Determination of the Generic Waste Acceptance Criteria Used in The National Mining Association's and the Fuel Cycle Facilities Forum's *White Paper on Direct Disposal of Non-11e. (2) Byproduct Materials in Uranium Mill Tailings Impoundments*

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Abstract - *The National Mining Association's and the Fuel Cycle Facilities Forum's White Paper on Direct Disposal of Non-11e. (2) Byproduct Materials in Uranium Mill Tailings Impoundments proposes generic waste acceptance criteria to assist licensees, regulatory agencies and others determine whether a given candidate non-11e. (2) waste material is suitable for direct disposal in a uranium mill tailings impoundment. These bounding criteria are determined through the use of the aggregate activity of the tailings generated by processing a "high quality" uranium ore in secular equilibrium as defined in the Generic Environmental Impact Statement (GEIS) for Uranium Milling through a uranium mill with an extraction efficiency of 93%. The aggregate activity of these defined tailings establishes the proposed upper bounding limit activity for various wastes for placement in a uranium mill tailings impoundment for direct disposal. Wastes at or below this upper bounding limit activity are proposed in the White Paper for direct disposal in uranium mill tailings impoundments with only modifications to the impoundments' cover designs for containment of potentially higher than normal radon releases. Activities of discrete types of wastes including wastes contaminated with thorium-232, depleted uranium, and radium-226 were examined to determine how they relate to the defined upper bounding limit activity. This examination showed that the use of the defined upper bounding limit activity coupled with modifications to the impoundments' cover designs for containment of potentially higher than normal radon releases would allow a broad spectrum of wastes to be placed in uranium mill tailings impoundments for direct disposal.*

I. INTRODUCTION

In April 1998 the National Mining Association (NMA) submitted a white paper entitled *Recommendations for a Coordinated Approach to Regulating the Uranium Recovery Industry*, (hereafter called the NMA White Paper) to the U.S. Nuclear Regulatory Commission (NRC). This document was submitted at the request of the Commission following a presentation by the members of the uranium recovery industry to the Commissioners on May 13, 1997. This presentation discussed a number of regulatory issues affecting uranium recovery licensees.

The Commission evaluated the issues raised by the NMA White Paper and issued several SECY papers related to these issues that were acted upon by the Commissioners.

One such SECY paper dated April 8, 1999 was entitled *Use of Uranium Mill Tailings Impoundments for the Disposal of Waste Other Than 11e.(2) Byproduct Material and Reviews of Applications to Process Material Other Than Natural Uranium Ores*. On July 26, 2000 the Commission issued a Staff Requirements Memorandum (SRM) entitled Staff Requirements – SECY-99-012 – *Use of Uranium Mill Tailings Impoundments for the Disposal of Waste Other Than 11e.(2) Byproduct Material and Reviews of Applications to Process Material Other Than Natural Uranium Ores.* This document stated:

> *The Commission has disapproved the staff's recommendation to pursue Option 3 - seek legislative changes regarding disposal of materials in mill tailings impoundments. Instead, the Commission has approved Option 2 - allow more flexibility in the disposal capacity for mill tailings impoundments - subject to the additional considerations noted below.*
>
> *The disposal of material other than 11e. (2) byproduct material - which may include listed hazardous wastes - in mill tailings impoundments should be allowed only if: 1) there is adequate protection of the public health, safety, and the environment; 2) the long-term custodian of the site has indicated its willingness to accept responsibility for maintenance of the site prior to NRC approving the disposal; and 3) necessary approvals of other affected regulators (e.g., States, EPA) have been obtained. Regarding consent of the long-term custodian, consideration should be given to requiring*

written confirmation from DOE or the State that it would accept responsibility for the maintenance of the site prior to NRC approving the disposal of non-11e. (2) material.

This Commission decision greatly broadened the categories of radioactive materials that could be placed in uranium mill tailings impoundments beyond merely 11e.(2) byproduct material. Under this decision, however, disposal of non-11e. (2) material in uranium mill tailings impoundments would still be subject to various additional considerations, including the granting of a license amendment.

