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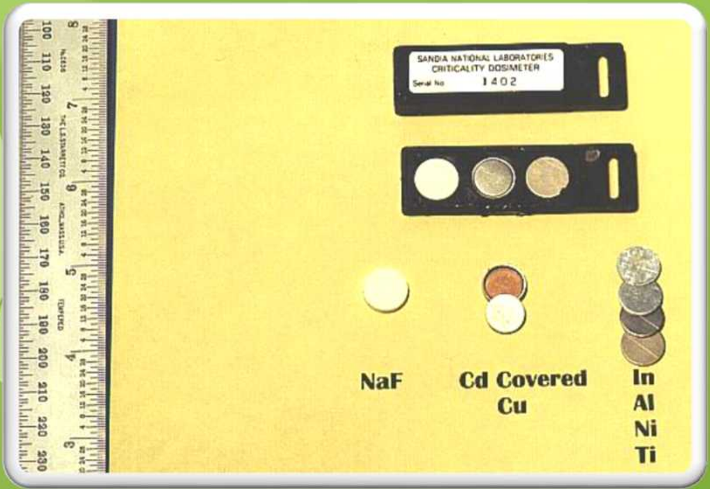
The Sandia Personal Nuclear Accident Dosimeter (PNAD)



Presented by

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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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Introduction

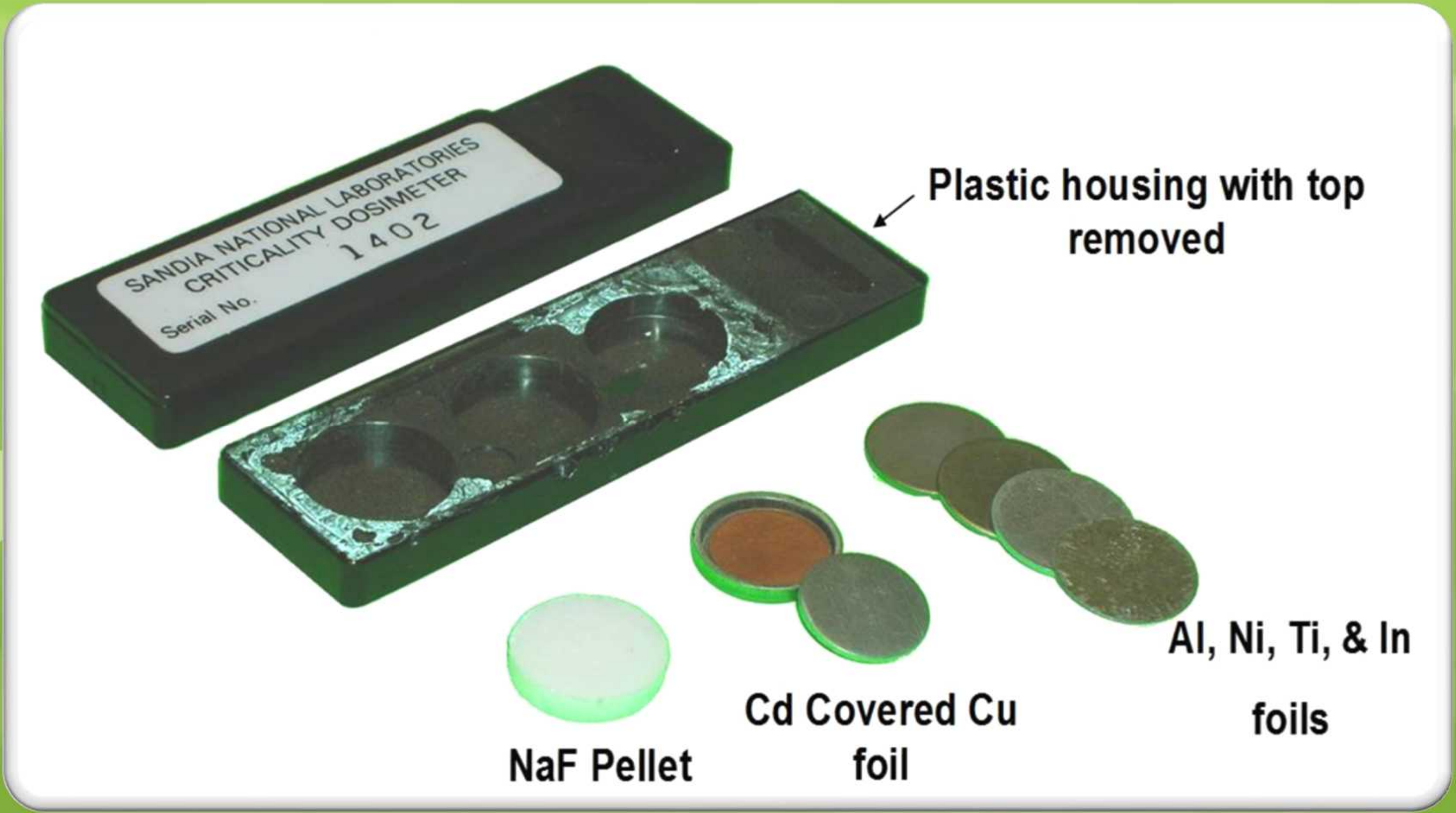
- The purpose of the SNL PNAD is to allow the estimation of absorbed neutron dose received by individuals who may have been involved in a criticality accident.

