MEMO

TO: Pinellas Plant Work Group
FROM: SC&A, Inc.
DATE: February 3, 2016
SUBJECT: Draft Pinellas Issues Matrix Issue #5: Gamma LOD for RTG Pu-238 Generators

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A sub-item of Issue #5 of the Pinellas draft issues matrix update provided to the Pinellas Plant Work Group (WG) on January 6, 2016, was the basis for the limit of detection (LOD) of 10 mrem for the post-1974 period in Table 6-9 of ORAUT-TKBS-0029-6 instead of the SC&A-recommended 20 mrem. For the reader's convenience, Attachment 1 provides a description of Issue #5 as it stood prior to the November 19, 2012, WG meeting. The sub-item was discussed at the November 19, 2012, WG meeting (pp. 44–50 of the November 19, 2012, transcript), where NIOSH indicated that it was going to look into the basis for an LOD of 10 mrem instead of the SC&A-recommended 20 mrem.

For film dosimetry and photons in the range of 30–250 kiloelectron volts (keV), SC&A believes that a 10 mrem LOD is acceptable. However, the issue arose as to whether workers exposed to Systems Nuclear Auxiliary Power (SNAP) plutonium-238 (Pu-238) radio-thermal generators (RTGs) were in a higher energy gamma field. Because dosimeter film is less sensitive to high-energy photons, a higher LOD would be appropriate for those workers. Recently, a detailed National Aeronautics and Space Administration (NASA) (TRW) report came to light that investigated the emissions from SNAP generators with a view to the impact on the scientific payload of deep space probes (TRW 1971). This memo summarizes the information contained in the NASA report as it pertains to the RTG photon emission energy spectrum that Pinellas workers would have encountered and to the appropriate LOD for dosimeter films worn by those workers.

The TRW (NASA) report was reviewed to ascertain the dose rate spectrum of photon emissions from SNAP generators (TRW 1971). This 191-page report summarizes a detailed investigation of the emission characteristics of SNAP generators to determine the feasibility of using them and the potential long-term impact of ionizing radiation emissions on specific payload instruments. The investigation included modeling and physical measurements of actual and simulated SNAP sources. This report serves as a good surrogate for an analysis of the gamma spectrum to which Pinellas RTG workers would have been exposed. There are a few potential caveats, though they turn out to be minor: There is some in-growth of fission and decay products over the multi-year lifetime of the generators; thus, "fresh" units did not necessarily exactly represent the concern that investigators had for instrument packages once the probe reached the outer planets. Also, orientation and partial shielding were very important with regard to exposure of specific instruments on the probe, whereas presumably workers were more likely to be exposed from a variety of angles around the generators. A detailed review of the report indicates that these issues have little bearing on the spectrum of photons that make it out of the very dense core.

The following extracted graphs and table show the spectrum of radiation that made it out of the RTG device and associated thermal and radiation shielding.

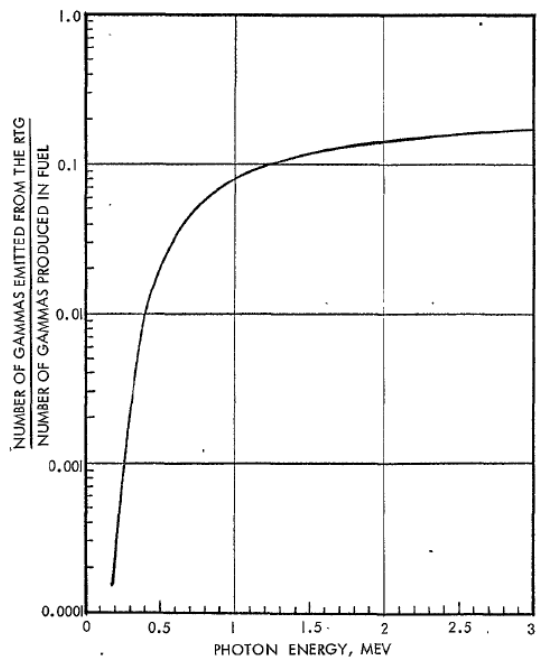

Figure 4-8. Ratio of Number of Gamma Escaping the RTG to Number of Gammas Produced in the Fuel for a Pair of SNAP-19 RTG's at 20° to the Longitudinal Axis.

Figure 4.8 from the report (above) describes the gamma flux leaving the cell. It can be seen that the majority of the flux will be above 500 keV.

