Response Capabilities of Two Radiation Detection Instruments to 0.1% A_2 of Radionuclides

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EMERGENCY CONCERNS

The ability to detect radioactive material released at accidents during transportation or at fixed facilities is of concern to emergency responders and radiological specialists since many radionuclides cannot be detected by commonly used survey instruments. In this paper the detection capabilities of two instruments were evaluated for the radionuclides listed in the 1985/1986 IAEA transportation regulations (IAEA 1986 and IAEA 1987). Although the limits on package content (the A_1 and A_2 values) of the IAEA regulations were derived for exposure routes applicable in transportation accidents, the considerations parallel those for accidents or spills at fixed facilities. In either situation, the central issue is the capability of the monitoring instrument to detect a potential radiological hazard. The "A_2 system" provides a normalization to a specific level of radiological hazard, rather than to a fixed level of activity. The radiological hazard per unit activity ranges over six orders of magnitude among the different radionuclides. Thus, it is better to determine response capabilities for a specific radiological hazard, as provided by the A_2 system.

DEFINITION OF RESPONSE CAPABILITIES

Response of two Civil Defense type instruments was computed for 0.1% of the A_2 quantity of all radionuclides listed in the 1985/1986 IAEA transportation regulations (IAEA 1986 and IAEA 1987). The response capabilities of the CDV-700 (a low range geiger instrument), both shield open and shield closed, was classified GOOD, SOME, and NONE.

GOOD (G). A GOOD response signifies that the instrument will read at least 0.1 mR/h (60 cpm) at a distance of one meter from 0.1% A_2 of the radionuclide. This response is approximately twice the meter fluctuations due to normal background radiation and 20% of full scale on the lowest range (0-0.5 mR/h).

SOME (S). The SOME response indicates that the instrument will respond to the emissions from the radionuclide but a reading of at least 0.1 mR/h (60 cpm) will be observed only if the instrument is closer than one meter to 0.1% A_2.

NONE (N). The NONE classification means that the instrument has no detection capability for the specific radionuclide when usual monitoring techniques are followed. No detection capability is expected for radionuclides that emit only alpha (e.g., Po-210) and low energy beta radiation (e.g., H-3).

The responses of the CDV-715 (high-range ion chamber instrument) were ranked as DETECTABLE and NONE.

DETECTABLE (D). A DETECTABLE response capability means that the CDV-715 will indicate an 10 mR/h or greater at one meter from a 0.1% A_2 quantity of the radionuclide when the instrument is on the lowest range (0-0.5 R/h). This response is only 2% of full scale.

NONE (N). The NONE response means that either the CDV-715 has no detection capability for detecting the emissions from the radionuclide or the detected response would be less than 10 mR/h if the emissions are detectable.

COMPUTATIONS AND OTHER CONSIDERATIONS

The distance of one meter between the instrument and the 0.1% A_2 sources was selected somewhat arbitrarily for the capability computations. However, one meter is the approximate distance an instrument is from the ground when a person stands with an instrument in hand.

The 0.1% fraction of the A_2 quantity was also selected somewhat arbitrarily. However, that fraction has been used in the establishment of the A_2 quantity for Type A packages. The 0.1% A_2 quantity is treated as a point source. The absorption of radiation within the source and attenuation and build up in air are neglected.

The CD-700 with shield open is considered to respond only to beta particles of energy greater than 150 keV. The gamma energy dependence of the CDV-700 response to photons is compensated based on reported data, while the gamma response of the CDV-715 was assumed to be independent of energy (NBS 1976 and Siebentritt 1987 and 1988).

The energy and intensity of emitted radiations, the branchings fractions, and half-lives of the radionuclides were taken from ICRP-Publication 38 (ICRP 1983).

Spontaneous fission has not been considered in this work. Thus, we have not evaluated the response of the instruments to neutron radiations, nor accounted for beta and gamma radiations promptly emitted by fission fragments. Spontaneous fission is an important decay mode for Cf-252, Cf-253, Cf-254, Cm-248, and Pu-244.

A response capability was included for mixed fission products, MFP. Such an entry was included in earlier IAEA regulations, (IAEA 1979) but not in the latest regulations. The A_1/A_2 values for MFP were computed using the mixture rule (IAEA 1986). Relative responses of GOOD and DETECTABLE were assigned to the CDV-700 and CDV-715, respectively.

To account for in-growth of daughter radionuclides in a transportation environment the following assumptions were made:

1. The only radionuclides present in a package when offered for transport are those shown on the shipping paper or package label.
2. If a daughter has a half-life of less than 1 day the release occurs in 1 hour.
3. If the daughter half-life is greater than 10 days, the release occurs in 10 days.
4. For half lives between 1 and 10 days the release occurs in 1 day.

