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for the
U. S. Department of Energy

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Summary of Docket File Survey

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ABSTRACT

A sampling of NRC Docket Files has been surveyed to identify radionuclides in industrial and medical use under NRC licenses currently without safeguards which might be candidates for safeguards against malevolent misuse. This survey identifies many more radionuclides on the assumption that quantities potentially available equal license limits than were previously identified on the basis of maximum single shipments. Information gleaned on details of the form and use of radionuclides was only fragmentary. Brief discussions of the rationale for this study, of the limitations inherent in this approach and limitations in its execution, and of the results are given. This study was done under the NRC project "Safeguards Analysis for Byproduct Materials and Small Quantities of SNM" (189 No. B6108) in partial fulfilment of milestones 2f and 2c.

PURPOSE

The purpose of this study was to identify radionuclides in industrial use under NRC licenses, which might be candidates for safeguarding against malevolent misuse. This study was intended to complement previous identifications (Chester and Chester, 1979; Randolph et al., 1980) based largely a summary of transportation of radionuclides in the U.S. (Simmons et al., 1976). The NRC Docket Files (at the Willste Building, 7915 Eastern Ave., Silver Spring, MD) contain copies of licenses, their justifications and occasionally further commentary. In addition to listing licensed amounts of specific radionuclides, a review of the Docket Files yields some insights into current practices and circumstances of industrial use.

METHOD AND SCOPE OF SURVEY

The planning for this Docket File study went as follows: First, based on the input data needs of the methods for estimating potential hazards developed in previous reports (Chester and Chester, 1979; Randolph et al., 1980) a preliminary list of "Desired Characteristics of Radionuclides" (Table 1) was composed. Then by an iterative procedure between NRC (G. Dan Smith, Project Officer at that time) and ORNL a "Questionaire" (Table 2) was derived for use in examining Docket Files.

Ideally a computerized survey of the entire Docket Files would be done using the Teknekron Energy Resource Analysis (TERA) computer system.* However, the system does not yet appear to be sufficiently implemented to make its use feasible with the resources and time available under this contract. Hence, manual inspection of a selected sampling of the licenses was done.

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The size of the entire Docket File (~10,000 licenses, with an average of perhaps 50-100 pages per license) precluded inspection of all licenses by hand.

Our criterion for selection of licenses to inspect have included:

a) Closest attention given to by-product licenses which NRC Office of Inspection and Enforcement have as Priority 1 (See Appendix A);

b) Priority 1 SNM licenses;

c) A sampling of Priority 2 licenses intended to represent radiographic inspection equipment, radiopharmaceutical suppliers, and others chosen essentially at random.

By agreement with the NRC Project Officer (George H. Gardes) our survey excluded licenses issues by the 25 "Agreement States". (See 10 CFR 150 1979). These states are: Alabama, Arizona, Arkansas, California, Colorado, Florida, Georgia, Idaho, Kansas, Kentucky, Louisiana, Maryland, Mississippi, Nebraska, Nevada, New Hampshire, New Mexico, New York, North Carolina, North Dakota, Oregon, South Carolina, Tennessee, Texas and Washington. The ERESS Report (1979, p. 44) gives the following examples of potentially large inventories in Agreement States. "General Electric, Pleasanton, CA, with several million curies of byproduct materials; Union Carbide, Tuxedo, NY, 50,000 Ci of irradiated metals, alloys components; Gamma Industries, Houston, Texas, 1000 Ci of Am-241, any form; or Nuclear Sources and Services, Houston, Texas, with 3300 Ci of Am-241, any form; PNWL, Richland, WA can possess 10,000,000 Ci of all nuclides; United Nuclear Industries, Richland, WA, can posess 20,000,000 Ci of all radionuclides." We have not included sample licenses from universities, hospitals, oil-well-logging companies, Department of Defense, or Department of Energy.

