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7. Abstract

This document devises a method of comparing radiological and non-radiological hazard control levels. Such a comparison will be useful in determining the design control features for facilities that handle radioactive mixed waste. The design control features of interest are those that assure the protection of workers and the environment from unsafe airborne levels of radiological or non-radiological hazards.

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HAZARD CONTROL INDICES FOR RADIOLOGICAL AND NON-RADIOLOGICAL MATERIALS

EXECUTIVE SUMMARY

A method of comparing relative airborne contamination controls for radiological and non-radiological constituents in radioactive mixed waste is developed. Radiological and non-radiological hazardous materials are assigned "Modified Hazard Control Indices" (Table 1) which can be compared in order to determine the relative airborne contamination controls needed. The modified indices are based on airborne concentration control levels. The indices take into consideration the resuspension potential (propensity to go airborne) of the material. Modified indices are assigned to four chemical/physical forms of materials:

1. Removable Contamination
2. Fixed Contamination
3. Wet Contamination
4. Volatile Liquids.

The relative airborne control measures needed for radiological and non-radiological materials can be determined from the modified hazard control indices and the ratios of material masses present in radioactive mixed waste.

The modified hazard control indices indicate that for equal masses of radiological and non-radiological materials in mixed waste, the radiological constituents generally require airborne contamination control levels many orders of magnitude greater than the non-radiological constituents.

The modified hazard control indices indicate that the most restrictive radioactive material relative to contamination control is smearable Pu-238, with an index of 1.00E+8. Comparatively, the most prevalent isotope of plutonium in the Hanford Site mixed waste on a mass basis, Pu-239, has an index of 6.17E+5.

The most common beta emitter, Sr-90, has a smearable index of 3.52E+5, which is comparable to Pu-239. This is contrary to the common assumption that alpha emitting radionuclides are more difficult to control than beta emitters, although this is still true on a Curie basis rather than a mass basis.

The modified hazard control indices also indicate that the most restrictive chemical (non-radiological) prevalent in the Hanford Site mixed waste is vinyl chloride with an index of 2.54E+01. This is due to the fact that although beryllium, with an index of 1.00, is the most toxic chemical on a mass basis, vinyl chloride is much more resuspendable than smearable beryllium.

The modified hazard control indices should be useful to designers and safety personnel during the initial assessment of the adequacy of mixed waste airborne contamination control features, such as gloveboxes, hoods, facility ventilation, etc. The indices should also be useful in estimating the relative degree of clean up required for the radiological and non-radiological components of a contaminated area, since clean up standards would logically be based on the same factors that the indices were based on (i.e., airborne control level).

Hazard Control Indices for Radiological and Non-radiological Materials

November 1994

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CONTENTS

HAZARD CONTROL INDICES FOR RADIOLOGICAL AND NON-RADIOLOGICAL MATERIALS

1.0 INTRODUCTION

1.1 THE NEED FOR HAZARD CONTROL INDICES

The need to compare airborne hazards from the radiological and non-radiological components of radioactive mixed waste (RMW) at the Hanford Site has become apparent. Facilities are being designed and constructed to process RMW and to prepare the waste for ultimate disposal. Examples of these facilities are the Waste Receiving and Processing (WRAP) Modules 1 and 2A.

The need to compare airborne hazards becomes evident when trying to determine the adequacy of airborne contamination controls for both radiological and non-radiological constituents. For example, if a glovebox or hood is designed to contain and control a given level of plutonium, is it also adequate to contain and control given levels of beryllium, cyclohexane, vinyl chloride, and other hazardous constituents? Another example for the need to compare radiological and non-radiological hazards is: In decontamination of equipment, structures and soils, if radiological contamination is cleaned up to radioactive threshold levels, could non-radiological threshold levels still be exceeded for a given RMW?

1.2 PURPOSE

It is the purpose of this document to devise a method of comparing radiological and non-radiological hazard control levels. Such a comparison will be useful in determining the design control features for facilities that handle RMW. The design control features of interest are those that assure the protection of workers and the environment from unsafe airborne levels of radiological or non-radiological hazards.

