

PAJ, Inc. / Prime Art & Jewel, 18325 Waterview Parkway, Dallas, TX 75252

May 27, 2008

Mr. Richard Struckmeyer
State Agreements and Industrial Safety Branch
Mail Control No. 022628
US Nuclear Regulatory Commission
Washington, D.C. , 20555-0001

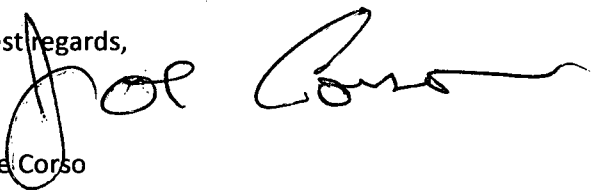
SUBJECT: In reference to your request for additional information dated April 29, 2008 concerning (PAJ, Inc.) Application for Material License

Dear Mr. Struckmeyer,

Enclosed you will find Mr. Andrew Karam's responses to the questions that you have in reference to the Technical Basis Document. I trust that you will find accurate and satisfactory explanations to your questions.

Any further questions or information that you may need, please contact me.

Best regards,


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May 26, 2008

Dear Mr. Struckmeyer:

You have asked several specific questions in your letter regarding the PAJ license application and the TBD. The answers to these questions constitute the balance of this document.

1. *Please indicate whether empirical data are available to support your assumption "that food materials offer the same activation targets as do gemstones," and that the much larger doses to gemstones do not activate contaminants to the concentration levels above those of 10 CFR 30.70. Please provide any additional information you may have in support of this comparison, or indicate whether you wish to continue the application process without reference to this information.*

As noted in the previously submitted Technical Basis Document, gemstones irradiated in a linear accelerator with energies of less than 7.5 MeV do not become activated unless they contain beryllium or deuterium. Therefore, unless irradiated gemstones contain beryllium or deuterium, they cannot be considered byproduct material. **Below the activation threshold, activation does not occur – thus, neither the total irradiation dose nor the chemical composition is relevant unless the gemstones contain deuterium or beryllium.** These factors are *only* relevant if activation is possible – for gemstones that are exposed to electron energies in excess of 7.5 MeV.

The following table summarizes the radiological properties of gemstones irradiated in an electron accelerator beam with an energy of 7.5 MeV, and that contain impurities that may become activated at this energy. The first column contains the target nuclide, these nuclides are those for which the electron and photon activation threshold is less than 7.5 MeV. For other nuclides, the amount of activity produced is zero because, below the activation threshold, the activation cross-section is equal to zero and no activation occurs. The second column shows the reaction that takes place (e.g. gamma-neutron or gamma-alpha) and the third column indicates the progeny nuclide that is formed. **Please note that many of the progeny nuclides are stable** – for example, in the reaction $D(\gamma,n)H$, where the deuterium parent atom gives rise to a stable hydrogen atom upon ejection of a neutron.

