VARSKIN 6

Case Study: 2008 Region IV Eye and Skin Dosimetry

Colby Mangini, PhD, CHP

VARSKIN Consultant

Paragon Scientific, LLC

Outline

- *Overview of the Incident*
- Approach to Determining Dose
- How was VARSKIN used
- Discussion
  - Was VARSKIN used correctly?
  - Was there a break down of underlying principles?

Overview of Incident

- On February 29, 2008, a licensee notified the NRC of a leaking Sr-90/Y-90 sealed source (thickness gauge) at their Idaho Falls facility
- In an attempt to remove a Sr-90/Y-90 sealed source from a source holder, the source was physically impacted
- The employee continued to handle the breached source while another employee performed a leak test analysis
- **When the analysis was complete and excessive removable contamination was detected, the employee who had been handling the breached source was found to be externally contaminated and had received an intake of Sr-90/Y-90.**
- The licensee's facility had become significantly contaminated and three other employees had been contaminated to a lesser extent.

Overview continued…

- March 2-3, 2008, the U.S. Department of Energy (DOE) Radiological Assistance Program (RAP) Region 6 entered the facility and conducted surveys in order to determine the scope and extent of radiological contamination
- Third party contractor was contracted to evaluate the internal and external exposures for four employees
- The internal exposure to all four employees was calculated from bioassay results
- The Deep Dose Equivalent (DDE), Lens of the Eye Dose Equivalent (LDE) and Shallow Dose Equivalent (SDE) were estimated for one of the individuals (Employee 1)

Results

SIPD Results

Table 2 - Assigned External Doses to Employee 1

Type	Estimated $\mu Ci/cm^2$	Whole Body DDE Rem	Eye LDE rem	Whole Body SDE rem	Extremity SDE Rem
Beta Contamination	0.346	0.000	0.138	1.95	3.66
Beta Radiation		0.000	0.012	0.24	0.00
Photon Radiation		0.030	0.030	0.03	0.32
Assigned Dose		0.030	0.180	2.22	3.98
Assigned TEDE (rem)		1.44			

Maximum Contamination Levels Based Upon Observed Dose Rates

- VARSKIN 3.0 was used to model dose rates from uniform 2D disk sources of various sizes
  - 60, 48, 36, 24, 12, 6, 3, 1 inch diameters
  - at distances of 1.0 cm, at 30.48 cm (1 ft) and at 1 meter.
- Distances correspond to distances for the table saw area **measured ionization chamber dose rates**
- Results were used to develop dose rate to activity conversion factors (i.e. rad hr^{-1} - uCi^{-1} cm^2)

Table 20 - Table Saw Area Radiological Data with Corrected Dose Rates

Data Type	Philotechnics	RAP Team	Units
Contact	0.92 to 1.83	> 0.78	rad/hr
One Foot	N/A	0.467	rad/hr
One Meter	0.458	N/A	rad/hr
Smear	N/A	390	mrad/hr

Table 22 - VARSKIN Model Parameters for Contact and 1 Foot Table Saw Readings

Smear VARSKIN 3.0 Model Parameters	Selection	Units
Select Source Geometry	2-D Disk	
Special Options	None selected	
Skin Averaging Area[1]	42	cm^2
Exposure Time	60	Minutes
Selected Radionuclides	Sr-90 0.5 Y-90 0.5	$\mu Ci/cm^2$
	Use Distributed Source	
2-D Disk Source Irradiation Geometry		
Skin Density Thickness[2]	3.5	mg/cm^2
Air Gap – Contact	3.28	cm
Air Gap – 1 foot	32.76	cm
Air Gap – 1 meter	102.38	cm
Protective Clothing	0	mm
Source Diameter	60, 48, 36, 24, 12, 6, 3, 1	Inches

Note: [1] Corresponds to the RO-20 detector diameter of 7.32 cm.
Note: [2] This value was used to compensate for the beta correction factor applied since these were based on a window thickness of 3.5 mg/cm^2 rather than the measured values where the window thickness was 7 mg/cm^2

Go to VARSKIN…

Table 23 - Calculated Dose Rates and Source Terms for Various Diameters Disk Sources for Measured Dose Rates at Contact and 1 Foot

