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March 8, 1993

U.S. Nuclear Regulatory Commission
Medical, Academic, and Commercial Use Safety Branch
ATTENTION: Mr. Bruce Carrico
Mail Stop OWFN-6H3
Washington DC 20555

Dear Mr. Carrico:

This letter is in response to those issues which were discussed on Tuesday, February 23, 1993, during a conference call involving Joe Wang (NRC), Bruce Carrico (NRC) and Steve Morris (MURR). The issues arise from an application filed with the U.S. Nuclear Regulatory Commission (NRC) by the Curators of the University of Missouri (Applicant) for an exempt license to distribute neutron transmutation doped semiconductor materials. The application was filed on February 1, 1993, and amended on February 4, 1993.

The MURR responses are in two parts beginning with a statement of the issue on which NRC requires additional information, followed by the MURR response. Tables in this response are designated with an "R" prefix to distinguish them from those in the application.

Issue 1: The NRC requests that the Applicant include the methodology by which the exempt concentration is calculated for those radionuclides not listed in 10 CFR 30.70 in the exempt concentration table. The NRC stated that the methodology the Applicant currently uses for that purpose under Exempt License 24-00513-36E is adequate but must be specifically stated in the instant application.

Applicant's Response to Issue 1:

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

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

where ALI is the annual limit of intake for ingestion[1] (μCi/year), 3000 refers to daily water intake for ICRP 23 Reference Man (g/day), and 365 is the days per year.

[1] 10 CFR 20, Appendix B to §§ 20.1001-20.2401, Table 1, Column 1.

Table R1. Total Effective Dose Equivalent (TEDE) Resulting from the Processing of NTD-Silicon

nuclide	half life	exempt conc. μCi/g	air effluent conc.* μCi/mL	derived air conc.† μCi/mL	work area conc.‡ μCi/mL	work area TEDE mrem/year
Na-22	2.6 y	4E-4	9E-10	3E-7	4E-12	0.1
Mn-54	312 d	1E-3	1E-9	3E-7	1E-11	0.2
Co-57	272 d	5E-3	9E-10	3E-7	5E-11	0.8
Co-60	5.27 y	5E-4	5E-11	1E-8	5E-12	2.5
Zn-65	244 d	1E-3	4E-10	1E-7	1E-11	0.5
Ag-110^m	250 d	3E-4	1E-10	4E-8	3E-12	0.4
Cs-134	2.06 y	9E-5	2E-10	4E-8	9E-13	0.1
Cs-137	30.2 y	9E-5	2E-10	6E-8	9E-13	0.1
Ba-133	10.5 y	2E-3	9E-10	3E-7	2E-11	0.3
Ce-144	285 d	1E-4	2E-11	6E-9	1E-12	0.8
Eu-152	13.3 y	7E-4	3E-11	1E-8	7E-12	3.5
Eu-154	8.56 y	5E-4	3E-11	8E-9	5E-12	3.1
Eu-155	4.68 y	2E-3	2E-10	4E-8	2E-11	2.5
Gd-153	242 d	2E-3	3E-10	6E-8	2E-11	1.7

*See note 2.
†See note 3.
‡The work area concentration is based on silica dust occupational limits recommended by ACGIH.

Issue 3: The NRC requests that the Applicant provide NTD-Silicon production capacities at the MURR.

Applicant's Response to Issue 3: The production rate of NTD-Silicon is dependent on the dopant concentration required which varies depending on the intended application. During FY92 the MURR irradiated and released approximately 12 metric tons of silicon. Assuming a similar distribution of requested dopant concentrations in the future, the MURR could increase its production capacity to approximately 50 metric tons per year.

Issue 4: The NRC requests that the Applicant provide an estimate of the external dose resulting from the occupational exposure to P-32 in NTD-Silicon.

Applicant's Response to Issue 4: At exempt concentrations, external dose rates from P-32 are minimal. P-32 decays totally by negative beta emission; therefore, only a fraction of the radiation produced reaches the surface of the silicon ingot. The activity in a thin layer near the surface of the ingot is considered in the dose calculation. In the model used, half of the betas in the surface layer are assumed to be emitted perpendicular to the surface. This is conservative since beta emission is isotropic; therefore, less than 50% of the betas in the "active" layer would, in fact, actually escape. The average P-32 beta energy is 0.695 MeV and its approximate range in silicon is 0.1 cm.[4] At exempt concentrations the P-32 activity (A) in a silicon ingot with the potential for producing an external exposure is given by:

$$A = C \cdot \rho \cdot r \cdot 0.5 = 2.33 \times 10^{-5}\ \mu Ci/cm^2$$

where A is the activity per unit area ($\mu Ci/cm^2$) available to cause an external dose, C is the exempt concentration of P-32 ($2 \times 10^{-4}\ \mu Ci/g$), ρ is the density of silicon ($2.33\ g/cm^3$), and r is the range (0.1 cm) of the beta having the average energy. This quantity of activity, if in contact with the skin, produces an external skin dose rate of 0.0004 mrem/hr. This dose rate was calculated using the computer code VARSKIN[5]. Based on continuously handling a NTD-Silicon ingot, at the exempt concentration, over a 40 hour week, 50 weeks per year, results in a calculated annual external dose of less than 1 mrem, which is negligible.

Issue 5: The NRC has informed the Applicant that any exempt license resulting from the instant application would be limited entirely to the release of NTD-Silicon. Other neutron transmutation doped semiconductor materials, such as high-purity germanium, must be further characterized by the Applicant prior to consideration by the NRC.

Applicant's Response to Issue 5: Applicant understands and accepts that its application to distribute neutron transmutation doped semiconductor materials under an exempt license will be restricted, by license condition, specifically to high-purity silicon until such time that Applicant successfully amends the license to include other semiconductor materials.

Issue 6: The NRC requests that Applicant provide additional information regarding the activity of radioisotopes routinely measured in NTD-Silicon.

Applicant's Response to Issue 6: The purity of silicon ingots submitted for neutron transmutation doping has continuously improved over the last 15 years. Impurities are typically well less than 1 nanogram per gram of silicon (ppb). Separate from the NTD-Silicon program, the Nuclear Analysis Program at the MURR routinely analyzes high-purity silicon (HpSi) used in the electronics industry.

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4 Health Physics and Radiological Health Handbook, B. Shlein and M.S. Terpilak (1984).

5 DRAFT NUREG/CR-4418 (PNL-5610): "Dose Calculation for Contamination of the Skin Including the Computer Code VARSKIN", R.J. Traub, et.al., October 1985.

A comprehensive listing of the elements sought in HpSi is given in Table R2. The upper level concentration, or detection limit, in nanograms impurity per gram of silicon (ppb) are given in column 2. Radionuclides that can be produced from these impurities, which are inclusive of those seen in NTD-Silicon, along with their half lives, are given in columns 3 and 4, respectively. The maximum expected activity for each impurity at that time when the Si-31 activity has reached its exempt concentration of 0.009 μCi/g are listed in column 5 in Table R2[6]. The exempt concentration from 10 CFR 30.70, or calculated from ALI data (see note 3, Table 1 of the February 1, 1993, Application; or, Applicant's response to Issue 1, above) is given in column 6, and the percent the maximum expected activity (column 5) is of the exempt concentration is listed in column 7 in Table R2. The activity data for impurities in NTD-Silicon that are given in Table R2 are upper limits within our experience at the MURR. Typically the sum of ratios of the gamma-ray emitters that are detected are well below 10%.

Table R2. Impurity concentrations (upper limits) and induced radioactivity in High-Purity Silicon (HpSi)

element	~conc. in HpSi ng/g(ppb) upper limits	product nuclide	half life	maximum expected act. in NTD-Si (μCi/g)*	exempt conc. (μCi/g)	maximum expected percent of exempt conc.
sodium	0.3	Na-24	14.96 h	6E-5	2E-3	3
potassium	0.8	K-42	12.36 h	2E-5	3E-3	0.7
calcium	10	Ca-45	165 d	3E-5	9E-5	33
calcium	10	Ca-47	4.54 d	1E-6	5E-4	0.2
chromium	0.04	Cr-51	27.7 d	2E-6	2E-2	0.01
iron	2	Fe-59	44.5 d	4E-7	6E-4	0.07
cobalt	0.004	Co-60	5.27 y	2E-7	5E-4	0.04

6 The NTD-Silicon program at the MURR utilizes thermal neutron flux densities ranging from 1×10^{12} to 4×10^{12} $n \cdot cm^{-2} \cdot sec^{-1}$ producing neutron fluences that range approximately from 1×10^{17} to 1×10^{18} $n \cdot cm^{-2}$ depending on the desired concentration of phosphorus dopant. Following irradiation, the NTD-Silicon is allowed to decay for a minimum of five days before it is processed for shipping. The activities listed in column 5 of Table R2 are based on a thermal flux of 1×10^{13} $n \cdot cm^{-2} \cdot sec^{-1}$ and an irradiation time of 27 hours producing a fluence of $\sim 10^{18}$ $n \cdot cm^{-2}$. Under these conditions the activity of Si-31 at the end of the irradiation is approximately 2.2×10^4 μCi/g. The time required for this Si-31 activity to decay to the exempt concentration of 0.009 μCi/g is approximately 56 hours which was used as the decay time for the computation of concentration data summarized in column 5 in Table R2.

