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OAK RIDGE NATIONAL LABORATORY

MARTIN MARIETTA

Source Inventory Limits

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OPERATED BY
MARTIN MARIETTA ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

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Health and Safety Research Division

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CONTENTS

ABSTRACT 1

INTRODUCTION 1

MANAGEMENT OF RADIOACTIVE SOURCES 2

SOURCE INVENTORY LIMITS 5

DISCUSSION 14

REFERENCES 15

SOURCE INVENTORY LIMITS

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ABSTRACT

A new set of values has been developed for exempting sealed sources of radioactive materials from inventory. The criteria for exemption are (a) the annual occupational dose from external radiation at 1 m from the source is approximately 10 mrem (100 μSv) or less, and (b) the source activity was approximately equal to the annual limit on intake by inhalation or less than 1000 μCi (4×10^7 Bq). These criteria were selected to correspond to an annual occupational dose of approximately 5 to 50 mrem and a small potential annual risk of approximately 1×10^{-6} to 1×10^{-5} fatal cancers or less.

INTRODUCTION

It is the policy of Martin Marietta Energy Systems, Inc., that sources of radioactive materials which are authorized for use in operations or experiments be handled in accordance with all orders and directives of the U.S. Department of Energy (DOE). This policy includes both sealed or unsealed sources. It is also a policy to maintain an inventory of all sealed sources of radioactive materials that might pose a significant health hazard to employees. All sealed sources must be labeled for easy identification and assigned to individuals who are trained to use the sources in a safe manner.

Currently, Martin Marietta Energy Systems, Inc., operates five facilities under contract with DOE. These include three facilities in Tennessee (the Oak Ridge National Laboratory, the Y-12 Plant, and the Oak Ridge Gaseous Diffusion Plant), one facility in Kentucky (the Paducah Gaseous Diffusion Plant), and one facility in Ohio (the Portsmouth Gaseous Diffusion Plant). Each of these facilities has its own source inventory system, based on its own unique history, needs, and resources. The work discussed in this report is a step toward the development and implementation of a standardized inventory system for sealed sources at all DOE facilities operated by Martin Marietta Energy Systems, Inc.

MANAGEMENT OF RADIOACTIVE SOURCES

The management of radioactive materials involves the control of radiation exposure to all sources of radioactive materials, whether sealed or unsealed (International Commission on Radiological Protection, 1977a). Good management also requires that an inventory be maintained for sealed sources because they are assigned typically to individual users for unspecified and long periods of time (see Figure 1). The specific procedures developed for the inventory and control of sealed radioactive sources may also be applied to several other types of radioactive sources that are not technically "sealed" but may be treated as such (International Commission on Radiological Protection, 1977; International Commission on Radiological Protection, 1970; National Bureau of Standards, 1960). An example is an emitter of either alpha or beta particles that has been electroplated on a metallic planchet for use in the calibration or checking of instruments.

