SPREADSHEET APPLICATION TO CLASSIFY RADIOACTIVE MATERIAL FOR SHIPMENT[a]

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INTRODUCTION

A spreadsheet application has been developed at the Idaho National Engineering and Environmental Laboratory to aid the shipper when classifying nuclide mixtures of normal form, radioactive materials. The results generated by this spreadsheet are used to confirm the proper U.S. Department of Transportation (DOT) classification when offering radioactive material packages for transport.

The user must input to the spreadsheet the mass of the material being classified, the physical form (liquid or not), and the activity of each regulated nuclide.

The spreadsheet uses these inputs to calculate two general values: (1) the specific activity of the material, and (2) a summation calculation of the nuclide content. The specific activity is used to determine if the material exceeds the DOT minimal threshhold for a radioactive material (Yes or No). If the material is calculated to be radioactive, the specific activity is also used to determine if the material meets the activity requirement for one of the three Low Specific Activity designations (LSA-I, LSA-II, LSA-III, or Not LSA). Again, if the material is calculated to be radioactive, the summation calculation is then used to determine which activity category the material will meet (Limited Quantity, Type A, Type B, or Highway Route Controlled Quantity).

This spreadsheet has proven to be an invaluable aid for shippers of radioactive materials at the Idaho National Engineering and Environmental Laboratory.

SPREADSHEET

This spreadsheet application was developed using Microsoft Excel 4.0 in the Macintosh operating environment. It has successfully been ported to Microsoft Excel 5.0 in the Windows 95 environment.

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The only inputs required to operate the spreadsheet are:

1. **What is the total, material mass?** in grams
2. **Is the material a liquid? y/n**
3. **Activity input** of each constituent isotope.

Cells J5 and L5 recognize a "y" response in cell G3, the answer to the "Is the material a liquid?" question. Any other answer would be considered a no response. This answer is used to determine the appropriate value which will be used in the LSA-II calculation and for the Limited Quantity calculation. A "y" or yes answer will create a value of 1E-5 in cell L5 for LSA-II and a value of 1E-4 in cell J5 for Limited Quantity. Any other answer will create values of 1E-4 for LSA-II and 1E-3 for Limited Quantity in their respective cells.

The individual activities are entered by the user in Column J. The activity of isotopes without an A_2 value (e.g., Ba-137m) are entered at the top of this column. The activity in this cell (J9) is only included in the calculation to determine if the material meets the definition of a radioactive material; the unity calculations and all other results do not include this activity.

Macro functionality has been added in the form of three buttons. Clicking on the first button will extract the nuclide data (nuclide names and activities) which have been input. These data are then sorted (biggest to smallest) according to the fraction of their individual A_2 values. The percentage contribution to the total radiotoxicity is also calculated. This is done so users can check their inputs for accuracy and also so they can copy the first 95% of the radiotoxicity onto the shipping paper. Again, the amount of activity listed in cell J9 (activities without an A_2 value) are not extracted.

Activating the second button will print the results which are given on the first two pages of the spreadsheet. This gives a hardcopy which can be readily examined and filed as a record of the shipment being made.

The third button clears the nuclide data which was input and the extraction area of the spreadsheet. It does not clear the mass or the answer to the "Is the material a liquid?" question.

There are nine columns of reference data and calculations. The spreadsheet has been developed in both curies and Terabecquerels format (two separate spreadsheets). What follows is a discussion of the curies format. The logic and results are the same, only the units are different in the Terabecquerel format.

Column I (Isotope) is a listing of all the isotopes currently regulated by the DOT. This listing is from the DOT regulations, 49 CFR 173.435, Table of A_1 and A_2 Values for Radionuclides.

Column J (Curies) is where the user inputs activities for the isotopes listed in Column 1. The spreadsheet is either written to make calculations with curies or else written to work with Becquerels. These are two separate spreadsheets.

The final value in this column is the total of the input values (the total curies input).

Column K (A_2 Value [Ci]) is the A_2 value for the listed isotopes. For the spreadsheet written to operate in curies, this value is calculated from the Terabecquerel value as listed in Column 5, which is regulatory (curies are not regulatory).

The conversion used is that A_2 in curies equals 27.03 times A_2 in Terabecquerels.

Some of the listed isotopes have unlimited A_2 values. These are listed as "unlmtd", and the A_2 fraction calculated in Column L is hard wired with a zero value.

