
- Monitor Basin (Drawing W132459): $4.5 \times 10^6 \text{ cm}^3$
- Machine Area (Drawing W132448): $2.8 \times 10^7 \text{ cm}^3$
- HTS & Bucket Storage (Drawings W132078, W132079): $6.0 \times 10^7 \text{ cm}^3$
- Transfer Bay Pit #1 and Pit #2 (Drawing W169514): $3.6 \times 10^6 \text{ cm}^3$

The above volumes represent conservative estimates since only overall basin dimensions were used and no consideration was given to the amount of basin floor space covered by structural materials.

From the volume of sludge calculated above, one can then determine the total mass of sludge to be assumed present, in each area of the disassembly basin, for this criticality safety evaluation. Assuming a density of 1.01 g/cc, the total mass of sludge for each section of the basin is as follows:

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- VTS: 4.04×10^7 g
 - Dry Cave Area: 2.93×10^7 g
 - Emergency Disassembly Area: 1.21×10^7 g
 - Monitor Basin: 4.55×10^6 g
 - Machine Area: 2.83×10^7 g
 - HTS & Bucket Storage: 6.06×10^7 g
 - Transfer Bay Pits: 3.64×10^6 g
- Put into table (columns)*

The final step in the calculational process is to determine the actual mass estimates of the isotopes that are of concern for criticality safety evaluations. This is accomplished by multiplying the total sludge mass by the concentration of the isotopes, in each section of the basin. The isotope masses for the various regions are then summed. This results in the total mass of each isotope present in the Monitor Basin after all sludge has been removed from the disassembly basin. The calculated masses are given in Table 2.

Criticality Safety Evaluation

The isotope masses calculated above must now be compared with the applicable limits to ensure subcriticality and, thus, criticality safety. The limits used in this evaluation are the applicable aqueous mixture subcritical mass limits published in accepted criticality safety references (References 6, 7 and 8). The subcritical limits of particular interest to this evaluation are given in Table 3.

Because the sludge contains a mixture of fissile isotopes, criticality safety evaluations must go beyond a simple comparison with the applicable individual limits. The criticality potential of the mixture as a whole must be considered. American National Standard (ANS)-8.15-1981 (Reference 6) provides guidance on performing these types of mixture analyses. This standard states that the subcritical limits may be applied to mixtures of fissile nuclides provided the sum of the ratios of the mass of each fissile nuclide to its limit does not exceed unity. In other words, divide the mass of each isotope by its subcritical limit and sum all of the results. If the sum is not greater than 1, there is a high confidence that the mixture will remain subcritical. Of course, as the margin from 1 increases, the confidence in subcriticality increases. For this evaluation, an upper limit of 0.9 for this "Rule of Fractions" (ROF) calculation will be used to declare that a mixture is subcritical. This is done to provide margin to account for uncertainties in the ROF methodology (Reference 9).

Prior to a discussion of the ROF results for this evaluation, two clarifications are in order. First of all, according to Reference 6, the ROF methodology is only applicable to aqueous (or well moderated) mixtures. This requirement is satisfied for this evaluation. If one considers the sludge sample density and composition analyses, one can determine that the sludge is at least 95 weight percent H_2O . One can

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then use this fact to determine that the hydrogen-to-fissile atom ratio is greater than 10^7 . This more than qualifies as a well-moderated mixture, and, since the hydrogen appears primarily in the form of water, the description of this sludge as an aqueous mixture is also appropriate.

The second clarification involves the isotopes (and associated subcritical limits) for which the ROF methodology is applicable. Reference 6 implies that uranium isotopes may not be used with the ROF methodology. It is generally accepted that this implied exclusion of uranium isotopes is not consistent with the actual intent of the authors of Reference 6. Reference 9, in fact, is an example of a ROF evaluation that includes U-235. As a result, this evaluation assumes that it is acceptable to include uranium isotopes in ROF calculations.

The above ROF methodology was applied to the calculated masses given in Table 2. The resulting "sum of the ratios" produced a value of 0.28. This value is much less than the subcritical guideline of 0.9 and, thus, indicates that the mixture is significantly subcritical because of insufficient fissile mass. This estimate does not include the effects of the U-238 present in the sludge, which would have made the system even more subcritical. This result means that the L Area cleanup process has an even greater subcritical margin than that associated with the K Area VTS cleanup (Reference 2).

