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April 14, 2006

2006-0025

U.S. Nuclear Regulatory Commission
Attn: Document Control Desk
Washington, D.C 20555

Ref: Potential Over-Exposure to Extremities –NRC License R-83
Event Notification: March 15, 06 12:07 EST
Event # 42424

To Whom It May Concern:

Enclosed, please find the Potential Over-Exposure Event follow-up report (requirement 10 CFR 20.2202) generated by the TAMU Nuclear Science Center. If you have any questions regarding this, please feel free to call me at (979) 845-7551.

Sincerely,

W. D. Reece

Dr. W. D. Reece, Director

Enclosure

LV/ym

xc: 2.11/Central File
USNRC, Region IV
Craig Bassett, NRC
NSC Special Reports File

Public Version

Summary of Potential Over-exposure Event
Report to the Nuclear Regulatory Commission
14 April 2006

Chronology of Event

On February 24, 2006, the Nuclear Science Center (NSC) received the January dosimetry report from Landauer, Inc. (dosimetry provider) indicating a ring badge reading of 75,800 mrem to the extremities for a NSC radiation worker (identified as Worker A in the rest of this report). We immediately stopped Worker A from any duties that would add to his extremity dose until we completed our investigation. This was the first time in our dosimetry reports that we have seen anything this significant. The past exposure history of this individual indicated only an average of 307 mrem to extremities. The employee and his coworkers were immediately interviewed as to whether he was involved with any medical procedures or any other handling of radioactive material of which the NSC was unaware. The employee had no recollection of anything out of the ordinary other than the high volume of neutron activation analysis (NAA) samples.

The NSC Worker A's primary responsibility was to complete the NAA task in January, performing analysis on thin plastic disks._ He handled about 140 samples of plastic disks for measurement of silver from January 17 through January 31 (Worker A was on vacation during 1 January until 16 January 2006). From January 1 through January 16, another NSC employee (Worker B) performed the same NAA task. Worker B's whole body dose for January was 103 mrem and his extremity dose was 180 mrem. Worker B handled about 195 NAA samples during this time. Based on this comparison and with the fact that that the employee's work duties had not changed, we contacted Landauer to confirm the badge readings. See Table 1.

The NSC had, in the past, received unusual readings on Landauer TLD reports for employees who had not used radioactive materials at all. Before the NSC could complete its internal investigation, the February badge results came from Landauer. On March 15th, we received the February dosimetry report from Landauer with a ring badge reading of 37540 mrem to extremities for Worker A. We immediately called the NRC and started a formal investigation. Following is a summary of our investigation.

Summary of Investigation

While the combined readings from the TLD ring badges were over 100 rem extremity dose for Worker A during January and February, his reported whole body dose was 40 mrem during this same period (34 for January and 6 mrem for February). This sort of ratio could only arise from handling of small sources and almost certainly only from beta sources. Therefore, our attention was focused on his activities during NAA.

Our initial investigation focused on determining the number and type of samples that Worker A handled during January and February. We quickly determined that no new type of work was done during this time period. Worker A was assigned NAA duties analyzing for silicon (Si) and silver (Ag) in trace amounts.

We have more than a year's dosimetry records for tasks such as these done in January and February, and six months of dosimetry records for the specific tasks that Worker A did. No doses over 1580 mrem were seen in these records. Worker A's maximum extremity dose noted in the previous months was 530 mrem.

Another worker performed the same tasks during December and January. His reported doses were below 200 mrem to ring badges. The numbers of samples and their badge TLD readings are shown in the Table 1 below. The table gives the sample type and the number of samples analyzed by Worker A and others in both January and February.

Table 1. NAA worker, sample type, and doses

Employee	No. of samples	Period	Ring badge result (mrem)
Worker C	226 (silicon)	October 2005	1580
Worker C	218 (silicon) 22 (silver)	November 2005	880
Worker B	88 (NIST silver)	December 2005	80
Worker B	195 (silver and iodine)	January 10-Jan 27	180
Worker A	140 (silver)	Jan17-Jan30	75,800
Worker A	141(silicon+silver+iodine)	Feb 6-Feb22	37,540
Worker D	4-5 silver	March 22-23	0 (minimal)

In a retrospective dose analysis we found the following.

Because these samples were immediately analyzed using HPGe detectors we have benefit of knowing the activities associated with each sample for those isotopes that emit gamma rays. All calculations indicate that the analysis for silver delivers the largest potential dose. The source activity during the time that it would have been handled by Worker A averaged 90 microcuries of Ag-108 and about 15 microcuries of I-128 as measured by the HPGe detectors and corrected for decay.

We did time-motion studies under the observation of an NRC inspector. These studies indicate that the worker's hands would be in contact with the sample for 15 seconds or less on average. During these studies, the ring badge worn by Worker D reenacting the NAA procedure for two samples showed no measurable dose (Landauer special report 3/27/06). A schematic of the configuration of the sample is shown in Figure 1 below. We used the actual sources to see if there were other components that could contribute to hand dose. The following readings were taken during reenactment.