The capabilities assigned by the computation methodology generally appear reasonable when compared to practice. It does appear, however, that the methodology overstates the ability to detect beta emitters with endpoint energies corresponding to the thickness of the wall of the geiger detector of the CDV-700. A case in point is S-35 with an endpoint energy of 167.5 keV. The computation methodology assigns a GOOD capability for the CDV-700 with the probe shield open, the assignment was changed to NONE to be consistent with actual experience in monitoring S-35 contamination.

Although the evaluations were based on routes of exposure associated with transportation accidents, they are meaningful for releases at fixed facilities. Also the response capabilities of the two Civil Defense type instruments should be useful to persons using commercially available instruments with similar detectors.

The methodology, its computer implementation, and numerical data-bases have been documented to facilitate future updating.

TABULATED RESULTS

The results shown in the table below are limited to a selected number of radionuclides that are commonly transported and used by medical, industrial, and government organizations.

The first column shows the name of the chemical element and the symbol for the radionuclide. The radionuclides are presented in alphabetical order by chemical name.

The half-lives are shown in their natural units, e.g., days (d), minutes (m) etc. The radiations emitted are identified as alpha (α), beta (β) (includes monoenergetic electrons), and gamma (γ) (which includes x-rays). The A_1 and A_2 values are shown in both SI and customary units and are from the 1985/1986 IAEA regulations. The three columns on the right side of the table show the response capability of the CDV-700 and CDV-715.

CONCLUDING REMARKS

A methodology was developed to rank the response capabilities of survey instruments to various radionuclides instruments which emergency personnel responding to transportation accidents might encounter. Elaborate calculations of radiation transport and detector efficiencies were not undertaken; rather simple formulations were considered adequate. While further efforts might refine these aspects of the problem, considerable additional information would be required to perform realistic simulations of exposures and an empirical verification of instrument readings under actual accident conditions.

A report of the analysis and computation efforts for this paper were done at Oak Ridge National Laboratory, and will appear with a detailed presentation of the methodology in a Sandia National Laboratories report later in 1989. The work at ORNL was done under Department of Energy contract DE-AC05-840R21400, with part of the funding for this effort provided by the Department of Transportation. If a reader desires a tabulation of the response capabilities for all radionuclides in the 1985/1986 IAEA regulations, a copy can be provided by contacting either author. If a copy of the full technical report from Sandia National Laboratory is wanted, it will be available by writing either author and asking for the report titled "Relative Response of Civil Defense Monitoring Instruments at Radiological Accidents."

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Response of Civil Defense Instruments
to Selected Radionuclides In Accidents

Nuclide	Half-life	Radiation	1985-86 IAEA Values - A_1 (TBq)	A_1 (Ci)	A_2 (TBq)	A_2 (Ci)	CD V-700 Shield open	CD V-700 Shield closed	CD V-715
Americium									
Am-241	432.2 y	α β γ	2	(50)	2E-4	(5E-3)	N	N	N
Antimony									
Sb-125	2.77 y	β γ	2	(50)	0.9	(20)	G	G	N
Argon									
Ar-41	1.827 h	β γ	0.6	(10)	0.6	(10)	G	G	N
Barium									
Ba-133	10.74 y	β γ	3	(80)	3	(80)	G	G	D
Cadmium									
Cd-109	464 d	β γ	40	(1000)	1	(20)	G	G	N
Calcium									
Ca-45	163 d	β γ	40	(1000)	0.9	(20)	G	N	N
Californium									
Cf-252	2.638 y	α β γ	0.1	(2)	1E-3	(0.02)	N	N	N
Carbon									
C-14	5730 y	β	40	(1000)	2	(50)	N	N	N
Cesium									
Cs-137	30.0 y	β γ	2.0	(50)	0.5	(10)	G	G	N
Chromium									
Cr-51	27.704 d	β γ	30	(800)	30	(800)	G	G	D
Cobalt									
Co-57	270.9 d	β γ	8	(200)	8	(200)	G	G	D
Co-60	5.271 y	β γ	0.4	(10)	0.4	(10)	G	G	D
Copper									
Cu-64	12.701 h	β γ	5	(100)	0.9	(20)	G	G	N
Curium									
Cm-244	18.11 y	α β γ	4	(100)	4E-4	(0.01)	N	N	N
Gadolinium									
Gd-153	242 d	β γ	10	(200)	5	(100)	G	G	D
Gallium									
Ga-67	78.26 h	β γ	6	(100)	6	(100)	G	G	D
Hydrogen									
H-3	12.35 y	β	40	(1000)	40	(1000)	N	N	N
Indium									
In-111	2.83 d	β γ	2	(50)	2	(50)	G	G	D
Iodine									
I-123	13.2 h	β γ	6	(100)	6	(100)	G	G	D
I-125	60.14 d	β γ	20	(500)	2	(50)	G	S	N
I-131	8.04 d	β γ	3	(80)	0.5	(10)	G	G	N
Iridium									
Ir-192	74.02 d	β γ	1	(20)	0.5	(10)	G	G	N