Consideration of Uncertainties

The primary sources of uncertainty in this analysis are the measurement uncertainty associated with the sample results and the uncertainty in the sludge depth, which affects the total mass of sludge. The calculations discussed above were repeated assuming a conservative measurement uncertainty (Reference 1) and a maximum sludge depth of 6 inches (Reference 5). Isotope masses were calculated assuming that fissile isotope concentrations increased by an amount equal to a measurement uncertainty of 30% and the U-238 concentration (the effects of which are discussed below) was decreased by the same percentage. It is assumed that the uncertainties in Reference 1 correspond to 1-sigma uncertainties. Under this assumption, using the 30% value provides a 3-sigma uncertainty adjustment for U-235 and U-238, and gives greater than 1-sigma adjustments to the other isotopes.

The Rule of Fractions calculation for the above conditions produced a value of 0.72, which is below 0.9 and indicates an acceptable margin of subcriticality. In addition, there are several favorable aspects that were not included in this evaluation which will further increase the subcritical margin:

- The presence of U-238 in the sludge was neglected. U-238 in the sludge serves as a neutron poison and will effectively increase the

*Could discuss enrichment
4.25/4.25 ratio to CRD = .00275 (less the 0.3% enrichment)
discussion is not likely to be applied here.*

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subcritical mass limit of the fissile isotopes. As an example, including the U-238 mass in the ROF evaluation that considered uncertainties decreases the ROF result from 0.72 to 0.25. This decrease corresponds to the U-238 effects on the U-235 subcritical mass limit alone and represents a significant increase in subcritical margin.

- The sludge contains iron (10-24 wt% of solids). The primary stable iron isotopes have thermal neutron capture cross sections that range from 2.5 b to 2.8 b. This is similar to the 2.7 b cross section of U-238. The effects of the presence of U-238 were demonstrated above. Therefore, with the iron present in the sludge, we have an additional neutron poison that was not considered in this evaluation.
- The ICP/MS concentrations, where applicable, were assumed to correspond exclusively to fissile isotopes. The possibility of other, non-fissile isotopes was ignored. The Am-242m concentration is a prime example of the conservatism introduced by this action. The possible presence of Pu-242 (a non-fissile isotope) was excluded. Based on past operating history, Pu-242, not Am-242m, should be the primary weight 242 isotope in the sludge. In the above ROF calculation that includes uncertainties, Am-242m accounted for approximately 0.12 of the 0.72 final result.
- As discussed earlier, the sludge depth is not 6 inches everywhere and, in addition, the calculation of sludge mass ignored the fact that some floor space in the disassembly basin is taken up by concrete supports. This would lead to a smaller calculated value of total sludge mass resulting in smaller calculated values for fissile isotope masses.
- The most conservative disassembly basin fissile isotope concentrations were used. This action resulted in a conservative increase in the calculated fissile isotope masses. In some cases, the region concentrations of certain isotopes vary by a factor of 3 or more.
- The actual concentrations of the fissile isotopes in the sludge are significantly less than the concentrations assumed to correspond to calculated critical masses for these isotopes. Previous calculations have shown that there is approximately 1.771×10^8 cm³, or 177100 liters, of sludge in the disassembly basin. If one converts all of the fissile isotope mass (with uncertainties) to an equivalent U-235 mass, the result is 504 g. This corresponds to a concentration of 0.003 g/liter. Table 2.1 of Reference 7 gives a subcritical concentration limit for U-235, in an aqueous solution, of 11.5 g/liter. The equivalent U-235 mass in the basin sludge would have to concentrate by more than 3 orders of magnitude to achieve this concentration. There is presently no mechanism

identified by which the U-235, or any of the other isotopes, could separate from the sludge mixture and preferentially accumulate in this manner.

CONCLUSION

The total mass of fissile material that could be present in the Monitor Basin after the cleanup of sludge in the L Area disassembly basin is less than that required to attain a critical configuration. As a result, there are no criticality safety operating limits required for this process. After the sludge has settled in the Monitor Basin, and prior to the transfer of the sludge from the Monitor Basin to permanent disposition, additional sludge composition analyses must be performed to verify that no changes have occurred that would invalidate this evaluation.

As a final comment, since the sludge removal process involves the movement of fissile isotopes, NIM operability must be verified and the movement of other components containing fissile material should be suspended during the sludge movement process.