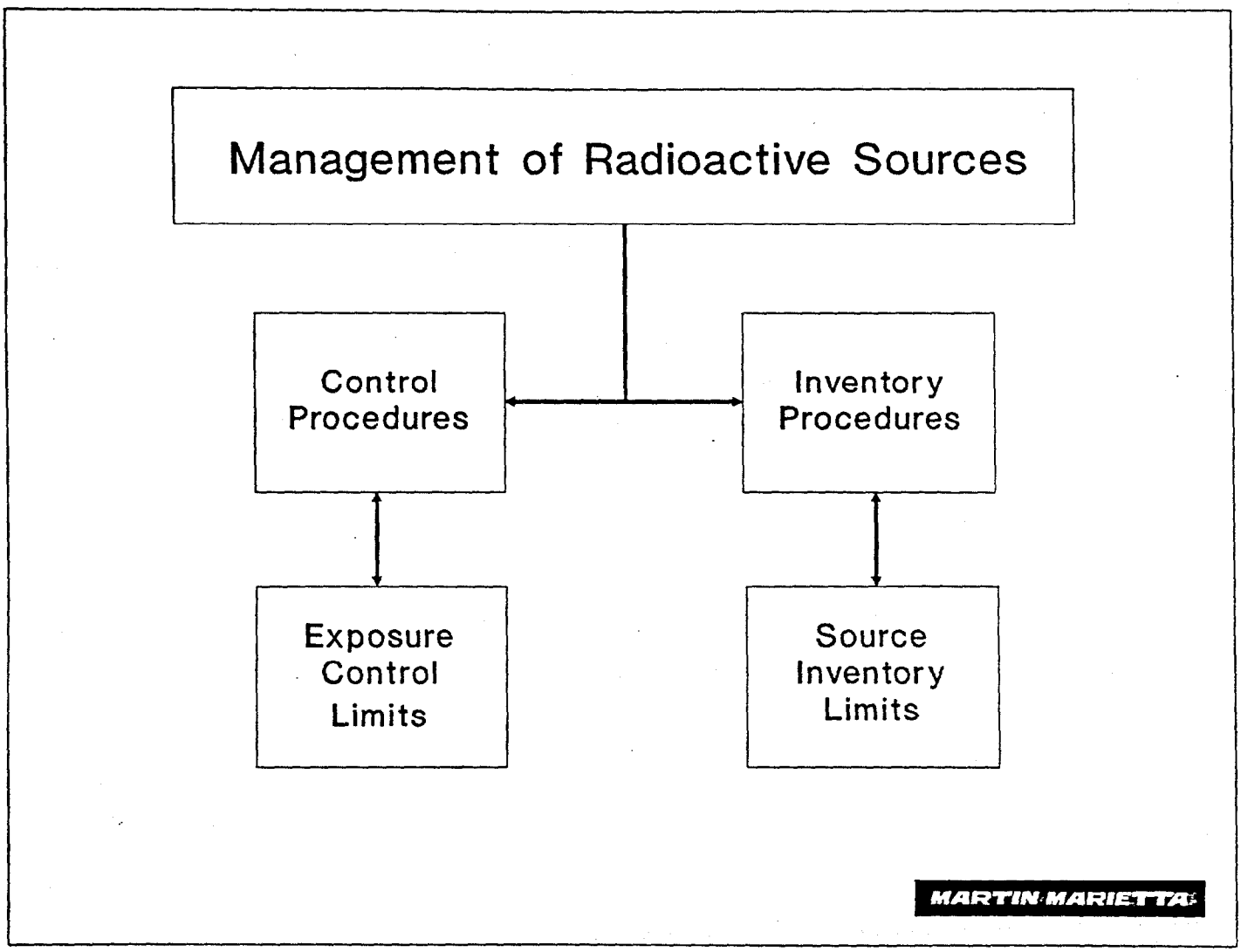

Figure 1. Inventory is a vital first set in the management and control of exposures to sealed sources of radioactive materials.

A sealed source is defined here as a discrete amount of radioactive material that is either bonded wholly within an inactive material, sealed in an inactive container or capsule, or plated on an inactive material, so as to prevent dispersion of the radioactive material during routine use. In the presence of gaseous radioisotopes, a source would be regarded as sealed only if the container or capsule is gastight (International Commission on Radiological Protection, 1960; National Bureau of Standards, 1978). Plated sources usually represent a somewhat greater potential for contamination than sealed sources, but less potential than the same amount of material in unsealed dispersible forms (International Commission on Radiological Protection, 1977a).

Sealed sources may have activities ranging from several hundreds of curies for research to nanocurie levels for calibration and checking of instruments. Because sealed sources are usually fabricated for a specific purpose and assigned to individuals who are trained to use the sources in a safe manner, it is not considered necessary to inventory sealed sources that have very small activity levels or reasonable to inventory sealed sources that contain radioactive materials with half lives of less than one month (30 days). It is also considered neither reasonable nor necessary to inventory sealed sources of radioactive materials that have been approved for use in consumer products, such as smoke detectors, static eliminators, and self-luminous signs (National Council on Radiation Protection and Measurements, 1977; National Bureau of Standards, 1978; Federal Code of Regulations, 1987). It needs to be emphasized, however, that exemption of a source from inventory does not imply that it is also exempt from radiation protection controls.