- Data obtained from a PNAD is considered to be the most reliable indicator of absorbed dose due to neutron radiation.

- If an accident occurs, the dosimeters must be retrieved within a few hours (2-8) and sent to a suitable counting facility. The Radiation Protection Sample Diagnostics Lab is the designated facility within SNL.

Description of the SNL PNAD

- PNADs are designed to be worn by individuals who enter locations in which installed criticality alarm systems are required.



Data Regarding PNAD Elements

PNAD Element	Diameter (inchs)	Thickness (inches)	Approximate Wt. (g) $\pm$ 1σ	Purity (%)
NaF pellet	0.500	0.100	0.406 $\pm$ 0.007	50% NaF by weight
Cadmium covered Copper foil	0.406	0.032	0.610 $\pm$ 0.003	99.9
Titanium foil	0.500	0.036	0.525 $\pm$ 0.004	99.9
Nickel foil	0.500	0.032	0.835 $\pm$ 0.006	99.9
Aluminum foil	0.500	0.032	0.271 $\pm$ 0.001	99.9
Indium foil	0.500	0.010	0.228 $\pm$ 0.003	99.9

More Data Regarding PNAD Elements

Material	Reaction	Half-Life	E_γ (keV)	Gamma Yield (%)	Threshold (MeV)
Al	$^{27}Al(n,\alpha)^{24}Na$	15 h	1368.633	100.0	8
Ti	$^{47}Ti(n,p)^{47}Sc$	3.4 d	159.381	67.9	2
Ni	$^{58}Ni(n,p)^{58}Co$	70.9 d	810.775	99.4	3
Cu	$^{63}Cu(n,\gamma)^{64}Cu$	12.9 h	1345.77	0.47	Epithermal
In	$^{115}In(n,n')^{115m}In$	4.36 h	336.241	45.9	1
	$^{115}In(n,\gamma)^{116m}In$	54.4 m	1293.54	84.4	Thermal[b]
Au[a]	$^{197}Au(n,\gamma)^{198}Au$	64.8 h	411.80	95.5	Thermal
Na	$^{23}Na(n,\gamma)^{24}Na$	15 h	1368.633	100.0	Epithermal

More Description of the SNL PNAD

- Each PNAD is a sealed unit.
- Each PNAD has a label with a unique serial number
- Dosimetry materials are removed by breaking the front cover away from the plastic body/holder.
- A pair of pliers and a strong screwdriver are recommended for use during opening.

Dosimetry Methodology

- In an effort to obtain dose assessments as efficiently as possible, dosimetry tables have been prepared which list many representative types of neutron spectra that could be created during a criticality accident (Ing and Makra, 1978).
- From this table, the dosimetrist can obtain spectrum weighted cross sections and fluence-to-dose conversion factors.
- The dosimetrist must however, be supplied with sufficient information about the accident in order to select the most appropriate neutron spectra from the table.