REFERENCES

1. Tovo, L. L., ... *formal report to be referenced here*
2. Rosser, M. A., "Criticality Safety Evaluation for K Area Disassembly VTS Cleanup (U)", RRD-RED-930306, August 18, 1993.
3. Reed, R. L., "Criticality Considerations in Disassembly Basin Sludge (U)", RRD-RTS-930020, January 25, 1993.
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6. "American National Standard for Nuclear Criticality Control of Special Actinide Elements," ANS-8.15-1981, November 9, 1981.
7. Nuclear Safety Guide, TID-7016, Revision 2, NUREG/CR-0095, June 1978.
8. "American National Standard for Nuclear Criticality Safety in Operations with Fissionable Materials Outside Reactors," ANS-8.1-1983, October 7, 1983.
9. Finch, D. R. and Williamson, T. G., "Validity of the Rule-of-Fractions for Assuring Criticality Safety Margins (U)", WSRC-TR-91-569, October, 1991.

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10. Tovo, L. L., "Results of K Area Vertical Tube Storage Basin Sludge Analyses (U)", SKTC-ADS-93-0335, June 16, 1993.

11. Drawing #W132078, Revision 68.

12. Drawing #W132079, Revision 17.

13. Drawing #W132025, Revision 24.

14. Drawing #W132054, Revision 16.

15. Drawing #W132448.

16. Drawing #W132555, Revision 43.

17. Drawing #W132548, Revision 15.

18. Drawing #W132459, Revision 17.

19. Drawing #W169514, Revision 25.

KEYWORDS
Technical
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} Revision = (omit) Rev

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TABLE 1

BASIN ISOTOPE CONCENTRATIONS (g/g of sample)

- VTS + D&E Canal

<u>ISOTOPE</u>	<u>CONCENTRATION (g/g)</u>	<u>DETERMINED BY</u>
U-233	1.01×10^{-8}	ICP/MS
U-235	2.91×10^{-7}	ICP/MS
Pu-239	5.92×10^{-8}	ICP/MS
Pu-241	2.62×10^{-9}	ICP/MS
Am-242m	3.55×10^{-9}	ICP/MS
Cm-243	1.25×10^{-9}	ICP/MS

- Machine Basin (Includes Dry Cave, Emergency Disassembly, Monitor Basin, Machine Area and HTS/Bucket Storage)

<u>ISOTOPE</u>	<u>CONCENTRATION (g/g)</u>	<u>DETERMINED BY</u>
U-233	9.16×10^{-9}	ICP/MS
U-235	8.25×10^{-7}	ICP/MS
Pu-239	1.11×10^{-7}	ICP/MS
Pu-241	1.80×10^{-9}	ICP/MS
Am-242m	3.89×10^{-9}	ICP/MS
Cm-243	2.81×10^{-9}	ICP/MS

Not that there are conservative choices (high values for fissile, low values for 238) as provided by SITE analysis. I would repeat all values from ADS report and highlight the values used in conservative analyses. A discussion of the degree of conservatism (ratios) would provide additional insight to argument.

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TABLE 1 (cont.)

BASIN ISOTOPE CONCENTRATIONS (g/g of sample)

- Transfer Bay

<u>ISOTOPE</u>	<u>CONCENTRATION (g/g)</u>	<u>DETERMINED BY</u>
U-233	7.83×10^{-9}	ICP/MS
U-235	6.19×10^{-7}	ICP/MS
Pu-239	1.11×10^{-7}	ICP/MS
Pu-241	9.53×10^{-9}	ICP/MS
Am-242m	2.32×10^{-9}	ICP/MS
Cm-243	1.67×10^{-9}	ICP/MS

TABLE 2

ESTIMATED BASIN SLUDGE FISSILE ISOTOPE MASSES (GRAMS)

<u>ISOTOPE</u>	<u>MASS (g)</u>
U-233	1.6
U-235	125.5
Pu-239	17.8
Pu-241	0.3
Am-242m	0.6
Cm-243	0.5

TABLE 3

MINIMUM SUBCRITICAL MASS LIMITS FOR VARIOUS ISOTOPES

<u>ISOTOPE</u>	<u>SUBCRIT. MASS LIMIT</u>	<u>REFERENCE NOTES</u>
U-233	500 g	A
U-235	700 g	A
Pu-239	450 g	A
Pu-241	200 g	B
Am-242m	13 g	B
Cm-243	90 g	B

Reference Notes:

- A. See Section 5.2 of Reference 8.
B. See Table 2 of Reference 6.

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