Covariances and Neutron Dosimetry: Status Report and Future Needs

Presentation to 2008 CSEWG

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Outline

- Community processes for establishing dosimetry “standards”
- Recent dosimetry standards activities
- Status of nuclear dosimetry
  - Where we are vs. where we want to be!
- Specific dosimetry needs

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Community processes for establishing dosimetry "standards"

- **Standards organizations**
  - **ASTM International**
  - **ANSI/ANS**
  - **ISO TC85 (Secretariat, administered by ASTM)**
    - » **US Nuclear Technical Advisory Group (NTAG)**
    - » *nuclear fuel, reactor technology and radiation protection standards development efforts of the International Organization for Standardization (ISO).*
- **Regulatory organizations**
  - **NRC**
- **Research organizations**
  - **Sandia National Laboratories**

ASTM International

- **Subcommittee E10.05: Nuclear radiation metrology**
  - Focus on neutron damage and pressure vessel surveillance
- **Subcommittee E10.07: Radiation dosimetry for radiation effects on materials and devices**
  - Focus on radiation test facilities
- **Subcommittee F1.11: Nuclear and space radiation effects**
  - Focus on radiation hardened electronics for space and electronic device test protocols.
  - Space parts working group
- **Subcommittee E10.01: Radiation processing: dosimetry and applications**
  - Food irradiation

ASTM International

- Consensus standards organization
  - International community
    - » Foreign participation facilitated by non-paying "affiliate" status
  - Volunteer standards support by community
  - Composition balance of users, producers, general
- Area specific international conferences/workshops
  - 14^{th} International Symposium on Reactor Dosimetry – every 3 years
  - 6^{th} International Workshop on Dosimetry for Radiation Processing – yearly
  - 24^{th} International Symposium on Effects of Radiation on Materials – every 2 years
- Journal of ASTM International (JAI) – online peer-reviewed journal

ANSI/ANS

- **Voluntary consensus standards body**
  - **US national standards organization**
- **Examples of standards under revision with nuclear data emphasis:**
  - ANS-6.1.2-200x, "Neutron and Gamma-Ray Cross Sections for Nuclear Radiation Protection Calculations for Nuclear Power Plants" (revision of ANSI/ANS-6.1.2-1999)
  - ANS-5.1-200x, "Decay Heat Power in Light Water Reactors" (revision of ANSI/ANS-5.1-2005)
  - ANS-8.12-200x, "Nuclear Criticality Control and Safety of Plutonium-Uranium Fuel Mixtures Outside Reactors" (revision of ANSI/ANS-8.12-1987; R1993; R2002)
  - ANS-19.1-200x, "Nuclear Data Sets for Reactor Design Calculations" (revision of ANSI/ANS-19.1-2002)
  - ANSI/ANS-8.27-2008, "Burnup Credit for LWR Fuel" (new standard, approved 8/14/08 – coming soon)

NRC

- 10 CFR50 Appendix H: reactor vessel surveillance program requirements
  - Pressurized thermal shock: PTS Rule, 10 CFR part 50.61
  - Fracture toughness testing, Charpy V-notch impact test
  - Embrittlement trend curve (ETC)
  - Advisory Committee for Reactor Safeguards (ACRS)
- ASTM generally develops the standard or methodology with community consensus, NRC adopts this standard or forms a “rule” based on the ASTM standard

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- **Internal CFRs and process documents cite the international standards**
  - SNLRML dosimetry cross sections, built upon ASTM E1018
  - Reactor test fidelity, requirements justified/endorsed by ASTM E1854
  - Use of transistors for 1-MeV(Si) equivalent dosimetry, defined in E1855
  - 14-MeV source characterization, consistent with E496

Recent Dosimetry Standards Activities

- E496 – 14-MeV DT source characterization
  - Ballot for reapproval – persuasive negative
- E1018 – Reactor dosimetry cross sections
  - Ballot with major update, committee ballot approved, going to Society ballot
  - Need to consider additional acceptance criteria
- More rigorous "precision and bias" section required
  - round-robin testing for Test Methods and Practices

Negative on E496 – 14-MeV Source Characterization

- Standard recommends:
  - Fluence determination from “flat” cross section, e.g. ^{93}Nb(n,2n)^{93m}Nb
  - Energy determination from ratio of increasing & decreasing cross section reactions, e.g. ^{54}Fe(n,p) / ^{58}Ni(n,2n)
- Issue was re-approval without update
  - ^{27}Al(n,p) uncertainty in 14-MeV region changed
    - » Standard: GLUCS, IRDF-90 evaluation, 15.6% uncertainty @ 14-MeV
    - » Latest: RRDF-2002, IRDF-2002, 1.5% uncertainty @ 14-MeV
    - » This difference does not reflect a typo!