This decision, however, was a vast improvement over the existing guidance entitled *Final Revised Guidance on Disposal of Non-Atomic Energy Act of 1954, Section 11e. (2) Byproduct Material in Tailings Impoundments* published in the Federal Register on Friday, September 22, 1995. This original 1995 guidance was restrictive and cumbersome. For example, it forbid the disposal of naturally occurring radioactive material (NORM) and technologically enhanced naturally occurring radioactive material (TENORM) in uranium mill tailings impoundments, stating:

2. Radioactive material not regulated under the AEA shall not be authorized for disposal in an 11e. (2) Byproduct material impoundment.

Naturally occurring radioactive material (NORM) and technologically enhanced naturally occurring radioactive material (TENORM) for example comprise large volumes of wastes (Egan, J.R and Seymour, J.F. 1992 and Thompson, A.J and Goo, M, L. 1992) and these materials were categorically excluded in the 1995 Final Guidance.

Following the release of the July 26, 2000 SRM, the Fuel Cycle Facilities Forum (FCFF) in conjunction with the National Mining Association (who through the Uranium Policy Council (UPC) represents a number of uranium recovery licensees in the United States, some of whom possess uranium mill tailings impoundments) decided to develop a white paper for submittal to the Commission entitled *The National Mining Association's and the Fuel Cycle Facilities Forum's White Paper on Direct Disposal of Non-11e.(2) Byproduct Materials in Uranium Mill Tailings Impoundments* hereafter referred to as the Direct Disposal White Paper. The purpose of this document was to propose generic waste acceptance criteria for disposal of radioactive wastes in uranium mill tailings impoundments. The FCFF and NMA prepared this document in the anticipation that the criteria proposed in it would be accepted so that any uranium recovery licensee with a mill tailings impoundment could accept radioactive wastes for direct disposal without the requirement for any further approvals provided that the wastes met the proposed criteria.

The purpose of this paper is to describe how the proposed activity criteria for the radioactive wastes were calculated.

II. PROPOSED ACTIVITY CRITERIA CALCULATION

Uranium mill tailings impoundments are designed to contain for a long period of time (at least 200 years and for a maximum of 1,000 years) 11e(2) byproduct materials, specifically the wastes generated by the processing of materials primarily for their source material content. The primary type of waste for which these impoundments are designed are mill tailings which are the materials remaining from ore processed for its source material content. These impoundments are discussed in detail in the *Final Generic Environmental Impact Statement (FGEIS) on Uranium Milling – U.S. Nuclear Regulatory Commission, September 1980.* This document (Section 6.2.8.2.2 – Sources of Radioactivity and Exposure Pathways) discusses uranium ore and defines a high quality ore as one "*... with 1% U3O8...*" It further describes the ore as being "...u*nder conditions of secular equilibrium...*" Thus this ore contains all of the progeny of both uranium decay chains (the Uranium-238 and the Uranium-235 decay chains) at the same levels of activity as the parent uranium isotopes. This ore containing 1% U3O8 at secular equilibrium becomes the design basis for the *Final Generic Environmental Impact Statement (FGEIS) on Uranium Milling.*

Uranium mill tailings are a polyisotopic radioactive waste in that mill tailings contain many radionuclides from two (2) uranium decay chains, the Uranium-238 and the Uranium-235 decay chains. *Table 1 – Total Activity of Tailings from 1% Ore* included at the end of this document shows the two (Uranium-238 and Uranium-235) decay chains, all of the member isotopes that are present in uranium mill tailings derived from uranium ore at secular equilibrium, the isotopes' individual activities and their cumulative activities based upon the assumptions discussed below. Some specific activities were obtained from 49 CFR 173.435 *Table of A_1 and A_2 Values for Radionuclides*, while others were calculated from half lives using formulas provided in the Radiological Health Handbook.

This table clearly illustrates that uranium-processing wastes contain a number of discrete radionuclides, all of which enter the tailings impoundment. Uranium mill tailings impoundments are designed to contain not just one or two but many distinct radioisotopes, thus are ideally suited as disposal sites for many forms of radioactive wastes provided that certain bounding limits are observed.

III. PROPOSED GENERAL BOUNDING LIMITS

The primary bounding limits are the activity limits created in the *Final Generic Environmental Impact Statement (FGEIS) on Uranium Milling* by its use of 1% uranium ore at secular equilibrium, the uranium recovery (extraction efficiency) of the mill of 93% (page 5-4) and the design capacity of the tailings impoundment in question. *Table 1 – Total Activity of Tailings from 1% Ore* at the end of this document shows the total estimated activity in uranium mill tailings derived from ore containing 1% uranium at secular equilibrium.

