Document Ref No.
BII-5112-FMEA-001

Customer Ref No.
5232-00-002/0032.2

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FAILURE MODE AND EFFECTS ANALYSIS (FMEA)
FOR THE
ADVANCED MIXED WASTE TREATMENT PROJECT (AMWTP)
RETRIEVAL BOX ASSAY SYSTEM (RBAS)

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CHANGE CONTROL

ISSUE/DATE	SECTION/PARA	DESCRIPTION OF CHANGE
Rev. 0 – Dec 00		Preliminary Review Copy
Rev. 1 – March 02	Entire Document	Updated per SC&TS #059 comments to Rev. 0 from BNFL Inc.
Rev. 2 – May 02	Appendix 2	Updated per SC&TS #176 comments to Rev. 1 from BNFL Inc. on 5/7/02.

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1. Introduction

This revised report reflects discussions among BNFL Instruments Inc. (BII) and AMWTP BNFL Inc. personnel held in February 2002. It is built on the investigations by BII into the design, planned maintenance, testing and operating procedures relating to the Retrieval Box Assay System that is documented in [1].

Since the time of the preparation of [1], BII has successfully implemented software quality control checking of key instrument performance parameters on other projects [2, 3, 4]. Implementation of key software controlled checks was offered to and accepted by AMWTP personnel for implementation on the RBAS. Implementation of these additional checks has several important benefits: 1) mean time between failures (MTBF) for unrevealed failures is significantly increased, 2) assay data with no quality flag does not require manual review, and 3) assay data with data quality flags is identifiable in the Data Management System. Assay data that fails quality checks will still require special investigation by a qualified physicist prior to acceptance.

The data quality flags that are now included in the RBAS operating software are as follows:

1. Checking for passive/active mass discrepancies (indication of active mode self shielding, or ^{235}U only sample).
2. Gamma dead time checking (saturation/gamma breakthrough).
3. Acceptable limits for average flux-per-grab (neutron generator performance, insurance that detection limits are met).
4. Heterogeneity checking (additional TMU is assigned to boxes which are flagged for potential heterogeneity).

These quality checks and the issues they address are described in more detail in Section 5.

This document summarizes key changes from the baseline analysis in [1] predicated on the new data quality flags. It also enumerates prohibited items (Appendix 2) at the request of AMWTP.

The revised conclusions, reflecting the benefits of these additional software checks, are presented here.

2. System Description

The Retrieval Box Assay system shall make Non-Destructive Assay (NDA) measurements to determine the radionuclide contents of solid waste boxes of various sizes. The system will provide fissile content measurements for criticality control of down-stream processes and radionuclide quantification for process control.

Specifically it will satisfy the requirements to:

1. Determine the ^{239}Pu FGE box content (grams) for TRU management and criticality control purposes.
2. Determine the TRU alpha activity concentration of the waste in the box (nCi/g) for plant control purposes.

The RBAS will assay a variety of waste types including soil, light metal waste, copper and steel, lead waste, dry combustibles, wet combustibles, plastic, non-borated glass, and borated glass. In addition, the system will be capable of assaying waste defined in INEL-95/0412, "Waste Description Information for Transuranically-Contaminated Wastes Stored at the Idaho National Engineering Laboratory", Ravio, Becker, Smith and Anderson, December 1995 with the following exceptions:

1. Waste not contained in boxes within the maximum size envelope defined in the technical specification.
2. Remote handled containers (i.e. containers with external surface dose rates greater than 200 mrem/hr).
3. Inorganic and organic homogeneous solids.
4. Concentrated Pu and concentrated uranium are assumed not to be present.

The box assay system will be qualified to measure up to 450 g ^{239}Pu FGE. Quantities above this limit will cause an out of range flag indicating that the content is out of the calibration range.

Details regarding calibration and qualification of the system may be found in [5,6].

3. Measurement Control Regime

Rigorous implementation of a robust measurement control program is the single most critical element in rapid identification and resolution of system anomalies. Much credit is taking for identification of failure modes through measurement control programs [7,8]. Measurement control comprises three elements: 1) standardization checks before each measurement, 2) verification ("pink box") measurement at the beginning and end of each operating day or shift and 3) annual calibration verification, which exercises elements of the calibration not routinely checked.

