Lawrence Livermore National Laboratory Plutonium Facility Personal Nuclear Accident Dosimeter

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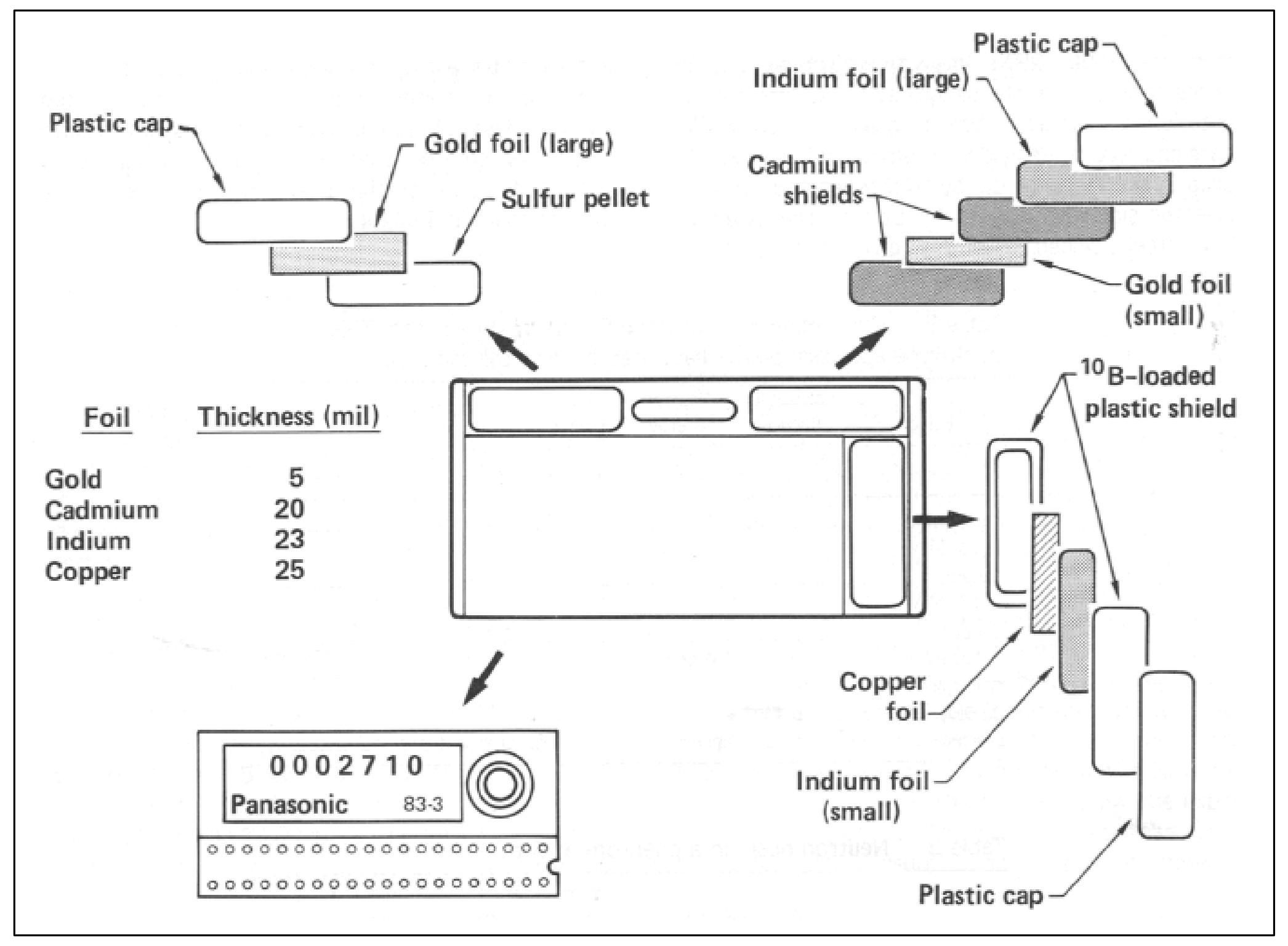
The LLNL Plutonium Facility contains significant quantities of fissile materials and thus must be able to provide dose estimates to effected individuals in the unlikely case of a nuclear criticality accident to meet the regulations set forth in the Code of Federal Regulations, 10CFR835.1304, *Nuclear Accident Dosimetry*. In order to do this, the LLNL personal nuclear accident dosimeter (pNAD) design provides a robust capability for measuring fluence in four energy ranges using metal foils, a sulfur pellet , and shielding materials for neutron activation analysis as well as a Panasonic Thermoluminescent Dosimeter (TLD) for gamma dose measurement. Experiments were conducted at CEA-Valduc in October 2009 using the SILENE reactor and in September 2010 using the CALIBAN reactor for validation of the dosimeter. Results from the experiments have demonstrated the LLNL pNAD design to be effective at evaluating the fluence and dose.