Target Nuclide	Rxn	Progeny Nuclide	Progeny Half-life	# progeny atoms produced	Progeny activity (pCi/gm for 1 ppm of parent)		
					Saturation	1 week	30 days
H-2	γ -n	H-1	Stable	N/A	N/A	N/A	N/A
Be-9	γ -n	Be-8	Stable	N/A	N/A	N/A	N/A
Mg-25	γ -n	Mg-24	Stable	N/A	N/A	N/A	N/A
Ge-73	γ -n	Ge-72	Stable	N/A	N/A	N/A	N/A
	γ - α	Zn-69	57 min	640	3.49	0	0
Zr-91	γ -n	Zr-90	Stable	N/A	N/A	N/A	N/A
	γ - α	Sr-87	Stable	N/A	N/A	N/A	N/A
Mo-95	γ -n	Mo-94	Stable	N/A	N/A	N/A	N/A
	γ - α	Zr-91	Stable	N/A	N/A	N/A	N/A
Mo-97	γ -n	Mo-96	Stable	N/A	N/A	N/A	N/A
	γ - α	Zr-93	1.5x10 ⁶ yrs	590	2.4x10 ⁻¹⁰	2.4x10 ⁻¹⁰	2.4x10 ⁻¹⁰
Pd-105	γ -n	Pd-104	Stable	N/A	N/A	N/A	N/A
	γ - α	Ru-101	Stable	N/A	N/A	N/A	N/A
Cd-111	γ -n	Cd-110	Stable	N/A	N/A	N/A	N/A
	γ - α	Pd-107	6.5x10 ⁶ yrs	690	6.4x10 ⁻¹¹	6.4x10 ⁻¹¹	6.4x10 ⁻¹¹
Cd-113	γ -n	Cd-112	Stable	N/A	N/A	N/A	N/A
	γ - α	Pd-109	1.36 hrs	651	150	0.00	0.00
Sn-117	γ -n	Sn-116	Stable	N/A	N/A	N/A	N/A
	γ - α	Cd-113	9.3x10 ¹⁵ yrs	39,000	2.5x10 ⁻¹⁸	2.5x10 ⁻¹⁸	2.5x10 ⁻¹⁸
Te-125	γ -n	Te-124	Stable	N/A	N/A	N/A	N/A
	γ - α	Sn-121	76 yrs	340	2.7x10 ⁻⁶	2.7x10 ⁻⁶	2.7x10 ⁻⁶
Sm-147	γ -n	Sm-146	7.0x10 ⁷ yrs	610	5.2x10 ⁻¹²	5.2x10 ⁻¹²	5.2x10 ⁻¹²
	γ - α	Nd-143	Stable	N/A	N/A	N/A	N/A
Sm-149	γ -n	Sm-148	Stable	N/A	N/A	N/A	N/A
	γ - α	Nd-145	Stable	N/A	N/A	N/A	N/A
W-183	γ -n	W-182	Stable	N/A	N/A	N/A	N/A
	γ - α	Hf-179	Stable	N/A	N/A	N/A	N/A
W-184	γ -n	W-183	Stable	N/A	N/A	N/A	N/A
	γ - α	Hf-180	Stable	N/A	N/A	N/A	N/A
W-186	γ -n	W-185	75 days	28,000	0.081	0.076	0.061
	γ - α	Hf-182	9.0x10 ⁶	95,000	6.2x10 ⁻⁹	6.2x10 ⁻⁹	6.2x10 ⁻⁹
Pb-207	γ -n	Pb-206	Stable	N/A	N/A	N/A	N/A
	γ -p	Tl-206	4.2 min	N/A	N/A	N/A	N/A
	γ - α	Hg-203	47 days	66,000	0.30	0.27	0.19
Pb-208	γ -n	Pb-207	Stable	N/A	N/A	N/A	N/A
	γ - α	Hg-204	Stable	N/A	N/A	N/A	N/A
Th-232	γ -n	Th-231	1.1 days	261,000	51	0.62	3.2x10 ⁻⁷
	γ - α	Ra-228	2.4 days	264,000	24	3.16	0.0041

Several nuclides produce short-lived progeny nuclides upon activation (for example, $\text{Ge-73}(\gamma, \alpha)\text{Zn-69}$, which has a 57-minute half-life. While such a nuclide will exist immediately following irradiation, it will undergo over 24 half-lives of decay in the first day alone and will not be present at the time such an irradiated gemstone would be shipped for setting, processing, and sale. Thus, the only gemstones that are a potential concern from the standpoint of release to the general public are those for which the progeny nuclide is radioactive and in which the half-life is sufficiently long as to not preclude decay to stability during post-irradiation processes.

The fifth column lists the total number of progeny atoms produced during an irradiation sufficiently long as to produce saturation. At saturation activity, the process of radioactive decay removes atoms at the same rate at which they are produced; thus, it is not possible to exceed saturation activities, regardless of the length of the time of irradiation in a beam of a given intensity. This was calculated by assuming that the electron beam consisted of monoenergetic electrons with an energy of 7.5 MeV, that the dose rate in the beam was 100 MRad/sec (i.e. 10^8 rad/sec¹). The electron fluence required to produce this radiation dose in 1 gram of target is 8.32×10^{15} electrons per gram of target, which is rounded off as 10^{16} electrons per gram of target material, and it is assumed (for the sake of conservatism) that this dose is delivered in one second. It is further assumed that each electron produces a photon with an energy of 7.5 MeV, clearly a conservative assumption. Thus, the formula used to determine the number of progeny atoms produced at saturation is $N_{\text{progeny}} = \phi \sigma N_{\text{target}}$. The activation cross-sections used were taken from the IAEA document referenced in the TBD, and ranged from <1-100 mb. A value of 1 mb was used for all reactions for which the cross-section was given as less than 1 mb as another conservative assumption.

For a target with an activation cross-section of 1 mb and in which the parent atom was present at a concentration of 1 ppm and has an atomic mass of 100 amu, the number of progeny atoms produced by this electron flux is

¹ Radiation dose rates of up to 1 Mrad/min are not unusual in research linear accelerators, and NUREG 5883 notes that gemstone irradiation may take place at dose rates of 250-500 Mrads/hr. The assumed dose rate used in these calculations, 100 Mrad/sec is substantially higher.

