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October 5, 1988

Rec'd 10-7-88 C Jones.

Ms. Cynthia Jones
U.S. Nuclear Regulatory Commission
Medical, Academic and Commercial Use Safety Branch
Mail Stop OWFN-6H3
Washington, DC 20555

Dear Ms. Jones:

In reference to our 9/21/88 telephone conversation, I am enclosing draft sections of MURR's gemstone license submittal describing the exemption requests which assess dose estimates and health risks due to wearing gemstones released to unlicensed persons. I would appreciate your preview of these sections and any suggestions for clarification you may see. Also enclosed are copies of some of the references and spreadsheets I have used in making these calculations. These sections will be incorporated into our total submittal, so section numbers, table numbers, appendix labels, and reference numbers may change from this draft. As per your request, I have enclosed our current organizational chart.

Please contact me if you have any questions on this material and we can "walk through" the specific areas in question. Thank you for your assistance.

Sincerely,

Susan M. Langhorst

Susan M. Langhorst, Ph.D., CHP
Manager
Reac Health Physics

SML/mbs

Enclosures

cc. B. Reilly

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AA. Information to Support Request for Exemption from Portion 10 CFR 32.11(c)

If NRC considers gemstones to be products intended for application to human beings, then an exemption from this portion of the requirements in 10 CFR 32.11(c) is requested. The level of radiation emitted from these gemstones is of insignificant health risk to unlicensed persons.

The following dose calculations have been based on topaz (ρ= 3.5 g/cm^3) with the assumption that the gemstone is a sphere having a homogenous exempt concentration for one isotope at first day of wear. Calculations are made considering a worst case scenario which is conservative but realistic in its estimate. An NRC required assumption for these calculations is that the gemstone is worn 24 hours per day, 365 days per year. The dose for the first year of wear is calculated using the initial dose rate and accounting for the decay of the radioisotope.

Three geometries are considered for the external dose calculations. In all calculations, a gemstone of five grams is assumed to provide the largest reasonable total activity for a gemstone worn for the prescribed time period.

Geometry 1 --The first geometry considered has the gemstone in contact with the skin (see Figure 1). The shallow dose is determined for one point assuming the gemstone is above this point 15% of the time. This geometry is designed to simulate a pendent setting for the gemstone. Dose due to beta, conversion electron, and gamma radiations are estimated where applicable.

Geometry 2 --The second geometry considered has the gemstone in a setting, fixed at one point three millimeters above the skin. This geometry is designed to simulate a ring or earring setting. Shallow dose is determined from gamma radiation only. Betas and conversion electrons are assumed to be absorbed by the setting.

Geometry 3 --The third geometry considered has the gemstone fixed at one point. The deep dose is determined from gamma radiation only at a point four centimeters below the skin.

Beta dose estimates are calculated using assumptions which simplify the equation but still provide conservatism. Not all of the betas emitted from decay in the gemstone can escape. Therefore, only that amount of activity on the surface of the gemstone that allows this escape is considered in the beta dose calculation. The depth from which betas are assumed to emerge is that distance, based on the stopping power of the average beta energy, which would reduce the average beta energy to 70 keV, the energy of beta which can no longer penetrate the dead layer of the skin.[1]

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[1]The Health Physics and Radiological Health Handbook, B. Shleien and M.S. Terpilak (1984), p. 35.

One half of the betas are assumed to be emitted perpendicular to the surface of the gemstone. The beta emissions are in reality isotropic and have a greater probability of being absorbed in the gemstone. This irradiation geometry assumed for the beta dose calculation is described in Figure 1. Only that section of the outer gemstone layer which can emit betas capable of penetration to a depth of 0.007 cm below the surface of the skin is considered in the dose calculation. The surface area of irradiated skin is defined by the radius, r_2. No attenuation of the betas leaving the stone layer is assumed and each beta is assumed to be at the average beta energy. In calculating the first year beta dose, all the energy of the emitted betas is assumed to be deposited in the first gram of live tissue beneath the area of the irradiated skin surface. The contribution of conversion electrons to the shallow dose estimate are included by modifying the average beta energy and/or the branching ratio where significant contribution is expected.

Gamma dose estimates are made assuming that no attenuation of the gammas occur in the gemstone and setting, or in traveling through tissue. The gamma flux is calculated for a point, "a" cm from the center of the gemstone, and assuming the gemstone is a homogeneous spherical source. The gamma dose is estimated from determining the total exposure at that point from the gemstone and assuming one roentgen is equal to one rem.

Equations used to calculate the dose estimates for the three geometries, based on the assumptions given above, are listed in Table 13. Input data for these equations are listed in Table 14 for the radionuclides found in MURR irradiated topaz which have not decayed away prior to release to unlicensed persons. An example calculation for Cs-134 is worked in Appendix A. Summary of the first year dose estimates for the three geometries is given in Table 15.

Considering the conservative assumptions, the dose estimates show that the wearing of gemstones adds little significant dose above background levels. The highest dose estimates were calculated for a gemstone having an exempt concentration of Co-60. This is the highest possible dose due to wearing a gemstone limited to exempt concentrations because the additional limit for the "sum of the ratios" must be below unity.

Data from recent NCRP Reports are used to assess the health risks to unlicensed persons. NCRP Report No. 91, "Recommendations on Limits for Exposure to Ionizing Radiation" (1987), recommends 5 rem/year as the shallow dose limit for nonoccupational exposure to members of the public. The highest shallow dose estimate for a 5 gram gemstone with exempt concentration of Co-60 is 307 mrem, or 6% of the recommended limit. From NCRP Report No. 93, "Ionizing Radiation Exposure of the Population of the United States" (1987), the annual effective dose equivalent in the U.S. from all sources is estimated to be 360 mrem/year (1 mrem/day), of which 83% is due to natural sources and 15% due to medical exposures. The actual doses can vary by 70 mrem/year, based only on differences in location. From NCRP Report No. 95, "Radiation Exposure of the U.S. Population from Consumer Products and Miscellaneous Sources" (1987), the average annual effective dose equivalent to the U.S. population from consumer products range from 6 - 13 mrem. Considering that these averages and variances are based on deep dose extimates, additional doses from wearing gemstones released under the MURR gemstone analysis criteria are well within these variations. Because there have been no observed health effects due to variations in annual dose from natural sources or consumer products, the health risk of wearing jewelry containing these gemstones is negligible.

BB. Information to Support Request for Exemption for Isotope Specific Exempt Concentrations Not Listed in 10 CFR 30.70

Four radionuclides found in MURR irradiated topaz do not have isotope specific entries in 10 CFR 30.70. An exemption is requested to develop isotope specific exempt concentration values by the same method existing values for exempt concentration were determined and apply these new isotope specific exempt concentrations to the MURR gemstone release criteria.

The exempt concentration table (10 CFR 30.70) was developed in the early 60s from calculations made by ICRP Committee II on MPC values in water for occupational exposure for a 168 hour week.[2] Three radionuclides found in MURR irradiated topaz (Na-22, Ce-139, and Pa-233) are restricted by the generic limit (1e-6 μCi/g), and one radionuclide (Ba-133) is not restricted by any entry in Table 30.70. With the advent of isotope specific data in the Proposed Change to 10 CFR 20, exempt concentrations for these radionuclides can be determined utilizing their corresponding ALIs and Reference Man data.

The isotope specific exempt concentration (C) is calculated as follows:

$$C = \frac{ALI}{(3000)(365)}$$

where, ALI = annual limit of intake for ingestion (μCi/y)

3000 = daily water intake for Reference Man (ml/d)

365 = days per year

The results for this calculation are given below:

Isotope	ALI (μCi/y)	C (μCi/g)
Na-22	400	4e-4
Ba-133	2000	2e-3
Ce-139	5000	5e-3
Pa-233	1000	9e-4

The dose estimates for these radionuclides listed in Table 15 are based on these calculated exempt concentrations. As noted in the previous section, the limiting radionuclide in these dose calculations is Co-60. Because the release limits based on exempt concentrations are also restricted by the "sum

[2]NRC Internal Memo from L.R. Rogers to J.R. Mason, dated February 1, 1960.

of the ratios" being less than unity, utilizing the calculated exempt concentrations for the radionuclides discussed here pose no additional dose hazard to unlicensed persons.

CC. Information to Support Request for Exemption from Exempt Concentration Limits for Gemstones of less than 0.25 grams

As gemstone sizes decrease, determination of activity concentration in each gemstone becomes more challenging. At some point, this determination for small gemstones holds little value because the dose due to wearing the gemstone is based on the total activity in the gemstone. An exemption from the requirement that no one gemstone will have greater than twice exempt concentration is requested for gemstones less than 0.25 g. Instead, gemstones of less than 0.25 g will be sorted separately and released from the NaI count based on the total activity in each gemstone being less than the total activity in a 0.25 g gemstone with exempt concentration. The release batch containing gemstones of less than 0.25 g would then be required to meet the same exempt concentration limits averaged over batch mass as do the larger stones for the subsequent beta and HRGRS analyses.

As in the previous calculations, Co-60 at exempt concentration will give the highest dose for a 0.25 g gemstone (radius = 0.26 cm). The first year dose for Geometry 2 is estimated to be 46 mrem. A smaller gemstone having the same total activity as this 0.25 g gemstone would give the same shallow dose. One setting may have multiple gemstones. Shallow dose from a multiple setting, i.e. a broach, is considered for one point on the skin, 3 mm from one gemstone (46 mrem/gemstone), 6 mm from 6 gemstones (19 mrem/gemstone), and 8.4 mm from 12 gemstones (11 mrem/gemstone). The first year shallow dose for this combined 4.75 g of gemstones is then estimated to be 292 mrem, or approximately the same as for a single 5 g gemstone. Release criteria for gemstones less than 0.25 g as requested above will result in no additional dose risk to unlicensed persons.

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TABLE 13 EQUATIONS USED FOR DOSE ESTIMATE

BETA

Eqn B1: $\theta = 90 - \arcsin \dfrac{0.007}{R_2}$

where, θ = angle defining volume of stone layer (degrees)

R_2 = range of E_{ave} beta in tissue (cm)

0.007 = average thickness for dead layer of skin (cm)

Eqn B2[40]: $V = \dfrac{2\pi}{3} (1-\cos\theta) [r_1^{3}-(r_1-R_1)^{3}]$

where, V = volume of stone layer (cm^3)

r_1 = radius of stone (cm)

R_1 = depth for $E_{ave} \rightarrow 70$ keV in stone (cm)

Eqn B3: $A = V \cdot \rho \cdot C$

where, A = total activity in stone layer volume (dps)

ρ = density of stone (g/cm^3)

C = exempt concentration (dps/g)

Eqn B4: $\dot{D}_{\beta C} = 1.38 \cdot \dfrac{A.BR}{2} \cdot E_{ave}$

where, $\dot{D}_{\beta C}$ = initial contact dose rate to first gram of tissue below irradiated surface area (mrem/day)

BR = branching ratio for betas (β/dis)

E_{ave} = average beta energy (MeV)

$1.38 = \dfrac{(1.6E\text{-}6^{erg}/MeV)(3600sec/hr)(24hr/d)(1E3mrem/rad)}{(1g)(100erg/g\text{-}rad)}$

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[40] Calculus and Analytic Geometry, Part II: "Vectors, Functions of Several Variables, Infinite Series, and Differential Equations," G.B. Thomas Jr. & R.L. Finney (1984), p. 927

Table 13, continued

Eqn B5: $D_{\beta C} = \frac{\dot{D}_{\beta C}}{\lambda} (1-e^{-365\lambda}) \cdot m$

where, $D_{\beta C}$ = contact dose for first year of wear (mrem)

λ = decay constant for radioisotope (day^{-1})

m = movement factor, 0.15 for Geometry 1 and 1.0 for Geometries 2 and 3

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Eqn G1[41]: $\phi = \frac{C \cdot \rho}{4a} \left[2 \cdot a \cdot r_1 - (a^2 - r_1^2) \cdot \ln \left(\frac{a+r_1}{a-r_1} \right) \right]$

where, ϕ = initial flux at distance "a" (dps/cm^2)