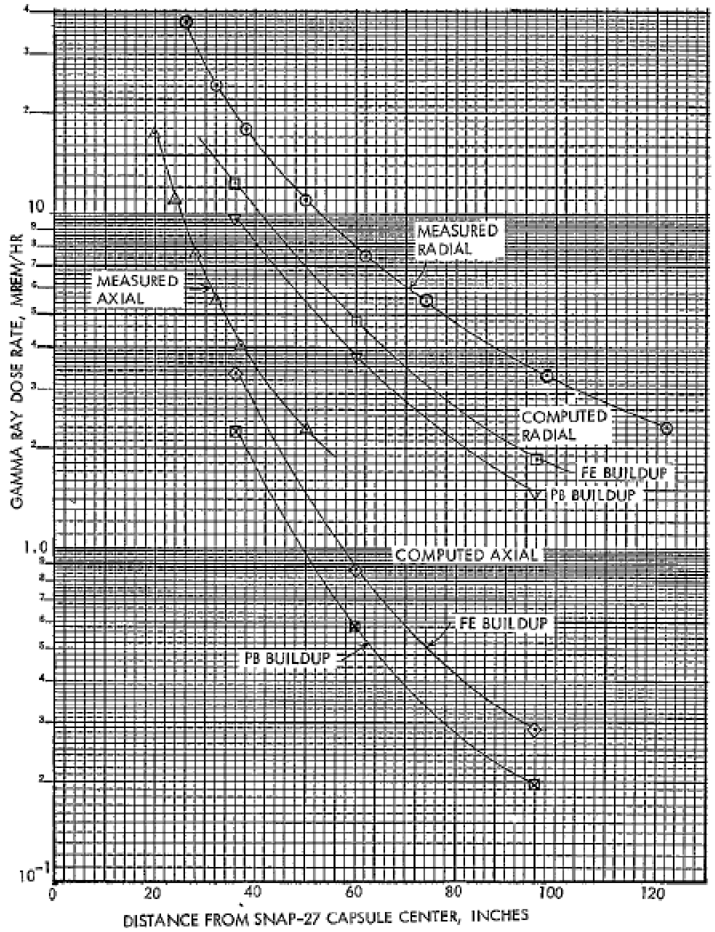

Figure 4-10. Gamma Dose Rates vs. Distance From the Center of a SNAP-27 Capsule

Figure 4.10 from the report (above) shows the dose rates at various distances from the generators. At 20 inches, 25–35 millirem per hour (mrem/hr) is measured. This dose rate will vary with geometry and the source/age of the fuel. However, this graph gives an indication that personnel exposures could have been significant at typical distances at which a worker would manipulate tools and equipment.

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Table 4-16. Computed Dose Rates and Fluxes as a Function of Energy in the SNAP-27 Mid-plane at 8 Feet.

Group	Energy Mev	Percent of total flux	Percent of total dose rate
1	0.05	1.078	0.192
2	0.100	56.461	11.817
3	0.150	11.90	4.258
4	0.200	1.094	0.561
5	0.800	21.101	45.60
6	1.00	1.707	4.425
7	1.50	0.389	1.380
8	2.00	0.253	1.101
9	2.50	5.968	30.229
10	3.00	0.158	0.334
11	4.00	0.011	0.0739
12	5.00	0.005	0.046
13	6.00	0.003	0.0255

Total flux is 1.989×10^3 photons/cm^2/sec and total dose is 1.47 mrem/hr.

Table 4.16 from the report (above) puts the emissions in discrete dose bins. It is readily seen that 83% of the dose is from >800 keV photons.

Based on this NASA report, it is clear that the RTG photon emissions are predominantly (83%) high-energy gamma. There will be some changes in the spectrum depending on the age of the fuel, the mode of fuel production, and the steps taken to remove impurities. (Production methods were varied in an attempt to minimize the impact of the generator emissions on science experiments in the space probes.) However, the contributions to external exposure will remain essentially high energy due to the physical dimensions and density of the source.

As is described for other work sites, film dosimeters respond well to lower energy photons and can readily detect 10 mrem. However, because a film dosimeter is less sensitive to high-energy photons, SC&A believes that the LOD for film dosimeters should be 20 mrem when high-energy gammas are prevalent. Associated IREP parameters should be modified accordingly.