Standardization Measurements

Standardization measurements occur before every assay, and are crucial to real time performance checking of the RBAS. The use of standardization measurements greatly reduces the likelihood of a hardware failure going unrevealed until the next verification measurement. The standardization sequence collects data from the active, passive and gamma modes, and verifies that key parameters do not exceed 3σ alarm limits set from data collected during commissioning. A standardization sequence consists of two phases, as described below.

Neutron Measurement Phase

The neutron measurement phase checks that the neutron generator and neutron counting hardware are operating correctly, providing a check of the full operation of the neutron counting system. The responses of the individual detectors with respect to the MA flux monitor detector are compared with stored responses to check the neutron counting hardware.

Gamma Measurement Phase

The gamma measurement phase confirms that the energy calibration of each HPGe detector is within acceptable limits. A ^{152}Eu source is placed in front of each HPGe detector and the standardization measurement is taken.

Once completed, standardization remains valid for the following measurement only. When the following measurements have elapsed, no further measurements can be performed until another standardization is carried out.

Following the successful completion of standardization, the RBAS is ready to accept a waste package for measurement.

Verification Measurements

Verification measurements will be performed periodically, typically at the beginning and end of each shift. The verification measurements are made in two phases, "no source" and "source." no source measurements check the background conditions; source measurements check the active and passive system response against predetermined tolerances.

No source verification

An empty container with no sources is measured and the background is checked against pre-defined limits for valid background results.

Source verification

Verification sources of depleted U, ^{252}Cf, or plutonium are used in a nominal matrix check box (the "pink box"). The verification assays are checked against pre-defined 3σ alarm limits set from data collect during on-site commissioning [6].

Annual Calibration Verification

An annual or semi-annual calibration check is not currently a regulatory requirement for the AMWTP RBAS, but is recommended. This will allow a thorough exercising and validation of the calibration. The calibration check should be performed annually or semi-annually and following any modifications or maintenance to the system. A different subset of the initial validation measurement listed in [6] should be performed for each calibration verification exercise.

4. Measurement Limitations

This section parallels the content of the original submittal [1], with the mitigating effects of the software quality checks added.

1. **Concentrated plutonium or concentrated uranium is assumed not to be present in the waste.**

This assumption is built into the active mode calibration, since the system was calibrated assuming dilute (i.e. non self-shielding) fissile material. However, this phenomenon is exclusive to the active mode; it does not affect a passive mode measurement. The measurement in the active mode of fissile material that exhibits self-shielding would result in an underestimation of the fissile content. Prior knowledge of the waste stream can be used to lessen the risk that concentrated plutonium or uranium is present in a given waste container, but it is imperfect. A software check has been added to generate a flag if the difference between the active and passive assays exceeds a preset threshold. This check is performed when counting statistics are sufficient to allow passive assay (generally between 1-5 g weapons grade plutonium). This check ensures that self-shielding does not go undetected for samples with significant plutonium content (above 1-5g).

This software check also flags the presence of ^{235}U in the absence of plutonium that is characterized by a large active signal with a negligible passive signal and the presence of uranium gamma peaks in the absence of plutonium gamma peaks.

Severity Category (if assumption invalidated) = 3 (>>100%)

2. **The calibration assumes that the characteristics of the measured waste matrix fall within the envelope of the simulated waste matrices used for the calibration.**

If the measured waste characteristics fall outside the range defining the matrix classes determined during calibration then an error message is generated and the operator must report the error to the qualified physicist for disposition. Sludge matrices are considered to be de facto outside of the current calibration, as their assay requires assumptions in addition to those made during calibration.

Also included within this assumption is that the RBAS correctly characterizes the waste matrix. That is, the measured matrix properties (neutron moderation and absorption) are correct for the waste package being measured. There are several possible scenarios that could result in the measured matrix properties not being appropriate for the waste package. The most probable cause is if the waste package is not properly scanned (i.e. measured in "grabs" along the length of the box) during the measurement. This risk in minimized by a software feature that checks plate position within tolerance on every grab. Alternatively, the matrix material may be highly heterogeneous which would bias the flux measurements (see Assumption 2.3). This possibility is minimized by the determination of the characteristic response for a worst case (horizontally stratified box) during Total Measurement Uncertainty characterization. Boxes that are identified as heterogeneous are assigned an additional TMU term to reflect the effects of heterogeneity; this is reflected in the reported FGE.