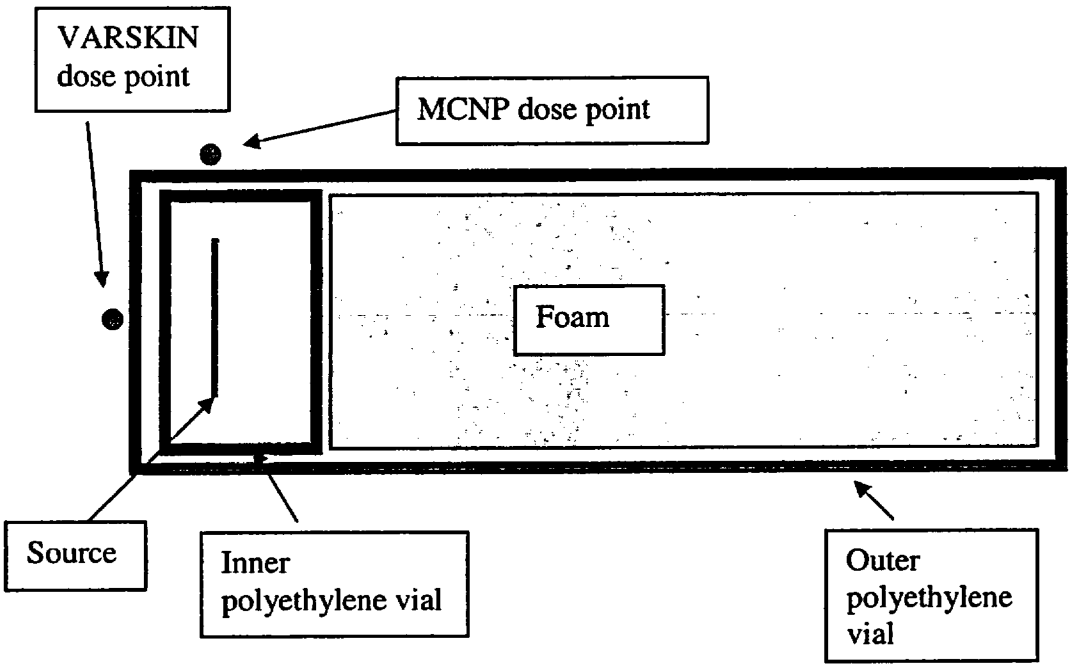

Figure 1. Schematic of source configuration

Test runs on NAA silver analysis 22 March 2006

Measurements were taken using VIC 451 (# 11321) ion chamber and also VIC 451B ion chamber (with a beta sliding window)

- With the beta window open, the contact reading was 2.6 R/h (contact reading on outer vial).
- Foam alone reads 470 mR/h (beta window open)
- Outer vial alone reads 26 mR/h (beta window open)
- Cartridge with plastic disk reads 2.4 R/h (beta window open)
- PIC reading on contact with the sample is 15 mR (15 sec handling)

For a volume correction factor of 10, the contact dose would be 26 R/hr. If the employee handled 140 samples in Jan 06 in full contact with the sample, his estimated dose would be 15.17 rem.

A second test run was performed for silicon analysis of the plastic disks. These samples were also was irradiated for 2 min. Measurements were taken as above.

- Contact reading on the outer vial is 12.5 mR/h (VIC 451 P beta window closed)
- Contact reading for the outer vial is 54 mR/h (VIC 451 B, beta window closed)

- With the beta window open, the reading is 330 mR/h on the outer vial
- PIC reading on contact with the vial is 2 mR

Based on a correction factor of 10, the calculated dose for full contact with sample would be equal to 20 mR for 15 sec (average handling per sample). Worker A handled about 27 samples in Feb 06; the estimated dose would be 540 mrem.

Worker A also handled 114 samples of silver during February 2006. The worst case scenario of full contact with the source as assumed above gives an estimate of 12.35 R to the hands.

Calculations of doses from samples

We also started calculations to assess the dose at various locations on the source container. We measured the thickness of the various containers between the source and the TLD ring. The basic source configuration is shown in Figure 1. The dimensions of the various components are summarized below.

- Plastic disk dimensions:
    - Thickness 0.16 mm, diameter 10mm
- Inner and outer vial wall thickness: 1 mm
- The amount of silver content in the plastic disk is about 15 ug in a 20 mg disk.
- The outer vial is 17 mm in diameter and 75 mm long.
- The inner vial is 12 mm in diameter and approximately 10 mm long.

The calculations are attached.

VARSKIN calculations

Because of limitations in the VARSKIN code the dose from the side of a disk source cannot be modeled directly. However, the dose center on the axis of the disk source can be modeled and this dose is conservative, that is, these dose rates will be higher than the dose rates from the side. Using SADDEMOD2 the beta characteristics were calculated for Ag-108 and I-128. These data were checked for consistency with other data as to the average energy and the scaled absorbed dose distribution coefficients and were as expected. For the geometry shown in Figure 1, the dose at the bottom of the outer vial was calculated. The beta dose rate from Ag-108 averaged over 1 cm^2 obtained from VARSKIN-Mod2 is 23.4 rad/hr (roughly equivalent to a TLD response). If the employee handled 140 samples, the dose to TLD at worse could be 13.65 rem. The beta dose rate from I-128 averaged over 1 cm^2 is 6.53 rad/hr (3.81 rem for 140 samples) giving a combined worse case beta dose of 17.46 rem (15 second contact, 140 samples). Even if maximum centerline doses were used (36.4 rad/hr for Ag-108 and 9.99 rad/hr for I-128) the TLD response would still only be 27.06 rem (15 second contact, 140 samples).