C = exempt concentration (dps/g)

ρ = density of stone (g/cm^3)

a = distance from center of stone (cm)

r_1 = radius of stone (cm)

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[41] "Radiation Fields from Extended Sources (Emphasis on Contact, or Near Contact, External Dose Estimates)," H.J. Moe, Health Physics Society Meeting/Professional Enrichment Program, Pittsburgh, PA, June, 1986

Eqn G2: $\dot{D}\gamma = 8.17E\text{-}3 \cdot \phi \cdot \Gamma$

where, $\dot{D}\gamma$ = initial dose rate at distance "a"(mrem/day)

= initial exposure rate at distance "a" (mR/day)

$= \dot{X}$

$\dot{X} = 6.57E\text{-}5 \cdot \phi \cdot \sum_i f_i E_i \, (\mu en/\rho)_i$

i = gamma emitted at energy E_i(MeV) for f_i(γ/dis) fraction of decays

$(\mu_{en}/\rho)_i$ = mass absorption coefficient for gamma i in air (cm^2/g)

$$6.57E\text{-}5 = \frac{(1.6E\text{-}6erg/MeV)(3600sec/hr)}{(87.7erg/g\text{-}R)}$$

Γ = gamma constant[42] for specific isotope $\left(\frac{R\text{-}cm^2}{mCi\text{-}hr}\right)$

$= 193 \cdot \sum_i f_i \cdot E_i (\mu en/\rho)_i$

$$\dot{X} = \frac{6.57E\text{-}5}{193} \cdot \phi \cdot \Gamma$$

$$8.17E\text{-}3 = \frac{6.57E\text{-}5}{193} (24hr/d)(1000mrem/R)$$

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[42]Introduction to Health Physics, 2nd Ed., H. Cember, 1983, p. 148

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TABLE 14. Radionuclide Input Data for Dose Calculations

Radionuclide			Beta Data				
Isotope	Decay Radiations Considered[a]	Exempt[b] Conc (μCi/g)	Eave[c] (MeV)	Branching[c] Ratio	Range to[d] Eave 70keV (cm)	Range Eave[e] in Tissue (cm)	Gamma[f] Factor $\left(\frac{R\text{-}cm^2}{h\text{-}mCi}\right)$
Major Radionuclides Found in MURR Irradiated Topaz							
* Na-22	B+,G	4.e-04[g]	0.216	1.00	0.018	0.049	12.00
Sc-46	B-,G	4.e-04	0.112	1.00	0.004	0.017	10.90
[illegible]-54	G	1.e-03	0.000	0.00	0.000	0.000[j]	4.70
[illegible]-65	B+,G	1.e-03	0.143	0.02	0.008	0.025	2.70
Cs-134	B-,G	9.e-05	0.157	1.00	0.009	0.030	8.70
Ta-182	B-,ce,G	4.e-04	0.125	1.30[i]	0.005	0.023	6.80
Additional Radionuclides Found in MURR Irradiated Topaz							
Cr-51	G	2.e-02	0.000	0.00	0.000	0.000[j]	0.16
Co-58	B+,G	1.e-03	0.201	0.15	0.016	0.044	5.50
Fe-59	B-,G	6.e-04	0.118	1.00	0.004	0.018	6.40
Co-60	B-,G	5.e-04	0.096	1.00	0.002	0.013	13.20
As-74	B+,B-,G	5.e-04	0.438	0.64	0.060	0.143	4.40
Sr-85	ce,G	1.e-03	0.499[h]	0.01[i]	0.072	0.172	3.00
Rb-86	B-,G	7.e-04	0.667	1.00	0.105	0.255	0.50
Y-91	B-,G	3.e-04	0.602	1.00	0.092	0.222	0.01
Zr-95	B-,G	6.e-04	0.116	1.00	0.004	0.018	4.10
Nb-95	B-,G	1.e-03	0.043	1.00	0.000	0.000[j]	4.20
Sn-113	(In-113)ce,G	9.e-04	0.390[h]	0.35[i]	0.050	0.121	1.70
Sb-124	B-,G	2.e-04	0.378	1.00	0.048	0.116	9.80
Sb-125	B-,G	1.e-03	0.087	1.00	0.001	0.011	2.70
Ba-133	ce,G	2.e-03[g]	0.320[h]	0.10[i]	0.037	0.090	2.40
Ce-139	ce,G	5.e-03[g]	0.156[h]	0.19[i]	0.009	0.029	0.65
Ce-141	B-,ce,G	9.e-04	0.145	1.20[i]	0.008	0.026	0.34
Hf-181	B-,ce,G	7.e-04	0.119	1.20[i]	0.005	0.019	3.10
Ir-192	B-,ce,G	4.e-04	0.180	1.00[i]	0.013	0.037	4.80
Hg-203	ce,G	2.e-04	0.270[h]	0.23[i]	0.028	0.070	1.30
Pa-233	ce,G	9.e-04[g]	0.200[h]	0.45[i]	0.016	0.044	0.86

(a) B+ or - = beta, ce = conversion electron, G = gamma
(b) 10 CFR 30.70
(c) Radioisotope Decay Tables, DOE/TIC-11026, D.C. Kocher (1981)
(d) Introduction to Radiological Physics and Radiation Dosimetry, F.H. Attix (1986), based on stopping powers listed on p. 584, borosilicae glass is assumed to approximate topaz.
(e) Ref. (d), p. 578, adipose tissue.
(f) The Health Physics and Radiological Health Handbook, B. Shleien and M.S. Terpilak (1984), p. 131 or calculated
(g) Calculated isotope specific exempt concentration. See Section BB for explanation and request for exemption.
(h) Beta energy modified to estimate contribution due to conversion electrons.
(i) Branching ratio modified to estimate contribution due to conversion electrons.
(j) Either no beta emission, or beta and conversion electron energies too low to penetrate dead layer of skin.

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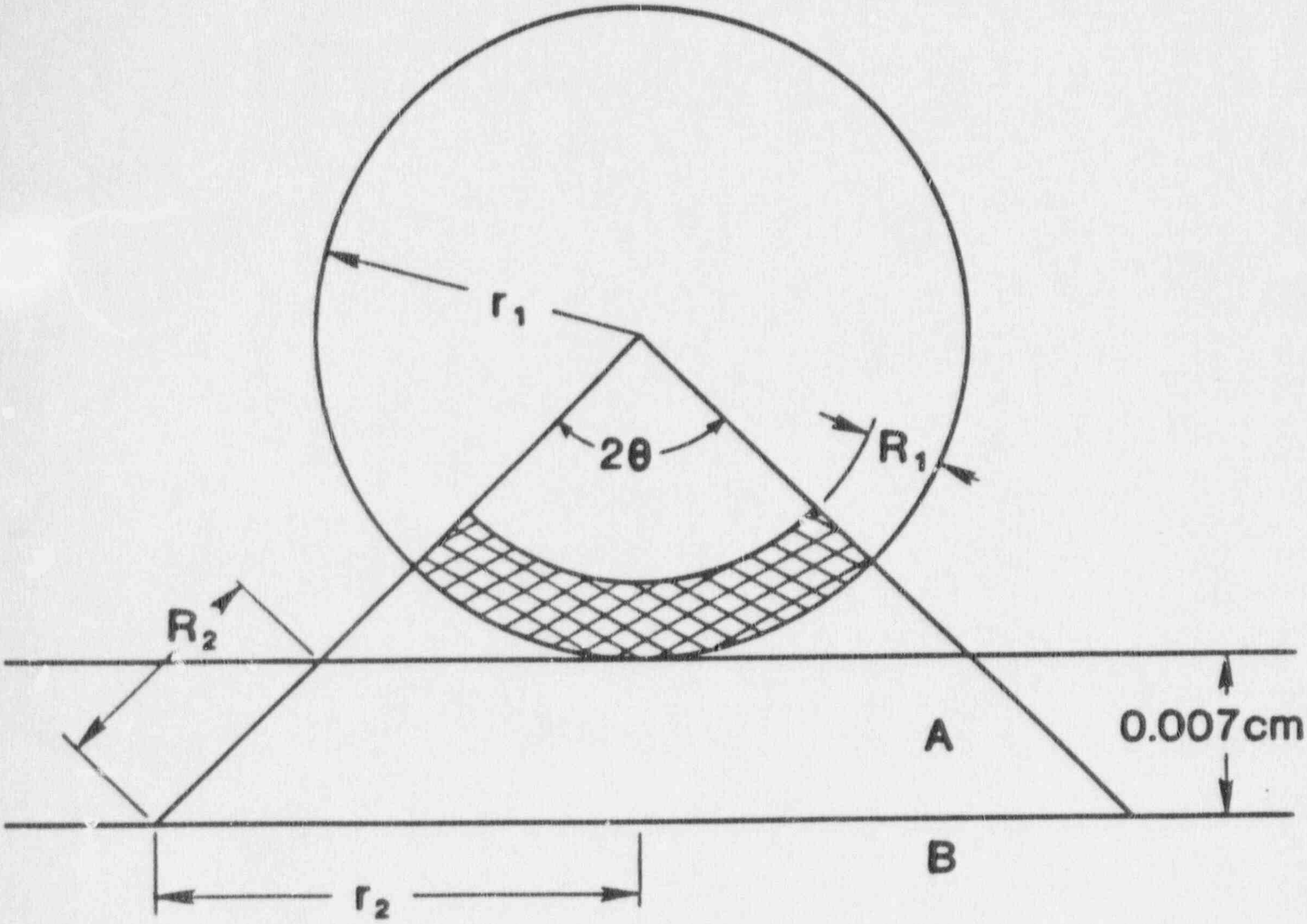
TABLE 15. Dose Estimates in First Year of Wear for 5 Gram Gemstone With Radionuclide at Exempt Concentration

Radionuclide	Geometry 1[(a)] Shallow Dose			Geometry 2[(b)] Shallow Dose	Geometry 3[(c)] Deep Dose
	Beta (mrem)	Gamma (mrem)	Total (mrem)	Gamma (mrem)	Gamma (mrem)
Major Radionuclides Found in MURR Irradiated Topaz					
Na-22[(d)]	18	85	103	209	8
Sc-46	0	28	28	68	3
Mn-54	0	65	65	160	6
Zn-65	0	34	34	84	3
Cs-134	1	13	14	33	1
Ta-182	1	22	23	54	2
Additional Radionuclides Found in MURR Irradiated Topaz					
Cr-51	0	7	7	17	1
Co-58	2	30	32	74	3
Fe-59	1	14	15	34	1
Co-60	1	125	126	307	12
As-74	8	3	11	8	0
Sr-85	0	15	15	37	2
Rb-86	45	1	46	1	0
Y-91	48	0	48	0	0
Zr-95	1	12	13	30	1
Nb-95	0	12	12	29	1
Sn-113	33	13	46	31	1
Sb-124	11	9	20	23	1
Sb-125	1	48	49	119	5
Ba-133[(d)]	30	94	124	231	9
Ce-139[(d)]	7	31	38	75	3
Ce-141	2	1	3	2	0
Hf-181	1	7	8	18	1
Ir-192	3	11	14	27	1
Hg-203	1	1	2	2	0
Pa-233[(d)]	2	2	4	4	0

(a) Gemstone in contact with skin above dose point 15% of the time.
(b) Gemstone fixed at one point, 3 mm above skin.
(c) Gemstone fixed at one point, dose calculated at 4 cm tissue depth.
(d) Calculated isotope specific exempt concentration used in dose calculation. See Section BB for explanation and request for exemption.

FIGURE 1

GEOMETRY ASSUMED FOR BETA DOSE ESTIMATE



- volume of stone containing activity considered for beta dose estimate

A - skin epidermis

B - skin dermis

r_1 - stone radius

r_2 - radius of irradiated skin surface

R_1 - depth for $E_{ave} \rightarrow$ 70 KeV

R_2 - range of E_{ave} beta in tissue

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APPENDIX A

Example of External Dose Calculation for Gemstones

External doses are calculated for a 5 g stone of topaz, assumed to be a sphere and having the exempt concentration of Cs-134.