SOURCE INVENTORY LIMITS

In practice, radiological protection guidance is needed in more readily measurable quantities than the primary limits on dose equivalent (National Council on Radiation Protection and Measurements, 1987). Guidance values of this type are normally called either secondary limits or derived working limits (Dunster and Johns, 1972). Such limits were established in this work for the exemption of sealed sources from inventory (see Table 1); the derived limits were based on considerations of the risk resulting from incorporation of radioactivity into the body or from external radiation that is deemed acceptable (International Commission on Radiological Protection, 1977b).

One widely used set of values for exempting sources from inventory can be found in Appendix C of 10CFR-Part 20 (Code of Federal Regulations, 1987). There is reasonable doubt concerning the exact origin of these values, but they appear to have been established as follows: (a) the annual occupational dose from external radiation at 1 m from the source was 10 mrem (100 μSv) or less, and (b) the source activity was equal to a maximum permissible body burden for the radionuclide or less than 1000 μCi (4×10^7 Bq). The maximum permissible body burdens for critical organs appear to be taken primarily from ICRP Publication 2 (International Commission on Radiological Protection, 1959).

A newer system for exempting sealed sources from inventory was developed in this work using data for annual limits on intake (ALIs) by inhalation from ICRP Publication 30 (International Commission on Radiological Protection, 1979a, 1979b, 1980, 1981a, 1981b, 1982a,

Table 1. Values for exemption of sealed sources from inventory.

Isotope	Half-life	Annual Limit on Intake (μCi)	Annual dose of 10 mrem at 1 m (μCi)	Inventory value (μCi)
H-3	12.35 y	8E+4	0	1000
Be-7	53.3 d	2E+4	900	1000
Be-10	1.6E+6 y	10	0	10
C-14	5730 y	2000	0	1000
Na-22	2.602 y	600	5	10
Al-26	7.16E+5 y	60	4	10
Si-32	450 y	5	0	10
S-35	87.44 d	2000	0	1000
Cl-36	3.01E+5 y	200	6E+4	100
K-40	1.28E+9 y	400	70	100
Ca-41	1.4E+5 y	4000	0	1000
Ca-45	163 d	800	1E+7	1000
Sc-46	83.83 d	200	20	10
Ti-44	47.3 y	6	4	10
V-49	330 d	2E+4	0	1000
Mn-53	3.7E+6 y	1E+4	0	1000
Mn-54	312.5 d	800	20	10
Fe-55	2.7 y	2000	0	1000
Fe-59	44.529 d	300	50	100
Fe-60	1.0E+5 y	6	60	10
Co-56	78.76 d	200	10	10
Co-57	270.9 d	700	90	100
Co-58	70.80 d	700	40	100
Co-60	5.271 y	30	4	10
Ni-59	7.5E+4 y	2000	0	1000
Ni-63	96 y	800	0	1000
Zn-65	243.9 d	300	30	10
Ge-68	288 d	100	10	10
As-73	80.30 d	2000	400	1000
Se-75	119.8 d	600	40	100
Se-79	6.5E+4 y	600	0	1000
Rb-83	86.2 d	1000	30	10
Rb-84	32.77 d	800	60	100
Rb-87	4.7E+10 y	2000	0	Unlimited
Sr-85	64.84 d	2000	40	100
Sr-89	50.5 d	100	6E+5	100
Sr-90	29.12 y	4	1E+5	10
Y-88	106.64 d	200	10	10
Y-91	58.51 d	100	1E+4	100
Zr-88	83.4 d	200	10	10
Zr-93	1.53E+6 y	6	4E+3	10
Zr-95	63.98 d	100	50	100

Table 1 - Continued.