The beta dose rate averaged over 10 cm^2 is 2.98 rem/hr for Ag-108 and 0.931 rem/hr for I-128, for a combined dose of 3.911 rem/hr and an accumulated dose of 2.28 rem (15 second contact, 140 samples). The VARSKIN output is attached. A summary is given in Table 2.

Table 2. VARSKIN doses for doses at the bottom of the outer vial

Dose area	Ag-108 rad/hr	I-128 rad/hr	Total rad/hr	Dose in 15s mrad	Dose 140 samples rad
1 cm^2	23.4	6.53	29.93	125	17.5
Centerline	36.4	9.99	46.39	193	27.1
10 cm^2	2.94	0.931	3.87	16.1	2.26

Gamma dose calculation from Microshield results in 144 mR/h (with buildup) on contact with the vial which is about what was measured using the ion chamber. The gamma doses are not included in this analysis, but obviously would be added to a final dose assessment.

MCNP calculations

MCNP was used to model the beta dose rate from a source containing 90 microcuries of Ag-108 and 15 microcuries of I-128. These calculations were also used to correct the TLD readings described below to doses that could be expected to the TLDs if this source were held in contact with the TLD badge. MCNP was used to calculate the dose along the axis of the outer vial and centerline dose at the bottom of the vial as a check on the VARSKIN results. The model geometry is shown in Figure 2. The source, inner vial, outer vial, and TLD positions are clearly seen. The input decks and output have been given to the NRC inspectors.

A summary of the MCNP results is given in Table 3.

Table 3. MCNP calculated contact doses for 15 second exposure

Geometry	Dose at side (15 s)	Dose at bottom
With glove and air 0.5 mm air gap	36 mrad	125 mrad
Without gloves or air gap	88 mrad	274 mrad

The 125 mrad dose at the bottom of the vial is indeed lower than 193 mrad calculated by VARSKIN, as expected.

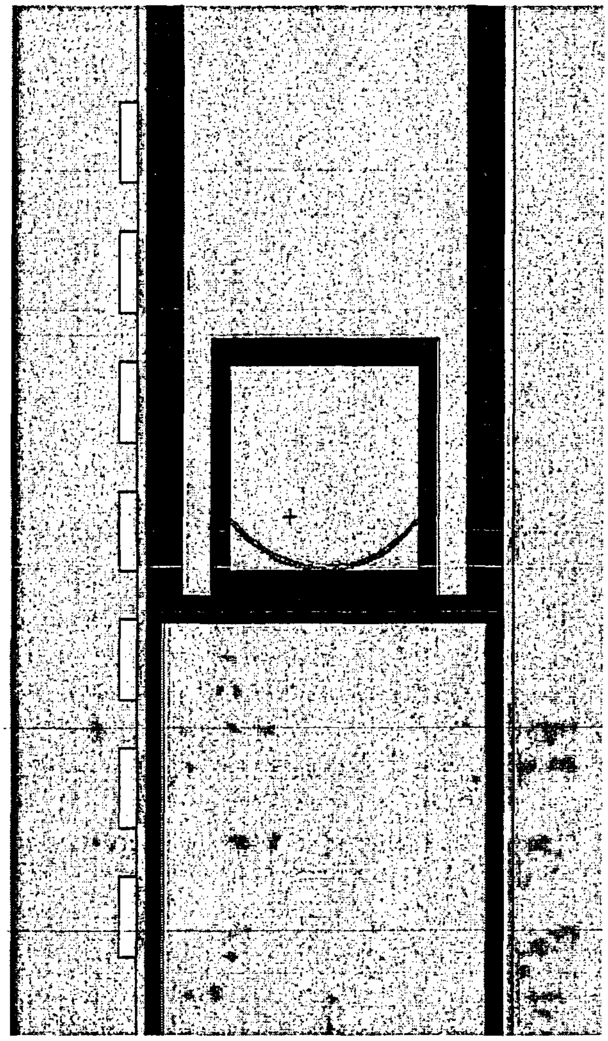

Figure 2. Drawing from MCNP of model geometry.

TLD measurements

TLD measurements were conducted for two purposes: to check the calculations and to insure that no beta-only emitting isotopes were present. TLDs were calibrated with 250 kV_p x-rays filtered through 2.2 mm of Cu against a NIST traceable Farmer's ion chamber and the calibration factors corrected to dose in tissue. Four dosimeters (2 replicates, 2 runs) were placed so as to be in contact with the source at the side of the outer vial (MCNP dose point in Figure 1). The TLDs were exposed without glove material interposed. The average of the 4 TLDs corrected to rad in tissue was 709±293 mrad for a 60 second exposure. For a 15 second exposure, the dose would be 177±72 mrad.