<u>Stone size</u> --

Density: $\rho = 3.5\ g/cm^3$

Stone Volume: $V_s = \frac{5g}{3.5g/cm^3} = 1.4\ cm^3$

Stone Radius: $r_1 = \left(\frac{3V_s}{4\pi} \right)^{1/3}$

$= \left(\frac{3 \cdot 1.4cm^3}{4\pi} \right)^{1/3}$

$= 0.70\ cm$

<u>Isotope parameters</u> --see Table 14 for input data

Half-life: $T_{1/2} = 2.06y = 752$ day

$\lambda = \frac{\ln 2}{T_{1/2}} = 9.2\ E\text{-}4\ day^{-1}$

Average β energy: $E_{ave} = 0.157$ MeV

Branching Ratio: BR = 1.0 β/dis

Range E_{ave} in tissue: $R_2 = 0.030$ cm

Stopping power of E_{ave} in topaz:

$S = 2.63\ \frac{MeV\text{-}cm^2}{g}$

Range to reduce $E_{ave} \rightarrow 70$ keV:

$$R_1 = \frac{E_{ave} - 0.070}{S \cdot \rho}$$

$$= \frac{(0.157 - 0.070)\ \text{MeV}}{(2.63\ \frac{\text{MeVcm}^2}{\text{g}})(3.5\ \text{g/cm}^3)}$$

$$= 0.009\ \text{cm}$$

Exempt Concentration: $C = 9\ \text{E-5}\ \mu\text{Ci/g}$

$= 3.33$ dps/g

Gamma Factor: $\Gamma = 8.7\ \frac{\text{R-cm}^2}{\text{mCi-hr}}$

β Dose Calculation -- Geometry 1

Determination of amount of stone (stone layer) emitting βs which are considered to contribute to skin dose (see Figure 1 and Table 13).

Angle of β radiation, Eqn B1:

$$\theta = 90° - \arcsin\left(\frac{0.07\ \text{cm}}{0.03\ \text{cm}}\right)$$

$$= 76.5°$$

Volume of stone layer, Eqn B2:

$$V = \frac{2\pi}{3}(1-\cos 76.5°)\ [(0.7\ \text{cm})^3-(0.7\text{cm}-0.009\text{cm})^3]$$

$$= 0.021\ \text{cm}^3$$

Activity in stone layer, Eqn B3:

$$A = (0.021\ \text{cm}^3)(3.5\text{g/cm}^3)(3.33\ \text{dps/g})$$

$$= 0.24\ \text{dps}$$

Dose to first gram of live skin tissue defined by ϕ, assuming half of βs emitted escape perpendicular to the stone surface, all βs have energy of E_{ave}, and no additional attenuation from stone or dead layer of skin occurs, Eqn B4:

$$\dot{D}_{\beta C} = (1.38\ \frac{\text{mrem-sec}}{\text{MeV-day}})\ \frac{(0.24\text{dps})(1\ \beta/\text{dis})}{2}(0.157\text{MeV}/\beta)$$

$$= 0.026\ \text{mrem/day}$$

First year integrated dose, Eqn B5:

$$D_{\beta C} = \frac{(0.026\ \text{mrem/day})}{(9.2\ \text{E-4 day}^{-1})}\ [1-e^{-(365\ \text{day})(9.2\text{E-4 day}^{-1})}]\ (0.15)$$

$$= (0.026\ \text{mrem/day})(310\ \text{day})\ (0.15)$$

$$= 1\ \text{mrem}$$

Gamma Dose Calculation --

Geometry 1: Gemstone at contact, shallow dose,

$$a = r_1 = 0.7\ \text{cm}$$

Flux, Eqn G1:

$$\phi = \frac{(3.33\ \text{dps})(3.5\ \text{g/cm}^3)}{(4)(0.7\text{cm})}\ [2(0.7\text{cm})^2-(0)]$$

$$= 4.1\ \text{dps/cm}^2$$

Gamma dose rate, Eqn G2:

$$\dot{D}_\gamma = (8.17\text{E-3}\ \frac{\text{m-rem-mCi-hr}}{\text{R-dps-day}})(4.1\ \text{dps/cm}^2)(8.7\ \frac{\text{R-cm}^2}{\text{mCi-hr}})$$

$$= 0.29\ \text{mrem/day}$$

First year integrated dose for stone at one point on skin for 15% of time (see Eqn B5):

$$D_\gamma = (0.29\ \text{mrem/day})(310\ \text{day})(0.15)$$

$$= 13\ \text{mrem}$$

Geometry 2: Gemstone at 3 mm from skin surface, shallow dose

$$a = r_1 + 0.3 = 1.0\ \text{cm}$$

Flux assuming no gamma attenuation from setting, Eqn G1:

$$\phi = \frac{(3.33 dps/g)(3.5 g/cm^3)}{(4)(1.0 cm)}\left[(2)(1)(0.7)-(1^2-0.7^2)\ln\frac{1+0.7}{1-0.7}\right]cm^2$$

$$= 1.5 \text{ dps/cm}^2$$

Gamma dose rate, Eqn G2:

$$\dot{D}_\gamma = (8.17E\text{-}3\ \frac{\text{mrem-mCi-hr}}{\text{R-dps-day}})(1.5\ \text{dps/cm}^2)(8.7\ \frac{\text{R-cm}^2}{\text{mCi-hr}})$$

$$= 0.11 \text{ mrem/day}$$

First year integrated dose (see Eqn B5 above):

$$D_\gamma = (0.11 \text{ mrem/day})(310 \text{ day})(1)$$

$$= 33 \text{ mrem}$$

Geometry 3: Gemstone at 4 cm, deep dose:

$$a = r_1 + 4 = 4.7 \text{ cm}$$

Flux, assuming no gamma attenuation from setting, Eqn G1:

$$\phi = \frac{(3.33 \text{ dps/g})(3.5 \text{ g/cm}^3)}{(4)(4.7 cm)}\left[(2)(4.7)(0.7)-(4.7^2-0.7^2)\ln\left(\frac{4.7+0.7}{4.7-0.7}\right)\right]cm^2$$

$$= 0.061 \text{ dps/cm}^2$$

Gamma dose rate, Eqn G2:

$$\dot{D}_\gamma = (8.17E\text{-}3\ \frac{\text{mrem-mCi-hr}}{\text{R-dps-day}})(0.061\ \text{dps/cm}^2)(8.7\ \frac{\text{R-cm}^2}{\text{mCi-hr}})$$

$$= 4.3E\text{-}3 \text{ mrem/day}$$

First year integrated dose (see Eqn B5):

$$D_\gamma = (4.3E\text{-}3 \text{ mrem/day})(310 \text{ day})(1)$$

$$= 1 \text{ mrem}$$

Summary --

Doses for first year of wear

Geometry 1, Shallow Dose: = 1 mrem + 13 mrem = 14 mrem

Geometry 2, Shallow Dose = 33 mrem

Geometry 3, Deep Dose = 1 mrem

History from Allen Brodsky

History

Mason

James R. Mason, Chief, Isotopes Branch
Division of Licensing and Regulation

Feb. 1, 1960

Lester R. Rogers, Chief, Radiation Safety Branch
Division of Licensing and Regulation

AMENDMENT TO PART 30 ON EXEMPT CONCENTRATIONS

Attached is background information on the Staff Paper dealing with the Exempt Concentrations Amendment to Part 30. I have obtained agreement from Dick Kirk and R. L. Price and concurrence from Forrest Western. We will revise the exempt concentration table values and use the lowest value for each isotope as given in Handbook 69 for occupational exposure for a 168-hour week. Attached is a copy of a revised table to be published with the Part 20 amendment. Appropriate values for the exempt concentrations amendment to Part 30 can be obtained by multiplying by 10 the values in Table II of Appendix "B" of the proposed amendment to Part 20. I assume that you will prepare the Staff Paper to the Commission, explaining changes in the values, together with the amendment of the regulation to be published in the Federal Register.

Al Brodsky will prepare a memorandum to the Files giving a hazard summary. However, I do not believe that you need this to proceed with the Staff Paper and the amendment to the regulation.

If you have any questions, I will be glad to discuss them with you.

Attachments:
Information on
Amendment to Part 30 -
Exempt Concentrations

Susan: Thought these items I found in old files might help answer your question.

Allen B.
3/18/88

DLR:RSB
LRR:fls
2-1-60

(Reprinted from 25 F. R. 7875, August 17, 1960)

Title 10—ATOMIC ENERGY

Chapter I—Atomic Energy Commission

PART 30—LICENSING OF BYPRODUCT MATERIAL

Exempt Concentrations

On October 31, 1958, the Commission issued for public comment a proposed amendment to "Licensing of Byproduct Material," 10 CFR Part 30, which would exempt byproduct material from licensing requirements when contained in products in specified low concentrations. The amendment published below retains the substantive provisions set forth in the proposed rule although changes have been made in the text and concentration values to reflect recent information from the National Committee on Radiation Protection and is consonant with the Radiation Protection Guide approved by the President on May 13, 1960.

The exemption is intended to facilitate the distribution of products subjected to control procedures involving the use of byproduct material. With the exception of the person who introduces the byproduct material into a product, a license will not be required in order to receive, use, transfer, or dispose of such products. The licensee who introduces byproduct material into a product may transfer the byproduct material only if the transfer is made in accordance with a license issued pursuant to § 30.24(h) of the amendment. This limitation, however, would not restrict the transfer to a duly licensed person of byproduct material intended for analytical or laboratory purposes or for waste disposal.

The license-exempt concentrations in § 30.73 *Schedule C*, of the following amendment are equal to the lowest value for each byproduct material given in Table I of National Bureau of Standards Handbook 69 for continuous occupational exposure (168-hour week). The values selected are those for soluble forms which in general are lower than for insoluble forms. The products in which license-exempt concentrations would be permitted are items such as oil, gasoline, plastics, and similar commercial or industrial items where inhalation or ingestion is unlikely. In addition, while the concentration values in NBS 69 are based on continuous exposure for a whole lifetime such exposure from the products involved here is highly unlikely. It is highly improbable, therefore, that any member of the public will receive an organ dose in excess of a small fraction of 0.5 rem, the Radiation Protection Guide for members of the general population recommended by the President in his memorandum dated May 13, 1960. The proposed exempt concentrations are high enough to make quality control applications feasible from the measurement standpoint and low enough to assure safety of the public.

The values set forth in the following amendment are established as concentrations which the Commission considers may be exempted from licensing requirements to the extent provided in this amendment. However, applicants for licenses pursuant to § 30.24(h) of the amendment will be required to show that, for their particular purpose, lower concentrations than those specified in § 30.73 are not feasible. The Commission does not propose to license the distribution of products containing byproduct material under this amendment if it is likely that such products will be ingested or inhaled.

Persons licensed under this amendment to distribute products containing byproduct material would be required to file an annual report describing the products transferred and the total amount of each byproduct material in such products transferred during the year. This will keep the Commission informed of the total amount of activity transferred in such concentrations and provide a basis for a continuing evaluation of the addition of radioactivity to the environment.

The scheduled concentrations pertain to the parent activity in those cases where a radioisotope disintegrates into other radioactive isotopes or daughter products. The proposed exemption does not extend to imports of byproduct material. Requirements for the issuance of a license authorizing the transfer of products or materials containing byproduct material are separately stated in § 30.24(h) of the amendment published below.

The Commission has found that the exemption set forth in this amendment will not constitute an unreasonable risk to the common defense and security and to the health and safety of the public.