This table uses the 93% mill recovery stated in the FGEIS and assumes a loss of radon (and its subsequent progeny) of 35% based on the default emanation coefficient of 0.35 stated in *Regulatory Guide 3.64 – Calculation of Radon Flux Attenuation by Earthen Uranium Mill Tailings Covers*. Thus uranium mill tailings impoundments as described and defined in the FGEIS are clearly capable of safely containing materials with a total activity (from all radionuclides present in the decay chains) of 8.12E5 Bq/Kg with no single radionuclide present in an activity greater than 1.04E5 Bq/Kg, in quantities equal to the design capacity of the impoundment. Materials of this type would include materials containing radium-226 at activities of up to 1.04E5 Bq/Kg and other similar materials. Materials of this type are proposed to be accepted without any site-specific radiation dose modeling or any other analyses except for modeling and analysis related to changes in the cover design to meet the requirements of 10 CFR Part 40 Appendix A 6-(1)(ii) which states:

> *(ii) limit releases of radon-222 from uranium byproduct materials, and radon-220 from thorium byproduct materials, to the atmosphere so as not to exceed an average release rate of 20 picoCuries per square meter per second (pCi/m^{2}s) to the extent practicable throughout the effective design life determined pursuant to (1)(i) of this Criterion. In computing required tailings cover thicknesses, moisture in soils in excess of amounts found normally in similar soils in similar circumstances may not be considered. Direct gamma exposure from the tailings or wastes should be reduced to background levels.*

Should the licensee desire to accept materials with a total decay chain activity in excess of 8.12E5 Bq/Kg and/or a single isotope in the material with an activity in excess of 1.04E5 Bq/Kg, the Direct Disposal White Paper proposes that the licensee would be required to perform a dose assessment and/or modeling to demonstrate that the dose from the materials following disposal did not cause the facility to exceed the dose limits in 40 CFR Part 190.10, which states in part:

> ***§ 190.10 Standards for normal operations.***
> *Operations covered by this subpart shall be conducted in such a manner as to provide reasonable assurance that:*
> *(a) The annual dose equivalent does not exceed 25 millirems to the whole body, 75 millirems to the thyroid, and 25 millirems to any other organ of any member of the public as the result of exposures to planned discharges of radioactive materials, radon and its daughters excepted, to the general environment from uranium fuel cycle operations and to radiation from these operations.*

In addition the licensee may have to resort to specialized disposal techniques such as dissolution of the waste in an acidic solution and pumping into the impoundment, slurrying the material and mixing with existing tailings, physical mixing of the waste with the existing tailings using equipment, or placement of the waste in a specially constructed area of the impoundment that is both lined and covered with engineered clays to encapsulate the material to minimize radon emanation.

The total activity of the tailings impoundment immediately prior to reclamation (point in time when the impoundment is full) could not exceed the design capacity of the impoundment in tons times 7.4E8 Bq per ton. This value of 7.4E8 Bq per ton times the design capacity of the impoundment in tons shall be defined as the *radiological design capacity* of the impoundment. The formula below shows the calculation of the 7.4E8 Bq per ton activity limit.

(8.12E5 Bq/Kg)(0.454 Kg per pound)*(2,000 pounds per ton)= 7.4E8 Bq per ton.*

A unit of Bq/ton is used in this situation since tailings are commonly measured in tons in the United States.

IV. APPLICATION OF THE ACTIVITY LIMIT TO NON 11(e).2 LOW ACTIVITY RADIOACTIVE WASTES

The activity limit of 8.12E5 Bq/Kg (7.4E8 Bq per ton) was compared to the activities of other types of waste with the following results:

IV.A. Naturally Occurring Radioactive Material (NORM)

The primary radionuclide of concern in NORM (oilfield pipe scale, water treatment sludges etc) is radium-226. Using the previously discussed upper bound assumption, materials containing up to 1.04E5 Bq/Kg radium-226 could be accepted without additional modeling, except for modeling in order to design the radon barrier to limit radon fluxes to below 0.74 Bq/m2-sec.