References

ORAUT-TKBS-0029-6. 2011. *Pinellas Plant – Occupational External Dose*, Revision 01, Oak Ridge Associated Universities Team. April 28, 2011.

TRW 1971. *RTG/Science Instrument Radiation Interactions Study for Deep Space Probes: Phase II, III, and IV Report*, R.A. Kaminskas, J.S. Brunhouse, and K.T. Hartwig, TRW Systems Group, Redondo Beach, CA, NASA/AMES Contract# NAS 2-5222. January, 31, 1971.

Attachment 1

The following is SC&A's response to Action Item #5 in the Work Plan proposed by SC&A on October 20, 2011, following the Pinellas Work Group meeting on October 13, 2011.

Action Item #5 was a result of the original Finding #5, "Problems with Personnel Dosimetry," documented in SCA-TR- TASK1-0015, "Review of the NIOSH Site Profile for the Pinellas Plant Site," performed by SC&A in September 2006. Finding # 5 was expressed as follows:

> *Section 6.2.2 of ORAUT-TKBS-0029-6 states the following:*
>
> *"This analysis was unable to locate specific designs of the film dosimeters used for approximately the first 20 years (1957 to 1974) at the Pinellas Plant, and there is limited documentation that indicates there was an early relationship with Nuclear-Chicago".*
>
> *Table 6-5 on page 16 of ORAUT-TKBS-0029-6 assigns a missed dose of 0.24 rem for beta/photons (monthly) for badges used during this time period. This assignment of missing dose evidently assumes that the badges used during this time period were equivalent to those provided by Nuclear-Chicago. Additional discussion is needed on the uncertainty associated with the assumed missing dose, given that the origin of the dosimetry is not clearly established.*

During the Pinellas Work Group meeting of October 13, 2011, NIOSH offered the following resolution to the finding:

> *Changes were made to the Dosimetry Technology and Missed Dose sections to address SC&A Finding #5. Updated information on the film badge characteristics post-1974 is contained in Tables 6-9 through 6-11 of the revised TBD-6. Pre-1974 performance characteristics are not available, so NIOSH uses the maximizing approach in "A Standard Complex-Wide Methodology for Overestimating External Doses Measured with Film Badge Dosimeters" (ORAUT-OTIB-0010).*

Subsequently, SC&A was authorized to review the performance characteristics identified by NIOSH and tabulated in ORAUT-TKBS-0029-6, Rev. 01, for dosimeters used in the post-June 1974 time period.

The three relevant tables were reviewed (Tables 6-9, 6-10, and 6-11) and portions of relevant references were examined, including technical information bulletins (OTIBs) and the Mound site profile, as Mound dosimetry was utilized at the site during the period in question. Generally, the assumptions in the revised tables under consideration are sound, except as noted in the observation below:

The original Table 6-5 in ORAUT-TKBS-0029-6 (September 15, 2005) used 0.02 rem as the minimum detection limit (MDL) for photons for Landauer film dosimetry. Table 6-9 in the current version (April 28, 2011) shows 0.01 rem for the limit of detection (LOD). No reason for the change is evident in the site profile document.

For film utilized in a high-energy photon environment, 0.02 rem is more realistic and claimant favorable as the LOD. The issue of film emulsion response to high-energy photons is well known and discussed in ORAUT-OTIB-0010.

The issue was also spelled out in the Idaho National Laboratory (INL) site profile review of December 2008 (*Idaho National Laboratory (INL) Site Profile Review Update*):