Section 274 of the Atomic Energy Act of 1954, as amended, establishes, among other things, procedures and criteria for the discontinuance of certain of the Commission's regulatory responsibilities with respect to byproduct, source, and special nuclear materials, and the assumption thereof by the states. Notwithstanding any agreement between the Commission and any state for the assumption of regulatory responsibilities previously exercised by the Commission, the Commission is authorized under subsection 274c. to require, by rule or order, "that the manufacturer, processor, or producer of any equipment, device, commodity, or other product containing source, byproduct, or special nuclear material shall not transfer possession or control of such product except pursuant to a license issued by the Commission."

Prior to executing any agreement providing for assumption of regulatory responsibilities by a state, the Commission will consider exercising the authority conferred on it by subsection 274c with respect to distribution of products covered by the following amendments.

Pursuant to the Administrative Procedure Act, Public Law 404, 79th Congress, 2d session, Title 10, Chapter I, Part 30, "Licensing of Byproduct Material," is amended as follows, effective thirty days after publication in the FEDERAL REGISTER:

1. Add a new § 30.9 to read as follows:

§ 30.9. Exempt concentrations.

(a) Except as provided in § 30.22(f), any person is exempt from the requirements for a license set forth in section 81 of the Act and from the regulations in this part to the extent that such person receives, possesses, uses, transfers, owns or acquires products or materials containing byproduct material in concentrations not in excess of those listed in § 30.73.

(b) This section shall not be deemed to authorize the import of byproduct material or products containing byproduct material.

§ 30.24 [Amendment]

2. Add a new § 30.24(h) to read as follows:

(h) *Licensing the transfer of products containing exempt concentrations of byproduct material.* (1) An application for a specific license to transfer possession or control of products or materials containing exempt concentrations of byproduct material which the transferor has introduced into the product or material will be approved if the applicant:

(i) Satisfies the general requirements specified in § 30.23;

(ii) Submits a description of the product or material into which the byproduct material will be introduced, intended use of the byproduct material and the product into which it is introduced, method of introduction, initial concentration of the byproduct material in the product or material, control methods to assure that no more than the specified concentration is introduced into the product or material, estimated time interval between introduction and transfer of the product or material, and estimated concentration of the radioisotope in the product or material at the time of transfer by the licensee; and

(iii) Provides reasonable assurance that the concentrations of the byproduct material at the time of transfer will not exceed the concentrations in § 30.73, that reconcentration of the byproduct material in concentrations exceeding those in § 30.73 is not likely, that the product or material is not likely to be inhaled or ingested, and that use of lower concentrations is not feasible.

(2) Each person licensed under this paragraph shall file an annual report with the Director, Division of Licensing

and Regulation, describing the kinds and quantities of products transferred, the concentration of byproduct material contained and the quantity of byproduct material transferred during the reporting period. Each report shall be filed as of June 30 and shall be filed within 30 days thereafter.

§ 30.32 [Amendment]

3. Add a new § 30.32(f) to read as follows:

(f) Notwithstanding the provisions of §§ 30.9 and 30.32(c) of this part, no person licensed by the Commission pursuant to the regulations in this part shall transfer possession or control of any product or material containing concentrations of byproduct material not exceeding those specified in § 30.73 which he has introduced into the product or material unless the transferor has received a license from the Commission pursuant to § 30.24(h) authorizing such transfer. The provisions of this paragraph (f) shall not apply to transfers to duly licensed persons of products or materials containing byproduct material for analytical, laboratory, or waste disposal purposes. This paragraph shall not be deemed to modify any authority granted to any person in a specific license issued by the Commission prior to the effective date of this paragraph.

4. Add a new § 30.73 to read as follows:

§ 30.73 Schedule C.

Element (atomic number)	Isotope	Column I Gas concentration uc/ml [1]	Column II Liquid and solid concentration uc/ml [2]
Antimony (51)	Sb 122	....	3×10^{-4}
	Sb 124	....	2×10^{-4}
	Sb 125	....	1×10^{-3}
Argon (18)	A 37	1×10^{-3}	....
	A 41	4×10^{-7}	....
Arsenic (33)	As 73	....	5×10^{-3}
	As 74	....	5×10^{-4}
	As 76	....	2×10^{-4}
	As 77	....	8×10^{-4}
Barium (56)	Ba 131	....	2×10^{-3}
	Ba 140	....	3×10^{-4}
Beryllium (4)	Be 7	....	2×10^{-2}
Bismuth (83)	Bi 206	....	4×10^{-4}
Bromine (35)	Br 82	4×10^{-7}	3×10^{-3}
Cadmium (48)	Cd 109	....	2×10^{-3}
	Cd 115m	....	3×10^{-4}
	Cd 115	....	3×10^{-4}
Calcium (20)	Ca 45	....	9×10^{-5}
	Ca 47	....	5×10^{-4}
Carbon (6)	C 14	1×10^{-6}	8×10^{-3}
Cerium (58)	Ce 141	....	9×10^{-4}
	Ce 143	....	4×10^{-4}
	Ce 144	....	1×10^{-4}
Cesium (55)	Cs 131	....	2×10^{-2}
	Cs 134m	....	6×10^{-2}
	Cs 134	....	9×10^{-5}
Chlorine (17)	Cl 38	9×10^{-7}	4×10^{-3}
Chromium (24)	Cr 51	....	2×10^{-2}
Cobalt (27)	Co 57	....	5×10^{-3}
	Co 58	....	1×10^{-3}
	Co 60	....	5×10^{-4}
Copper (29)	Cu 64	....	3×10^{-3}
Dysprosium (66)	Dy 165	....	4×10^{-3}
	Dy 166	....	4×10^{-4}
Erbium (68)	Er 169	....	9×10^{-4}
	Er 171	....	1×10^{-3}
Europium (63)	Eu 152 (T/2=9.2 Hrs)	....	6×10^{-4}
	Eu 155	....	2×10^{-3}
Fluorine (9)	F 18	2×10^{-6}	8×10^{-3}
Gadolinium (64)	Gd 153	....	2×10^{-3}
	Gd 159	....	8×10^{-4}
Gallium (31)	Ga 72	....	4×10^{-4}
Germanium (32)	Ge 71	....	2×10^{-2}
Gold (79)	Au 196	....	2×10^{-3}
	Au 198	....	5×10^{-4}
	Au 199	....	2×10^{-3}
Hafnium (72)	Hf 181	....	7×10^{-4}
Hydrogen (1)	H 3	5×10^{-6}	3×10^{-2}
Indium (49)	In 113m	....	1×10^{-2}
	In 114m	....	2×10^{-4}
Iodine (53)	I 126	3×10^{-9}	2×10^{-5}
	I 131	3×10^{-9}	2×10^{-5}
	I 132	8×10^{-8}	6×10^{-4}
	I 133	1×10^{-8}	7×10^{-5}
	I 134	2×10^{-7}	1×10^{-3}
Iridium (77)	Ir 190	....	2×10^{-3}
	Ir 192	....	4×10^{-4}
	Ir 194	....	3×10^{-4}
Iron (26)	Fe 55	....	8×10^{-3}
	Fe 59	....	6×10^{-4}
Krypton (36)	Kr 85m	1×10^{-6}	....
	Kr 85	3×10^{-6}	....
Lanthanum (57)	La 140	....	2×10^{-4}
Lead (82)	Pb 203	....	4×10^{-3}
Lutetium (71)	Lu 177	....	1×10^{-3}
Manganese (25)	Mn 52	....	3×10^{-4}
	Mn 54	....	1×10^{-3}
	Mn 56	....	1×10^{-3}
Mercury (80)	Hg 197m	....	2×10^{-3}
	Hg 197	....	3×10^{-3}
	Hg 203	....	2×10^{-4}
Molybdenum (42)	Mo 99	....	2×10^{-3}
Neodymium (60)	Nd 147	....	6×10^{-4}
	Nd 149	....	3×10^{-3}
Nickel (28)	Ni 65	....	1×10^{-3}
Niobium (Columbium) (41)	Nb 95	....	1×10^{-3}
	Nb 97	....	9×10^{-3}
Osmium (76)	Os 185	....	7×10^{-4}
	Os 191m	....	3×10^{-2}
	Os 191	....	2×10^{-3}
	Os 193	....	6×10^{-4}
Palladium (46)	Pd 103	....	3×10^{-3}
	Pd 109	....	9×10^{-4}
Phosphorus (15)	P 32	....	2×10^{-4}
Platinum (78)	Pt 191	....	1×10^{-3}
	Pt 193m	....	1×10^{-2}
	Pt 197m	....	1×10^{-2}
	Pt 197	....	1×10^{-3}
Potassium (19)	K 42	....	3×10^{-3}
Praseodymium (59)	Pr 142	....	3×10^{-4}
	Pr 143	....	5×10^{-4}
Promethium (61)	Pm 147	....	2×10^{-3}
	Pm 149	....	4×10^{-4}
Rhenium (75)	Re 183	....	6×10^{-3}
	Re 186	....	9×10^{-4}
	Re 188	....	6×10^{-4}
Rhodium (45)	Rh 103m	....	1×10^{-1}
	Rh 105	....	1×10^{-3}
Rubidium (37)	Rb 86	....	7×10^{-4}
Ruthenium (44)	Ru 97	....	4×10^{-3}
	Ru 103	....	8×10^{-4}
	Ru 105	....	1×10^{-3}
	Ru 106	....	1×10^{-4}
Samarium (62)	Sm 153	....	8×10^{-4}
Scandium (21)	Sc 46	....	4×10^{-4}
	Sc 47	....	9×10^{-4}
	Sc 48	....	3×10^{-4}
Selenium (34)	Se 75	....	3×10^{-3}
Silicon (14)	Si 31	....	9×10^{-3}
Silver (47)	Ag 105	....	1×10^{-3}
	Ag 110m	....	3×10^{-4}
	Ag 111	....	4×10^{-4}
Sodium (11)	Na 24	....	2×10^{-3}
Strontium (38)	Sr 89	....	1×10^{-4}
	Sr 91	....	7×10^{-4}
	Sr 92	....	7×10^{-4}
Sulfur (16)	S 35	9×10^{-8}	6×10^{-4}
Tantalum (73)	Ta 182	....	4×10^{-4}
Technetium (43)	Tc 96m	....	1×10^{-1}
	Tc 96	....	1×10^{-3}
Tellurium (52)	Te 125m	....	2×10^{-3}
	Te 127m	....	6×10^{-4}
	Te 127	....	3×10^{-3}
	Te 129m	....	3×10^{-4}
	Te 131m	....	6×10^{-4}
	Te 132	....	3×10^{-4}
Terbium (65)	Tb 160	....	4×10^{-4}
Thallium (81)	Tl 200	....	4×10^{-3}
	Tl 201	....	3×10^{-3}
	Tl 202	....	1×10^{-3}
	Tl 204	....	1×10^{-3}
Thulium (69)	Tm 170	....	5×10^{-4}
	Tm 171	....	5×10^{-3}
Tin (50)	Sn 113	....	9×10^{-4}
	Sn 125	....	2×10^{-4}
Tungsten (Wolfram) (74)	W 181	....	4×10^{-3}
	W 187	....	7×10^{-4}
Vanadium (23)	V 48	....	3×10^{-4}
Xenon (54)	Xe 131m	4×10^{-6}	....
	Xe 133	3×10^{-6}	....
	Xe 135	1×10^{-6}	....
Ytterbium (70)	Yb 175	....	1×10^{-3}
Yttrium (39)	Y 90	....	2×10^{-4}
	Y 91m	....	3×10^{-2}
	Y 91	....	3×10^{-4}
	Y 92	....	6×10^{-4}
	Y 93	....	3×10^{-4}
Zinc (30)	Zn 65	....	1×10^{-3}
	Zn 69m	....	7×10^{-4}
	Zn 69	....	2×10^{-2}
Zirconium (40)	Zr 95	....	6×10^{-4}
	Zr 97	....	2×10^{-4}
Beta and/or gamma emitting byproduct material not listed above with half-life less than 3 years.	....	1×10^{-10}	1×10^{-6}

See footnotes at end of table.

NOTE 1: Many radioisotopes disintegrate into isotopes which are also radioactive. In expressing the concentrations in Schedule C, the activity stated is that of the parent isotope and takes into account the daughters.