Table R2 continued.

element	~conc. in HpSi ng/g(ppb) upper limits	product nuclide	half life	maximum expected act. in NTD-Si (μCi/g)*	exempt conc. (μCi/g)	maximum expected percent of exempt conc.
copper	0.02	Cu-64	12.7 h	6E-6	3E-3	0.2
zinc	0.1	Zn-65	244 d	3E-7	1E-3	0.03
arsenic	0.007	As-76	26.3 h	9E-6	2E-4	4.5
selenium	0.04	Se-75	120 d	3E-7	3E-3	0.01
bromine	0.003	Br-82	35.3 h	2E-6	3E-3	0.07
zirconium	2	Zr-95	64.0 d	4E-7	6E-4	0.07
zirconium	2	Zr-97	16.74 h	9E-7	2E-4	0.5
molybdenum	0.04	Mo-99	65.94 h	6E-7	2E-3	0.03
silver	0.02	Ag-110m	250 d	3E-7	3E-4	0.01
cadmium	0.07	Cd-115	55.46 h	2E-6	3E-4	0.7
antimony	0.007	Sb-122	2.70 d	8E-6	3E-4	2.7
antimony	0.007	Sb-124	60.2 d	3E-7	2E-4	0.1
cesium	0.004	Cs-134	2.06 y	2E-7	9E-5	0.2
lanthanum	0.001	La-140	40.27 h	1E-6	2E-4	0.5
cerium	0.04	Ce-141	32.5 d	5E-7	9E-4	0.06
neodymium	0.001	Nd-147	10.98 d	2E-8	6E-4	0.003
europium	0.002	Eu-152m	9.32 h	4E-5	6E-4	6.7
europium	0.002	Eu-152	13.33 y	7E-7	7E-4	0.1
gadolinium	0.01	Gd-159	18.56 h	1E-6	8E-4	0.1
terbium	0.002	Tb-160	72.3 d	7E-7	4E-4	0.2
ytterbium	0.03	Yb-169	32.0 d	3E-6	6E-4	0.5
ytterbium	0.03	Yb-175	4.19 d	1E-4	1E-3	10
lutetium	0.03	Lu-177	6.71 d	1E-4	1E-3	10

Table R2 continued.

element	~conc. in HpSi ng/g(ppb) upper limits	product nuclide	half life	maximum expected act. in NTD-Si (μCi/g)*	exempt conc. (μCi/g)	maximum expected percent of exempt conc.
hafnium	0.003	Hf-181	42.39 d	2E-7	7E-4	0.03
tantalum	0.004	Ta-182	114.5 d	8E-7	4E-4	0.2
tungsten	0.004	W-187	23.9 h	6E-6	7E-4	0.9
rhenium	0.01	Re-186	90.64 h	6E-5	9E-4	6.7
rhenium	0.01	Re-188	16.98 h	3E-5	6E-4	5
iridium	0.0001	Ir-192	73.83 d	3E-7	4E-4	0.08
iridium	0.0001	Ir-194	19.15 h	7E-7	3E-4	0.2
gold	0.001	Au-198	2.70 d	2E-5	5E-4	4
mercury	0.1	Hg-197	64.1 h	5E-5	3E-3	2
mercury	0.01	Hg-203	46.61 d	2E-6	2E-4	1
uranium	0.01	Np-239	2.36 d	2E-5	2E-3	1

*Based on a 27 hour irradiation at a thermal neutron flux density of 1×10^{13} $n \cdot cm^{-2} \cdot sec^{-1}$ and a decay period of approximately 56 hours.

This concludes Applicant's response to the issues raised in the February 23, 1993, conference call. If you have additional questions or require additional information, please contact me at 314-882-5265; or, if more convenient, my FAX number is 314-882-6360.

Sincerely,

J. Steven Morris, PhD
Coordinator, Nuclear Analysis Program
Adjunct Professor of Chemistry