Several new dosimetry evaluations will affect E496

- New evaluations by Zolotarev made available by IAEA
  - ^{27}Al(n,p) – first available in 2006
  - ^{24}Mg(n,p) – first available in 2008
  - ^{32}S(n,p) – first available in 2008
  - ^{64}Zn(n,p) – first available in 2006
  - ^{65}Cu(n,2n) – first available in 2006
  - ^{63}Cu(n,2n) – first available in 2006
- Of 14 cross sections in E496, 6 have recent updates that were not considered

E496 Update Consideration

- Several of the previous cross sections used in E496 came from the GLUCS simultaneous least squares adjustment
  - ^{27}Al(n,p) with a 15.6% uncertainty @ 14-MeV
  - ^{32}S(n,p) with a 8% uncertainty @ 14-MeV
- The typical reactor dosimetry monitor, ^{58}Ni(n,p) is used in E496 and has a ENDF/B-VI specified uncertainty of 18.6% at 14-MeV
  - JENDL 3.3 has a smaller uncertainty, ~10%
- New uncertainties are all in the 1-2% region
- Selecting baseline evaluation based on the lowest uncertainty is NOT a valid criterion, but the most recent evaluation data is a valid criterion.

E496: Path Forward

- Need: Advice on the GLUCS simultaneous evaluation results
- Desire: An activity consistency test on reactions at 14-MeV
  - Pursue this with ASP with AWE and NPL cooperation
- Consideration: Is a least squares adjustment of “dosimetry-only” cross sections worth considering for our purposes?
  - Not proposed for general evaluations, just for a special dosimetry library
  - Strong negatives and positives

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ASTM E1018

- Recent ballot of update of recommended dosimetry cross sections and associated nuclear data
- Recommended cross sections require:
  - Drawn from documented cross section evaluations
  - Covariance matrix consistent with cross section
  - Format: ENDF-6 or 640-multigroup with LSL covariance
  - *Specify associated nuclear data, i.e. half-life and natural abundance
  - *Validated for LWR-applications using benchmark field data
  - Periodic cross section file review
  - Easy cross section file availability

Update of E1018: Dosimetry Cross Sections (1/2)

Dosimetry Reaction	Material ID in Primary Library	Cross Section Library					Comment
		ENDF/B-VI.8 **(4)**	JENDL/D-99 **(44)**	JEFF 3.1 **(9)**	RRDF-2002 **(40)**	IRDF-2002 **(36)**	
$^{6}Li(n,X)^{4}He$	325	P				•	*C, B, P, M*
$^{10}B(n,X)^{4}He$	525	P				•	*A, B, P, M*
$^{23}Na(n,\gamma)^{24}Na$	1125	P				•	*F*
$^{24}Mg(n,p)^{24}Na$	1225					•	*O*
$^{27}Al(n,p)^{27}Mg$	1325				P	•	*Q*
$^{27}Al(n,\alpha)^{24}Na$	1325				P	•	*Q*
$^{32}S(n,p)^{32}P$	1625					•	*R, T*
$^{45}Sc(n,\gamma)^{46}Sc$	2126					•	*F, S*
$^{46}Ti(n,p)^{46}Sc$	2225				P	•	*G, Q*
$^{47}Ti(n,p)^{47}Sc$	2228				P	•	*G, Q*
$^{48}Ti(n,p)^{48}Sc$	2231				P	•	*Q*
$^{55}Mn(n,\gamma)^{56}Mn$	2525	P				•	*F*
$^{55}Mn(n,2n)^{54}Mn$	2525	P					*V*
$^{54}Fe(n,p)^{54}Mn$	2625	P				•	*T*
$^{56}Fe(n,p)^{56}Mn$	2631				P	•	
$^{58}Fe(n,\gamma)^{59}Fe$	2637		P			•	*F, U*
$^{nat}Fe(n,X)dpa$	2600					•	*J, I*
$^{59}Co(n,p)^{59}Fe$	2725	P					*V*
$^{59}Co(n,\gamma)^{60}Co$	2726/2725					•	*T, W*
$^{59}Co(n,\alpha)^{56}Mn$	2712				P		*T*
$^{59}Co(n,2n)^{58}Co$	2726/2725					•	*T*
$^{58}Ni(n,p)^{58}Co$	6433/2825				P	•	
$^{58}Ni(n,2n)^{57}Ni$	2825			P		•	
$^{60}Ni(n,p)^{60}Co$	2831	P				•	