RESULTS

In this survey 42 licenses (docket files) for 25 companies were examined (Table 3). Of the 77 radionuclides specifically mentioned in these licenses, license limits for 49 nuclides were found to be sufficient to consider them as potentially significant by the criterion that at least one license limit is greater than 7.4 X 10^{11} Bq(20 Ci) for beta-gamma emitters or greater than 3.7 X 10^{8} Bq (0.01 Ci) for alpha emitters (Table 4).* Several "ground rules" used in compiling this Table are given in its footnotes.

In Table 5 a comparison is given between the radionuclides selected by these criteria and by the similar shipping criteria of 7.4 X 10^{11} Bq of gamma emitters or 3.7 X 10^{7} Bq of alpha emitters shipped in one year in the U.S. (Simmons et al., 1976) as used previously for first-cut selection of radionuclides (Chester and Chester, 1979; Randolph et al., 1980). Of the 60 nuclides listed, 20 are included by both criteria, 29 are included only by the license data, and 11 are included only by the shipping data. We find no clear correlation between inclusion by either data set and radioactive half-life.

Other information listed in the questionaire and sought for in the docket files was only fragmentary. Inventories of but 8 radionuclides from one company and 2 from another gave, on the (statistically questionable) average, the possession values as about 20% of the license limits. (More comparisons of inventories and license limits would be desirable.) Shipping

*The transportation study Simmons et al. (1976) was previously used to obtain a first-cut selection of radionuclides. There shipments are listed in groups with limits of 0.001,3,20, etc. curies. In our previous studies (Chester and Chester, 1979; Randolph et al., 1980) we have used 20 curies as a lower limit for listing beta-gamma emitters and 0.001 curie for alpha emitters, thus allowing for a quality facto of >10 for alpha particles. Since consideration of 0.001 curie of an alpha emitter seems too inclusive, we here use a 0.01 curie lower limit for consideration of alpha emitters.

records from 4 (or fewer licenses) revealed no cases in which the annual amount of a radionuclide shipped was as great as the possession limit or the maximum single shipment in the U.S. no more than 25% the annual amount shipped in the U.S. The docket files generally contain nothing on transport mode, chemical concentration or specific activity. Physical and chemical form are usually given as "Any". Packaging of radionuclides during storage and/or shipping is merely stated, or more often implied, as being in compliance with NRC (e.g. 10 CF3, Part 73) and/or DOT regulations. The physical deterrents, access restrictions and accounting procedures are variously described but with distinctly more detail and control for SNM than by-product licenses.

DISCUSSION AND CONCLUSIONS

The most important result of this docket file study is that, based on quantity limits in licenses issued, there are many more radionuclides identified as candidates to be considered for safeguards regulations than were identified previously by similar limits of maximum single radionuclide shipments, (see Table 5). The list of candidate radionuclides found here may be questioned on various grounds including the following:

a. The sample size of dockets reviewed is small. A larger sample size might increase the number of candidate radionuclides.

b. The license limits inherently tend to be overestimates of possession values. However, since our meager sampling of radionuclide inventories versus license limits gave the average inventory as about 20% of the license limit, use of licenses limits seems only a modestly conservative approach. (A more intensive study of NRC inspection reports might be useful.) This may be no more conservative than choice of the maximum in a 5 to 1 range (e.g., 200-1000 curies/shipment) in shipping records.

c. Restriction of our list to radionuclides specifically mentioned in licenses may exclude some important candidates. Blanket licenses (e.g., see 10 CFR 33, 1979) for by-product materials usually are for only small amounts of radionuclides with atomic number 3 to 83 but some blanket licenses, especially SNM licenses, allow great amounts of unspecified by-product nuclides (e.g., Westinghouse Electric license SNM 770 allows 4,000,000 total curies of by-product materials. If this amount were distributed equally among 1000 nuclides, there would be 4,000 curies per nuclide and all should then be included as candidate radionuclides.)

Inclusion of all nuclides listed here in a final appraisal of relative hazards of radionuclides seems in order. Although this could be done by the methods given previously (Randolph et al., 1980), such calculations are beyond the scope of this report.

The vast differences (in terms of quantities of radioactivity, technical safeguards, records, and plant security) that apparently exist between operations conducted under most licenses and those conducted under SNM licenses seem to justify considering such licenses separately.