Severity Category (if assumption invalidated) = 3 (>>100%)

3. **The pallet centers the waste package and the system correctly scans the package in the RBAS measurement chamber.**

Correct determination of the matrix neutron absorption and moderation properties is dependent on the centering and correct scanning of the waste package in the RBAS measurement chamber. This is because the flux monitor detector located in the measurement chamber relies upon the waste being centered and correctly scanned. Improper positioning may result in an underestimation or overestimation of the fissile mass result as the measured signal may be under-corrected for matrix effects. Again, this risk in minimized by a software feature that checks plate position within tolerance on every grab.

It is worth noting that a negative mass may arise at small fissile masses, where the signal is comparable with the background. However, overestimation of the background will result in underestimation of the fissile mass at all masses.

Severity Category (if assumption invalidated) = 3 (>>100%)

4. **The use of flux monitor detectors to measure the matrix characteristics assumes that there are not small volumes of highly interfering material surrounding or in proximity to fissile material. This could result in regions of the waste matrix not being accurately characterized.**

If small volumes of highly interfering material surround or are in proximity to fissile material, the neutron moderation and absorption properties could be underestimated. Highly interfering material, such a boron or cadmium, disproportionately capture low energy neutrons, such as those of the interrogating active mode flux; they have little effect on the high energy neutrons emitted in spontaneous fission. Thus, this phenomenon is predominantly an active mode phenomenon. Software quality control checking of the difference between passive and active masses can again be used to provide assurance that a significant mass did not go underreported as it was only measured in the active mode under these conditions.

Severity Category (if assumption invalidated) = 2 (~100%)

5. **The measurement assumes that there is not a significant gamma dose rate impinging on the neutron detectors, large enough to result in gamma events being detected as neutrons.**

If gamma breakthrough were to occur, the net effect would not necessarily be an overestimation of the fissile mass, as the type of detector affected is the determining factor. If the flux monitor detectors are affected, then this could bias the matrix selection, which could result in a significant underestimation of the fissile mass. The external surface dose rate limits of waste received is 200mrem/hr. Gamma breakthrough is not expected to occur at dose rates less than 1 rem/hr. Software quality control features that check gamma dead time on a sample specific basis will be used to initiate special investigation of these containers in real time, and prevent spurious assay results from entering the DMS.

Severity Category (if assumption invalidated) = 1 (~10%)

6. **The fissile signal is assumed to vary linearly with fissile mass over the instrument operating range of 0-450g $^{239}Pu_{equivalent}$.**

The matrix calibration will be carried out using a single source, and therefore the assumption that the fissile signal varies linearly with fissile mass is made. Linearity test data over the mass range will show that this assumption is valid [6].

Severity Category (if assumption invalidated) = 3 (>>100%)

7. **The calibration sources are assumed to be appropriate.**

The standards used for the RBAS calibration are traceable to national standards [6].

Severity Category (if assumption invalidated) = 1 (~10%)

8. The neutronic properties of the waste matrix do not affect either the magnitude of the self-shielding effects in the calibration standards, or the fissile isotope equivalence relationship.

The average energy of the neutron interrogation flux will be affected by the moderation and absorption properties of the waste matrix. Differences in the energy of the interrogation flux will affect the magnitude of the self-shielding effects in the standards used for the calibration. Similarly, the equivalence between the fissile isotopes, i.e. ^{235}U, ^{239}Pu, and ^{241}Pu, is also dependent on the energy of the neutron interrogation flux. The calibration does not include any matrix dependence in either the fissile isotope equivalence or the self-shielding effect.

Severity Category (if assumption invalidated) = 1 (~10%)

5. Fault Analysis

Failure modes were originally identified and obtained by brainstorming involving the original Technical Team. The detailed description of faults, their causes and effects are contained within the original report [1] and its supporting spreadsheet [7]. The probability and severity of each failure mode have been categorized and used to determine Mean Times Between Unrevealed Failures (MTBF) values for each severity category and overall for any severity category.