NOTE 2: For purposes of § 30.9 where there is involved a combination of isotopes, the limit for the combination should be derived as follows:

Determine for each isotope in the product the ratio between the concentration present in the product and the exempt concentration established in Schedule C for the specific isotope when not in combination. The sum of such ratios may not exceed "1" (i.e., unity).

Example:

$$\frac{\text{Concentration of Isotope A in Product}}{\text{Exempt concentration of Isotope A}} + \frac{\text{Concentration of Isotope B in Product}}{\text{Exempt concentration of Isotope B}} \leq 1$$

[1] Values are given only for those materials normally used as gases.

[2] uc/gm for solids.

Dated at Germantown, Md., this 8th day of August 1960.

For the Atomic Energy Commission.

R. E. HOLLINGSWORTH,
Acting General Manager.

[F.R. Doc. 60-7618; Filed, Aug. 16, 1960; 8:46 a.m.]

Calc + Anal geom.
G B Thomas Jr.
R. L. Finney

Ref Book

The volume element in spherical coordinates is

$$dV = \rho^2 \sin\phi \, d\rho \, d\phi \, d\theta \tag{2}$$

(as shown in Fig. 16.42) and triple integrals take the form

$$\iiint F(\rho, \phi, \theta)\,dV = \iiint F(\rho, \phi, \theta)\rho^2 \sin\phi \, d\rho \, d\phi \, d\theta. \tag{3}$$

To evaluate these integrals we first integrate with respect to ρ. The procedure for finding the limits of integration for a region D in space is therefore the following:

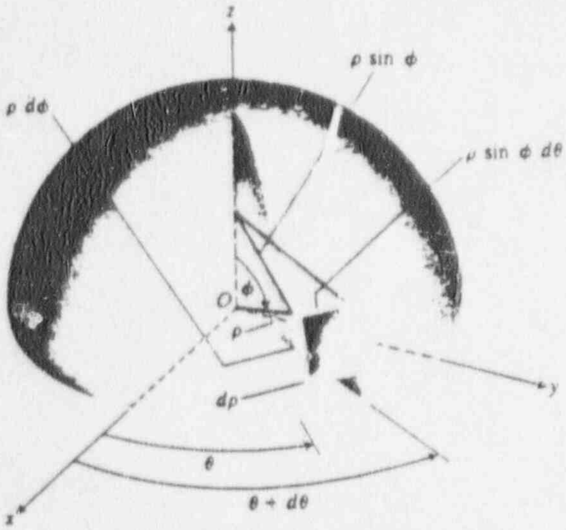
1. Hold ϕ and θ fixed and let ρ increase. This gives a ray out from the origin.
2. Integrate from the ρ-value where the ray first enters D to the ρ-value where the ray leaves D. This gives the limits for ρ.
3. Hold θ fixed and let ϕ increase. (This gives a family of rays that make a "fan.") Integrate over the ϕ-values for which the rays pass through D.
4. Choose θ-limits that include all the fans that intersect D.

EXAMPLE 3 Find the volume cut from the sphere $\rho = a$ by the cone $\phi = \alpha$. (See Fig. 16.43.)

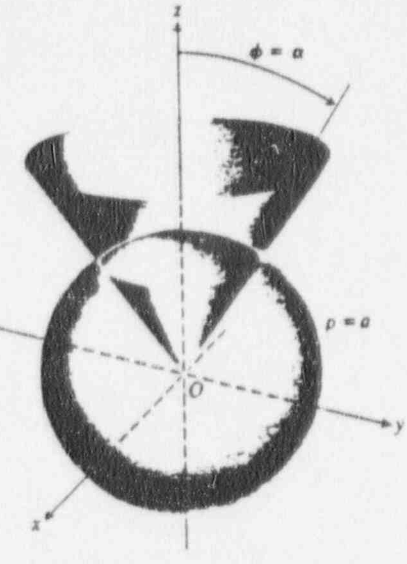
Solution The volume is given by

$$V = \int_0^{2\pi}\int_0^{\alpha}\int_0^{a} \rho^2 \sin\phi \, d\rho \, d\phi \, d\theta = \frac{2\pi a^3}{3}(1 - \cos\alpha).$$

As a check, we note that the special cases $\alpha = \pi/2$ and $\alpha = \pi$ correspond to the cases of a hemisphere and a sphere, of volumes $2\pi a^3/3$ and $4\pi a^3/3$, respectively. □



16.42 The volume element in spherical coordinates is $dV = d\rho \cdot \rho\, d\phi \cdot \rho \sin\phi\, d\theta$.



16.43 The volume cut from the sphere $\rho = a$ by the cone $\phi = \alpha$.

APPENDIX E. *(Continued)*

Adipose Tissue (ICRP)

ENERGY	STOPPING POWER COLLISION	STOPPING POWER RADIATIVE	TOTAL	CSDA RANGE	RADIATION YIELD	DENS. EFF. CORR. (DELTA)
MeV	MeV cm²/g	MeV cm²/g	MeV cm²/g	g/cm²		
0.0100	2.347E+01	3.168E-03	2.347E+01	2.406E-04	7.396E-05	0.0
0.0125	1.971E+01	3.184E-03	1.971E+01	3.574E-04	8.8[illegible]-05	0.0
0.0150	1.709E+01	3.194E-03	1.709E+01	4.940E-04	1.031E-04	0.0
0.0175	1.515E+01	3.201E-03	1.515E+01	6.497E-04	1.1[illegible]E-04	0.0
0.0200	1.365E+01	3.207E-03	1.365E+01	8.237E-04	1.301E-04	0.0
0.0250	1.148E+01	3.217E-03	1.149E+01	1.225E-03	1.556E-04	0.0
0.0300	9.984E+00	3.227E-03	9.987E+00	1.693E-03	1.800E-04	0.0
0.0350	8.881E+00	3.238E-03	8.884E+00	2.225E-03	2.034E-04	0.0
0.0400	8.034E+00	3.249E-03	8.037E+00	2.818E-03	2.260E-04	0.0
0.0450	7.362E+00	3.262E-03	7.365E+00	3.468E-03	2.480E-04	0.0
0.0500	6.816E+00	3.275E-03	6.819E+00	4.175E-03	2.693E-04	0.0
0.0550	6.362E+00	3.290E-03	6.365E+00	4.934E-03	2.902E-04	0.0
0.0600	5.979E+00	3.305E-03	5.983E+00	5.745E-03	3.106E-04	0.0
0.0700	5.369E+00	3.338E-03	5.372E+00	7.513E-03	3.501E-04	0.0
0.0800	4.903E+00	3.373E-03	4.906E+00	9.464E-03	3.881E-04	0.0
0.0900	4.535E+00	3.411E-03	4.539E+00	1.159E-02	4.250E-04	0.0
0.1000	4.238E+00	3.452E-03	4.241E+00	1.387E-02	4.608E-04	0.0
0.1250	3.696E+00	3.562E-03	3.700E+00	2.020E-02	5.464E-04	0.0
0.1500	3.330E+00	3.681E-03	3.334E+00	2.734E-02	6.277E-04	0.0
0.1750	3.068E+00	3.808E-03	3.071E+00	3.517E-02	7.055E-04	0.0
0.2000	2.871E+00	3.943E-03	2.875E+00	4.359E-02	7.806E-04	0.0
0.2500	2.597E+00	4.232E-03	2.601E+00	6.194E-02	9.244E-04	0.0
0.3000	2.418E+00	4.547E-03	2.422E+00	8.190E-02	1.062E-03	0.0
0.3500	2.294E+00	4.885E-03	2.299E+00	1.031E-01	1.196E-03	0.0
0.4000	2.204E+00	5.244E-03	2.209E+00	1.253E-01	1.328E-03	0.0
0.4500	2.135E+00	5.623E-03	2.141E+00	1.483E-01	1.458E-03	1.471E-02
0.5000	2.081E+00	6.020E-03	2.087E+00	1.720E-01	1.588E-03	4.184E-02
0.5500	2.039E+00	6.433E-03	2.045E+00	1.962E-01	1.718E-03	7.141E-02
0.6000	2.005E+00	6.360E-03	2.011E+00	2.209E-01	1.848E-03	1.028E-01
0.7000	1.954E+00	7.753E-03	1.962E+00	2.712E-01	2.109E-03	1.691E-01
0.8000	1.921E+00	8.692E-03	1.929E+00	3.227E-01	2.374E-03	2.381E-01
0.9000	1.897E+00	9.674E-03	1.907E+00	3.748E-01	2.642E-03	3.080E-01
1.0000	1.880E+00	1.070E-02	1.891E+00	4.275E-01	2.915E-03	3.776E-01
1.2500	1.858E+00	1.340E-02	1.871E+00	5.605E-01	3.612E-03	5.471E-01
1.5000	1.849E+00	1.629E-02	1.865E+00	6.9[illegible]E-01	4.334E-03	7.067E-01
1.7500	1.848E+00	1.934E-02	1.867E+00	8.244E-01	5.078E-03	8.554E-01
2.0000	1.850E+00	2.252E-02	1.873E+00	9.621E-01	5.842E-03	9.934E-01
2.5000	1.860E+00	2.921E-02	1.889E+00	1.228E+00	7.421E-03	1.242E+00
3.0000	1.872E+00	3.626E-02	1.908E+00	1.491E+00	9.055E-03	1.459E+00
3.5000	1.885E+00	4.360E-02	1.928E+00	1.752E+00	1.073E-02	1.652E+00
4.0000	1.897E+00	5.120E-02	1.948E+00	2.010E+00	1.245E-02	1.825E+00
4.5000	1.909E+00	5.901E-02	1.968E+00	2.265E+00	1.419E-02	1.981E+00
5.0000	1.920E+00	6.701E-02	1.987E+00	2.518E+00	1.596E-02	2.125E+00
5.5000	1.930E+00	7.518E-02	2.005E+00	2.769E+00	1.774E-02	2.257E+00
6.0000	1.939E+00	8.350E-02	2.023E+00	3.017E+00	1.955E-02	2.379E+00
7.0000	1.956E+00	1.005E-01	2.057E+00	3.507E+00	2.319E-02	2.601E+00
8.0000	1.972E+00	1.181E-01	2.090E+00	3.990E+00	2.688E-02	2.798E+00
9.0000	1.985E+00	1.360E-01	2.121E+00	4.465E+00	3.059E-02	2.976E+00
10.0000	1.997E+00	1.542E-01	2.151E+00	4.933E+00	3.432E-02	3.137E+00
12.5000	2.022E+00	2.010E-01	2.223E+00	6.076E+00	4.368E-02	3.491E+00
15.0000	2.042E+00	2.492E-01	2.291E+00	7.183E+00	5.300E-02	3.790E+00
17.5000	2.059E+00	2.984E-01	2.357E+00	8.259E+00	6.225E-02	4.050E+00
20.0000	2.073E+00	3.485E-01	2.421E+00	9.305E+00	7.138E-02	4.282E+00
25.0000	2.095E+00	4.505E-01	2.[illegible]46E+00	1.132E+01	8.923E-02	4.679E+00
30.0000	2.113E+00	5.544E-01	2.668E+00	1.324E+01	1.065E-01	5.012E+00
35.0000	2.128E+00	6.597E-01	2.788E+00	1.507E+01	1.230E-01	5.299E+00
40.0000	2.141E+00	7.661E-01	2.907E+00	1.683E+01	1.389E-01	5.551E+00
45.0000	2.152E+00	8.734E-01	3.025E+00	1.851E+01	1.542E-01	5.776E+00
50.0000	2.161E+00	9.815E-01	3.143E+00	2.013E+01	1.688E-01	5.979E+00
55.0000	2.170E+00	1.090E+00	3.260E+00	2.170E+01	1.829E-01	6.163E+00
60.0000	2.178E+00	1.200E+00	3.377E+00	2.320E+01	1.964E-01	6.332E+00
70.0000	2.192E+00	1.420E+00	3.611E+00	2.607E+01	2.218E-01	6.632E+00
80.0000	2.203E+00	1.642E+00	3.843E+00	2.875E+01	2.454E-01	6.894E+00
90.0000	2.214E+00	1.865E+00	4.079E+00	3.127E+01	2.673E-01	7.126E+00