1.3 SCOPE AND LIMITATIONS

It must be emphasized that the comparisons made in this document are not based on the biological hazards or the ill health effects of radioactive materials and chemicals. Rather, the comparisons are based on documented, generally accepted, industry-wide airborne levels of control. More specifically: In nuclear facilities, great efforts are made to limit airborne concentrations of radioactive materials in working air to 10% of the Derived Air Concentrations (DAC), listed in the Code of Federal Regulations (CFR 1993). If airborne concentrations exceed 10% of the DAC, an alarm usually sounds and the area is evacuated. In the case of chemical airborne concentrations, the analogous control levels are the Threshold Limiting Values (TLV), listed by the American Conference of Governmental Industrial Hygienists (ACGIH 1992) or the Occupational Safety and Health Act (OSHA) Permissible

Exposure Limit (PEL) given in 29 CFR 1910. Workers are generally not allowed to be exposed to levels above the TLV or PEL without respiratory protection.

Although the DAC and the TLV are generally proportional to the actual biological hazard of a given material, no claim is made in this document that the hazard control indices developed herein are related to risk. This is because airborne concentration limits are related to only one pathway of human exposure: inhalation. It is true that the inhalation pathway is probably the dominant pathway for both occupational and environmental exposures, through the resuspension of materials in the work place or from soils. However, there could be exceptions to this in cases where mechanisms for concentrating contamination are possible.

The radioactive materials and chemicals that are specifically dealt with in this document are those commonly found in the Hanford Site RMW. However, the methodology presented here could easily be extrapolated to any other materials.

2.0 METHODOLOGY

2.1 BASIS OF COMPARISON

In this document, a basis of comparison is established between all common radionuclides and chemicals found in the Hanford Site RMW. The basis of comparison is an index, proportional to airborne contamination control levels. The 10% DAC control level is used for radionuclides and is converted from uCi/cc to g/cc. The TLV (g/cc) control level is used for chemical substances and physical agents. The index is adjusted for the resuspension potential of the physical or chemical waste form. The final, adjusted index which is proportional to the required level of airborne contamination control for equal masses in a waste matrix is termed the "Modified Hazard Control Index" (last columns, Table 1). The derivation of and justification for the columns of Table 1, including the Modified Hazard Control Index, is described in detail below.

TABLE 1. HAZARD CONTROL INDEX

Radiological/ Chemical Material	Control Limit[1] (g/cc)	Relative Hazard Control Index[2]	Modified Hazard Control Index			
			REMOVABLE[3]	FIXED[4]	WET[5]	VOLATILE[6]
H 3	2.07E-16	1.56E-02	9.63E+03	9.63E-01	9.63E+01	NA
C 14	2.24E-14	1.44E-04	8.88E+01	8.88E-03	8.88E-01	NA
Co 60	8.85E-19	3.65E+00	2.25E+06	2.25E+02	NA	NA
Ni 63	4.86E-16	6.65E-03	4.10E+03	4.10E-01	4.10E+01	NA
Se 79	2.88E-13	1.12E-05	6.91E+00	6.91E-04	6.91E-02	NA
Sr 90	5.67E-18	5.70E-01	3.52E+05	3.52E+01	NA	NA

Radiological/ Chemical Material	Control Limit[1] (g/cc)	Relative Hazard Control Index[2]	Modified Hazard Control Index			
			REMOVABLE[3]	FIXED[4]	WET[5]	VOLATILE[6]
Zr 93	3.83E-13	8.43E-06	5.20E+00	5.20E-04	NA	NA
Nb 94	7.84E-15	4.12E-04	2.54E+02	2.54E-02	NA	NA
Mo 99	1.27E-19	2.54E+01	1.57E+07	1.57E+03	1.57E+05	NA
Tc 99	1.76E-12	1.84E-06	1.14E+00	1.14E-04	1.14E-02	NA
Sn 113	2.16E-18	1.49E+00	9.20E+05	9.20E+01	9.20E+03	NA
Sn 126	4.12E-14	7.84E-05	4.84E+01	4.84E-03	4.84E-01	NA
I 129	2.45E-12	1.55E-06	9.57E-01	9.57E-05	9.57E-03	NA
Cs 137	8.08E-17	4.00E-02	2.47E+04	2.47E+00	NA	NA
Sm 151	1.18E-16	2.74E-02	1.69E+04	1.69E+00	NA	NA
Pb 210	1.45E-19	2.23E+01	1.38E+07	1.38E+03	1.38E+05	NA
Ra 226	3.07E-17	1.05E-01	6.48E+04	6.48E+00	NA	NA
Ra 228	2.15E-19	1.50E+01	9.26E+06	9.26E+02	NA	NA
Th 230	1.56E-17	2.07E-01	1.28E+05	1.28E+01	NA	NA
Th 232	4.55E-13	7.10E-06	4.38E+00	4.38E-04	NA	NA
Pa 231	1.56E-18	2.07E+00	1.28E+06	1.28E+02	NA	NA
U 233	2.07E-16	1.56E-02	9.63E+03	9.63E-01	9.63E+01	NA
U 234	3.20E-16	1.01E-02	6.23E+03	6.23E-01	6.23E+01	NA
U 235	9.30E-13	3.49E-06	2.15E+00	2.15E-04	2.15E-02	NA
U 236	3.09E-14	1.05E-04	6.48E+01	6.48E-03	6.48E-01	NA
U 238	5.95E-12	5.43E-07	3.35E-01	3.35E-05	3.35E-03	NA
Pu 238	1.75E-20	1.84E+02	1.14E+08	1.14E+04	NA	NA
Pu 239	3.23E-18	1.00E+00	6.17E+05	6.17E+01	NA	NA
Pu 240	8.81E-19	3.67E+00	2.27E+06	2.27E+02	NA	NA
Pu 241	9.71E-15	3.33E-04	2.06E+02	2.06E-02	NA	NA
Pu 242	6.71E-17	4.81E-02	2.97E+04	2.97E+00	NA	NA
Am 241	6.17E-20	5.86E+01	3.62E+07	3.62E+03	NA	NA
Am 243	1.08E-20	3.35E+02	5.40E+07	5.40E+03	NA	NA
Acetone	1.78E-06	1.81E-12	NA	NA	NA	1.50E-01
Beryllium	2.00E-12	1.62E-06	1.00E+00	1.00E-04	NA	NA