IV.B. Wastes Contaminated with Thorium-232

The *Final Generic Environmental Impact Statement (FGEIS) on Uranium Milling* (Section 6.2.8.2.2) states:

> *"Uranium ores may also contain small amounts of long-lived thorium-232 and its daughter products. The radiological parameters associated with the Th-232 series are such that the impact of these isotopes is relatively inconsequential, even when they are present in amounts comparable to the natural uranium concentration in ore."*

Wastes contaminated with 1% thorium-232 attain secular equilibrium quickly with a maximum activity for the entire decay chain of 2.83E5 Bq/Kg. The total activity for wastes from the processing of 1% uranium ore at secular equilibrium is estimated to be 8.12E5 Bq/Kg. Thus materials contaminated with up to 2.5% thorium-232 could be placed in uranium mill tailings impoundments and remain within the limits set by the *Final Generic Environmental Impact Statement (FGEIS) on Uranium Milling.*

IV.C. Wastes Contaminated with Depleted Uranium

Depleted uranium is defined in 10 CFR Part 40.4 as:

> *"...the source material uranium in which the isotope uranium-235 is less than 0.711 weight percent of the total uranium present. Depleted uranium does not include special nuclear material."*

Wastes contaminated with depleted uranium possess less activity by definition than wastes contaminated with natural uranium. A waste containing only the uranium-238 isotope (100% depleted uranium) would have an in-grown activity (at 1,000 years – the reclamation life of a tailings impoundment) of 4.88E5 Bq/Kg curies per gram. Using the total activity of tailings from 1% uranium ore at secular equilibrium of 8.12E5 Bq/Kg, a waste with a concentration of 1.68% of fully depleted uranium (100% uranium-238) could be placed in a uranium mill tailings impoundment and still remain within the limits of the *Final Generic Environmental Impact Statement (FGEIS) on Uranium Milling* at 1,000 years. Wastes with higher concentrations of fully depleted uranium or residual uranium-235 in addition to 1.68% uranium-238 could be placed following dose modeling to demonstrate compliance with 40 CFR Part 190.10.

IV.D. Wastes Contaminated with Natural Uranium

These wastes contain uranium in its natural isotopic distribution (Uranium-238 – 99.283%, Uranium-235 – 0.711% and Uranium-234 – 0.0054%). Initially their activity is less than that of natural uranium ore at equilibrium or tailings created by processing natural uranium ore at equilibrium since Uranium-238 and Uranium-235 have relatively long half-lives (4.51E9 and 7.1E8 years respectively) and require a substantial time to fully ingrow. However, as time progresses and decay products in-grow, the wastes' activity will increase. The activity of any waste containing 1% natural uranium will not exceed the activity of tailings created by processing 1% uranium ore at secular equilibrium within the 1,000 year reclamation life of the impoundment. Thus, wastes containing up to 1% natural uranium could be placed in uranium mill tailings impoundments.

V. CONCLUSIONS

Uranium mill tailings are polyisotopic wastes due to the variety of isotopes in the two (2) uranium decay chains. The *Final Generic Environmental Impact Statement (FGEIS) on Uranium Milling* defines a high quality ore as one "*... with 1% U3O8...*", "*...under conditions of secular equilibrium...*". Further it establishes a 93% mill recovery for uranium. *Regulatory Guide 3.64 – Calculation of Radon Flux Attenuation by Earthen Uranium Mill Tailings Covers* assumes a loss of radon (and its subsequent progeny) of 35% based on the default emanation coefficient of 0.35. Based upon these values, a maximum design activity for uranium mill tailings is calculated to be 8.12E5 Bq/Kg or 7.4E8 Bq per ton. In addition, the maximum activity for a single isotope in the uranium decay chains is 1.04E5 Bq/Kg establishing the maximum activity for a single isotope for acceptable wastes. This maximum design activity becomes the proposed maximum acceptable specific activity for wastes for placement in uranium mill tailings impoundments as described in the Direct Disposal White Paper. This proposed maximum design activity would allow a broad spectrum of low activity radioactive wastes to be placed in uranium mill tailings impoundments for disposal.