Due to the extensive checks carried out in the RBAS standardization measurements, verification measurements and during the each production measurement, the original MTBF value of 1.91 for unrevealed faults was driven almost solely by the probability of undetectable heterogeneity existing in the waste [1,7]. Since the original FMEA Report, BII has added the following software quality control checks to the RBAS software:

- Checking for passive/active mass discrepancies
- Gamma dead time checking
- Acceptable limits for average flux-per-grab
- Heterogeneity checking

These software quality checks lessen probability of unrevealed failures for the elements previously of concern [8]. Revised MTBF values are shown in Table 1. MTBF values are presented with the recommendations from this report implemented.

	RBAS system (with recommendations in this report completed)
Severity Category	**MTBF/yrs**
1 (~10%)	20.01
2 (~100%)	1485
3 (>>100%)	1485
Total	**19.48**

Table 1 - Mean Time Between Unrevealed Failures
Category 1 relates to events that can cause underestimates of up to approx. 10%; category 2 to those that could cause underestimates of the same order of magnitude as the assay result; and category 3 to those events with the potential to cause even greater underestimates.

The total MTBF for unrevealed failures is now 19.48 years [8]. This significant improvement reflects the additional software quality checking controls to prevent an unacceptable assay from being unidentified.

6. Recommendations for Operation of RBAS

The following recommendations are facility administrative controls that are recommended to reduce the probability of a failure.

1. Prohibited item list (Appendix 2) shall be provided at the RBAS operation and in the operating procedure.
2. The operator instruction shall include confirmation that RBAS prohibited materials are not present within the waste package.
3. Radiography data shall be provided to RBAS operations prior to sample assay to assist in identification of prohibited items.
4. The operator instruction should clearly state what action to take in the event that an invalid or unverifiable result is displayed by the RBAS.
5. Assay results with data quality flags shall be reviewed by a qualified individual prior to release.

6. Assays of prohibited items shall not be qualified through special investigation review.
7. Standardization and verification limits shall be at the 3σ level set from field calibration data to ensure that they are a realistic reflection of field conditions.
8. The operator should ensure the waste package is centered on the RBAS pallet.
9. The operator should visually confirm that the turntable is rotating properly (180 degrees halfway through the measurement) during the measurement.
10. The electronics cabinets should be secured within lockable cabinets.
11. It is recommended that package measurement data be routinely archived from the system.
12. Preventative maintenance must be conducted in accordance with the recommended schedule [9] and should reference BNFL Instruments operations and maintenance manuals.
13. Modifications to the system and adjustments to settings on the electronics units must be restricted to authorized staff in accordance with approved instructions.

7. Analysis Conclusions

A MTBF for unrevealed failures of 19.5 years may be obtained for the RBAS operation through rigorous implementation of the recommended measurement control program, implemented of automated software quality assurance checks for key quantities, and administrative controls that identify and prevent the assay of prohibited items. Physical and mechanical controls must be maintained for the RBAS operation to prevent unauthorized or accidental configuration changes.

8. References

1 BII-5112-FMEA, Rev 0, 12/12/00, Failure Mode and Effects Analysis (FMEA) for the Advanced Mixed Waste Treatment Project (AMWTP) Retrieval Box Assay System (RBAS)

2 BII-5103-SDD-001, Rocky Flats Environmental technology Site (RFETS) IPAN Drum Counter System Software Description Document

3 BII-5111-SDD-001, SuperHENC Gamma Energy Analysis System Software Description Document

4 BII-5126-SDD-000, Rev 0, Automatic Independent Technical Review Software Definition Document

5 BII-5112-FCP-001, Rev 1, AMWTP Retrieval Box Assay System Factory Calibration Plan

6 BII-5112-SATP-001, Rev 1, Retrieval Box Assay System Site Acceptance Test Plan

7 RBAS FMEA Spreadsheet, Rev 0, January 29, 2001

8 RBAS FMEA Spreadsheet, Rev 1, March 16, 2002

9 BII-5112-MM-001, AMWTP Retrieval Box assay System RBAS Maintenance Manual

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Appendix 1
Summary Failure Mode
and
Effects Analysis Spreadsheet

Appendix 2
Prohibited Items List

THE FOLLOWING ITEMS ARE PROHIBITED FROM ASSAY AT THE RBAS:

- INDIVIDUAL 55-GALLON DRUMS
- ALL SLUDGE ITEM DESCRIPTION CODES
- WASTE CRATES WITH DIMENSIONS EXCEEDING 60.5” W x 78.5”H x 98” L
- WASTE CRATES EXCEEDING 10,000 LBS. GROSS WEIGHT