Dosimetry Methodology

- In addition to the data supplied by Ing and Makra, measured spectra for the Godiva and SHEBA reactors, which are operated at Los Alamos National Laboratories (LANL) have been included (Casson, 1995).
- Spectrum-weighted cross-section values and dose conversion factors have been calculated for the LANL spectra using the SAND II code (McElroy et al., 1967).

Analysis of Dosimeter Materials

- The analysis of dosimeter materials requires two items of information.
  - The first item is **induced activity per gram of material**.
  - The second item is **knowledge of the neutron spectrum**.

Induced Activity per Gram of Material

- The PNAD must be opened and each foil weighted individually.
-
- The activity in each foil is then determined by using gamma spectral analysis.
  - A high purity germanium detector and a multichannel analyzer are required.

Knowledge of The Neutron Spectrum

- A more efficient method is to use a reasonable approximation of the incident neutron spectrum, for which spectrum-weighted cross-section values (for each foil) and fluence-to-dose conversion factors have already been calculated.
- Tables of representative spectra for which spectrum-weighted cross-section values and fluence-to-dose conversion values have been calculated, are used.

Dosimetry Data for PNAD Materials

Spectrum-Averaged Cross Section (barns)	Spectrum Type #11 ACRR Central Cavity	Spectrum Type #12 GODIVA Bare, Measured at LANL
$^{63}Cu(n,\gamma)^{64}Cu$	0.148	0.101
$^{115}In(n,n')^{115m}In$	0.0579	0.101
$^{58}Ni\ (n,p)^{58}Co$	0.0256	0.0607
$^{47}Ti(n,p)^{47}Sc$	0.00463	0.0103
$^{27}Al(n,\alpha)^{24}Na$	0.000151	0.000693
$^{23}Na(n,\gamma)^{24}Na$	0.0414	0.0191
$^{197}Au(n,\gamma)^{198}Au$	52.4	24.9
$\overline{K}\ \frac{nrad}{n/cm^2}$	1.15	1.79
$\overline{D}\ \frac{nrad}{n/cm^2}$	1.30	2.07
$\overline{DE}\ \frac{nrem}{n/cm^2}$	13.8	20.7
$\overline{D_\gamma}\ \frac{nrad}{n/cm^2}$	0.273	0.255

Neutron Fluence Conversion Equations

- The following equation estimates the total neutron fluence (Φ, in units of n/cm^2) based upon:
  - measured specific foil activities (A, in units of μCi/g)
  - and use of the appropriate spectrum-weighted cross-section value (σ, in units of barns) from the dosimetry Data Table.

Reaction	E_γ used for Analysis	Fluence Conversion Equations*
$^{115}In(n,n')^{115m}In$	336 keV	$\Phi = \frac{A}{5.985x10^{-12}\sigma}$

Absorbed Dose Calculation

$$\Phi = \frac{A}{5.985\, x 10^{-12}\, \sigma}$$

$$Dose(rad) = \Phi\left(\frac{n}{cm^2}\right)\overline{D}\left(\frac{nrad}{n/cm^2}\right)x10^{-9}\,\frac{rad}{nrad}$$

Combining Neutron and Photon Dose Values

- The neutron and photon dose values should be summed and reported as absorbed dose (rad).