$N_d = 10^{16} \times 10^{-27} \times \frac{1}{10^6} \times \frac{6.022 \times 10^{23}}{100} = 60,220 \text{ atoms}$. If the progeny atoms have a half-life of

100 days, the amount of induced activity at saturation is

$$A = \lambda N = \frac{\ln(2)}{100d} \times \frac{1 \text{ day}}{86,400 \text{ sec}} \times 60,220 \text{ atoms} = 0.0048 \text{ Bq} \Rightarrow 0.13 \text{ pCi}$$

Thus, in a 1-gram sample exposed to this electron flux, the amount of induced activity is about 0.13 pCi/gm at the time the irradiation stops. For a given electron flux, the amount of induced activity will increase as the activation cross-section increases, as the concentration of the parent atom increases, and as the half-life of the progeny nuclide decreases. **As it is impossible to exceed saturation activity for a given flux, the total time of irradiation is irrelevant – only the electron flux is important.**

The number of target atoms was calculated based on the number of parts per million (ppm) of the relevant impurity (from the previous table) and the atomic weight of the impurity atom.

The final columns convert the number of radioactive atoms produced to an activity (in units of pCi/gm) at saturation activity and following 1 week and 1 month of post-irradiation decay using the equations $A = \lambda N$, and $A_t = A_0 e^{-\lambda t}$. These calculations clearly show that the majority of reactions do not produce radioactive progenys, and that those that are formed are almost all too long-lived or too short-lived to be a concern.

However, of all of the radioactive activation products formed, only one (Ra-228) is present in concentrations that exceed 1 pCi/gm 1 week post-irradiation. **No progeny nuclides are formed in activity concentrations that exceed 1 nCi/gm at any time, even using the conservative assumptions outlined above.** The reason for this relative paucity of induced activity is a combination of factors:

1. The low abundance of target atoms (which are present only as impurities)
2. The low activation cross-section for activation reactions with electrons and photons of so low an energy
3. The very long half-life of most progeny nuclides means that more atoms are required for each unit of activity induced
4. The relatively short half-life of most other progeny nuclides means that the activity that is formed decays to stability quickly post-irradiation

These tables clearly show that there are only a few nuclides that will form radioactive progeny atoms following irradiation with a 7.5 MeV electron beam and that, of these, only 4 (Ge-73, Cd-113, Pb-207, and Th-232) yield progeny activities in excess of 1 pCi/gm at saturation activity following irradiation. Of these, only Pb-207 and Th-232 produce progeny nuclides whose activity concentrations exceed 0.1 pCi/gm one week post-irradiation, and only Th-232 produces a progeny nuclide (β -emitting Ra-228) that will be present in an activity concentration in excess of 1 pCi/gm one week post-irradiation – assuming that the parent nuclide (Th-232) is present in a concentration of 1 ppm in the irradiated gemstones. Since Th-232 is found in such high concentrations in only one gemstone – zircon – those gemstones that are routinely irradiated (e.g. topaz, diamond) will not contain either Th-232 or Ra-228 in measurable quantities.

It also bears noting that the NRC has published a report (NUREG 5883) that cites the scientific literature in stating that “the induced activity began at about 15 MeV. This statement supports the calculations presented above.

These calculations are conservative because:

- The assumed electron flux is substantially higher than what is reported in NUREG 5883 (page 12)
- The induced activity calculated is saturation activity, which is the highest possible induced activity concentration
- The calculations were based on nominal trace element concentrations of 1 ppm, which is significantly higher than those noted in the scientific literature
- The scientific literature (cited on page 12 of NUREG 5883) notes that activation products are not noted at electron energies of less than 15 MeV, which is twice the electron energy noted in the TBD and in this letter.
- Only lead and thorium have the potential of forming activation products in an electron accelerator with electron energies of less than 7.5 MeV, and these are of regulatory significance only if they are present in concentrations in excess of a few thousand ppm. Such concentrations of trace elements are far higher than what is found in either food or gemstones.

Based on this assessment, it seems reasonable to conclude that irradiation of gemstones in an electron accelerator with a beam energy of less than 7.5 MeV does not induce radioactivity to an extent requiring regulation. In addition, it is clear that exposing

beryllium-containing gems to such irradiation does not induce radioactivity because the nuclide produced, Be-8, is stable. Thus, PAJ asserts that gemstones (including those containing beryllium) treated by irradiation in an electron beam of less than 7.5 MeV are not byproduct material and do not require licensure. Only those gemstones exposed to energies in excess of 7.5 MeV have the potential to become activated to the point of requiring licensure.