APPENDIX E. *(Continued)*

Borosilicate Glass

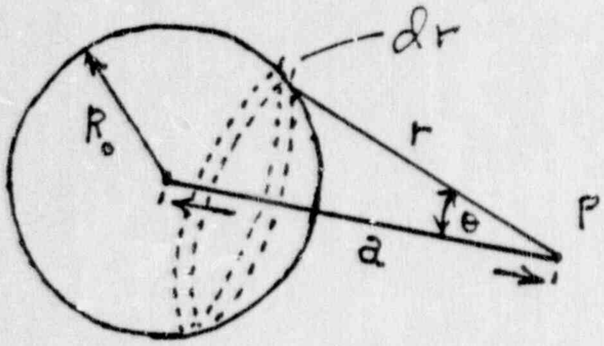
ENERGY	STOPPING POWER COLLISION	STOPPING POWER RADIATIVE	STOPPING POWER TOTAL	CSDA RANGE	RADIATION YIELD	DENS. EFF. CORR. (DELTA)
MeV	MeV cm²/g	MeV cm²/g	MeV cm²/g	g/cm²		
0.0100	1.767E+01	5.400E-03	1.788E+01	3.237E-04	1.632E-04	0.0
0.0125	1.511E+01	5.488E-03	1.512E+01	4.764E-04	1.971E-04	0.0
0.0150	1.317E+01	5.548E-03	1.317E+01	6.540E-04	2.296E-04	0.0
0.0175	1.172E+01	5.593E-03	1.173E+01	8.55[illegible]E-04	2.610E-04	0.0
0.0200	1.060E+01	5.626E-03	1.060E+01	1.080E-03	2.914E-04	0.0
0.0250	8.962E+00	5.674E-03	8.968E+00	1.595E-03	3.495E-04	0.0
0.0300	7.822E+00	5.707E-03	7.828E+00	2.194E-03	4.048E-04	0.0
0.0350	6.980E+00	5.735E-03	6.986E+00	2.871E-03	4.578E-04	0.0
0.0400	6.331E+00	5.759E-03	6.336E+00	3.624E-03	5.087E-04	0.0
0.0450	5.814E+00	5.781E-03	5.820E+00	4.448E-03	5.579E-04	0.0
0.0500	5.393E+00	5.803E-03	5.398E+00	5.341E-03	6.055E-04	0.0
0.0550	5.0[illegible]2E+00	5.824E-03	5.048E+00	6.300E-03	6.518E-04	0.0
0.0600	4.746E+00	5.847E-03	4.752E+00	7.321E-03	6.968E-04	0.0
0.0700	4.272E+00	5.893E-03	4.278E+00	9.544E-03	7.837E-04	0.0
0.0800	3.909E+00	5.943E-03	3.915E+00	1.199E-02	8.666E-04	0.0
0.0900	3.622E+00	5.997E-03	3.628E+00	1.465E-02	9.467E-04	0.0
0.1000	3.390E+00	6.055E-03	3.396E+00	1.750E-02	1.024E-03	0.0
0.1250	2.966E+00	6.215E-03	2.972E+00	2.540E-02	1.207E-03	0.0
0.1500	2.679E+00	6.393E-03	2.685E+00	3.427E-02	1.379E-03	0.0
0.1750	2.473E+00	6.588E-03	2.479E+00	4.398E-02	1.542E-03	0.0
0.2000	2.318E+00	6.796E-03	2.325E+00	5.440E-02	1.698E-03	0.0
0.2500	2.102E+00	7.250E-03	2.110E+00	7.706E-02	1.995E-03	0.0
0.3000	1.962E+00	7.749E-03	1.970E+00	1.016E-01	2.277E-03	0.0
0.3500	1.864E+00	8.286E-03	1.873E+00	1.277E-01	2.549E-03	0.0
0.4000	1.793E+00	8.857E-03	1.802E+00	1.549E-01	2.814E-03	8.985E-03
0.4500	1.739E+00	9.461E-03	1.749E+00	1.831E-01	3.075E-03	2.665E-02
0.5000	1.698E+00	1.009E-02	1.708E+00	2.121E-01	3.333E-03	4.637E-02
0.5500	1.665E+00	1.075E-02	1.676E+00	2.416E-01	3.590E-03	6.760E-02
0.6000	1.640E+00	1.143E-02	1.651E+00	2.717E-01	3.846E-03	8.997E-02
0.7000	1.603E+00	1.285E-02	1.616E+00	3.330E-01	4.359E-03	1.371E-01
0.8000	1.579E+00	1.434E-02	1.593E+00	3.953E-01	4.873E-03	1.860E-01
0.9000	1.563E+00	1.590E-02	1.579E+00	4.584E-01	5.391E-03	2.359E-01
1.0000	1.552E+00	1.751E-02	1.570E+00	5.220E-01	5.913E-03	2.859E-01
1.2500	1.540E+00	2.179E-02	1.561E+00	6.818E-01	7.240E-03	4.090E-01
1.5000	1.538E+00	2.636E-02	1.564E+00	8.418E-01	8.599E-03	5.271E-01
1.7500	1.541E+00	3.117E-02	1.572E+00	1.001E+00	9.990E-03	6.390E-01
2.0000	1.547E+00	3.617E-02	1.583E+00	1.160E+00	1.141E-02	7.448E-01
2.5000	1.561E+00	4.668E-02	1.608E+00	1.473E+00	1.431E-02	9.392E-01
3.0000	1.576E+00	5.771E-02	1.634E+00	1.782E+00	1.729E-02	1.114E+00
3.5000	1.590E+00	6.918E-02	1.660E+00	2.085E+00	2.032E-02	1.273E+00
4.0000	1.604E+00	8.102E-02	1.685E+00	2.384E+00	2.339E-02	1.419E+00
4.5000	1.616E+00	9.315E-02	1.709E+00	2.679E+00	2.649E-02	1.554E+00
5.0000	1.627E+00	1.056E-01	1.733E+00	2.970E+00	2.961E-02	1.679E+00
5.5000	1.637E+00	1.182E-01	1.756E+00	3.256E+00	3.275E-02	1.797E+00
6.0000	1.647E+00	1.311E-01	1.778E+00	3.539E+00	3.590E-02	1.907E+00
7.0000	1.664E+00	1.574E-01	1.821E+00	4.095E+00	4.222E-02	2.110E+00
8.0000	1.678E+00	1.844E-01	1.863E+00	4.638E+00	4.853E-02	2.292E+00
9.0000	1.691E+00	2.119E-01	1.903E+00	5.169E+00	5.483E-02	2.458E+00
10.0000	1.703E+00	2.399E-01	1.943E+00	5.689E+00	6.109E-02	2.611E+00
12.5000	1.726E+00	3.115E-01	2.038E+00	6.945E+00	7.653E-02	2.945E+00
15.0000	1.746E+00	3.850E-01	2.131E+00	8.145E+00	9.159E-02	3.229E+00
17.5000	1.761E+00	4.599E-01	2.221E+00	9.294E+00	1.062E-01	3.476E+00
20.0000	1.775E+00	5.360E-01	2.311E+00	1.040E+01	1.204E-01	3.695E+00
25.0000	1.797E+00	6.906E-01	2.487E+00	1.248E+01	1.474E-01	4.071E+00
30.0000	1.814E+00	8.477E-01	2.662E+00	1.442E+01	1.725E-01	4.388E+00
35.0000	1.828E+00	1.007E+00	2.835E+00	1.624E+01	1.961E-01	4.661E+00
40.0000	1.840E+00	1.167E+00	3.007E+00	1.796E+01	2.180E-01	4.901E+00
45.0000	1.851E+00	1.329E+00	3.179E+00	1.957E+01	2.386E-01	5.115E+00
50.0000	1.860E+00	1.491E+00	3.351E+00	2.111E+01	2.579E-01	5.309E+00
55.0000	1.868E+00	1.655E+00	3.523E+00	2.256E+01	2.761E-01	5.486E+00
60.0000	1.876E+00	1.819E+00	3.695E+00	2.395E+01	2.932E-01	5.649E+00
70.0000	1.889E+00	2.150E+00	4.039E+00	2.653E+01	3.246E-01	5.940E+00
80.0000	1.900E+00	2.483E+00	4.383E+00	2.891E+01	3.527E-01	6.194E+00
90.0000	1.909E+00	2.817E+00	4.727E+00	3.111E+01	3.782E-01	6.420E+00

Figures 6 and 7, which are taken from Rockwell[11], give values for the more frequently used exponential integral functions. Once again, for other than small values of b, the buildup of scattered radiation must be considered. From an inspection of the above equation, one can see that when $\theta \to \frac{\pi}{2}$ (an infinite plane), then:

$$\phi_p = \frac{S_A}{2} E_1 (\mu t).$$

So that one can quickly compute an estimate of the flux density, whether there is attenuation or not, provided μt is not too large, for then the buildup would have to be accounted for. References 11, 14, 25 – Chap. 6.

3. SPHERICAL VOLUME SOURCE



The differential flux density from the volume element (dV) along r is

$$d\phi_p = \frac{S_v dV}{4\pi r^2} \quad \text{where}$$

$$S_v = \frac{S}{\frac{4}{3}\pi R_o^3} \quad \frac{ph}{cc\text{-}s}$$

and $dV = 2\pi r^2 (1 - \cos\theta)\, dr$

$$R_o^2 = r^2 + a^2 - 2ar\cos\theta$$

$$\cos\theta = \frac{r}{2a} + \frac{(a^2 - R_o^2)}{2ar}$$

which leads to:

$$\phi_p = \frac{S_v}{2} \int_{a - R_o}^{a + R_o} (1 - \cos\theta)\, dr$$

by expressing cosθ in terms of r and integrating, the following result is obtained for a point outside the sphere:

$$\phi_p = \frac{S_v}{4a}\left[2aR_o - (a^2 - R_o{}^2)\ln\frac{a + R_o}{a - R_o}\right].$$

Other results which can be obtained are:

Point at center of sphere: $\phi_p = S_V R_o$

Point at surface of sphere: $\phi_p = \frac{S_v R_o}{2}$

Reference 25 has these examples w/ & w/o shielding

Example: Given a small, thin-walled sphere of diameter 2 cm filled with a NaI solution. The sphere contains 10 mCi of ^{131}I. Compute the exposure rate at the surface of the sphere. Assume that all beta is absorbed in the sphere and neglect any gamma absorption.