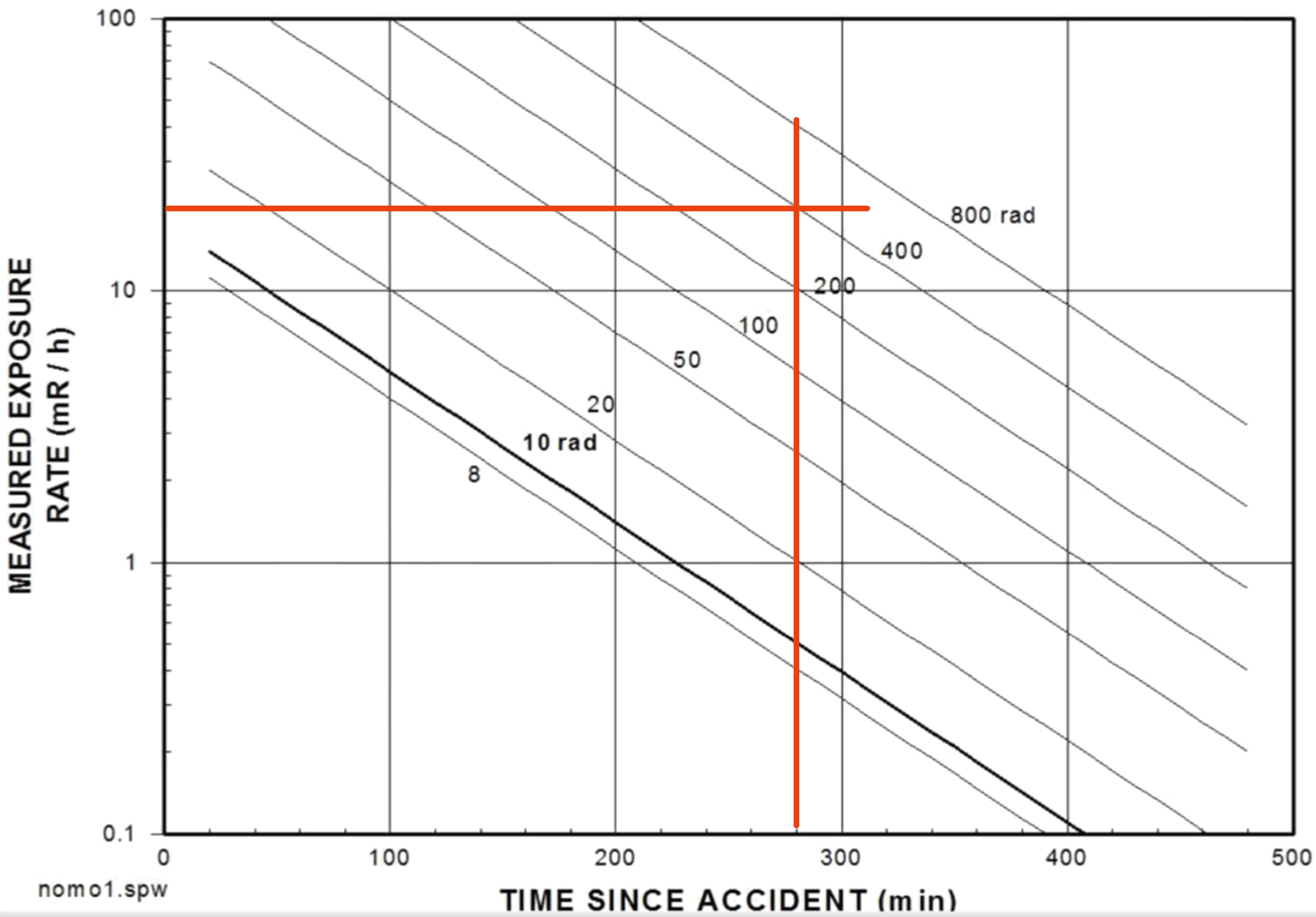
Quick-Scan Procedure for PNADs

- Initial screening of personnel involved in a criticality accident, to determine whether significant exposures to neutron radiation occurred, can be performed.

- The screening (or Quick-Scan Procedure) is accomplished by checking the PNAD for induced activity using portable health physics survey equipment, and a nomogram