Partly because of the great diversity of applications of radionuclides, several ways individual plants are run, and detail included in docket files, satisfactory general answers to many of the specific data sought in the questionaire seem unattainable by this approach.

ACKNOWLEDGMENTS

We are grateful to G. D. Smith, G. H. Gardes, George Kligfield, Ed Cook and the Docket File Staff of NRC for much help in conducting this survey and to R. O. Chester of ORNL for much patient advice during its progress.

APPENDIX A

Priority definitions

The top two priority definitions for the NRC Inspection and Enforcement Division have been summarized as follows:

PRIORITY I

Initial inspections are made within 1 month after the initial license is received in the Regional Office.

Routine inspections are made at a frequency of:

- 2 per year for processors and distributors with complex programs, and
- 1 per year for processors and distributors with relatively simple programs.

PRIORITY II

Initial inspections are made within 6 months after the initial license is received in the Regional Office.

Routine inspections are made at a frequency of 1 per year.

In addition there are defined several lower priorities for which less frequent inspections are made, (NRC, 1976).

Our identification of specific licenses within these priority categories has come from the ERESS Report (ERESS, 1979), pp. 48-60.

REFERENCES

C. V. Chester and R. O. Chester, *Preliminary Evaluation of the Needs for Protection Against Dispersal of Byproduct Materials and Small Quantities of SNM*, (U) ORNL/NUREG-46 (1979), (CNSI).

M. L. Randolph, M. T. Ryan, D. K. Halford, K. K. Kanak, and R. O. Chester, *Revised Selection of Shipped Radionuclides for Potential Safeguarding Against Malevolent Operators*, (U) ORNL/NUREG-69 (in review), (CNSI).

J. L. Simmons, M. O. Cloniger, B. M. Cole and A. E. Medford, "Survey of Radioactive Material Shipments in the United States," BNWL-1972, (April 1976).

NRC Manual, Chapter 2801, page 2805-E2-1, 1 Oct. 1976.

Environmental Radiation and Emergency Support Section Planning, (ERESS), NRC, Washington, D.C., October 1979.

10 CFR. Code of Federal Regulations, Title 10 Energy, Part 150. "Exemptions and Continued regulatory authority in Agreement States," under Section 274, January 1979.

Table 1. Desired characteristics of radioisotope shipments, use, and possession (10/26/79)

	Items	Examples
1.	Radioisotope	^{239}Pa, ^{137}Cs, ...
2.	Number of shipments by curie size (especially maximum size)	^{131}I 400 shipments of >1-3 Ci ^{131}I 127 shipments of >3-20 Ci ^{131}I 34 shipments of >20-100 Ci ^{131}I 3 shipments of 200 Ci ^{131}I 0 shipments of >200 Ci
3.	Chemical form of shipments	(a) ^{238}U as U_3O_8 (b) ^{235}U as uranyl nitrate, $UO_2(NO_3)_2.6H_2O$
4.	Chemical purity/concentration	(a) >90% U_3O_8 (b) 0.1 molar uranyl nitrate
5.	Isotopic purity (parent, radionuclide and daughters)	(a) recently separated ^{235}U with <1% ^{238}U, <0.001% ^{234}U, ^{232}Th, in secular equilibrium with ^{235}U (b) natural uranium (c) 100% ^{99}Mo on September 26, 1979, to be delivered October 5, 1979
	(other isotopes of same element)	(d) 0.2% ^{32}P, 99.8% ^{31}P
6.	Physical form	(a) loose powder with average particle diameter 10 microns (b) 10 kg ingots of metallic U (c) liquid in 5 gallon containers (d) gas at $500/in^2$ pressure in 1 cu. ft tank (e) random size loose pieces (f) encapsulated
7.	Shipping container per package	(a) 55 gallon drum (b) standard 10 ton fuel shipment case, Type B, ANSI No. ___ (c) 1000 lb. Pb shielding pig
8.	Transport mode	(a) single shipment truck (b) rail freight (c) safe and secure transport (d) shipped "piggy back" with safeguarded shipment