Radiological/ Chemical Material	Control Limit[1] (g/cc)	Relative Hazard Control Index[2]	Modified Hazard Control Index			
			REMOVABLE[3]	FIXED[4]	WET[5]	VOLATILE[6]
Butyl alcohol	1.52E-07	2.13E-11	NA	NA	1.31E-07	NA
Carbon tetrachloride	3.10E-08	1.04E-10	NA	NA	NA	1.12E+00
Cyclohexane	1.03E-06	3.13E-12	NA	NA	NA	1.58E-02
Ethanol	1.88E-06	1.72E-12	NA	NA	NA	2.87E-03
Hydrazine	1.30E-11	2.48E-07	NA	NA	1.53E-03	NA
Hydrofluoric acid	2.60E-09	1.24E-09	NA	NA	NA	1.41E+01
Isopropyl alcohol	9.80E-07	3.30E-12	NA	NA	NA	5.50E-03
Methanol	2.62E-07	1.23E-11	NA	NA	NA	3.07E-02
Methyl ethyl ketone	5.90E-07	5.47E-12	NA	NA	NA	2.29E-02
Methyl isobutyl ketone	2.05E-07	1.58E-11	NA	NA	9.75E-08	NA
Nitric acid	5.00E-09	6.46E-10	NA	NA	NA	1.43E+00
Phosphoric acid	1.00E-09	3.23E-09	NA	NA	1.99E-05	NA
Sodium Hydroxide	2.00E-09	1.62E-09	1.00E-03	1.00E-07	NA	NA
Styrene	2.13E-07	1.52E-11	NA	NA	9.38E-08	NA
Sulfuric acid	1.00E-09	3.23E-09	NA	NA	1.99E-05	NA
Tetrahydro-furan	5.90E-07	5.47E-12	NA	NA	NA	3.93E-02
Toluene	1.88E-07	1.72E-11	NA	NA	1.06E-07	NA
Vinyl chloride	1.30E-08	2.48E-10	NA	NA	NA	2.54E+01
Xylene	4.34E-07	7.44E-12	NA	NA	4.59E-08	NA

NOTES FOR TABLE 1

1. Control Limit (g/cc)

   - For the radiological material: 10% of the DAC value which was converted from uCi/cc to g/cc by dividing by specific activity (uCi/g). Inhalation Category D was used for Sr-90; for other radionuclides the lower values of the DAC were used.

   - For the chemical material: Taken from the PEL or TLV/TWA values.

2. Relative Hazard Control Index

   - For the radiological material:

     $RHCI_R$ = Control limit for Pu-239 / Control limit for a radionuclide

   - For the chemical material:

     $RHCI_C$ = Control limit for Pu-239 (g/cc) / Control limit for a chemical (g/cc)

3. Removable Contamination

   - The Relative Hazard Control Index (RHCI) values were multiplied by (1.0E+6)/1.62, the multiplier determined for removable contamination in Section 2.4.