Quick-Scan Screening Process

Nomogram for PNAD Quick-Scan Procedure

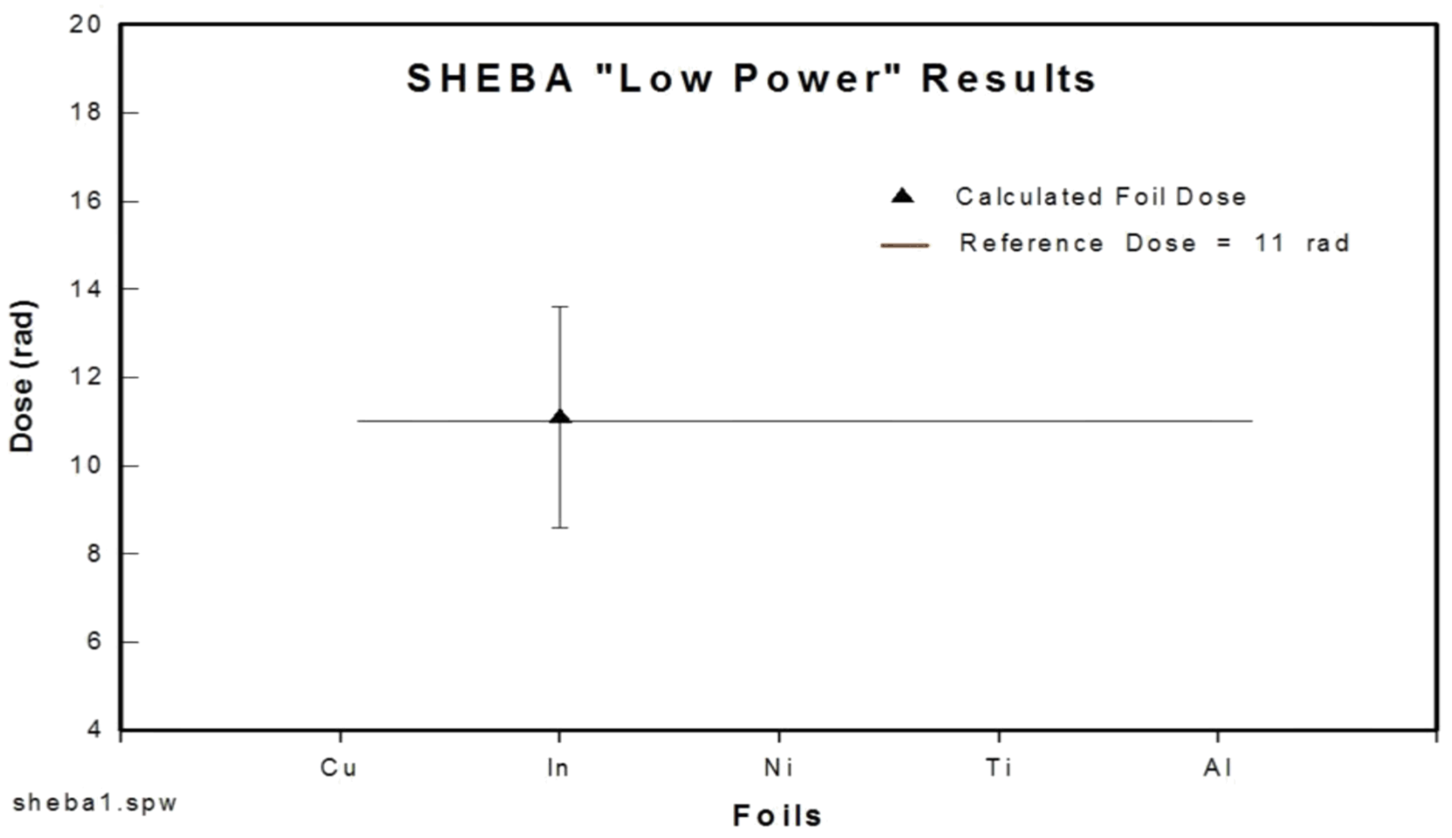


PNAD Foil Analysis

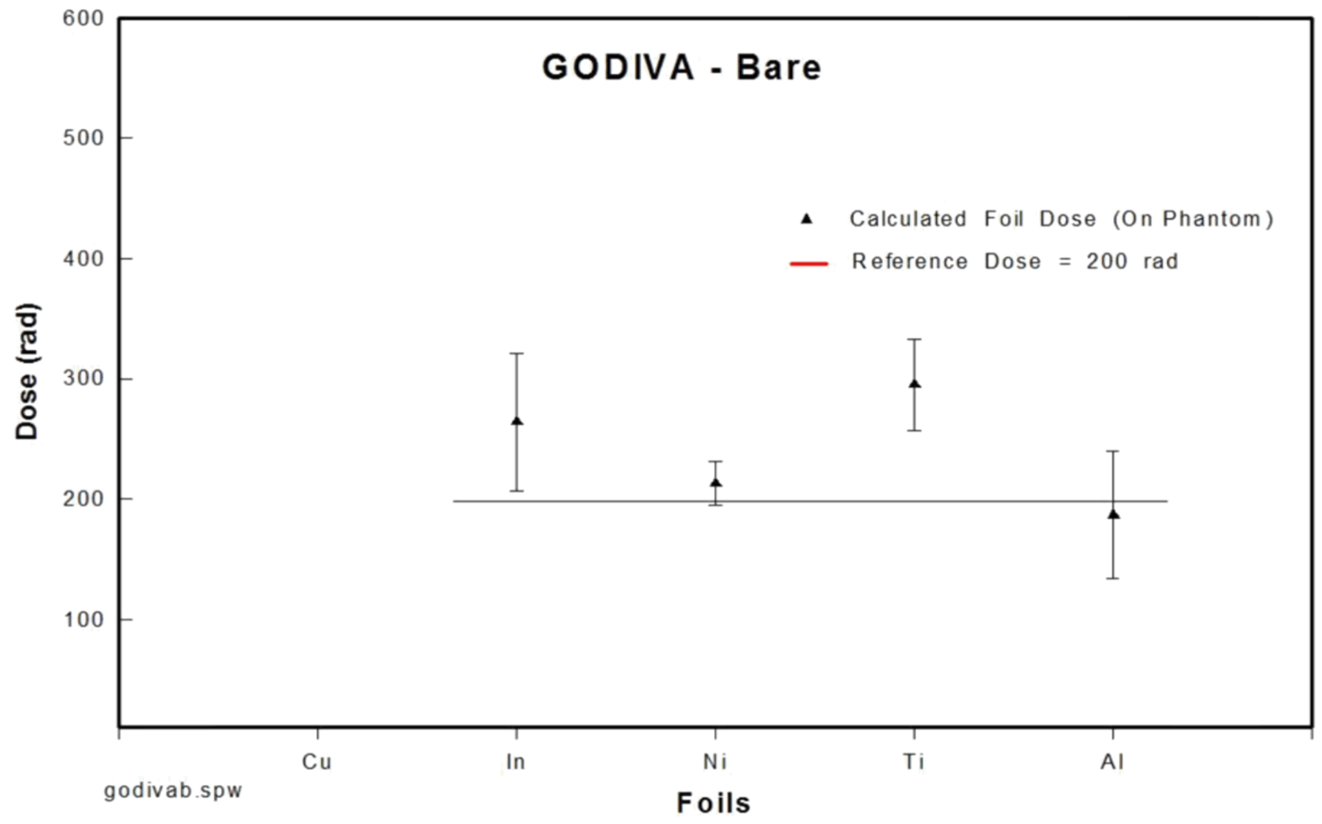
- Each PNAD contains six foils. The foils are removed from PNAD and are counted in the following order:
  - the Sodium pellet is counted first for 10 minutes,
  - the Copper foil is removed from the Cadmium cup and is counted for 20 minutes,
  - the Titanium, Nickel, and Aluminum foils are counted together[C3] for 60 minutes, and
  - the Indium foil is counted last for 20 minutes.

[C3] The uncertainty introduced by stacking the foils was evaluated and determined to be less than 1%.

Intercomparison Results From NAD23



Intercomparison Results From NAD23



Sources of Additional Information

- American National Standards Institute (ANSI) N13.3-2013, “Dosimetry For Criticality Accidents”
- H. Ing, S. Makra, 1978, “Compendium of Neutron spectra in Criticality Accident Dosimetry,” Technical Reports Series No. 180, International Atomic Energy Agency, Vienna.

NOTE

- The concept of dose-equivalent is of limited use in accidents when doses in excess of 25 rads have been received. The quality factor in such situations is not uniquely defined, although it is generally assumed (RBE Committee, 1963) to be between one and two. The dose equivalent ( ) values presented in Table A-1 have been calculated using the quality factors normally adopted for radiation protection. These values are provided for the convenience of determining the dose-equivalent for those individuals exposed to doses less than 25 rem and for whom the dose equivalent received in a criticality incident must be added to the already accumulated record (Ing & Makra, 1978).