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Table 1 Total Activity of Tailings from 1% Ore

Decay Chain Element	Isotope	Decay Chain Split Factor	Half Life	Half Life Unit	**Specific Activity** Some specific activities obtained from 49CFR173.435 Table of A_1 and A_2 values for radionuclides $_{others}$ calculated from half-lives.	Activity in One (1) Percent Ore at Equilibrium Corrected for Chain Split	Activity in Tailings from One (1) Percent Ore
Uranium-238					**(Bq/Kg)**	**(Bq/Kg)**	**(Bq/Kg)**
Uranium	238	1	4.5100E+09	Years	1.258E+07	1.06E+05	7.414E+03
Thorium	234	1	24.1	Days	8.510E+17	1.04E+05	7.269E+03
Protactinium – M	234	1	1.17	Minutes	2.541E+22	1.04E+05	7.269E+03
Protactinium	234	0.0013	6.75	Hours	7.341E+19	1.35E+02	9.449E+00
Uranium	234	1	2.4700E+05	Years	2.294E+11	1.04E+05	7.269E+03
Thorium	230	1	8.00E+04	Years	7.770E+11	1.04E+05	1.038E+05
Radium	226	1	1602	Years	3.657E+13	1.04E+05	1.038E+05
Radon	222	1	3.823	Days	5.550E+18	1.04E+05	6.750E+04
Polonium	218	1	3.05	Minutes	1.046E+22	1.04E+05	6.750E+04
Lead	214	0.9998	26.8	Minutes	1.213E+21	1.04E+05	6.748E+04
Astatine	218	0.0002	2	Seconds	9.572E+23	2.08E+01	1.350E+01
Bismuth	214	1	19.7	Minutes	4.459E+07	1.04E+05	6.750E+04
Polonium	214	0.9998	1.64E-04	Seconds	1.189E+28	1.04E+05	6.748E+04
Thallium	210	0.0002	1.32	Minutes	2.509E+22	2.08E+01	1.350E+01
Lead	210	1	21	Years	7.600E+01	1.04E+05	6.750E+04
Bismuth	210	1	5.013	Days	4.590E+18	1.04E+05	6.750E+04
Polonium	210	0.9999987	138.4	Days	1.665E+17	1.04E+05	6.750E+04
Thallium	206	0.0000013	4.19	Minutes	8.059E+21	1.35E-01	8.774E-02
Lead	206	STABLE					
Subtotal Activity (Uranium-238 Chain):							7.769E+05
Uranium-235							
Uranium	235	1	7.1000E+08	Years	8.140E+07	4.91E+03	3.435E+02
Thorium	231	1	25.5	Hours	1.961E+19	4.78E+03	3.349E+02
Protactinium	231	1	3.25E+04	Years	1.739E+12	4.78E+03	4.784E+03
Actinium	227	1	21.6	Years	2.664E+15	4.78E+03	4.784E+03
Francium	223	0.014	22	Minutes	1.418E+21	6.70E+01	6.697E+01
Thorium	227	0.986	18.2	Days	1.147E+18	4.72E+03	4.717E+03
Radium	223	1	11.43	Days	1.887E+18	4.78E+03	4.784E+03
Radon	219	1	4	Seconds	4.764E+23	4.78E+03	3.110E+03
Polonium	215	1	1.78E-03	Seconds	1.091E+27	4.78E+03	3.110E+03
Lead	211	0.9999977	36.1	Minutes	9.132E+20	4.78E+03	3.110E+03
Astatine	215	0.0000023	1.00E-04	Seconds	1.941E+28	1.10E-02	7.152E-03
Bismuth	211	1	2.15	Minutes	1.533E+22	4.78E+03	3.110E+03
Polonium	211	0.0028	0.52	Seconds	3.804E+24	1.34E+01	8.707E+00
Thallium	207	0.9972	4.79	Minutes	7.015E+21	4.77E+03	3.101E+03
Lead	207	STABLE					
Subtotal Activity (Uranium-235 Chain):							3.54E+04
		Total Activity:					8.12E+05

Notes: [green shading] Splits in the decay chain with split fractions.

The Regulatory Guide 3.64 default emanation coefficient of 0.35 (35%) radon released was used.

This was applied to radon in each decay chain plus all radon progeny.

Measured emanation coefficients are often less resulting in larger activities retained by the tailings.

A 93% recovery rate for the mill was used as per the FGEIS.

This 93% recovery was applied to all uranium isotopes

This 93% recovery was also applied to all short half-life near term uranium daughters.

Decay chain splits were considered.

Radium-226 calculates to 1.038E5 Bq/Kg which approximates the 1.04E5 Bq/Kg used in Regulatory Guide 3.64
This is one cross check on the calculation.

Radiometric equilibrium for both the Uranium-238 and Uranium-235 decay chains in the ore was assumed as per the FGEIS.