This particular spreadsheet is written to use curies although it is recognized that Terabecquerels are the regulatory limits. This spreadsheet has also been converted to a separate spreadsheet with curies eliminated.

Column L (A_2 Fraction) is the first column of actual calculations. The input value (activity) in Column J is divided by the regulatory limit, the A_2 value of Column K. This column lists the contribution of each isotope to the A_2 fraction for the mixture of isotopes.

The final value in Column L is the total of the calculated values—the total A_2 fraction for the input isotopes. This value is used for several other calculations.

For isotopes with an unlimited A_2 value, the fraction is not calculated. It is given a value of zero so the cell may still be included in the summation at the bottom of the column.

Column M is empty.

Column N (A_2 Value [TBq]) is the listing of the regulatory limits—A_2 values in Terabecquerels. These values are only used to calculate the A_2 values in curies that are listed in Column K.

Column O (Reportable Quantity [Ci]) is a listing of the reportable quantities for the DOT-regulated isotopes. This does not include all isotopes regulated by the U.S. Environmental Protection Agency. This is one potential area where this spreadsheet could be considered incomplete: an isotope included in the mixture may not be regulated by DOT and would not be involved in the spreadsheet's calculation of Reportable Quantity. The unlisted isotopes however, should still be part of the calculation and should be contributors to the determination of whether a mixture of isotopes is a Reportable Quantity or not.

For isotopes without a specific amount listed in 49 CFR 172.101, Table 2, Radionuclides, the regulatory amount of 1 curie was entered as the limit. This is from Footnote EEE† of Table 2. The curie values were taken to be the regulatory limits.

Column P (RQ Fraction) is the second column of calculations made by the spreadsheet. The input value (activity) in Column K is divided by the regulatory limit, the Reportable Quantity value of Column O.

The final value in Column P is the total of the calculated values—the total Reportable Quantity fraction for the input isotopes. If this total is 1 or greater, the mixture is reported on the results page as a Reportable Quantity.

A single isotope within a mixture that exceeds the Reportable Quantity limit is not reported individually; only the sum being greater than one for all the isotopes is reported. The user could review this column to find which isotopes are reportable quantities by themselves, if that were desired.

Column Q (Disintegration Energy [MeV]) is a listing of total decay energies in millions of electron volts (MeV) for each individual isotope. Most of these were collected from the Fourteenth Edition of *Nuclides and Isotopes* published by the General Electric Company (Walker et al. 1989).

These values are likely an over estimation for calculating the decay heat in a package. They were included because many radioactive material packagings have decay heat limits.

Column R (Decay Heat [Watts]) is the calculation of the decay heat contribution for each entered isotope. These individual values are summed at the bottom of the Column R in cell R397; that sum is also reported on the results page in cell G32.

The activity of Column J (user input) is converted to total decay energy by using the reference data of Column Q and a conversion factor to change the units of electron volts to watts. The conversion factors used are given below:

1 electron volt equals 1.6022E-19 joules
1 curie equals 3.7E10 disintegrations per second
1 watt equals 1 joule per second.

The final conversion factor is 5.928E-3 [W/MeV/Ci]. This value is multiplied by the disintegration energy (Column Q) and by the activity in curies (Column J). In the metric version of this spreadsheet, where activity is input as Terabecquerels, the conversion factor is 0.16022 [W/MeV/TBq]

RESULTS

The remainder of the spreadsheet is a statement of results. Many of these results are based upon the unity calculation (a summation of the fractions for each nuclide of the quantity present divided by the A_2 value for that nuclide—often referred to as "have divided by allowed"). The unity calculation is applicable to all mixtures of nuclides. The spreadsheet only sums the A_2 fractions once. This value subsequently has the appropriate factor applied for comparison to the requirements for a DOT designation. For example, to determine if a mixture is a Limited Quantity, the summation of fractions (cell J397) is divided by (the value in cell J5) 1E-4 if the material is a liquid or is divided by 1E-3 if the material is a solid or gas. If the result of this division is less than 1 (unity), the mixture represents a Limited Quantity. The same type of comparison is made for each of the LSA designations and for the Type A designation.

The Reportable Quantity designation uses a separate summation because the "allowed" values are not the same as the A_2 value. This summation is at the bottom of Column 7 in cell P397. If this cell exceeds unity, the mixture is reported as a Reportable Quantity on the results page (cell G24).