LLNL PNAD DESIGN

The LLNL personnel nuclear accident dosimeter (pNAD) consists of neutron activation elements which are placed around a Panasonic Thermoluminescent Dosimeter (TLD) as seen below.



LLNL Personnel Nuclear Accident Dosimeter Design

The neutron activation elements consist of 5 metal foils (2 Au, 2 In, 1 Cu) and a sulfur pellet. Together with the appropriate shielding, the activation elements can be used to resolve the neutron spectrum through neutron activation analysis. The activation elements and corresponding energy regions are shown in the table and explained below.

Energy Range and Corresponding Activation Elements

Energy Range	Activation Elements
Thermal	Gold (unshielded) minus Gold (shielded)
1 eV to 1 MeV	Copper
1 MeV to 3 MeV	Indium minus Sulfur
> 3 MeV	Sulfur

Using the measured activation in each of the elements, the neutron fluence can be calculated with constants and material properties such as: the time since irradiation, decay constant, atomic weight, Avogadro's number, and cross section. Once the fluence is calculated a dose conversion factor is applied to each region and the total dose determined by summation.

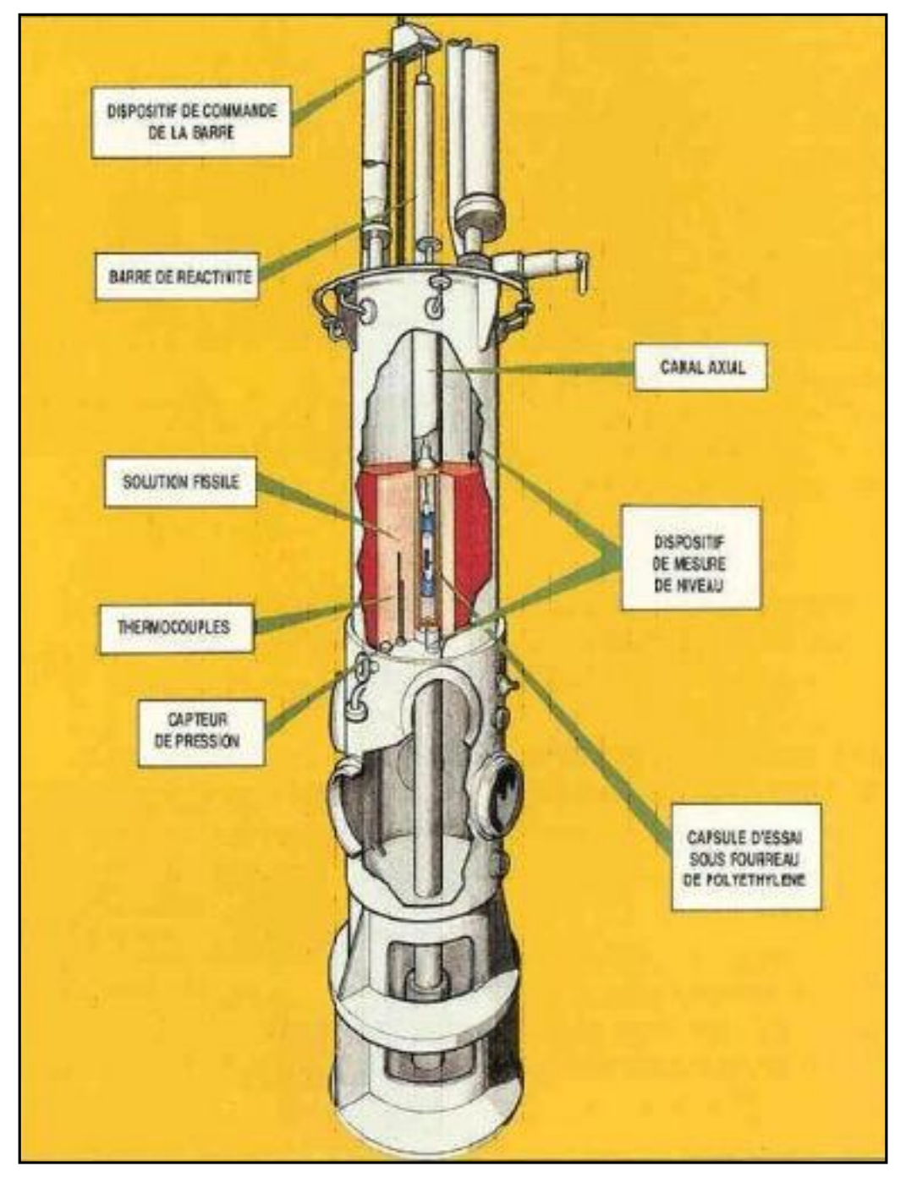
Gamma doses are measured using the commercial Panasonic TLD system which sits inside of the LLNL pNAD. The irradiated TLDs are fed into a Panasonic reader which measures the gamma exposure seen by the TLD components and automatically reports the results.