A. Compute ϕ_p: $a = R_o = 1$ cm

$$S_v = \frac{S}{\frac{4}{3}\pi R_o{}^3} = \frac{10 \text{ mCi } (3.7 \times 10^7)}{\frac{4}{3}\pi\ (1.0)^3} = 8.83 \times 10^7 \ \frac{\text{ph}}{\text{cm}^3\text{-s}}$$

$$\phi_p = \frac{S_v R_o}{2} = \frac{8.83 \times 10^7 (1)}{2} = 4.42 \times 10^7 \left(\frac{\text{ph}}{\text{cm}^2\text{-s}}\right)$$

B. Compute $\dot{X}$ - From Mird Pamphlet No. 10 (Fig. 8), ^{131}I emits 3 photons which account for 90% of all photon emissions. Using these to get $\dot{X}$:

n_i	$\bar{E}_i$	$\left(\frac{\mu_{en}}{\rho}\right)_i$	$n_i\bar{E}_i\left(\frac{\mu_{en}}{\rho}\right)_i$
0.0578	.2843	.0285	4.68×10^{-4}
0.8201	.3644	.0295	8.82×10^{-3}
0.0653	.6367	.0297	1.23×10^{-3}
			$\sum_i = 1.05 \times 10^{-2}$

and

$$\dot{X} = 6.57 \times 10^{-5}\ \phi \sum_i n_i \bar{E}_i \left(\frac{\mu_{en}}{\rho}\right)_i$$

$$= 6.57 \times 10^{-5}\ (4.42 \times 10^{7})(1.05 \times 10^{-2}) = 30.5\ \text{R/h}.$$

For a sphere in which one can neglect absorption, the ratio of the flux density at the surface of the sphere, computed by the exact expression, to that obtained by assuming all the activity is located as a point source at the sphere center, is only 1.5. Thus, when the ratio $a/R_o > 2$, one may use the point source approximation:

$$\phi_p = \frac{S}{4\pi a^2} = \frac{S_v\ R_o^3}{3\ a^2},$$

since the error will only be about 6% for this ratio. ≠ a = 2R₀

When there is self-absorption in the sphere, the expression for the flux density outside the sphere does not yield a simple solution. References 18-20 treat methods of approximate solutions to determine the uncollided flux density, but do not deal with buildup. The exact solution of the flux density expression for a sphere with self-absorption and external attenuation leads to the following integral[18]

Worksheet 1

Topaz Isotopes, Data, and Beta Dose Calculations

Density: 3.5 gm/cm^3
Stone Mass: 5.00 grams
Stone Radius: 0.70 cm

Columns A thru I are input data

Isotope	Half-Life (days) T1 / 2	Beta E ave (MeV)	Branching Ratio	Stopping Power (MeVcm^2/g)	Range to Eave 10keV (cm)	Max Conc (uCi/g)	Max Conc (dps/g)	Range Eave in Tissue (cm)
Na-22	949.00	0.216	1.00	2.256	0.018	1.e-06	0.037	0.049
* Na-22	949.00	0.216	1.00	2.256	0.018	4.e-04	14.800	0.049
Sc-46	83.85	0.112	1.00	3.192	0.004	4.e-04	14.800	0.017
Mn-54	312.50	0.000	0.00	0.000	0.000	1.e-03	37.000	0.000
Zn-65	234.80	0.143	0.02	2.765	0.008	1.e-03	37.000	0.025
Cs-134	751.90	0.157	1.00	2.627	0.009	9.e-05	3.330	0.030
T -182	114.50	0.125	1.30	2.972	0.005	4.e-04	14.800	0.020

Columns A thru I are input data for additional isotopes

Isotope	Half-Life (days) T1 / 2	Beta E ave (MeV)	Branching Ratio	Stopping Power (MeVcm^2/g)	Range to Eave 70keV (cm)	Max Conc (uCi/g)	Max Conc (dps/g)	Range Eave in Tissue (cm)
Cr-51	27.70	0.000	0.00	0.000	0.000	2.e-02	740.000	0.000
Co-58	70.80	0.201	0.15	2.321	0.016	1.e-03	37.000	0.044
Fe-59	44.63	0.118	1.00	3.091	0.004	6.e-04	22.200	0.018
Co-60	1923.92	0.095	1.00	3.489	0.002	5.e-04	18.500	0.013
As-74	17.77	0.438	0.64	1.762	0.060	5.e-04	18.500	0.143
Sr-85	64.84	0.499	0.01	1.708	0.072	1.e-03	37.000	0.172
Rb-86	18.66	0.667	1.00	1.628	0.105	7.e-04	25.900	0.255
Y-91	58.51	0.602	1.00	1.650	0.092	3.e-04	11.100	0.222
Zr-95	64.02	0.116	1.00	3.125	0.004	6.e-04	22.200	0.018
Nb-95	35.06	0.043	1.00	0.000	0.000	1.e-03	37.000	0.000
Sn-113	115.10	0.390	0.35	1.816	0.050	9.e-04	33.300	0.121
Sb-124	60.20	0.378	1.00	1.833	0.048	2.e-04	7.400	0.116
Sb-125	1011.05	0.037	1.00	3.714	0.001	1.e-03	37.000	0.011
Ba-133	3832.50	0.320	0.10	1.931	0.037	0.e+00	0.000	0.090
* Ba-133	3832.50	0.320	0.10	1.931	0.037	2.e-03	74.000	0.090
Ce-139	137.66	0.156	0.19	2.636	0.009	1.e-06	0.037	0.029
* Ce-139	137.66	0.156	0.19	2.636	0.009	5.e-03	185.000	0.029
Ce-141	32.50	0.145	1.20	2.742	0.008	9.e-04	33.300	0.026
Hf-181	42.39	0.119	1.20	3.074	0.005	7.e-04	25.900	0.019
Ir-192	74.02	0.180	1.00	2.448	0.013	4.e-04	14.800	0.037
Hg-203	46.60	0.270	0.23	2.054	0.028	2.e-04	7.400	0.070
Pa-233	27.00	0.200	0.45	2.325	0.016	1.e-06	0.037	0.044
* Pa-233	27.00	0.200	0.45	2.325	0.016	9.e-04	33.300	0.044

5 gram gemstone

Columns K thru Q are dose calculations

Isotope	Theta	Vol coef	Topaz layer w/ beta (cm^3)	Half Activity (Bq)	Initial dose rate (mrem/day)	Beta Dose for first year (mrem)	w/movement Beta Dose for first year (mrem)
Na-22	81.79	1.80	4.73e-02	3.06e-03	9.14e-04	0	0
* Na-22	81.79	1.80	4.73e-02	1.23e+00	3.65e-01	117	18
Sc-46	65.53	1.23	6.72e-03	1.74e-01	2.69e-02	3	0
Mn-54	0.00	0.00	0.00e+00	0.00e+00	0.00e+00	0	0
Zn-65	73.94	1.51	1.66e-02	2.14e-02	4.23e-03	1	0
Cs-134	76.27	1.60	2.18e-02	1.27e-01	2.76e-02	9	1
Ta-182	69.72	1.37	1.05e-02	3.54e-01	6.11e-02	9	1

Columns K thru Q are dose calculations

5 gram gemstone

Isotope	Theta	Vol coef	Topaz layer w/ beta (cm^3)	Half Activity (Bq)	Initial dose rate (mrem/day)	Beta Dose for first year (mrem)	w/movement Beta Dose for first year (mrem)
Cr-51	0.00	0.00	0.00e+00	0.00e+00	0.00e+00	0	0
Co-58	80.85	1.76	4.06e-02	3.95e-01	1.09e-01	11	2
Fe-59	67.64	1.30	8.38e-03	3.25e-01	5.30e-02	3	1
Co-60	57.42	0.97	3.00e-03	9.73e-02	1.29e-02	4	1
As-74	87.19	1.99	1.60e-01	3.31e+00	2.00e+00	51	8
Sr-85	0.00	0.00	0.00e+00	0.00e+00	0.00e+00	0	0
Rb-86	88.43	2.04	2.68e-01	1.21e+01	1.12e+01	301	45
Y-91	88.19	2.03	2.39e-01	4.65e+00	3.86e+00	321	48
Zr-95	66.98	1.28	7.81e-03	3.03e-01	4.86e-02	4	1
Nb-95	0.00	0.00	0.00e+00	0.00e+00	0.00e+00	0	0
Sn-113	86.68	1.97	1.35e-01	2.76e+00	1.48e+00	219	33
Sb-124	86.54	1.97	1.29e-01	1.67e+00	8.72e-01	75	11
Sb-125	50.48	0.76	1.46e-03	9.43e-02	1.13e-02	4	1
Ba-133	85.56	1.93	9.92e-02	0.00e+00	0.00e+00	0	0
* Ba-133	85.56	1.93	9.92e-02	1.28e+00	5.67e-01	200	30
Ce-139	76.13	1.59	2.14e-02	2.64e-04	5.66e-05	0	0
* Ce-139	76.13	1.59	2.14e-02	1.32e+00	2.84e-01	47	7
Ce-141	74.32	1.53	1.73e-02	1.21e+00	2.42e-01	11	2
Hf-181	68.02	1.31	8.68e-03	4.72e-01	7.76e-02	5	1
Ir-192	79.06	1.70	3.13e-02	8.11e-01	2.02e-01	21	3
Hg-203	84.25	1.88	7.38e-02	2.20e-01	8.19e-02	5	1
Pa-233	80.76	1.76	4.02e-02	1.17e-03	3.23e-04	0	0
* Pa-233	80.76	1.76	4.02e-02	1.05e+00	2.91e-01	11	2

A5

Columns K thru Q are dose calculations   0.25 g gemstone

Isotope	Theta	Vol coef	Topaz layer w/ beta (cm^3)	Half Activity (Bq)	Initial dose rate (mrem/day)	Beta Dose for first year (mrem)	w/movement Beta Dose for first year (mrem)
Na-22	81.79	1.80	6.13e-03	3.97e-04	1.18e-04	0	0
* Na-22	81.79	1.80	6.13e-03	1.59e-01	4.74e-02	15	2
Sc-46	65.53	1.23	9.03e-04	2.34e-02	3.62e-03	0	0
Mn-54	0.00	0.00	0.00e+00	0.00e+00	0.00e+00	0	0
Zn-65	73.94	1.51	2.21e-03	2.86e-03	5.64e-04	0	0
Cs-134	76.27	1.60	2.90e-03	1.69e-02	3.66e-03	1	0
Ta-182	69.72	1.37	1.41e-03	4.74e-02	8.18e-03	1	0

Columns K thru Q are dose calculations

0.25 g gemstone

Isotope	Theta	Vol coef	Topaz layer w/ beta (cm^3)	Half Activity (Bq)	Initial dose rate (mrem/day)	Beta Dose for first year (mrem)	w/movement Beta Dose for first year (mrem)
Cr-51	0.00	0.00	0.00e+00	0.00e+00	0.00e+00	0	0
Co-58	80.85	1.76	5.30e-03	5.15e-02	1.43e-02	1	0
Fe-59	67.64	1.30	1.12e-03	4.37e-02	7.11e-03	0	0
Co-60	57.42	0.97	4.06e-04	1.31e-02	1.74e-03	1	0
As-74	87.19	1.99	1.86e-02	3.85e-01	2.33e-01	6	1
Sr-85	0.00	0.00	0.00e+00	0.00e+00	0.00e+00	0	0
Rb-86	88.43	2.04	2.75e-02	1.25e+00	1.15e+00	31	5
Y-91	88.19	2.03	2.54e-02	4.94e-01	4.10e-01	34	5
Zr-95	66.98	1.28	1.05e-03	4.07e-02	6.52e-03	1	0
Nb-95	0.00	0.00	0.00e+00	0.00e+00	0.00e+00	0	0
Sn-113	86.68	1.97	1.61e-02	3.29e-01	1.77e-01	26	4
Sb-124	86.54	1.97	1.55e-02	2.01e-01	1.05e-01	9	1
Sb-125	50.48	0.76	1.97e-04	1.28e-02	1.53e-03	0	0
Ba-133	85.56	1.93	1.23e-02	0.00e+00	0.00e+00	0	0
* Ba-133	85.56	1.93	1.23e-02	1.59e-01	7.01e-02	25	4
Ce-139	76.13	1.59	2.84e-03	3.50e-05	7.53e-06	0	0
* Ce-139	76.13	1.59	2.84e-03	1.75e-01	3.77e-02	6	1
Ce-141	74.32	1.53	2.30e-03	1.61e-01	3.22e-02	2	0
Hf-181	68.02	1.31	1.17e-03	6.34e-02	1.04e-02	1	0
Ir-192	79.96	1.70	4.12e-03	1.07e-01	2.65e-02	3	0
Hg-203	84.25	1.88	9.34e-03	2.78e-02	1.04e-02	1	0
Pa-233	80.76	1.76	5.24e-03	1.53e-04	4.22e-05	0	0
* Pa-233	80.76	1.76	5.24e-03	1.37e-01	3.79e-02	1	0