Nuclide	Half-life	Radia- tion	1985-86 IAEA Values - --- A_1 --- (TBq)	(Ci)	--- A_2 --- (TBq)	(Ci)	-CD V-700- Shield open	closed	CD V-715
Iron									
Fe-55	2.7 y	β γ	40	(1000)	40	(1000)	N	N	N
Fe-59	44.529 d	β γ	0.8	(20)	0.8	(20)	G	G	D
Krypton									
Kr-85	10.72 y	β γ	20	(500)	10	(200)	G	G	N
Lead									
Pb-203	52.05 h	β γ	3	(80)	3	(80)	G	G	D
Pb-210	22.3 y	α β γ	0.6	(10)	9E-3	(0.2)	G	N	N
Manganese									
Mn-54	312.5 d	β γ	1	(20)	1	(20)	G	G	D
Mn-56	2.5785 h	β γ	0.2	(5)	0.2	(5)	G	G	N
Mercury									
Hg-203	46.60 d	β γ	4	(100)	0.9	(20)	G	G	N
Mixed Fission									
Products	----	β γ	0.2	(5)	0.2	(5)	G	G	D
Molybdenum									
Mo-99	66.0 h	β γ	0.6	(10)	0.5	(10)	G	G	N
Nickel									
Ni-63	96 y	β	40	(1000)	30	(800)	N	N	N
Phosphorus									
P-32	14.29 d	β	0.3	(8)	0.3	(8)	G	N	N
P-33	25.4 d	β	40	(1000)	0.9	(20)	G	N	N
Plutonium									
Pu-238	87.74 y	α β γ	2	(50)	2E-4	(5E-3)	N	N	N
Pu-239	24065 y	α β γ	2	(50)	2E-4	(5E-3)	N	N	N
Pu-241	14.4 y	α β γ	40	(1000)	0.01	(0.2)	N	N	N
Polonium									
Po-210	138.38 d	α β γ	40	(1000)	0.02	(0.5)	N	N	N
Potassium									
K-43	22.6 h	β γ	1	(20)	0.5	(10)	G	G	N
Radium									
Ra-226	1600 y	α β γ	0.3	(8)	0.02	(0.5)	G	G	N
Ra-228	5.75 y	β γ	0.6	(10)	0.04	(1)	G	G	N
Radon									
Rn-222	3.8235 d	α β γ	0.2	(5)	4E-3	(0.1)	G	S	N
Ruthenium									
Ru-103	39.28 d	β γ	2	(50)	0.9	(20)	G	G	N
Selenium									
Se-75	119.8 d	β γ	3	(80)	3	(80)	G	G	D
Sodium									
Na-22	2.602 y	β γ	0.5	(10)	0.5	(10)	G	G	D
Na-24	15.00 h	β γ	0.2	(5)	0.2	(5)	G	G	N
Strontium									
Sr-89	50.5 d	β γ	0.6	(10)	0.5	(10)	G	N	N
Sr-90	29.12 y	β γ	0.2	(5)	0.1	(2)	G	N	N

Nuclide	Half-lif	Radia- tion	1985-86 IAEA Values - --- A_1 --- (TBq)	(Ci)	--- A_2 --- (TBq)	(Ci)	-CD V-700- Shield open	closed	CD V-715
Sulfur									
S-35	87.44 d	β	40	(1000)	2	(50)	N	N	N
Technetium									
Tc-99	2.13E5 y	β	40	(1000)	0.9	(20)	G	N	N
Tc-99m	6.02 h	β γ	8	(200)	8	(200)	G	G	D
Thallium									
Tl-201	3.044 d	β γ	10	(200)	10	(200)	G	G	D
Thorium									
Th-230	7.7E4 y	α β γ	2	(50)	2E-4	(5E-3)	N	N	N
Th-232	1.405E10y	α β γ	Unlimited		Unlimited		N	N	N
Tungsten									
W-181	121.2 d	β γ	30	(800)	30	(800)	G	G	D
Uranium									
U-234	2.445E5 y	α β γ	10	(200)	1E-3	(0.02)	N	N	N
U-235	703.8E6 y	α β γ	Unlimited		Unlimited		G	G	N
Xenon									
Xe-133	5.245 d	β γ	20	(500)	20	(500)	G	G	D
Zinc									
Zn-65	243.9 d	β γ	2	(50)	2	(50)	G	G	D