Source Diameter Inches	Source Area cm^2	VARSKIN 3 Dose factor (rad/hr-$\mu Ci/cm^2$ @ 3.28 cm air with 3.5 mg/cm^2)	Estimated Distributed Activity $\mu Ci/cm^2$	Estimated Distributed Activity dpm/ 100 cm^2	Disk Total Activity µCi	% of Decayed Source Activity
1.833 rad/hr Contact Reading 3.28 cm						
60	1.8E+04	5.26	0.348	7.7E+07	6.4E+03	6%
48	1.2E+04	5.08	0.361	8.0E+07	4.2E+03	4%
36	6.6E+03	4.84	0.379	8.4E+07	2.5E+03	2%
24	2.9E+03	4.38	0.418	9.3E+07	1.2E+03	1%
12	7.3E+02	3.29	0.557	1.2E+08	4.1E+02	0.4%
6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1	5.1E+00	0.11	16.662	3.7E+09	8.5E+01	0.07%
0.467 rad/hr 1 Foot Reading (32.76 cm)						
60	1.8E+04	1.36	0.344	7.6E+07	6.3E+03	6%
48	1.2E+04	1.16	0.403	8.9E+07	4.7E+03	4%
36	6.6E+03	0.903	0.518	1.1E+08	3.4E+03	3%
24	2.9E+03	0.558	0.838	1.9E+08	2.5E+03	2%
12	7.3E+02	0.185	2.526	5.6E+08	1.9E+03	1.6%
6	1.8E+02	0.0505	9.255	2.1E+09	1.7E+03	1.5%
3	4.6E+01	0.0129	36.230	8.0E+09	1.7E+03	1.5%
1	5.1E+00	0.00145	322.323	7.2E+10	1.6E+03	1.4%

$1.833\ rad\ hr^{-1} / 5.26\ rad\ hr^{-1} - uCi^{-1}\ cm^2 = 0.348\ uCi\ cm^{-2}$

What does this show…

- The surface contamination levels calculated for a 60 inch diameter source with the measured dose rates of 1.833 rad/hr contact and 0.467rad/hr at 1 foot are well correlated
  - contamination levels of between 0.344 and 0.348 uCi/cm^2
- A distributed contamination level of 0.346 uCi/cm^2 provides a reasonable, but conservative estimate of the area contamination levels based upon the observed dose rates

- Further verification using VARSKIN and smear test results

Maximum Contamination Levels Based Upon Loose Contamination Survey Results

- The RAP Team reported smears in the table saw area that measured up to 390 mrad/hr at contact
- VARSKIN 3.0 was used to estimate the activity corresponding to center-line of detector dose rate of 390 mrad/hr at a distance of 3.28 cm
- The source size on the smear could vary from 1.85 to 0.5 inches
- A 2-D Disk geometry was used and the dose rate corresponding to 1 uCi/cm^2 over the surface of the source was calculated

Table 25 - VARSKIN 3.0 Smear Model Parameters

Smear VARSKIN 3.0 Input	Selection	Units
Select Source Geometry	2-D Disk	
Special Options	None selected	
Skin Averaging Area[1]	42	cm^2
Exposure Time	60	Minutes
Select Radionuclides	Sr-90 0.5 Y-90 0.5	$\mu Ci/cm^2$
	Use Distributed Source	
2-D Disk Source Irradiation Geometry		
Skin Density Thickness[2]	3.5	mg/cm^2

Smear VARSKIN 3.0 Input	Selection	Units
Air Gap	3.28	cm
Protective Clothing	0	Mm
Source Diameter – Case 1 , Case 2	1.85	Inches
	0.5	Inches

Note: [1] RO-20 tube diameter of 7.32 cm is 42 cm^2 area

Note: [2] This value was used to compensate for the beta correction factor applied since these were based on a window thickness of 3.5 mg/cm^2 rather than the measured values where the window thickness was 7 mg/cm^2

VARSKIN Results

Table 26 - Estimated Range of Contamination Levels for 390 mrad/hr Smear

Source Diameter	Source Radius	VARSKIN rad/hr-µCi/cm^2 @ 2.28 cm 3.5 mg/cm^2	Area cm^2	Est. Distributed µCi/cm^2	Activity on Smear dpm
1.85	0.925	0.354	17.34	0.743	4.24E+07
0.50	0.25	0.279	1.27	0.935	3.93E+06

0.390 rad hr^{-1} / 0.354 rad hr^{-1} - uCi^{-1} cm^2 = 1.111 uCi cm^{-2}

Despite the error (potential)…

- Range corresponds to a smear collection efficiency 5% to 55%
- Reasonable compared to normally accepted values for collection efficiencies 10% to 30%
- This comparison suggests reasonable corroboration of the calculated contamination levels