4. Fixed Contamination

   - The RHCI values were multiplied by (1.0E+2)/1.62, the multiplier determined for fixed contamination in Section 2.4.

5. Wet Contamination

   - The RHCI values were multiplied by (1.0E+4)/1.62, the multiplier determined for wet contamination in Section 2.4.

   - Wet Contamination is defined as non-volatile liquids (having a boiling point of 100 C° or more) or contamination that is wet with water or a non-volatile liquid.

6. Volatile Liquids

   - The RHCI values were multiplied by (1.0E+06)/1.62 x 4.26E+2 x m, the multiplier determined for volatile liquids in Section 2.4.

   - Volatile liquids are defined as liquids with boiling points less than 100 C°.

2.2 AIRBORNE CONTROL LEVELS

The second column of Table 1 gives the airborne contamination control levels in terms of g/cc for the radionuclides or chemicals listed in the first column. It can be readily seen that on a mass basis, radioactive materials are controlled far more strictly than non-radiological materials.

2.3 NORMALIZATION OF AIRBORNE CONTROL LEVELS

The first step as an aid in comparing radiological and non-radiological controls is to normalize the airborne control levels to PU-239. Plutonium-239 was chosen because its control level is the most restrictive among the common radionuclides. To get the RHCI of Column 3 in Table 1, the Control Limit of column 2 for PU-239, 3.23E-18 g/cc (10% of the DAC), is divided by the Control Limit for each radiological/chemical material. This makes the RHCI for Pu-239 equal to 1.0, and all other RHCIs can be compared with that level of control.

2.4 RESUSPENSION FACTORS

The physical and chemical form of a material greatly determines to what degree it will go airborne, which is proportional to the degree of airborne contamination control needed. The propensity to become airborne is called the resuspension factor. In order to compare the control aspects of various radiological and non-radiological materials, normalization relative to resuspension is necessary.

Four types of materials with respect to resuspension are defined:

Removable Contamination: Powders, fines < 10 microns, smearable surface contamination, etc.

Fixed Contamination: Hunks, coarse material > 10 micron, painted over contamination, etc.

Wet Contamination: Non-volatile liquids, contamination that is wet or dissolved in water or non-volatile liquids, sludges, etc.

Volatile Liquids: Organic compounds with a boiling point less than 100 degrees C.

The resuspension factor for radioactive materials (i.e., the ratio of airborne contamination in uCi/cm^3 to surface contamination in uCi/cm_2) is given by Cember (Cember 1969) as ranging from 1.0E-4/cm to 1.0E-8/cm. Therefore, for removable contamination the resuspension factor is assumed to be the upper bound of 1.0E-4/cm, and for fixed contamination the lower bound of 1.0E-8/cm is used. These radiological resuspension factors are valid for comparable non-radiological material forms. The resuspension factor for fixed contamination is probably much lower than 1.0E-8, but 1.0E-8 is being used here as a bounding case, since a relative comparison is being made. It is also assumed that the maximum resuspension factor of 1.0E-4/cm roughly corresponds to the maximum dust loading of air of 1.0E-8 g/cc (Schleien 1984). This means that if removable contamination is assigned a relative resuspension value of 1, then the value for fixed contamination would be on the order of 1.0E-4.

The biggest uncertainty in normalizing resuspension factors is relating the resuspension of removable or fixed contamination (radiological or non-radiological) to the resuspension of wet contamination and volatile liquids.

It is assumed that the resuspension of wet contamination is somewhere between the resuspension of fixed contamination and the resuspension of removable contamination. That is, water fixes the contamination somewhere between removable and fixed. Therefore, the resuspension of wet contamination is arbitrarily assumed to be 1.0E-6/cm. This means that the relative resuspension of removable contamination, fixed contamination and wet contamination are in the following ratios:

Smearable/Fixed/Wet = 1:1.0E-4:1.0E-2

It should be pointed out that wet contamination, as it is defined here, does not include water solutions of contaminants. The resuspension of water solutions would involve "partition factors" rather than mechanical resuspension, and water solutions are not considered in this document.