Table 1. Desired characteristics of radioisotope shipments, use, and possession (continued)

Items	Examples
9. Present administrative/ accounting practices	(a) accountable to nuclear materials management safeguards system (b) shippers' commercial accountability only
10. Intended use of radioisotope	(a) nuclear fuel fabrication (b) medical irradiation unit (c) well logging (d) radiography source (30 Curies ^{192}Ir, ^{137}Cs)
11. Shipping routes	(a) 500 Ci shipments by truck from Oak Ridge through Nashville to St. Louis (500 miles, less than 1 day enroute)
12. Periodicity of shipments	(a) normally shipped on first and third Wednesday of each month (b) irregular
13. Current storage procedures	(a) radiological protection such as shielding (b) physical access such as locked rooms or vaults (c) administrative records such as written trace of radionuclide from receipt to disposal or shipping elsewhere (d) periodic inventories
14. Current use procedures	(a) training of users (b) static radiological source and/or protection such as fixed source in shielded rooms (c) mobile radiobiological source and/or protection ^{192}Ir teletherapy, source and Pb gloves and aprons (d) administrative restraints to deny unauthorized persons access (e) number of users

Table 2. Question Set (02/19/80)

1. Name of facility, address and phone number:

2. License Number: ______________________________

3. Essential information for each isotope (see attached table).

4. Are any of the radioisotopes consumed during use?

5. What are the physical deterrents against loss or theft?

6. How is each radioisotope packaged during storage?

7. How is each radioisotope packaged during shipments?

8. What are the required qualifications for authorized access to each radioisotope?

9. How many persons have access to each radioisotope and for what reasons?

10. What are your administrative and/or accounting procedures for keeping track of each radioisotope?

TABLE OF ESSENTIAL RADIOISOTOPIC INFORMATION

Isotope	Handling Activity	Possession Limit (Ci)	Inventory (Ci)		Quantity per Shipment (Ci)		Annual Thruput (Ci)		Transport Mode	Physical Form	Chemical Form	Chemical Concentration	Specific Activity (Ci/g)
			Avg.	Max.	Avg.	Max.	Receipts	Shipments					

Table 3. Companies and license numbers examined

NRC I&E Priority	Company	Location	License Number
1	Abbott Laboratories	Chicago, IL	12-00621-03
	*Amersham Corp.	Arlington Heights, IL.	12-12836-01
	Automation Industries, Inc.	Phoenixville, PA.	37-00611-09
	CIS RAdiopharmacenticals, Inc.	Bedford, MA	20-13695-01
	Mallinckrodt, Inc.	St. Louis, MO	24-04206-01
	*Medi Physics, Inc.	South Plainfield, N.J.	29-15360-01
	*Minnesota Mining and Manufacturing	St. Paul, MN	22-00057-06
	*New England Nuclear Corp.	Boston, MA	20-00320-09
	New England Nuclear Corp.	Boston, MA	20-00320-13
	New England Nuclear Corp.	Boston, MA	20-11888-01
	Pacific Radiopharmacy, Ltd.	Honolulu, HA.	53-16991-01MD
	Permagrain Products, Inc.	Media. PA	37-17860-01
	*Picker Corp.	Cleveland, OH	34-07225-09
	E.R. Squibb and Sons, Inc.	New Frunswick, N.J.	29-00139-02
	E.R. Squibb and Sons, Inc.	Lawrenceville & Three Bridges, N.J.	29-00139-02
	Technical Operations	Burlington, MA	20-00277-03
	*U.S. RadiCorp.	Bloomsburg, PA	37-00030-08
	Monsanto Research Crop.	Dayton, OH	SNM-567
	*Westinghouse Electric Corp.	Pittsburgh, PA	SNM-770
	Westinghouse Electric Corp.	Pittsburgh, PA	SNM-1460
2	Alaska Industrial X-ray	Anchorage, AK	50-16084-01
	Allis Chalmers	York, PA	37-16382-01
	*Combustion Engineering, Inc.	Tulsa, OK	35-02325-02
	Industrial Gamma Inspection	Blackwell, OK	35-16760-01
	Newport Shipbuilding and Dry Dock Co.	Newport News, VA	45-09428-02
	Teledyne Isotopes, Inc.	Westwood, N.J.	29-00055-14
3	*Amersham Corp.	Arlington Heights, IL	12-12836-02
	Amersham Corp.	Arlington Heights, IL	12-12836-03MD
	Amersham Corp.	Arlington Heights, IL	12-12836-04G
	Amersham Corp.	Arlington Heights, IL	2-12836-05MD
	*Combustion Engineering, Inc.	Tulsa, OK	35-02325-02
	Arnold Greene Testing Labs, Inc.	Natick, MA	20-01074-02
	*Medi Physics, Inc.	Arlington Heights, IL	12-13813-01
	Bill Miller X-ray, Inc.	Tulsa, OK	35-15112-01
	*Minnesota Mining and Manufacturing	St. Paul, MN	22-00057-07
	*Picker Corp.	Cleveland, OH	34-07225-04
	*Picker Corp.	Cleveland, OH	34-07225-15
	*U.S. Radium Corp.	Bloomsburg, PA	37-00030-09G
	*U.S. Radium Corp.	Bloomsburg, PA	37-00030-10G
	*Westinghouse Electric Corp.	Pittsburgh, PA	37-00497-09