- **0.346 uCi/cm^2 was used for dose calculations**

Results

Table 2 - Assigned External Doses to Employee 1

Type	Estimated $\mu Ci/cm^2$	Whole Body DDE Rem	Eye LDE rem	Whole Body SDE rem	Extremity SDE Rem
Beta Contamination	0.346	0.000	0.138	1.95	3.66
Beta Radiation		0.000	0.012	0.24	0.00
Photon Radiation		0.030	0.030	0.03	0.32
Assigned Dose		0.030	0.180	2.22	3.98
Assigned TEDE (rem)		1.44			

Estimated Shallow Dose Equivalent and Lens of the Eye Dose Equivalent from Personnel Contamination

- 0.346 uCi/cm^2 conservative estimate of the total contamination levels in Employee 1's work area during the event
- Only a fraction of the total source term is transferred to the gloves and only a fraction of the source term on the glove would be transferred to the skin or eye
- VARSKIN calculations showed that if the individual had the full table saw area source term of 0.346 uCi/cm^2 on their skin and eye for 110 minutes the resulting dose would be 3.90 rem SDE averaged over 10 cm^2 and 0.276 rem LDE averaged over 1 cm^2

Realistically though…

- Analysis assumed that Employee 1 touched his face with his contaminated glove, and transferred 50 % of the average contamination level to his face/eye
- Contamination on the skin and eye was 0.173 uCi/cm^2 Sr-90/Y-90
- Exposure duration was 110 minutes
- Assumed source/contamination diameters were varied
- The most conservative source size (largest dose) was used

Table 27 - Dose Factors for Various Disk Source Sizes for Shallow, Lens and Deep Dose Equivalent Determined from VARSKIN, rad hr^{-1} cm2 uCi^{-1}

Source Dia. Inches	SDE rad/hr-µCi/cm^2	LDE rad/hr-µCi/cm^2	DDE rad/hr-µCi/cm^2
6	6.15	0.435	0.00
5	6.15	0.435	0.00
4	6.15	0.435	0.00
3	6.15	0.435	0.00
2	6.16	0.435	0.00
1	3.13	0.435	0.00
0.5	0.781	0.339	0.00
Tissue Area	10 cm^2	1 cm^2	1 cm^2
mg/cm^2	7	300	1000
Exposure Time		60	Min

Estimated Shallow Dose Equivalent and Lens of the Eye Dose Equivalent from Personnel Contamination

- Using a 110 minute exposure time and the dose conversion factors for a 2 inch diameter source
  - shallow dose equivalent (SDE) = 1.951 rem
  - lens dose equivalent (LDE) = 0.138 rem

$6.15\ \text{rad hr}^{-1}\ \text{- uCi}^{-1}\ \text{cm}^2\ \text{x}\ 0.173\ \text{uCi cm}^{-2} = 1.06\ \text{rad hr}^{-1}$

$1.06\ \text{rad hr}^{-1}\ \text{x}\ 1.83\ \text{hr} = 1.951\ \text{rad (rem)}$

Results

Table 2 - Assigned External Doses to Employee 1

Type	Estimated $\mu Ci/cm^2$	Whole Body DDE Rem	Eye LDE rem	Whole Body SDE rem	Extremity SDE Rem
Beta Contamination	0.346	0.000	0.138	1.95	3.66
Beta Radiation		0.000	0.012	0.24	0.00
Photon Radiation		0.030	0.030	0.03	0.32
Assigned Dose		0.030	0.180	2.22	3.98
Assigned TEDE (rem)		1.44			

Direct Radiation Exposure (Skin)

- Using VARSKIN 3.0
- The dose to the skin of the face from the table saw contamination was calculated
  - Assuming 1 foot air gap
  - 60 in^2 2D source at 0.346 uCi/cm^2
  - 30 minute exposure time

- The assigned direct radiation dose was 0.243 rem

Table 28 - VARSKIN 3.0 Direct Radiation Shallow Dose Equivalent at 1 Foot

Direct SDE VARSKIN 3.0 Model Parameters	Selection	Units
Select Source Geometry	2-D Disk	
Special Options	None selected	
Skin Averaging Area	10	Cm^2
Exposure Time	60	Minutes
Select Radionuclides	Sr-90 0.173 0.173 Y-90	µCi/cm2
	Use Distributed source	
2-D Disk Source Irradiation Geometry		
Skin Density Thickness	7	mg/cm^2
Air Gap	30.48	cm
Protective Clothing	0	mm
Source Diameter	60	Inches
Result	0.486	rad/hr