MCNP calculations indicate that interposing one layer of glove material between the source and TLD lowers the dose by a factor of 2.44 (see Table 3 above). The corrected TLD measured dose would be 72.5±30 mrad for a 15 second exposure. Two Landauer ring badges were also placed in contact with the outer vial over the source for 60 seconds at the same time that NSC TLDs were exposed, again with no glove material interposed. Landauer reported the doses as 390 mrad and 460 mrad. The average dose from the two badges for 15 seconds is 106±12 mrad. The correction factor for the two Landauer rings if worn under gloves is about a factor of 2. This data is summarized in Table 4.

Table 4. Summary of TLD measurements and corrections.

	Average dose (1 min)	Average dose (15 seconds)	Corrected to 15 s dose under glove
NSC TLD	709 mrad	177 mrad	72.5 mrad
Landauer ring	425 mrad	106 mrad	~50 mrad

Worker practices during NAA

We provided tongs to handle samples and workers were trained to use them. On the other hand, workers were not forbidden to briefly touch samples on the end away from the source because sometimes the foam would get stuck in the outer vial. This practice will be changed; see corrective actions below. Nevertheless, for the purposes of dose reconstruction, we calculated the dose rates 5 cm above the source using VARSKIN-MOD2 and these calculations indicate that the dose rate is approximately 50 times lower than the dose rate directly below the source. See attached VARSKIN output.

We have done time motion-studies repeatedly with Worker A and we find that his practices do not differ remarkably from Worker B. Because Worker A is left-handed, some differences occur and, as instructed, he wore his dosimeter on the hand he thought would receive the highest dose – in this case his right hand. During reenactment, indeed, his right hand would receive the highest dose. Worker B is left-handed, wears his ring badge on the left hand and during reenactment, his left hand would receive the highest dose.

Other possible sources of exposure for Worker A

No other employee has ever received hand doses unexpectedly, particularly at these levels. No other work has ever produced such hand doses, nor should it be possible if procedures are followed. The possibility remains that the rings were removed and placed next to a source for an extended time, but Worker A does not recall any such circumstance. We also investigated the possibility of hot particle contamination of the ring, but found no potential sources of these particles from the foam, other any other sources.

Summary of Results

Measurements of dose rate with TLDs gave a 709±293 mrad dose (in tissue) for 1 minute exposure. For 15 seconds, this dose would be 177±72 mrad. There were no glove material between the source and TLDs during measurements. Using the ratio from MCNP calculations we get 72.5±30 mrad for a 15 second exposure. VARSKIN results indicate 193 mrad for a 15 second exposure, but this is known to be conservative. MCNP suggests 36 mrad from Ag-108 and I-128. Landauer rings yield about 50 mrad.

There are obviously things we don't understand about this incident; however the calculations and measurements agree remarkably well given that 1 mm of change in position can half the dose.

The TLD measurements preclude significant amounts of other isotopes that generate beta-rays but would not show up on our HPGe detectors. We also investigated other known trace isotopes in the sample. The largest contributor in the Ag-108 samples is 3 microcuries of Al-28. This isotope would contribute 3.1 mrad to the 36 mrad dose calculated by MCNP, but all of this is bounded by taking a factor of 2 higher than Ag-108/I-128 calculation. Fortunately, we are not looking for a few percent one way or the other because the difference we are trying to understand is about a factor of 5 to 10.

In summary, based on these calculations and measurements, even in full contact with the source, doses reported by Landauer cannot be reached. For 140 samples and 75,800 mrem collective dose, the dose per sample would have to be 541 mrad (for a 15 second exposure). Our measurements and calculations suggest that the maximum dose to the TLD per sample is around 72 mrad. Even if we triple the handling time, 75,800 mrad cannot be delivered to the ring badge TLD.

Dose Assessment

As demonstrated above, there is no plausible explanation for the TLD readings for Worker A. If we double the MCNP dose so that it is the same as the dose measured with NSC TLDs, we have 72.5 mrad for each source (assuming 15 second handling). For 140 samples, the total dose to the TLD would be 10.1 rem.

Furthermore, this dose is the maximum. If we average over 10 cm^2, this dose falls to 4.34 rem. To calculate this average, we conservatively assumed that the entire vial is in contact with the skin of the hand, so that the dose to the skin is only a function of axial distance along the vial. Figure 3 shows the source and hand opened after clasping the vial. The disk is the approximate area over which the dose may be averaged.