Worksheet 2

B2

Topaz Gamma Dose Calculation

Density:	3.5	gram/cm^3
Stone Mass:	5.00	grams
Stone Radius:	0.70	cm
Stone Volume:	1.4286	cm^3

a =	0.70
Generic flux	0.9763

a =	1.00
LN	1.733
Generic flux	0.513

a =	4.70
LN	0.[illegible]00
Generic flux	0.097

Isotope	Half-Life (days) T1 / 2	Max Conc (dps/g)	Gamma Factor (Rcm^2/hmCi)	Activity (dps)	AT SURFACE Flux (dps/cm^2)	AT SURFACE Dose rate (mR/day)	Integrated Dose Factor (day)	AT SURFACE Total first year dose (mrem)	Geom 1 AT SURFACE w/movement Total first year dose (mrem)	AT 3 MM Flux (dps/cm^2)	Geom 2 AT 3 MM Total first year dose (mrem)	AT 4 CM Flux (dps/cm^2)	Geom 3 AT 4 CM Total first year dose (mrem)
Na-22	949.00	0.037	12.00	0.13	4.52e-02	4.44e-03	320	1	0	1.66e-02	1	6.70e-04	0
* Na-22	949.00	14.800	12.00	51.80	1.81e+01	1.78e+00	320	569	85	6.65e+00	209	2.68e-01	8
Sc-46	83.83	14.800	10.90	51.80	1.81e+01	1.61e+00	115	186	28	6.65e+00	68	2.68e-01	3
Mn-54	312.70	37.000	4.70	129.50	4.52e+01	1.74e+00	250	435	65	1.66e+01	160	6.70e-01	6
Zn-65	244.40	37.000	2.70	129.50	4.52e+01	9.99e-01	227	227	34	1.66e+01	84	6.70e-01	3
Cs-134	752.63	3.330	8.70	11.66	4.07e+00	2.90e-01	310	90	13	1.50e+00	33	6.03e-02	1
Ta-182	114.74	14.800	6.80	51.80	1.81e+01	1.01e+00	147	148	22	6.65e+00	54	2.68e-01	2

Input data for additional isotopes

Isotope	Half-Life (days) T1 / 2	Max Conc (dps/g)	Gamma Factor (Rcm^2/hmCi)	Activity (dps)	AT SURFACE Flux (dps/cm^2)	AT SURFACE Dose rate (mR/day)	Integrated Dose Factor (day)	AT SURFACE Total first year dose (mrem)	AT SURFACE w/movement Total first year dose (mrem)	AT 3 MM Flux (dps/cm^2)	AT 3 MM Total first year dose (mrem)	AT 4 CM Flux (dps/cm^2)	AT 4 CM Total first year dose (mrem)
Cr-51	27.70	740.0	0.16	3700.00	9.05e+02	1.18e+00	40	47	7	3.33e+02	17	1.34e+01	1
Co-58	70.80	37.0	5.50	185.00	4.52e+01	2.04e+00	99	202	30	1.66e+01	74	6.70e-01	3
Fe-59	44.63	22.2	6.40	111.00	2.71e+01	1.42e+00	64	91	14	9.98e+00	34	4.02e-01	1
Co-60	1923.92	18.5	13.20	92.50	2.26e+01	2.44e+00	342	835	125	8.32e+00	307	3.35e-01	12
As-74	17.77	18.5	4.40	92.50	2.26e+01	8.14e-01	26	21	3	8.32e+00	8	3.35e-01	0
Sr-85	64.84	37.0	3.00	185.00	4.52e+01	1.11e+00	92	102	15	1.66e+01	37	6.70e-01	2
Rb-86	18.66	25.9	0.50	129.50	3.17e+01	1.30e-01	27	3	1	1.15e+01	1	4.69e-01	0
Y-91	58.51	11.1	0.01	55.50	1.36e+01	1.11e-03	83	0	0	4.99e+00	0	2.01e-01	0
Zr-95	64.02	22.2	4.10	111.00	2.71e+01	9.10e-01	91	82	12	9.98e+00	30	4.02e-01	1
Nb-95	35.06	37.0	4.20	185.00	4.52e+01	1.55e+00	51	79	12	1.66e+01	29	6.70e-01	1
Sn-113	115.10	33.3	1.70	166.50	4.07e+01	5.66e-01	148	84	13	1.50e+01	31	6.03e-01	1
Sb-124	60.20	7.4	9.80	37.00	9.05e+00	7.25e-01	86	62	9	3.33e+00	23	1.34e-01	1
Sb-125	1011.05	37.0	2.70	185.00	4.52e+01	9.99e-01	32[illegible]	323	48	1.66e+01	119	6.70e-01	5
Ba-133	3832.50	0.0	2.40	0.00	0.00e+00	0.00e+00	353	0	0	0.00e+00	0	0.00e+00	0
* Ba-133	3832.50	74.0	2.40	370.00	9.05e+01	1.78e+00	353	627	94	3.33e+01	231	1.34e+00	9
Ce-139	137.66	0.0	0.66	0.19	4.52e-02	2.44e-04	167	0	0	1.66e-02	0	6.70e-04	0
* Ce-139	137.66	185.0	0.66	925.00	2.26e+02	1.22e+00	167	204	31	8.32e+01	75	3.35e+00	3
Ce-141	32.50	33.3	0.34	166.50	4.07e+01	1.13e-01	47	5	1	1.50e+01	2	6.03e-01	0
Hf-181	42.39	25.9	3.10	129.50	3.17e+01	8.03e-01	61	49	7	1.16e+01	18	4.69e-01	1
Ir-192	74.02	14.8	4.80	74.00	1.81e+01	7.11e-01	103	73	11	6.65e+00	27	2.68e-01	1
Hg-203	46.60	7.4	1.30	37.00	9.05e+00	9.62e-02	67	6	1	3.33e+00	2	1.34e-01	0
Pa-233	27.00	0.0	0.86	0.19	4.52e-02	3.18e-04	39	0	0	1.66e-02	0	6.70e-04	0
* Pa-233	27.00	33.3	0.86	166.50	4.07e+01	2.86e-01	39	11	2	1.50e+01	4	6.03e-01	9

Worksheet 2

B2

Topaz Gamma Dose Calculation

Density:	3.5	gram/cm^3
Stone Mass:	<0.25	grams
Stone Radius:	0.26	cm
Stone Volume:	0.0714	cm^3

a =	0.26
Generic flux	0.1325

a =	0.56
LN	0.999
Generic flux	0.043

a =	4.26
LN	0.121
Generic flux	0.005

Isotope	Half-Life (days) T1 / 2	Max Conc (dps/g)	Gamma Factor (Rcm^2/hmCi)	Activity (dps)	AT SURFACE Flux (dps/cm^2)	AT SURFACE Dose rate (mR/day)	Integrated Dose Factor (day)	AT SURFACE Total first year dose (mrem)	Geom 1 AT SURFACE w/movement Total first year dose (mrem)	AT 3 MM Flux (dps/cm^2)	Geom 2 AT 3 MM Total first year dose (mrem)	AT 4 CM Flux (dps/cm^2)	Geom 3 AT 4 CM Total first year dose (mrem)
Na-22	949.00	0.037	12.00	0.13	1.67e-02	1.64e-03	320	1	0	2.48e-03	0	4.06e-05	0
* Na-22	949.00	14.800	12.00	51.80	6.67e+00	6.54e-01	320	210	31	9.92e-01	31	1.63e-02	1
Sc-46	83.83	14.800	10.90	51.80	6.67e+00	5.94e-01	115	68	10	9.92e-01	10	1.63e-02	0
Mn-54	312.[illegible]	37.000	4.70	129.50	1.67e+01	6.41e-01	250	160	24	2.48e+00	24	4.06e-02	0
Zn-65	244.40	37.000	2.70	129.50	1.67e+01	3.68e-01	227	84	13	2.48e+00	12	4.06e-02	0
Cs-134	752.63	3.330	8.70	11.66	1.50e+00	1.07e-01	310	33	5	2.23e-01	5	3.66e-03	0
Ta-182	114.74	14.800	6.80	51.80	6.67e+00	3.71e-01	147	55	8	9.92e-01	8	1.63e-02	0

Input data for additional isotopes

Isotope	Half-Life (days) T1 / 2	Max Conc (dps/g)	Gamma Factor (Rcm^2/hmCi)	Activity (dps)	AT SURFACE Flux (dps/cm^2)	AT SURFACE Dose rate (mR/day)	Integrated Dose Factor (day)	AT SURFACE Total first year dose (mrem)	AT SURFACE w/movement Total first year dose (mrem)	AT 3 MM Flux (dps/cm^2)	AT 3 MM Total first year dose (mrem)	AT 4 CM Flux (dps/cm^2)	AT 4 CM Total first year dose (mrem)
Cr-51	27.70	740.0	0.16	185.00	3.33e+02	4.36e-01	40	17	3	4.96e+01	3	8.13e-01	0
Co-58	70.80	37.0	5.50	9.25	1.67e+01	7.50e-01	99	74	11	2.48e+00	11	4.06e-02	0
Fe-59	44.63	22.2	6.40	5.55	1.00e+01	5.24e-01	64	34	5	1.49e+00	5	2.44e-02	0
Co-60	1923.92	18.5	13.20	4.63	8.33e+00	9.00e-01	342	308	46	1.24e+00	46	2.03e-02	1
As-74	17.77	18.5	4.40	4.63	8.33e+00	3.00e-01	26	8	1	1.24e+00	1	2.03e-02	0
Sr-85	64.84	37.0	3.00	9.25	1.67e+01	4.09e-01	92	37	6	2.48e+00	6	4.06e-02	0
Rb-86	18.66	25.9	0.50	6.48	1.17e+01	4.77e-02	27	1	0	1.74e+00	0	2.84e-02	0
Y-91	58.51	11.1	0.01	2.78	5.00e+00	4.09e-04	83	0	0	7.44e-01	0	1.22e-02	0
Zr-95	64.02	22.2	4.10	5.55	1.00e+01	3.35e-01	91	30	5	1.49e+00	5	2.44e-02	0
Nb-95	35.06	37.0	4.20	9.25	1.67e+01	5.73e-01	51	29	4	2.48e+00	4	4.06e-02	0
Sn-113	115.10	33.3	1.70	8.33	1.50e+01	2.09e-01	148	31	5	2.23e+00	5	3.66e-02	0
Sb-124	60.20	7.4	9.80	1.85	3.33e+00	2.67e-01	86	23	3	4.96e-01	3	8.13e-03	0
Sb-125	1011.05	37.0	2.70	9.25	1.67e+01	3.68e-01	323	119	18	2.48e+00	18	4.06e-02	0
Ba-133	3832.50	0.0	2.40	0.00	0.00e+00	0.00e+00	353	0	0	0.00e+00	0	0.00e+00	0
* Ba-133	3832.50	74.0	2.40	18.50	3.33e+01	6.54e-01	353	231	35	4.96e+00	34	8.13e-02	1
Ce-139	137.66	0.0	0.66	0.01	1.67e-02	9.00e-05	167	0	0	2.48e-03	0	4.06e-05	0
* Ce-139	137.66	185.0	0.66	46.25	8.33e+01	4.50e-01	167	75	11	1.24e+01	11	2.03e-01	0
Ce-141	32.50	33.3	0.34	8.33	1.50e+01	4.17e-02	47	2	0	2.23e+00	0	3.66e-02	0
Hf-181	42.39	25.9	3.10	6.48	1.17e+01	2.96e-01	61	18	3	1.74e+00	3	2.84e-02	0
Ir-192	74.02	14.8	4.80	3.70	6.67e+00	2.62e-01	103	27	4	9.92e-01	4	1.63e-02	0
Hg-203	46.60	7.4	1.30	1.85	3.33e+00	3.54e-02	67	2	0	4.96e-01	0	8.13e-03	0
Pa-233	27.00	0.0	0.86	0.01	1.67e-02	1.17e-04	39	0	0	2.48e-03	0	4.06e-05	0
* Pa-233	27.00	33.3	0.86	8.33	1.50e+01	1.06e-01	39	4	1	2.[illegible]3e+00	1	3.66e-02	0