EXPERIMENTAL SETUP

2009 Experiment using SILENE Reactor at CEA-Valduc

The SILENE reactor:

- Solution reactor (71 g/L of uranyl nitrate with 93% enriched uranium)
- Operated in three modes: pulse, free evolution, and steady state
- Pulse mode results in a fission burst and spectrum that mimics a criticality accident
- Neutron spectrum of each pulse was changed by varying the yield and adding lead shielding around the reactor core
- LLNL pNADs placed around reactor core at distances of 2 m, 4 m, and 6 m
- Three pulse modes were measured



SILENE Reactor

2010 Experiment using CALIBAN Reactor at CEA-Valduc

CALIBAN Reactor

The CALIBAN reactor:

- Unreflected highly enriched uranium metal fast burst reactor
- 93.5% enriched uranium metal alloyed with 10 wt% molybdenum
- Consists of ten fuel discs and four control rods
- Pulse mode used to mimic criticality accident
- LLNL pNADs placed around reactor core at distances of 2 m, 3 m, and 4 m
- Two pulse modes were measured

Post Irradiation Experimental Procedure

Upon receipt of the dosimeters after irradiation by SILENE or CALIBAN they were disassembled into separate activation components and measured by the LLNL dosimetry team using gamma and beta detectors. The resulting measurements provided data to use in neutron activation analysis which allowed for the rapid determination of neutron dose. The gamma dose from the pNADs could not be calculated in the field as the Panasonic TLDs must be read by the Panasonic TLD reader which was located back at the home laboratory in Livermore, California. The gamma dose results were determined months after the reactor pulses when the equipment had been shipped back from France.

EXPERIMENTAL RESULTS & DISCUSSION

Neutron Dose Results

Year	Pulse	Shield	Distance (m)	Valduc	LLNL
2009	1	Lead	2	690	791
			4	190	232
			6	110	109
	2	None	2	320	344
	3	None	6	150	159
2010	1	None	2	510	490
			3	260	290
			4	170	220
	2	None	2	720	707

LLNL Neutron Dose (Rad) Results

Year	Pulse	Shield	Distance (m)	Valduc	LLNL
2009	1	Lead	2	1	1.15
			4	1	1.22
			6	1	0.99
	2	None	2	1	1.08
	3	None	6	1	1.06
2010	1	None	2	1	0.96
			3	1	1.12
			4	1	**1.29**
	2	None	2	1	0.98

LLNL Neutron Dose Ratios

Gamma Dose Results

Year	Pulse	Shield	Distance (m)	Valduc	LLNL
2009	1	Lead	2	50	221
			4	30	46
			6	20	28
	2	None	2	380	432
	3	None	6	210	172
2010	1	None	2	70	64
			3	50	18
			4	40	18
	2	None	2	100	87

LLNL Gamma Dose (Rad) Results

Year	Pulse	Shield	Distance (m)	Valduc	LLNL
2009	1	Lead	2	1	**4.42**
			4	1	**1.53**
			6	1	**1.40**
	2	None	2	1	1.14
	3	None	6	1	0.82
2010	1	None	2	1	0.91
			3	1	**0.36**
			4	1	**0.45**
	2	None	2	1	0.87

LLNL Gamma Dose Ratios

The tables on the left show the measured results for neutron and gamma dose in Rad. To see which results were inside of the ± 25% performance objective set by the ANSI/HPS N13.3 D*osimetry for Criticality Accidents* standard, the ratios of the results were compared. The tables on the right show the ratios of the LLNL doses compared to the Valduc reference doses. Values that do not meet the objective (outside of the range 0.75-1.25) are bolded.

Discussion

The CEA-Valduc exercises confirmed the LLNL nuclear accident dosimetry system meets United States regulations and standards. The dosimetry team was able to rapidly disassemble and measure all dosimeters immediately following irradiation despite new personnel who had never participated in the procedure prior to the experiment.

As is seen the tables on the right side above, only one of nine neutron dose predictions fell outside of the recommended window of ± 25%. The neutron dose is the dominant component in overall dose so there is an emphasis put on being able to accurately predict this component. The gamma dose measurements were not as successful as only four of nine gamma doses were predicted to within ± 25%. This inaccuracy demonstrates that more analysis and experimentation is necessary. However it is important to note the relatively small contribution of gamma radiation to overall dose. Since the neutron doses were predicted accurately, the overall dose estimates would still fall within the ± 25% objective in seven of 9 cases. Nonetheless future testing and research into improving the gamma dosimetry system is already underway.

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