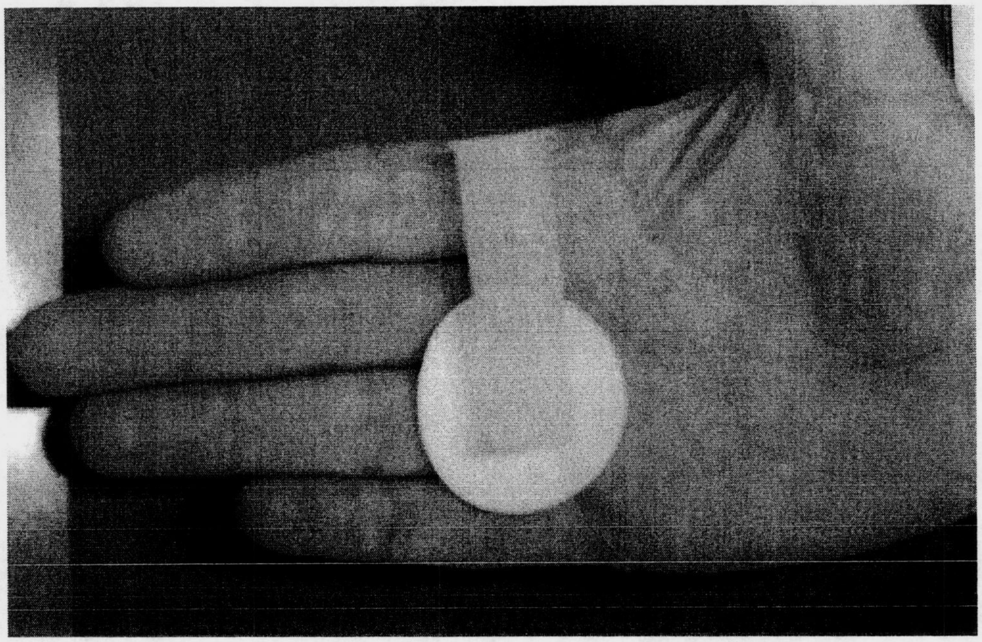

Figure 3. Source and averaging area

Figure 4 shows the lines of constant dose (isopleths) from being in contact around the circumference of the vial.

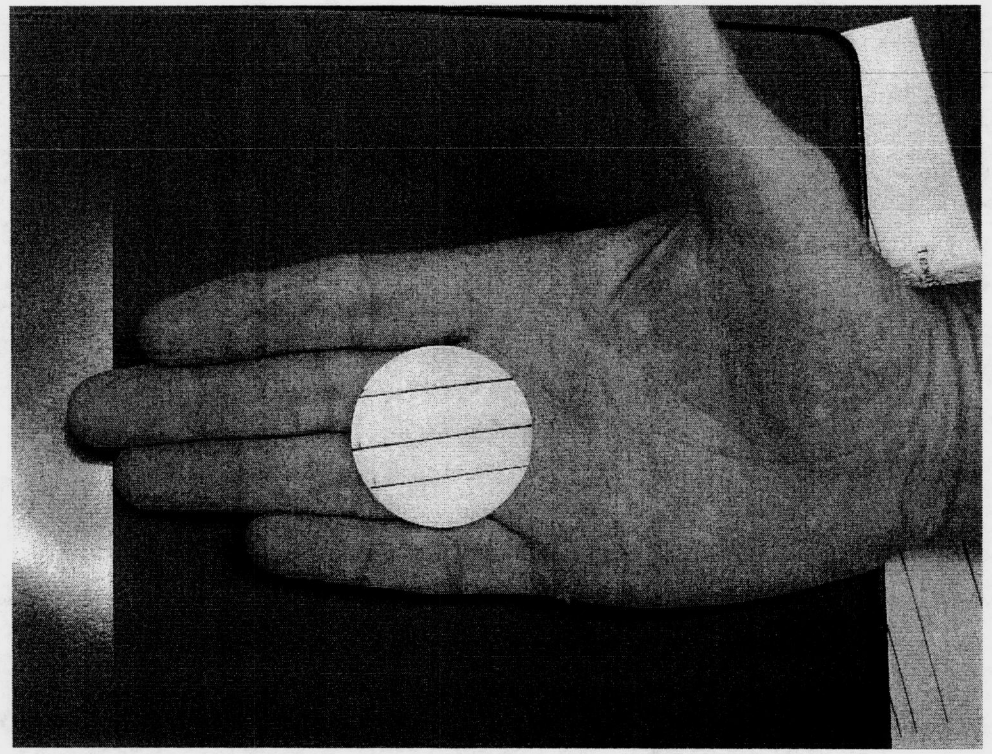

Figure 4. Isopleths for dose along vial axis

MCNP dose versus axial distance along the vial were fit with a cubic spline (Table 5 gives MCNP values; Figure 5 is a plot of the spline fit).

Table 5. Doses for 15 second exposure to 90 microcuries of Ag-108 and 15 microcuries of I-128 as a function of axial distance along the outer vial. The source is at 0 and negative distances are below the end of the vial.

Distance from source (cm)	Dose for 15 seconds (mrem)
1.5	2.7
1.0	6.8
0.5	22.3
0.0	35.5
-0.5	12.4
-1.0	9.5
-1.5	5.9