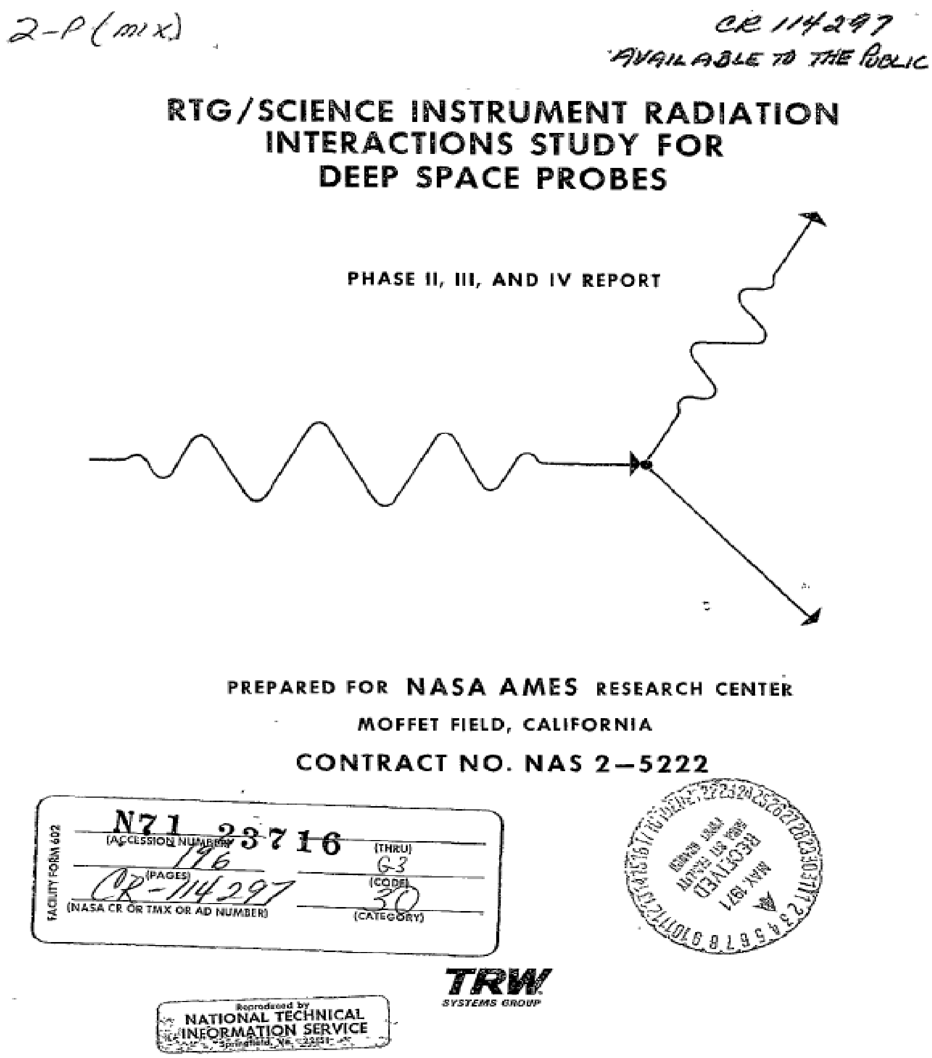
> ***[3.2 ISSUE 26: MINIMUM DETECTION LIMIT***
>
> *The selection of 10 mrem as the MDL [minimum detection limit] for high energy gamma is questionable. Even for modern densitometers and film, it is a challenge to achieve this level, as a single density "click" can correspond to greater than 10 mrem for high-energy gamma radiation; this is not a problem, however, for intermediate and low-energy x-rays. Rather, one click of the densitometry system may correspond to 15 or 20 mrem for 660 keV or 1.2 MeV gammas, for example. If the claim is made that 10 mrem is a valid choice for the MDL, then supporting materials should be provided, such as film dose-to-density curves and densitometer calibration data. Other sites (e.g., Savannah River Site - SRS) have adopted 40 mrem as the high-energy gamma MDL for early film.]*

For doses for the "pre-1974 period," the tables in the revised Pinellas site profile show a generous 0.04 rem as the LOD for photons and electrons detected with photographic film. This is based on ORAUT-OTIB-0010. Thus, for non-Landauer film, a 40 mrem LOD is being recommended, but 10 mrem is being recommended for Landauer film. The revised tables do not specifically state why the lower 10 mrem LOD for Landauer film was chosen. Speculating, it might be based on a broad-brush claim by Landauer of an LOD of 10 mrem in older dosimetry reports and client literature. However, for Landauer or any other film dosimeter from the era in question, 10 mrem was more correctly the LOD for lower energy photons. LOD is dependent on a host of issues, including film emulsion age (background fog), processing, densitometer set up, calibration, etc. Thus, although a 10 mrem high-energy photon detection threshold might have been attainable on a "good day," it should not be adopted as the LOD for establishing missed dose.

Based on the above, it is recommended that the photon LOD in Table 6-9 should be returned to the original 0.02 rem for Landauer beta/gamma film.

All other assumptions that were examined appear reasonable and claimant favorable.

Attachment 2 – Copies of the First Two Cover Pages of the TRW 1971 (NASA) Report:



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NAS 2-5222

SUBMITTED TO:

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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31 January 1971

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