In considering the resuspension of volatile liquids, it is also recognized that a mechanical process is no longer involved, but a thermodynamic one. However, the resuspension of volatile liquids can be related to mechanical resuspension by using the maximum particulate loading of air and the Ideal Gas Law. Assuming that: (1) Partial pressure of a volatile liquid is equal to the vapor pressure of the liquid (2) The ideal Gas Law is valid over the range of concern (3) Ambient conditions can be assumed for facility environs, the following relationship can be derived from the Ideal Gas Law:

w (g/cc) = MW x VP (mm Hg) x 1.316E-6 where:

w = mass of volatile liquid in air

MW = gram molecular weight of volatile liquid

VP = vapor pressure of volatile liquid

1.31E-6 = constant that gives w in terms of g/cc

From the above equation, the maximum amount of water that air can hold at standard conditions (760 mm Hg, 298 degrees K), is 4.26E-6 g/cc, which compares with a particulate mass loading of 1.0E-8 g/cc. It appears then, that air can hold 4.26E-6/1.0E-8 = 426 times more water by thermodynamic processes than particulate by mechanical resuspension processes. Therefore, the ratios of relative resuspension are as follows:

Removable:Fixed:Wet:Water = 1:1.0E-4:1.0E-2:4.26E+2

For volatile liquids, the 4.26+2 can be multiplied by the factor m:

$$m = (MW_{liquid}) \times VP_{liquid}) /(MW_{water} \times VP_{water})$$

Then we have:

Removable:Fixed:Wet:Volatile = 1:1.0E-4:1.0E-2:(4.26E+2 x m)

In accordance with the above discussion, the Modified Hazard Control Index (MHCI) is calculated by multiplying the RHCI of Column 3 in Table 1 by the factors indicated below in order to normalize for resuspension potential, and also to bring the most toxic chemical (beryllium) index up to 1.0, for ease of comparison.

MHCI for Removable = RHCI x (1.0E+6/1.62)

MHCI for Fixed = RHCI x (1.0E+6/1.61) x 1.0E-4

MHCI for Wet = RHCI x (1.0E+6/1.61) x 1.0E-2

MHCI for Volatile = RHCI x (1.0E+6/1.61) x 4.26E+2 x m

2.5 MODIFIED HAZARD CONTROL INDEX

The parameter derived from the RHCI and the multipliers above is defined as the MHCI. This index is specific to the type of radiological material, specific chemical, and the waste form. It can be used to determine the relative levels of containment and control needed for equal quantities (mass) of the various radiological and non-radiological constituents of mixed waste. The ratio of the quantities of a material present can be used as a multiplier of the MHCI to determine which material requires the most containment and control. The use of the index is thoroughly explained in Section 3 below.

3.0 RESULTS

As already stated, Table 1 indicates that for equal masses of materials in RMW, the radiological constituents are controlled much more strictly. The use of Table 1 is best demonstrated by two examples.

Example 1. Assume that a drum of RMW contained 1,000 grams of beryllium powder contaminated with one gram of smearable Pu-239. The drum is to be opened in a hood that has a demonstrated protection factor adequate to control a gram of smearable Pu-239. The protection factor of a containment device is the ratio of airborne concentration inside the containment to the airborne concentration outside the containment. Protection factors for containments relative to radioactivity are well established and are as follows:

GLOVEBOX = 1.0E+8 (CEMBER 1969)

HOODS (DRY OPERATIONS)
FACE HOODS = 1,000 (10 CFR 20 [CFR 1991])
OPEN FACED HOODS W/PORTS = 50 (Sudmann 1983)

FULL FACE MASK = TYPICALLY 50 (10 CFR 20)

SUPPLIED AIR = TYPICALLY 5,000 (10 CFR 20)

The question is, although the hood is adequate to contain the Pu-239, is it adequate to contain the more prevalent beryllium?

To answer this question, the MHCIs for Pu-239 and beryllium are ratioed:

$$(6.17E+5)/(1.00E+0) = 6.17E+5$$

The above ratio means that on an equal mass basis, Pu-239 is 6.17+5 times more strictly controlled. However, since beryllium is 1,000 times more prevalent, the ratio is modified to:

$$(6.17E+5)/(1.00E+0 \times 1,000) = 6.17E+2$$

The above ratio means that the beryllium would be controlled more than adequately. In fact, there could be 617 times more beryllium in the RMW and the containment would still be adequate for control of beryllium. If the above ratio exceeded one, it would mean that the hood containment may not be adequate to control beryllium.

Example 2. Assume that an accident occurred in the hood postulated in example 1 above. That is, the hood contained a drum with 1,000 g beryllium and 1.0 g Pu-239. Assume that some of the contents of the drum were released to the environment resulting in building contamination and soil contamination. Since the release fractions for Pu-239 and beryllium would logically be the same, the MHCI and the mass ratios in the waste can be used to ensure that if the Pu-239 is cleaned up to some standard, the beryllium would also be cleaned up to any standard that might be derived for that chemical.

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