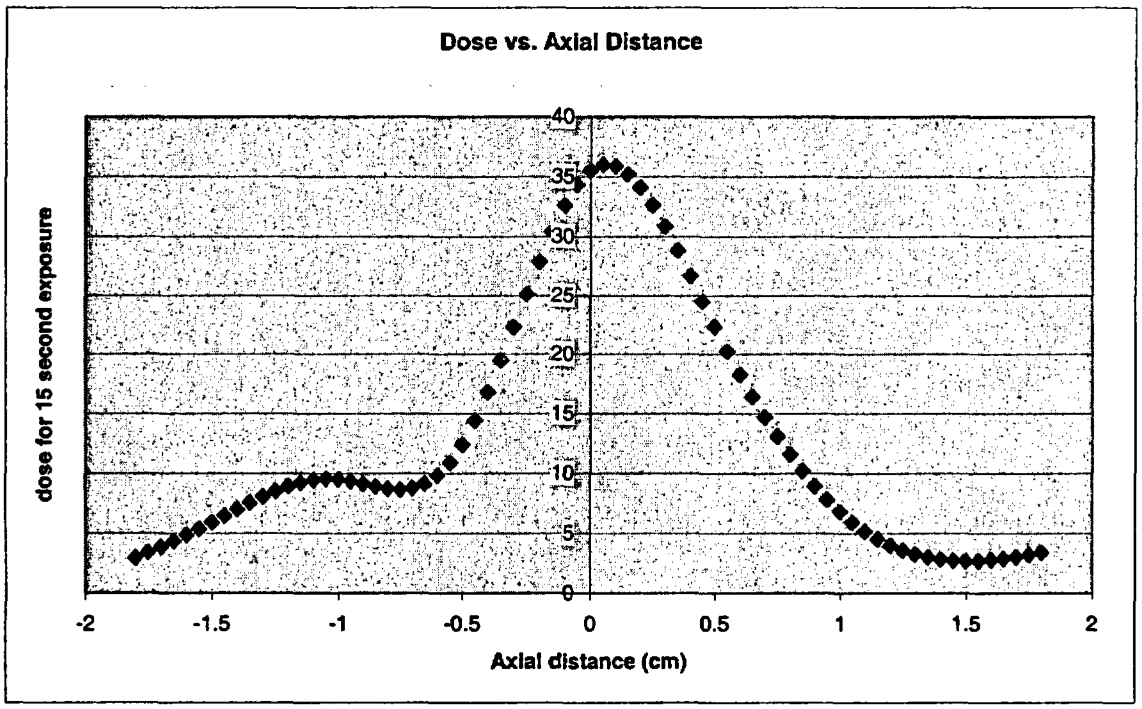

Figure 5. Spline fit of dose versus axial position along vial

Using these values, the dose was numerically averaged using an Excel spreadsheet (attached). For 36 mrad maximum dose, the averaged dose is 15.4. Multiplying this ratio times 10.1 rem, we get 4.34 rem.

If the badges had been lost and we were asked to assign the most conservative possible dose to the hand for the NAA work, based on these calculations and measurements, we would assign a dose of 4.34 rem each month (a total of 8.68 rem for January and February combined) plus whatever small contribution from gamma rays.

However, we do not request that these doses be entered as the dose of record. We are as troubled as anyone by the badge readings and request that the dose be assigned as 49 rem for January and February unless or until other findings come to light.

Another approach is to accept the TLD readings (as improbable as they are), assume that they were in contact with the source, and average the dose over 10 cm^2. If this were done for the January and February doses to Worker A, this averaged dose would be 48.5 rem for the two months. To get this number, we summed the reported doses and divided by 36/15.4, the ratio of maximum dose to averaged dose as described above.

Worker A has been to have his hand examined by a physician. No effects were observed. Even assuming that the TLD readings are correct, the literature suggests that there will never be an observable effect, nor will there be any adverse health effects.

One potential lapse by the NSC is in prompt reporting of the January dosimetry report. In hindsight, we should have. Hopefully as this report shows, we had a multitude of reasons to question the reading. We did immediately stop Worker A from any work that would contribute to hand dose until we could confirm the reading and we did call the NRC within five minutes after receiving the February dosimetry report. Worker A's ring badge for 1 March 2006 to 22 March 2006 was sent to Landauer for immediate processing. The reported dose was 40 mrem (Landauer 2/27/06). We expect this to be the same as his whole body exposure.

The 1580 mrem extremity dose to Worker C had already triggered the manufacture of holders and manipulators. We try to control exposures to low fractions of allowed dose. We have administrative controls so that any whole body dose over 100 mrem per month as monitored by our pocket ion chambers triggers an automatic review, for example.

It is difficult to assign a root cause for this incident. One thing for certain is, that in our decades of doing NAA work, this individual is unique. One contributing factor could be that his work practices, in spite of training and procedure, differ from his fellow workers. During reenactment here with the NRC inspectors, Worker A held the source in his hand sometimes. During interviews during this investigation he said that he would grasp the vial in his hand although he was unsure if this practice was habitual.

During reenactments with the other NAA workers we saw no evidence that they grasped the vials. We also queried the other NAA workers and during interviews they denied ever grasping the vials in their hands. These other workers also confirmed that any direct contact with the vial was minimal. We have reviewed video tapes of Worker C that we made to train workers for NAA and he did not grasp the vial in his hand.

Besides the hand dose information given in Table 1 for NAA workers, we have reviewed all dosimetry records for the past two years to verify that no NAA worker has received appreciable dose. Worker C's hand dose of 1580 mrem in October was indeed the highest hand dose per month among NAA workers. As stated above, this dose had already triggered us to build beta shields for this type of NAA work. Unfortunately we had not yet implemented use of these shields.