Isotope	Half-life	Annual Limit on Intake (μCi)	Annual dose of 10 mrem at 1 m (μCi)	Inventory value (μCi)
Nb-93m	13.6 y	200	100	100
Nb-94	2.03E+4 y	200	6	10
Nb-95	35.15 d	1000	90	100
Mo-93	3.5E+3 y	200	20	10
Tc-95m	61 d	2000	30	10
Tc-97	2.6E+6 y	6000	20	10
Tc-97m	87 d	1000	80	100
Tc-98	4.2E+6 y	300	7	10
Tc-99	2.13E+5 y	700	0	1000
Ru-103	39.28 d	600	100	100
Ru-106	368.2 d	10	60	10
Rh-101	3.2 y	200	10	10
Rh-102	2.9 y	60	4	10
Rh-102m	207 d	100	20	10
Pd-107	6.5E+6 y	400	0	1000
Ag-105	41.0 d	1000	90	100
Ag-108m	127 y	20	5	10
Ag-110m	249.9 d	90	6	10
Cd-109	464 d	40	6	10
Cd-113	9.3E+15 y	2	0	Unlimited
Cd-113m	13.6 y	2	0	1
In-114m	49.51 d	60	300	100
In-115	5.1E+15 y	1	0	Unlimited
Sn-113	115.1 d	500	50	100
Sn-119m	293.0 d	1000	100	100
Sn-121m	55 y	500	200	100
Sn-123	129.2 d	200	3E+3	100
Sn-126	1.0E+5 y	60	5	10
Sb-124	60.20 d	200	20	10
Sb-125	2.77 y	500	20	10
Te-121m	154 d	200	20	10
Te-123	1.0E+13 y	200	50	Unlimited
Te-123m	119.7 d	200	100	100
Te-125m	58 d	400	100	100
Te-127m	109 d	300	300	100
Te-129m	33.6 d	200	800	100
I-125	60.14 d	60	100	100
I-129	1.57E+7 y	9	50	10
Cs-134	2.062 y	100	7	10
Cs-135	2.3E+6 y	1000	0	1000
Cs-137	30.0 y	200	20	10
Ba-133	10.74 y	700	20	10

Table 1 - Continued.

Isotope	Half-life	Annual Limit on Intake (μCi)	Annual dose of 10 mrem at 1 m (μCi)	Inventory value (μCi)
La-137	6.0E+4 y	60	100	100
La-138	1.35E+11 y	4	8	10
Ce-139	137.66 d	700	100	100
Ce-141	32.501 d	600	1E+3	1000
Ce-144	284.3 d	10	500	10
Pm-143	265 d	600	40	100
Pm-144	363 d	100	8	10
Pm-145	17.7 y	200	100	100
Pm-146	5.53 y	40	10	10
Pm-147	2.6234 y	100	2E+6	100
Pm-148m	41.3 d	300	30	10
Sm-145	340 d	500	80	1000
Sm-146	1.03E+8 y	0.04	0	0.1
Sm-147	1.06E+11 y	0.04	0	0.1
Sm-151	90 y	100	2E+5	100
Eu-148	54.5 d	400	20	10
Eu-149	93.1 d	3000	200	100
Eu-150	34.2 y	20	6	10
Eu-152	13.33 y	20	8	10
Eu-154	8.8 y	20	8	10
Eu-155	4.96 y	90	100	100
Gd-146	48.3 d	100	20	10
Gd-148	93 y	0.008	0	0.01
Gd-151	120 d	400	200	100
Gd-152	1.08E+14 y	0.01	0	Unlimited
Gd-153	242 d	100	90	100
Tb-157	150 y	300	2E+3	100
Tb-158	150 y	20	10	10
Tb-160	72.3 d	200	30	10
Dy-159	144.4 d	2000	200	100
Ho-166m	1.20E+3 y	7	5	10
Tm-170	128.6 d	200	4E+3	100
Tm-171	1.92 y	300	1E+4	100
Yb-169	32.01 d	700	200	100
Lu-173	1.37 y	300	80	100
Lu-174	3.31 y	100	80	100
Lu-174m	142 d	200	200	100
Lu-176	3.60E+10 y	5	20	10
Lu-177m	160.9 d	80	20	10
Hf-172	1.87 y	9	6	10
Hf-175	70 d	900	90	100
Hf-178m	31 y	1	4	1

Table 1 - Continued.