*Multiple licenses for this company were examined.

Table 4A. A sampling of industrial license limits [a,b] (curies) for byproduct and SMN materials. Beta-gamma emitters with license limits ≥ 20 Ci for 1 or more licenses examined. Nuclides listed by atomic number.

Nuclides	All Licenses		Byproduct License		SNM Licenses		Annual U.S. Shipments [c]	
	Total	Max. Single Licenses	Total	Max. Single Licenses	Total	Max. Single Licenses	Total	Max. Single Shipment [d]
^{3}H	223,204	100,000	223,204	100,000	0	0	221,000	4,400
^{14}C	324	200	324	200	0	0	237	3
^{32}P	411	300	411	300	0	0	1,885	20
^{35}S	1,110	1,000	1,100	1,000	0	0	23	3
^{51}Cr	112	100	112	100	0	0	53	3
^{55}Fe	100	100	100	100	0	0	281	200
^{60}Co [e]	2,368,000	2,105,000	2,368,000	2,105,000	251	250	2,520,000	32,000
^{63}Ni	500	500	500	500	0	0	5.2	3
^{75}Se	313	200	313	200	0	0	134	3
^{85}Kr	11,555	10,000	11,555	10,000	0	0	28,000	28,000
^{90}Sr	3,769	3,000	3,519	3,000	250	250	150	200
^{99}Mo	17,010	10,000	17,010	10,000	0	0	406,000	200
^{99m}Tc	15,000	10,000	15,000	10,000	0	0	170,000	3,300
^{99}Tc	0	0	0	0	0	0	4.3	3

Table 4A. A sampling of industrial license limits [a,b] (curies) for byproduct and SMN materials. Beta-gamma emitters with license limits $\geq$ 20 Ci for 1 or more licenses examined. Nuclides listed by atomic number (Continued)

Nuclides	All Licenses		Byproduct License		SNM Licenses		Annual U.S. Shipments [c]	
	Total	Max. Single Licenses	Total	Max. Single Licenses	Total	Max. Single Licenses	Total	Max. Single Shipment [d]
^{113m}In	50	50	50	50	0	0	N/A	N/A
^{113}Sn	51.1	50	51.1	50	0	0	17	3
^{125}Sn	25	25	25	25	0	0	N/A	N/A
^{124}Sb	50.2	50	0.2	0.2	50	50	N/A	N/A
^{125}I	88	50	88	50	0	0	374	20
^{131}I	801	500	801	500	0.2	0.2	9,106	200
^{131m}Xe	20	20	20	20	0	0	N/A	N/A
^{133m}Xe	25	25	25	25	0	0	N/A	N/A
^{133}Xe	1,274	1,000	1,274	1,000	0	0	29,600	1,000
^{137}Cs	70,044	40,000	69,844	40,000	200	200	32,000	15,000
^{147}Pm	20,070	15,000	20,000	15,000	70	70	13,600	3,200
^{170}Tm	5,035	5,000	5,035	5,000	0	0	54	200
^{169}Yb	100	100	100	100	0	0	307	20
^{182}Ta	200	200	200	200	0	0	3.6	3