Worker C's total hand dose for 2005 was 6160 mrem, the highest among all NAA workers for that year. Worker C's hand dose for 2004 was 1130 mrem.

Finally, Worker A's hand dose for 2005 was 1880 mrem; Worker A's hand dose for 2004 was 1190 mrem.

Corrective Actions

We feel that with the following corrective actions will eliminate any possibility of significant exposure from NAA activities.

- Employee A will perform no radiation work during calendar year 2006.
- We have built holders and manipulators that will eliminate beta dose for this type of NAA work.
- Although the NRC noted no inadequacies in our radiation worker program, training, or procedures, or in NAA training, we have conducted a briefing for all NAA workers with emphasis on handling compact sources. We have conducted general training for all radiation workers on handling radioactive materials.
- We have developed written handling procedures for NAA work.
- We will immediately report any potential exposure over annual limits to the NRC before any internal review.
- We have contractual agreements in place with Landauer to immediately notify us of any dose more than one tenth of the annual limit.
- We will require ring badges on both hands for NAA workers for the next 90 days to evaluate distribution of dose to each hand. We will evaluate these badges every two weeks.
- We have ordered a radiation detector and we will permanently mount this detector in the pneumatics hood so that NAA workers will be able to note any unusually high radiation levels.

Program VARSKIN-MOD2

I-128 from disk

Cylindrical Source Geometry

Nuclide :	I-128	
1.8*X90 Distance :	7.986600E-01	cm
Average Beta Energy :	8.138000E-01	MeV
No gamma dose calculation		
Source Strength :	1194.000000	uCi/cm^3
Source Density :	1.000000	g/cm^3
Diameter of Disk :	10000.000000	um
Thickness of Disk :	160.000000	um
Skin Depth :	7.000000	mg/cm^2
Thickness of Cover :	2.900000	mm
Cover Density :	9.000000E-01	g/cm^3
Air Gap Thickness :	5.000000E-01	mm
Irradiation Time :	60.000000	min

Calculated Results:

Radial Distance (cm)	Dose Rate (rad/hr)
.0000	9.99E+00
.1128	9.70E+00
.1596	9.41E+00
.1954	9.12E+00
.2257	8.83E+00
.2523	8.53E+00
.2764	8.24E+00
.2985	7.95E+00
.3192	7.67E+00
.3385	7.38E+00
.3568	7.10E+00
.3742	6.82E+00
.3909	6.55E+00
.4068	6.28E+00
.4222	6.02E+00
.4370	5.77E+00
.4514	5.52E+00
.4652	5.28E+00
.4787	5.04E+00
.4918	4.81E+00
.5046	4.61E+00
.5171	4.40E+00
.5293	4.19E+00
.5412	4.00E+00
.5528	3.80E+00
.5642	3.62E+00

The area of irradiation is larger than 1.0000 square cm

The beta dose rate averaged over 1.0000 square cm = 6.53E+00 rad/hr
The total beta dose averaged over 1.0000 square cm = 6.53E+00 rad

Program VARSKIN-MOD2

I-128 from disk

Cylindrical Source Geometry

```
              Nuclide : I-128
     1.8*X90 Distance :    7.986600E-01 cm
  Average Beta Energy :    8.138000E-01 MeV
        No gamma dose calculation
      Source Strength :    1194.000000 uCi/cm^3
       Source Density :       1.000000 g/cm^3
     Diameter of Disk :   10000.000000 um
    Thickness of Disk :     160.000000 um
           Skin Depth :       7.000000 mg/cm^2
   Thickness of Cover :       2.900000 mm
        Cover Density :    9.000000E-01 g/cm^3
    Air Gap Thickness :    5.000000E-01 mm
      Irradiation Time :      60.000000 min
```

Calculated Results:

Radial Distance (cm)	Dose Rate (rad/hr)
.0000	9.99E+00
.0607	9.91E+00
.1215	9.66E+00
.1822	9.23E+00
.2430	8.64E+00
.3037	7.88E+00
.3645	6.98E+00
.4252	5.97E+00
.4860	4.92E+00
.5467	3.90E+00
.6075	2.97E+00
.6682	2.18E+00
.7290	1.54E+00
.7897	1.05E+00
.8505	6.93E-01
.9112	4.39E-01
.9720	2.66E-01
1.0327	1.54E-01
1.0934	8.33E-02
1.1542	4.18E-02
1.2149	1.93E-02
1.2757	7.70E-03
1.3364	2.49E-03

1.3972	5.07E-04
1.4579	1.13E-05
1.5187	0.00E+00

The dose rate averaged over the area of irradiation
(radius = 1.5187 cm) = 1.29E+00 rad/hr

The beta dose rate averaged over 10.0000 square cm = 9.31E-01 rad/hr
The total beta dose averaged over 10.0000 square cm = 9.31E-01 rad