Update of E1018: Dosimetry Cross Sections (2/2)

$^{59}Co(n,2n)^{58}Co$	2726/2725					•	*T*
$^{58}Ni(n,p)^{58}Co$	6433/2825				P	•	
$^{58}Ni(n,2n)^{57}Ni$	2825			P		•	
$^{60}Ni(n,p)^{60}Co$	2831	P				•	
$^{63}Cu(n,\gamma)^{64}Cu$	2925	P				•	
$^{63}Cu(n,2n)^{62}Cu$	2925	P				•	
$^{63}Cu(n,\alpha)^{60}Co$	6435/2925				P	•	
$^{65}Cu(n,2n)^{64}Cu$	2931	P				•	
$^{64}Zn(n,p)^{64}Cu$	3025				P		
$^{90}Zr(n,2n)^{89}Zr$	4025		P				
$^{93}Nb(n,\gamma)^{94}Nb$	4125	P				•	
$^{93}Nb(n,2n)^{92m}Nb$	4112				P	•	
$^{93}Nb(n,n')^{93m}Nb$	4112				P	•	*I*
$^{103}Rh(n,n')^{103m}Rh$	4511				P	•	*I*
$^{109}Ag(n,\gamma)^{110m}Ag$	4731					•	*S*
$^{115}In(n,\gamma)^{116m}In$	4931	P				•	
$^{115}In(n,n')^{115}In$	4932/4931				P	•	*I*
$^{197}Au(n,\gamma)^{198}Au$	7925	P				•	*P*
$^{197}Au(n,2n)^{196}Au$	7925					•	
$^{232}Th(n,f)$F.P.	9040	P				•	*I*
$^{235}U(n,f)$F.P.	9228	P				•	*M, P*
$^{238}U(n,f)$F.P.	9237		P			•	*M, I, P*
$^{237}Np(n,f)$F.P.	9346				P	•	*I*
$^{239}Pu(n,f)$F.P.	9437		P			•	

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Does E1018 Need More Changes?

- Do we need additional requirements on the recommended cross section evaluations?
  - Badikov as well as Gai&Pronyaev (nd2007) propose additional covariance acceptance criteria
    - » Specify positive definite covariance – Yes, normally standard procedure
    - » Average and uncertainty in average of covariance elements is a conserved quantity – True but not useful for us
    - » Shape consistency (model vs. data) – True but not useful for us
    - » Relation in integral uncertainties – True but not useful for us
  - Badikov et al. suggested application of three of these metrics to the IRDF2002 in an ISRD13 presentation

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Does E1018 Need More Changes?

- Force consideration of resonance integral match of evaluation to experiment
- Force consideration of thermal cross section match of evaluation to experiment – typically done
- Force "consistency" checks on reaction cross sections

Precision & Bias Statements

- Precision and bias statements on test methods generally need to be validated by community round-robin testing
  - Too few dosimetry laboratories are willing to participate in testing
    - » Too few remaining dosimetry laboratories
    - » Costs are one reason not to participate
    - » Only down-side, no up-side for labs to participate, even given anonymity in results
  - One recent success: NIST coordinated a ^{237}Np round robin
  - Interlaboratory comparisons are important to maintain and demonstrate competence

Major Concern: people/expertise

- Loss of expertise on dosimetry standards committees
  - Decline in industry participation
    - » Very pronounced in the reactor industry
      - Driven by even minimal cost of staff participation, lean six sigma trims this as “fat”
      - New reactor construction (even if in China) may turn this around
    - » Exception is the food processing area
      - Industrial funding and participation are very high in this area
- New people are not entering the nuclear area
  - Maintenance of capabilities is an issue
  - Many standards are being withdrawn for lack of committee expertise.
  - This does reflect a lack of current use but reconstituting the standard will be quite difficult

Specific Dosimetry Needs

- ^{237}Np(n,f) cross section and uncertainty, 10 keV – 500 keV MeV
  - Uncertainty decreased from 30% to <7%
  - Critical to spectrum adjustment, used with B_4C cover, currently uses a diagonal covariance matrix
- Covariance for covers, ^{nat}Cd, B_4C, ^{nat}Gd
  - For Cd, will take anything and will then evaluate the importance of a better cross section
  - For ^{10}B, need to extend the covariance for the “standard” to include the full range
- Uncertainty in energy-dependent branching ratio for ^{58}Ni(n,p)$^{58g+58m}$Co
  - Used as early-time dosimetry monitor