- 2. Please clarify how the efficiency values were determined, and whether the listed values refer to intrinsic efficiency or absolute efficiency. If you maintain that the term "absolute counting efficiency" is used correctly in the TBD, please cite a reference for this definition.*

Absolute counting efficiency is used in the TBD in the same manner mentioned in this letter – the intrinsic counting efficiency multiplied by the geometric counting efficiency.

NRC cites references that the intrinsic counting efficiency for gamma radiation of the energy cited in the TBD ranges from 25%-50%. To achieve an absolute counting efficiency of 5%, it is necessary to show that the geometric counting efficiency is 20% or greater. With 2π counting geometry, the geometric counting efficiency is 50%, giving an absolute counting efficiency of 12.5%.

The counting procedure to be used by PAJ calls for counting samples with a 2"x2" NaI(Tl) detector. Placing this detector on contact with the sample would give a counting geometry of about 2π , placing the detector at a distance of 1" from the sample produces a counting geometry of about 1π because the opening angle for a 2" (5 cm) diameter detector at a distance of 1" is about 90° , or about 1π . Thus, surveying a sample using a 2"x2" NaI detector at a distance of 1" produces a geometric efficiency of about 25%. Thus, for this counting geometry, the absolute counting efficiency is 25% (intrinsic efficiency) \times 25% (geometric efficiency) = 6.25%, which is greater than the 5% counting efficiency cited in the TBD. Because the counting procedure calls for placing the detector at a distance of 1 cm from the gemstones to be surveyed PAJ expects to observe a higher counting efficiency. The value of 5% was used as a conservatively low estimate.

3. Questions regarding MDA determination and counting procedure.

- a. Please indicate what type of instrument is to be used for measuring the gemstones, namely is it a rate meter or a counting instrument.***

PAJ will use a 2"x2" NaI(Tl) probe to detect gamma-emitting radionuclides and a GM "pancake" type probe to detect beta-emitting radionuclides. The meter to which the probes will be attached will be used to indicate the total number of counts (the integrated counts) over the counting period. Thus, the person checking the gemstones will record the integrated counts recorded during the counting period, as displayed on a digital readout on the instrument.

- b. Indicate the type and configuration of shielding to be used.***

PAJ will use shielding as required to reduce background count rate to less than 20 cpm with the GM probe and less than 500 cpm with the NaI(Tl) probe. The shielding will be large enough to permit counting the sample, and it will be made of lead, steel, and/or concrete as appropriate. Because the sole purpose of the shielding is to reduce background count rate to or below the levels noted above, the exact composition may vary according to the availability of materials, budget, and space. Alternately, PAJ may choose to shield the detector by surrounding it with lead sheeting or by purchasing a shielded probe such as the Ludlum Model 44-40.

- c. Indicate how the gems are to be scanned, whether a conveyor belt will be used, and if so, how its speed may affect the measurement process.***

The procedure noted in the TBD calls for counting a sample of 5 grams for a total of 5 minutes. The sample will be placed beneath the detector for the duration of the integration period; neither the sample nor the probe will move while counting.

- d. If a rate meter is to be used, please indicate how the MDA for this system is to be determined, based on the response time of the rate indicating circuits.***

Although a rate meter will be used, the meter will be used to measure the integrated counts over a 5-minute counting period. Thus, the meter will not be used in rate meter mode and the response time of the meter will not affect the sensitivity of the measurement system.

- e. Indicate how the efficiency of the instrument(s) will be determined for the different types of radiation expected to be measured, how the background count rate will be determined, how long the sample will be counted, and any other details relevant to the remaining questions.*

Background count rate will be determined by integrating counts for 5 minutes and dividing by 5. Samples will be counted for 5 minutes, integrating the total number of counts during this time. The net count rate will be calculated as the difference between the integrated sample counts and the integrated background counts. Instrument counting efficiency is assumed to be 5% for all nuclides and all detectors as a conservative assumption.

- f. Based on the characteristics of your specific system, including efficiencies, counting times for background and sample, etc., describe the method to be used to decide whether or not a batch shows activity that is above background, and indicate the MDA that you expect to obtain and show that it meets regulatory requirements.*

This table (copied from page 11 of the TBD) shows the net count rate (cpm) for a 5-gram sample that contain induced radioactivities at the exemption limit for the nuclides shown, and values for L_C and N_D for a 5-minute counting time. These values assume that shielding is used to reduce background count rates to 20 cpm and 500 cpm with, respectively, GM and NaI(Tl) detectors, and they assume that the absolute counting efficiency is 5% for NaI and 20% for GM (as noted in the TBD). Thus, a 5-gram sample counted for 5 minutes that contains Cs-134 at the exempt concentration limit gives a net count rate of 35 cpm with a GM and 90 cpm with an NaI detector. The net integrated counts (net cpm x 5 minutes) will be recorded; **integrated counts in excess of 175 with a GM or greater than 450 counts with an NaI will indicate the possible presence of Cs-**

134 at greater than exempt concentration limits. Lower values will indicate the absence of radionuclides above exemption limits.