Table 4A. A sampling of industrial license limits [a,b] (curies) for byproduct and SMN materials. Beta-gamma emitters with license limits $\geq$ 20 Ci for 1 or more licenses examined. Nuclides listed by atomic number (Continued)

Nuclides	All Licenses		Byproduct License		SNM Licenses		Annual U.S. Shipments [c]	
	Total	Max. Single Licenses	Total	Max. Single Licenses	Total	Max. Single Licenses	Total	Max. Single Shipment [d]
^{183}Ta	200	25	25	25	0	0	N/A	N/A
^{192}Ir [e]	62,550	25,000	62,550	25,000	0	0	8,300,000	80,000
^{198}Au	200.2	200	200.2	200	0	0	2,446	20
^{204}Tl	50	50	0	0	50	50	2.6	3
^{210}Bi	250	200	200	200	50	50	N/A	N/A
^{227}Ac [f]	25+	25	25+	25	0	0	N/A	N/A
^{242}Cm [f]	600+	600	0.02	0.02	600	600	1.8	3

Footnotes for Table 4A

a. For broad scope licenses we have assumed 0 curies of each nuclide unless a specific value is given in the license.

b. For cases where a license states X curies/sealed source we have assumed there are 5 such sources and hence an effective license limit of 5X curies.

c. U.S. Transportation data for March 1974 through February 1975 are from Simmons et al. (1976).

d. Where maximum shipment size has been listed as >1,000 Ci, we have assumed the maximum shipment size to be given by

$$S = 2\left[\frac{\text{(Total curies)} - (1{,}000 \times \text{No. shipments of } 200 - 1{,}000 \text{ Ci})}{\text{No. shipments} > 1{,}000 \text{ Ci}}\right]$$

Where maximum shipment size has been listed as A to B Ci, we have assumed the larger limit.

e. Recent NRC licenses permit ^{60}Co and ^{192}Ir sealed sources to exceed nominal source strengths by 10% and 20% respectively. We have used the larger values as effective license limits.

f. Although these nuclides are themselves beta particle emitters, their greatest radiobiological effect is probably from alpha particles emitted by their short-lived daughter nuclei.

Table 4B. A sampling of industrial license limits[a,b] (curies) for byproduct and SNM materials. Alpha emitters with license limits ≥ 0.01 Ci for 1 or more licenses examined. Nuclides listed by atomic numbers.

Nuclide	All Licenses		Byproduct Licenses		SNM Licenses		Annual U.S. Shipments[c]	
	Total	Max. Single License	Total	Max. Single License	Total	Max. Single License	Total	Max. Single Shipment[d]
^{208}Po	1.01	0.01	0.01	0.01	0	0	N/A	N/A
^{210}Po	7,016	4,000	4,016	4,000	3,000	3,000	1,756	1,000
^{227}Ac[e]	25+	25	25+	25	0	0	N/A	N/A
^{228}Th	50	50	50	50	0	0	?	0.001
^{234}U	13.1	7.7	0	0	13.1	7.7	N/A	N/A
^{235}U	1.09	0.79	0	0	1.09	0.79	600	3
^{238}U	12.7	7.3	1.4	1.4	11.3	7.3	11,140	3
^{237}Np	0.12	0.1	0.02	0.02	0.1	0.1	0.03	3
^{238}Pu	147,009	140,000	8.7	8.7	147,000	140,000	N/A	N/A
^{239}Pu	25,203	24,000	2.0	2.0	25,000	24,000	18,140	200
^{240}Pu	4,720	4,500	0	0	4,720	4,500	13	20
^{241}Am	7,854	6,000	1,859	1,000	6,000	6,000	29,507	1,000
^{242}Cm[e]	600+	600	0.02	0.02	600	600	1.8	3
^{243}Cm	10	10	0	0	10	10	N/A	N/A
^{244}Cm	600.5	600	0.5	0.5	600	600	242	20
^{252}Cf	5.9	5.4	0.54	0.54	5.4	5.4	420	20