Program VARSKIN-MOD2

Ag-108 from disk

Cylindrical Source Geometry

```
               Nuclide : Ag-108
     1.8*X90 Distance :    5.952600E-01 cm
  Average Beta Energy :    6.274000E-01 MeV
        No gamma dose calculation
      Source Strength :     7162.000000 uCi/cm^3
       Source Density :        1.000000 g/cm^3
     Diameter of Disk :    10000.000000 um
    Thickness of Disk :      160.000000 um
           Skin Depth :        7.000000 mg/cm^2
   Thickness of Cover :        2.900000 mm
        Cover Density :    9.000000E-01 g/cm^3
    Air Gap Thickness :    5.000000E-01 mm
      Irradiation Time :      60.000000 min
```

Calculated Results:

Radial Distance (cm)	Dose Rate (rad/hr)
.0000	3.64E+01
.1128	3.55E+01
.1596	3.45E+01
.1954	3.35E+01
.2257	3.25E+01
.2523	3.14E+01
.2764	3.03E+01
.2985	2.92E+01
.3192	2.81E+01
.3385	2.70E+01
.3568	2.59E+01
.3742	2.48E+01
.3909	2.37E+01
.4068	2.26E+01
.4222	2.15E+01
.4370	2.04E+01
.4514	1.94E+01
.4652	1.84E+01
.4787	1.74E+01
.4918	1.65E+01
.5046	1.56E+01
.5171	1.47E+01
.5293	1.39E+01
.5412	1.31E+01
.5528	1.23E+01
.5642	1.15E+01

The area of irradiation is larger than 1.0000 square cm

The beta dose rate averaged over 1.0000 square cm = 2.34E+01 rad/hr
The total beta dose averaged over 1.0000 square cm = 2.34E+01 rad

Program VARSKIN-MOD2

Ag-108 from disk

Cylindrical Source Geometry

```
             Nuclide : Ag-108
   1.8*X90 Distance :    5.952600E-01 cm
Average Beta Energy :    6.274000E-01 MeV
        No gamma dose calculation
    Source Strength :    7162.000000 uCi/cm^3
     Source Density :       1.000000 g/cm^3
   Diameter of Disk :   10000.000000 um
  Thickness of Disk :     160.000000 um
         Skin Depth :       7.000000 mg/cm^2
 Thickness of Cover :       2.900000 mm
      Cover Density :    9.000000E-01 g/cm^3
  Air Gap Thickness :    5.000000E-01 mm
    Irradiation Time :      60.000000 min
```

Calculated Results:

Radial Distance (cm)	Dose Rate (rad/hr)
.0000	3.64E+01
.0488	3.62E+01
.0976	3.57E+01
.1464	3.48E+01
.1951	3.35E+01
.2439	3.18E+01
.2927	2.95E+01
.3415	2.68E+01
.3903	2.37E+01
.4391	2.03E+01
.4879	1.68E+01
.5366	1.34E+01
.5854	1.02E+01
.6342	7.46E+00
.6830	5.23E+00
.7318	3.50E+00
.7806	2.23E+00
.8294	1.34E+00
.8781	7.64E-01
.9269	4.00E-01
.9757	1.91E-01
1.0245	7.93E-02
1.0733	2.66E-02

1.1221	6.02E-03
1.1709	2.17E-04
1.2196	0.00E+00

The dose rate averaged over the area of irradiation (radius = 1.2196 cm) = 6.37E+00 rad/hr

The beta dose rate averaged over 10.0000 square cm = 2.98E+00 rad/hr

The total beta dose averaged over 10.0000 square cm = 2.98E+00 rad

Program VARSKIN-MOD2

Ag-108 dose 5 cm up

Cylindrical Source Geometry

```
                 Nuclide : Ag-108
      1.8*X90 Distance :    5.952600E-01 cm
   Average Beta Energy :    6.274000E-01 MeV
          No gamma dose calculation
       Source Strength :     7162.000000 uCi/cm^3
        Source Density :        1.000000 g/cm^3
      Diameter of Disk :    10000.000000 um
     Thickness of Disk :      160.000000 um
            Skin Depth :        7.000000 mg/cm^2
    Thickness of Cover :        2.900000 mm
         Cover Density :    9.000000E-01 g/cm^3
     Air Gap Thickness :       50.000000 mm
      Irradiation Time :       60.000000 min
```

Calculated Results:

Radial Distance (cm)	Dose Rate (rad/hr)
.0000	5.21E-01
.1128	5.20E-01
.1596	5.20E-01
.1954	5.20E-01
.2257	5.19E-01
.2523	5.19E-01
.2764	5.18E-01
.2985	5.18E-01
.3192	5.17E-01
.3385	5.17E-01
.3568	5.17E-01
.3742	5.16E-01
.3909	5.16E-01
.4068	5.15E-01
.4222	5.15E-01
.4370	5.14E-01
.4514	5.14E-01
.4652	5.14E-01
.4787	5.13E-01
.4918	5.13E-01
.5046	5.14E-01
.5171	5.14E-01
.5293	5.13E-01
.5412	5.13E-01
.5528	5.12E-01
.5642	5.12E-01

The area of irradiation is larger than 1.0000 square cm

The beta dose rate averaged over 1.0000 square cm = 5.12E-01 rad/hr
The total beta dose averaged over 1.0000 square cm = 5.12E-01 rad