As indicated by this table, these values are greater than the lower detection limit; thus, the MDA for this counting methodology is lower than the exempt concentration limits for these radionuclides.

Nuclide	At exempt concentrations, for a 5-gram sample		For a 5-minute counting time			
	CPM (GM)	CPM (1"x1"NaI)	Lc (CPM)		Nd (CPM)	
			GM	NaI	GM	NaI
P-32	175	N/A	7	36	15	73
Sc-46	N/A	445	7	36	15	73
Cr-51	N/A	2220	7	36	15	73
Mn-54	N/A	555	7	36	15	73
Fe-59	N/A	335	7	36	15	73
Zn-65	N/A	285	7	36	15	73
Sb-124	N/A	160	7	36	15	73
Cs-134	35	90	7	36	15	73
Ta-182	N/A	260	7	36	15	73

To provide a margin of error, any samples in which the net integrated counts exceed 150 counts with a GM or 400 counts with a NaI detector will be re-counted to confirm the readings and, if readings remain elevated, will be determined to contain radionuclide levels in excess of exempt concentration limits. The shipment from which such gemstones were obtained may then be sent to a licensed analytical facility for nuclide identification or may be stored until radionuclide concentrations are lower than exemption limits.

Based on the above, the counting procedure to be used by PAJ will be based on what is outlined below:

1. Perform 5-minute background count with both GM and NaI detectors and record results. If the integrated counts are greater than 100 (GM) or 2500 (NaI), add additional shielding and repeat the background count.

2. Select 5 grams of gemstones and place into sample holder. Place probe on top of sample with the probe no more than 1 cm from the sample.
 3. Using the GM probe, count for five minutes and record the integrated counts. Subtract the 5-minute background counts from the total and record the remaining counts (the net counts). If the net counts are greater than 150, the sample shall be recounted.
 4. Using the NaI probe, count the sample for five minutes and record the integrated counts. If the net counts are greater than 400 cpm, the sample shall be recounted.
 5. If the sample exceeds both of the limits noted above (150 net counts with a GM, 400 net counts with an NaI), the sample and the shipment from which it was obtained shall be assumed to contain radionuclides that exceed exempt concentration limits. These samples may be placed in storage pending decay and re-counting or they may be sent for more detailed analysis by a license facility.
- g. If a counting instrument is to be used, please provide details on the counting set-up, including: how is the background to be determined (how long a count is to be used), what is the counting time for the gemstones, and what net count is to be used to determine whether the indication of the instrument shows the presence or otherwise of radioactivity that differs from background.*

Background count rate will be determined by performing a 5-minute count with no sample beneath the counter, recording the integrated counts, and dividing by the 5-minute counting period. For example, if the integrated number of counts is 100, the background count rate is 20 cpm. As noted on page 12 of the TBD, each sample will be counted for 5 minutes. As noted above, shielding will be used to reduce background to a count rate of 20 cpm (GM) and 500 cpm (NaI). Thus, the L_c and ND are calculated to be 7 and 15 cpm (respectively) above background using a GM and 36 and 73 cpm (respectively) above background when counting with a sodium iodide detector. In a 5-minute counting period in which the integrated counts are recorded, the following total integrated counts will be taken to indicate the presence of induced radionuclides at levels exceeding the L_c and ND:

Detector	Background	Count rate (above background)		Integrated counts (including background)	
		Lc	ND	Lc	ND
GM	20	7	15	135	175
NaI	500	36	73	2680	2865

h. Indicate any tests that will be performed on a regular basis to ensure that the detection system and its associated electronics continue to function properly without any changes over time that might affect the ability of the system to perform its intended function.

Background radiation will be counted and recorded daily with each detector on the days that the meter and detectors are in use. Each detector will be checked for appropriate response ($\pm 20\%$) to a source of known strength daily. The background counts and the results of the response checks will be recorded on a control chart, which will be reviewed periodically to look for trends in these values that might indicate incipient problems. Any instrument/probe combination that fails the response check will be sent for calibration or repair. All instruments and detectors will be calibrated annually by a licensed calibration facility and will be adjusted or repaired as necessary and appropriate.