Footnotes for Table 4B

a. For broad scope licenses we have assumed 0 Curies of each unless a definite value is given in the license.

b. For cases where a license states X curies/sealed source we have assumed there are 5 such sources and hence an effective license limit of 5X curies.

c. U.S. transportation data from March 1974 through February 1975 taken from Simmons, et al. (1976).

d. Where maximum shipment size has been listed as A to B curies, we have assumed the greater limit.

e. Although these nuclei are themselves beta particle emitters, their greatest radiological effectis probably from alpha particles emitted by short-lived daughter nuclei.

Table 5. Comparison of radionuclides selected by licenses and by annual shipping records. (See Text.) Po and all the higher Z nuclides are essentially alpha emitters. Nuclides are listed b atomic number.

Nuclide	Inclusion by License	Inclusion by Shipping	Approx. Half-life (y)	Nuclide	Inclusion by License	Inclusion by Shipping	Approx. Half-life (y)
^{3}H	X	X	12	^{90}Sr	X	X	28
^{14}C	X		5,700	^{99}Mo	X	X	0.008
^{18}F		X	0.0002	^{99}Tc	X	X	0.0007
^{24}Na		X	0.0017	^{99}Tc	X	X	210,000
^{28}Mg		X	0.0024	^{113m}In	X		0.0002
^{32}P	X		0.039	^{113}Sn	X		0.31
^{35}S	X		0.24	^{125}Sn	X		0.026
^{51}Cr	X		0.076	^{124}Sb	X		0.17
^{54}Mn		X	0.83	^{125}I	X		0.16
^{55}Fe	X	X	2.6	^{131}I	X	X	0.022
^{60}Co	X	X	5.3	^{131m}Xe	X		0.032
^{63}Ni	X		92	^{133m}Xe	X		0.006
^{67}Ga		X	0.009	^{133}Xe	X	X	0.014
^{75}Se	X		0.33	^{137}Cs	X	X	30
^{85}Kr	X	X	11	^{147}Pm	X	X	2.5

Table 5. Comparison of radionuclides selected by licenses and by annual shipping records. (See Text.) Po and all the higher Z nuclides are essentially alpha emitters. Nuclides are listed by atomic number. (Continued)

Nuclide	Inclusion by License	Inclusion by Shipping	Approx. Half-life (y)	Nuclide	Inclusion by License	Inclusion by Shipping	Approx. Half-life (y)
^{170}Tm	X		0.35	^{234}U	X		250,000
^{169}Yb	X		0.088	^{235}U	X	X	7×10^{8}
^{182}Ta	X		0.31	^{238}U	X	X	4.5×10^{9}
^{183}Ta	X		0.014	^{237}Np	X		2×10^{6}
^{192}Ir	X	X	0.20	^{238}Pu	X	X	86
^{198}Au	X		0.0074	^{239}Pu	X	X	24,000
^{204}Tl	X		3.8	^{240}Pu	X	X	6,600
^{210}Bi	X		370,000	^{241}Pu		X	13
^{208}Po	X		2.9	^{242}Pu		X	380,000
^{210}Po	X	X	0.38	^{244}Pu		X	8×10^{7}
^{227}Ac[a]	X		22	^{241}Am	X	X	460
^{228}Th	X		1.9	^{242}Cm[a]	X		0.45
^{232}Th		X	1.4×10^{10}	^{243}Cm	X		32
^{232}U		X	74	^{244}Cm	X		18
^{233}U		X	160,000	^{252}Cf	X		2.7
			Total	60	49	31	

[a]These nuclei are themselves beta emitters, but their greatest radiobiological effect is probably from alpha particles emitted by short-lived daughter nuclei.

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