Isotope	Half-life	Annual Limit on Intake (μCi)	Annual dose of 10 mrem at 1 m (μCi)	Inventory value (μCi)
Hf-181	42.4 d	200	100	100
Hf-182	9.0E+6 y	0.8	10	1
Ta-179	664.9 d	900	200	100
Ta-180	1.0E+13 y	20	20	Unlimited
Ta-182	115.0 d	100	20	10
W-181	121.2 d	3E+4	400	1000
W-185	75.1 d	7000	4E+5	1000
W-188	69.4 d	1000	500	1000
Re-184	38.0 d	1000	70	100
Re-184m	165 d	400	20	10
Re-186m	2.0E+5 y	200	50	100
Re-187	5.0E+10 y	1E+5	0	Unlimited
Os-185	94 d	500	30	10
Os-194	6.0 y	8	90	10
Ir-192	74.02d	200	40	100
Ir-192m	241 y	20	10	10
Ir-194m	171 d	90	7	10
Pt-193	50 y	2E+4	100	100
Au-195	183 d	400	80	100
Hg-194	260 y	30	8	10
Hg-203	46.6 d	800	200	100
Tl-204	3.779 y	2000	4E+3	1000
Pb-202	3.0E+5 y	50	20	10
Pb-205	1.43E+7 y	1000	90	100
Pb-210	22.3 y	0.2	70	0.1
Bi-207	38 y	400	6	10
Bi-210m	3.0E+6 y	0.7	30	1
Po-210	138.38 d	0.6	2E+6	1
Ra-226	1600 y	0.6	6	1
Ra-228	5.75 y	1	7	1
Ac-227	21.773 y	4E-4	700	0.001
Th-228	1.9131 y	0.01	8	0.01
Th-229	7340 y	9E-4	9	0.001
Th-230	7.7E+4 y	0.006	200	0.01
Th-232	1.405E+10 y	0.001	70	0.001
Pa-231	3.276E+4 y	0.002	20	0.001
U-232	72 y	0.008	30	0.01
U-233	1.585E+5 y	0.04	200	0.1
U-234	2.445E+5 y	0.04	100	0.1
U-235	7.038E+8 y	0.04	10	0.1
U-236	2.3415E+7 y	0.04	100	0.1
U-238	4.468E+9 y	0.04	70	0.1

Table 1 - Continued.

Isotope	Half-life	Annual Limit on Intake (μCi)	Annual dose of 10 mrem at 1 m (μCi)	Inventory value (μCi)
Np-235	396.1 d	800	50	100
Np-236	1.15E+5 y	0.02	10	0.01
Np-237	2.14E+6 y	0.004	10	0.01
Pu-236	2.851 y	0.02	100	0.01
Pu-237	45.3 d	3000	100	100
Pu-238	87.74 y	0.007	100	0.01
Pu-239	24065 y	0.006	300	0.01
Pu-240	6537 y	0.006	100	0.01
Pu-241	14.4 y	0.3	2E+5	0.1
Pu-242	3.763E+5 y	0.007	200	0.01
Pu-244	8.26E+7 y	0.007	10	0.01
Am-241	432.2 y	0.006	20	0.01
Am-242m	152 y	0.006	50	0.01
Am-243	7380 y	0.006	10	0.01
Cm-241	32.8 d	30	6	10
Cm-242	162.8 d	0.3	300	0.1
Cm-243	28.5 y	0.009	20	0.01
Cm-244	18.11 y	0.01	100	0.01
Cm-245	8500 y	0.006	20	0.01
Cm-246	7430 y	0.006	200	0.01
Cm-247	1.56E+7 y	0.006	20	0.01
Cm-248	3.39E+5 y	0.002	40	0.001
Cm-250	6900 y	3E-4	5	0.001
Bk-247	1380 y	0.004	40	0.01
Bk-249	320 d	2	8E+6	1
Cf-248	333.5 d	0.06	300	0.1
Cf-249	350.6 y	0.004	20	0.01
Cf-250	13.08 y	0.009	200	0.01
Cf-251	898 y	0.004	20	0.01
Cf-252	2.638 y	0.02	90	0.01
Cf-254	60.5 d	0.02	20	0.01
Es-254	275.7 d	0.07	10	0.1
Fm-257	100.5 d	0.2	6	0.1
Md-258	55 d	0.2	6E+6	0.1

1982b, 1988). The ALIs in Publication 30 (which supersede those in Publication 2) incorporate the considerable advances in the state of knowledge of radionuclide dosimetry and biological transport in humans in the past few decades (Eckerman et al., 1988). They also reflect the transition from limitation based on dose in the critical organ of the body to limitation based on doses to all organs at radiological risk (International Commission on Radiological Protection, 1977b).