The Highway Route Controlled Quantity designation uses the summation of the A_2 fractions. If the total activity exceeds 27,000 curies or the summation of A_2 fractions exceeds 3000, the mixture is reported as a Highway Route Controlled Quantity on the results page (cell G27).

The results page designation for Fissile Quantity is not all inclusive of the Fissile Quantity exceptions (49 CFR 173.453). The only comparison made is to determine if more than 15 grams of fissile nuclides are present in the mixture. The material may quality for one of the other exceptions if it has been calculated to contain greater than 15 grams of fissile material.

The spreadsheet converts the activity input by the user of currently regulated DOT fissile isotopes (U-233, U-235, Pu-238, Pu-239, Pu-241) to mass by using the respective specific activities for each nuclide. The mass of each fissile nuclide is reported in cells H60 through H64. The total fissile mass is summed and reported in cell H66 and also repeated in cell G43. If the sum is greater than 15 grams the mixture is reported as a Fissile Quantity (cell G30).

The total activity for nuclides with A_2 values [does not include nuclides without specified A_2 values (cell J9)] is summed in cell J397. This value is reported on the results page (cell G37) and is also converted to the alternate activity units and repeated in cell G38.

The A_2 value for the mixture is calculated by dividing the total activity [sum of nuclides with A_2 values (cell J397)] by the sum of the A_2 fractions (cell L397). With minimal mathematical manipulation of the equation stated in 49 CFR 173.433(d) and recalling the "have divided by allowed" principle, this calculation method can be easily proven correct.

The result is reported in cell G39. The calculation for this cell does not include the activity of unspecified nuclides as can be entered by the user in cell J9. However, this cell is given a minimal value of 5.41E-4 curies (or 2E-5 TBq). This is the smallest A_2 value for any isotope (Ac-227) and was copied from 49 CFR 173.433, Table 10, General Values for A_1 and A_2, for alpha-emitting nuclides. It is the most restrictive A_2 value and would be reported and used in calculations if no nuclides with specified A_2 values are entered by the user.

For LSA shipments where there is a conveyance limit, the number of A_2 quantities in the calculation is reported in cell G41. This calculation is made by dividing the total activity of cell G37 by the A_2 value for the mixture. One (1) is added to the integer value of this result. Therefore, the minimum value reported in this cell will be 1. (The activities must be entered as positive values.)

The specific activity for the mixture of nuclides distributed throughout the material is reported as activity per gram in cell G45. This calcutlation is made by summing the activities of nuclides with specified A_2 values (cell J397) and the activity input for nuclides without specified A_2 values (cell J9) and then dividing by the material mass (cell G4).

The total decay heat which would be generated by the input activity (summation from cell R397) is reported in cell G47. This is a useful datum for packaging with decay heat limits.

The second page of results is included for the user to check input values. All data entered by the user is extracted (with the extract button at the top of the spreadsheet) and then subsequently sorted according to the magnitude of the A_2 fraction (radiotoxicity). The user can then copy directly onto the shipping paper the included isotopes in their appropriate order and quantity (both curies and Terabecquerels are listed).

In addition, the physical state of the material and the weight as input by the user are repeated. The mass of fissile nuclides, as already discussed, is also listed on this page.

CONCLUSION

This spreadsheet has proven to be a robust and user friendly tool.

Some of the author's concerns are the misuse of this tool. One particular concern is the application of LSA designations. There are other requirements (relatively uniform nuclide distribution, radiation levels, physical state, leaching etc., depending upon the LSA category) that must be met before a material can be fully classified as LSA. A second concern is that the data and logic designed into the spreadsheet can be overwritten or 'doctored' to give a wrong answer or give a shipper's desired answer for a lesser packaging. A third concern is that this tool could be relied upon by shippers who are unable to distinguish an appropriate classification from an improper one. One final issue is that the regulatory A_2 values and Reportable Quantity values occasionally change. A user's copy of this spreadsheet will not automatically be updated.

To date this spreadsheet has only been used to confirm an already established classification. Without further security controls to protect the logic and the reference data within the spreadsheet, it should only be used cautiously to confirm the classification for mixtures of radionuclides.

REFERENCES

F. W. Walker, J. R. Parrington, and F. Feiner, *Nuclides and Isotopes,* Fourteenth Edition, General Electric Company, Nuclear Energy Operations, 175 Curtner Avenue, San Jose, CA 95125 USA, 1989.