Direct Radiation Exposure (eye)

- Employee 1 wore prescription eye glasses while handling the source
- LDE is determined by assuming a 2 mm thickness of unit density material
  - Assuming 1 foot air gap
  - 60 in^2 2D source at 0.346 uCi/cm^2
  - 30 minute exposure time

- Resulted in 24 mrad/hr
- For a 30 minute exposure time, this corresponds to a dose of 0.120 rem from direct beta radiation

Results

Table 2 - Assigned External Doses to Employee 1

Type	Estimated $\mu Ci/cm^2$	Whole Body DDE Rem	Eye LDE rem	Whole Body SDE rem	Extremity SDE Rem
Beta Contamination	0.346	0.000	0.138	1.95	3.66
Beta Radiation		0.000	0.012	0.24	0.00
Photon Radiation		0.030	0.030	0.03	0.32
Assigned Dose		0.030	0.180	2.22	3.98
Assigned TEDE (rem)		1.44			

Glove Contamination

- After delivering the leak test smear for evaluation, Employee 1 returned the source in the source shield
- To ensure a conservative estimate of potential extremity dose, the glove was assumed to be contaminated at ten-times that of the table saw area or 3.46 uCi/cm^2
- For added conservatism, the glove was assumed to have been worn for 30 minutes

- SDE to the hand from a 30 minute exposure and a 2 inch diameter source is 3.66 rad

Table 37 - VARSKIN 3.0 Contaminated Gloves Shallow Dose Equivalent

Direct SDE VARSKIN 3.0 Model Parameters	Selection	Units
Select Source Geometry	2-D Disk	
Special Options	None selected	
Skin Averaging Area	10	cm^2
Exposure Time	30	Minutes
Select Radionuclides	Sr-90 1.73 1.73 Y-90	µCi/cm2
	Use Distributed source	
2-D Disk Source Irradiation Geometry		
Skin Density Thickness	7	mg/cm^2
Air Gap	0	inches
Protective Clothing	0.45	mm
Clothing Density	1.1	g/cm^3
Source Diameter[1]	2	inches

1 Conservative source size as seen in Table 38.

Results

Table 2 - Assigned External Doses to Employee 1

Type	Estimated $\mu Ci/cm^2$	Whole Body DDE Rem	Eye LDE rem	Whole Body SDE rem	Extremity SDE Rem
Beta Contamination	0.346	0.000	0.138	1.95	3.66
Beta Radiation		0.000	0.012	0.24	0.00
Photon Radiation		0.030	0.030	0.03	0.32
Assigned Dose		0.030	0.180	2.22	3.98
Assigned TEDE (rem)		1.44			

Direct Beta Radiation (Extremity)

- The aluminum backing and steel plug backing are 5.39 mm thick.
- The maximum range of the 2.28 MeV Y-90 beta particle in aluminum is 5 mm.
- The beta would be absorbed by the aluminum backing and steel plug backing.
- VARSKIN calculations using a cover of 0.539 cm, and overall density of 5.35 g/cm^3, calculated a 0.00 rad/hr dose rate on contact with the top of the steel plug

Results

Table 2 - Assigned External Doses to Employee 1

Type	Estimated $\mu Ci/cm^2$	Whole Body DDE Rem	Eye LDE rem	Whole Body SDE rem	Extremity SDE Rem
Beta Contamination	0.346	0.000	0.138	1.95	3.66
Beta Radiation		0.000	0.012	0.24	0.00
Photon Radiation		0.030	0.030	0.03	0.32
Assigned Dose		0.030	0.180	2.22	3.98
Assigned TEDE (rem)		1.44			

Conclusions

- The post-incident radiation survey results and VARSKIN 3.0 were used to estimate the contamination level of the table saw surface as 0.346 uCi/cm^2 distributed in an approximated 60 inch diameter disk source.
- This contamination level corresponds to the highest loose surface contamination levels noted by the DOE RAP Team and third party contractor
- This, combined with conservative exposure times, led to very conservative dose results
- ALL beta doses calculated in VARSKIN

- Was VARSKIN used properly?
- Was there a break down in the physics/theory of VARSKIN?

Questions