A major part of this effort involved calculation of the annual occupational dose for a worker exposed to external radiation from a sealed source. The annual dose equivalent to the worker was calculated assuming that the worker was exposed continuously at 1 m from the source for 2000 h (i.e., 40 hours per week times 50 weeks per year) and there was no attenuation of radiation within the source (i.e., the source could be treated as a point source). It was also assumed that only the parent radionuclude was present initially (see 1st column of Table 1). The calculations were then made to reflect the dependence of the dose rate on time due to the decay of the parent radionuclide and the ingrowth of any daughter radionuclides over the period of a year. Information on the energies and intensities of the gamma and x-rays emitted by the radionuclides, their half lives, and identification of all daughter radionuclides was taken from ICRP Publication 38 (International Commission on Radiological Protection, 1983).

Table 1 provides a set of new source inventory limits that incorporates state-of-the-art dosimetry and still maintains the spirit of Appendix C in 10CFR-Part 20 (Code of Federal Regulations, 1987). These newer inventory limits for sealed sources with half lives of thirty days or more were established as follows: (a) the annual

occupational dose from external radiation at 1 m from the source was approximately 10 mrem (100 μSv) or less, and (b) the source activity was approximately equal to the most restrictive value of the ALI for inhalation of any compound of the radionuclide or less than 1000 μCi (4×10^7 Bq). In a few instances, however, the inventory value is listed as unlimited because of the extremely low specific activity of the source material (e.g., 1000 μCi of Rb-87 has a mass of approximately 10 kg and 20 μCi of Ta-180 has a mass of nearly 100 kg). If the inventory value is less than 1000 μCi, then it was obtained by decade rounding (e.g., 3 or less was rounded downward to 1, and 4 or more was rounded upward to 10).

The annual whole-body dose of 10 mrem for external radiation from a sealed source was based on exposure at 1 m for 2000 h (i.e., 40 hours per week times 50 weeks in a year). This corresponds to a dose equivalent rate of 0.005 mrem/h at 1 m or 0.05 mrem/h at 30 cm (see Figure 2). Thus, the source inventory limit for external radiation from a sealed source is approximately 100 less than the exposure control limit of 5 mrem/h at 30 cm in DOE Order 5480.11 (U.S. Department of Energy, 1988). The exposure control limit for internal exposure, the ALI, corresponds to an effective dose equivalent of 5 rem (Figure 2). It is expected that less than 1 percent of the radioactive material would be dispersed or inhaled in an accident involving either a sealed or plated source (International Atomic Energy Agency, 1987). Thus, the source inventory limit for internal radiation would correspond to about 5 to 50 mrem of dose equivalent to the total body or about 100 to 1000 times less than the exposure control limit (Figure 2). A dose equivalent of 5 to 50 mrem to the total body represents an overall risk

Type of hazard	Exposure control limit*	Source inventory limit
External	Dose rate of 5 mrem/h at 30 cm	Annual dose of 10 mrem at 1 m
Internal	Annual dose of 5 rem	Annual dose of 5 to 50 mrem

*DOE Order 5480.11 (12/21/88)

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Figure 2. Comparision of limits for control and inventory of sealed sources.

of between 1×10^{-6} and 1×10^{-5} fatal cancers (International Commission on Radiological Protection, 1977b; Committee on Biological Effects of Ionizing Radiation, 1989).

DISCUSSION

Inventory is a vital first step in the management and control of sealed radioactive sources. The purpose of this work was to develop inventory limits (exempt levels); control strategies for sealed sources with activity levels above these exempt levels (see Table 1) is the objective of a separate effort. It is recommended, however, that a reasonable minimum level of control might be an annual verification request to each person responsible for a nonexempt source to ascertain that he (or she) still has the source in his (or her) possession. This level of control is similar to other inventories such as those applied to tools and precious metals. For many sealed sources with low activity levels, this minimum level of control may be all that is needed. For some nonexempt sources with higher activity levels, additional control procedures would need to be performed on a routine basis by a health physicist (and/or radiation safety officer). These control procedures might include such items as a physical inspection of the sealed source, leak testing, and external radiation surveys about the sealed source and its storage area. Finally, it needs to be restated that exemption of a source from inventory does not imply that the source is also exempted from radiation protection controls.

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