Major Issue: *a priori* ^{235}U spectrum covariance

- **Needed for spectrum adjustment of reactor spectra**
  - **Required to eliminate model-induced tight correlation for energies > 2 MeV**

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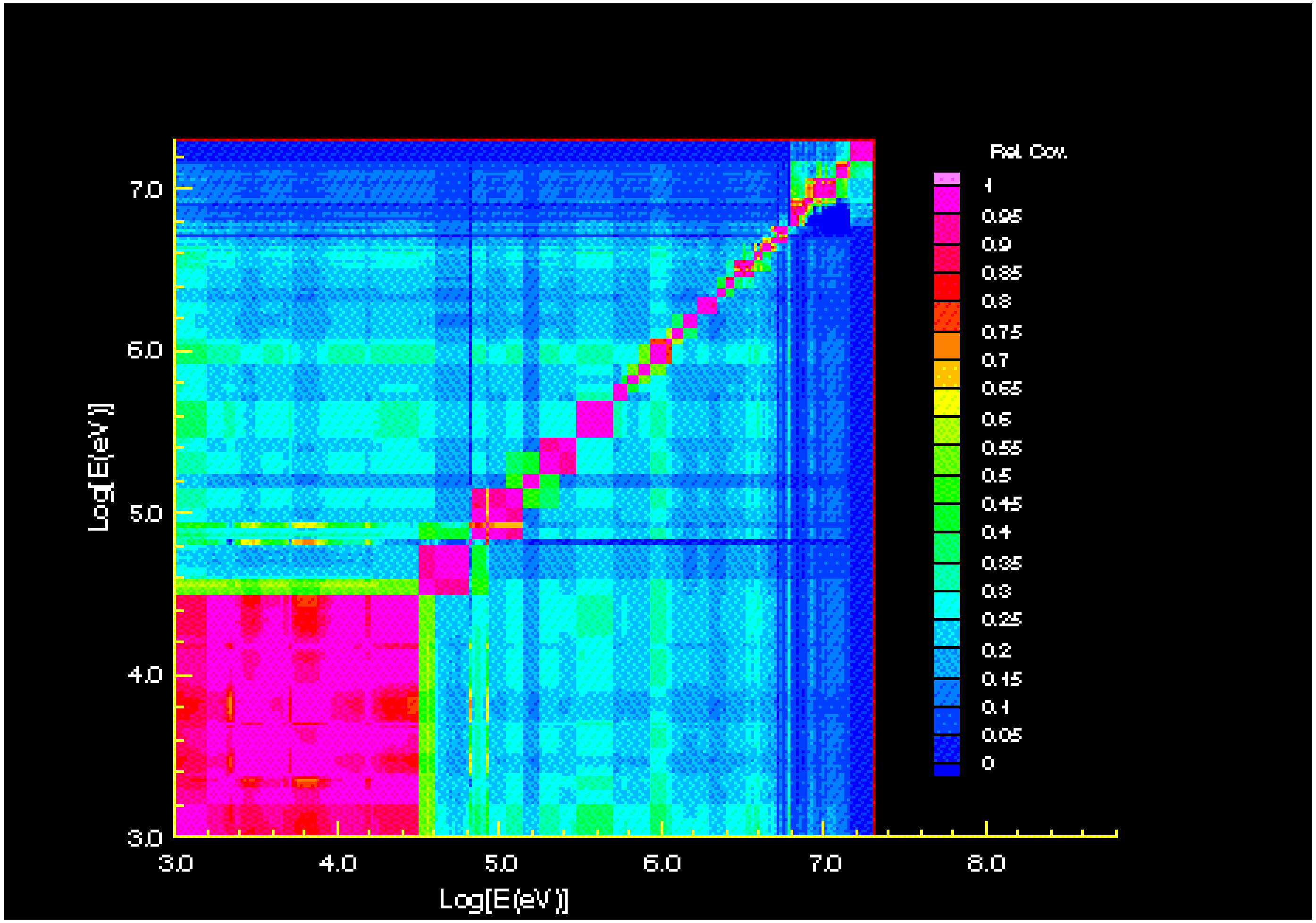
Update to covariance for 1-MeV(Si) Response



Questions???

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