Summary of WANDA session

Nuclear Data for High Energy Ion Interactions and Secondary Particle Production

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ORNL is managed by UT-Battelle, LLC for the US Department of Energy
Session Description

• Wide energy and species range of GCRs

• Interaction of GCRs with spacecraft materials creates a large complex cascade of secondaries

• These secondaries can harm humans and electronic systems

• How can we improve the nuclear data pipeline to understand these effects and enable safe space exploration?
Energy Range and Particle Types

- Wide range of energies and particle species for space applications

Diagram:
- Heavy ions: "Blocked" by Coulomb barrier
- Ion Beam Analysis
- Isotopes
- Nucleosynthesis
- Fusion Reactors
- Spallation Sources
- Fission Reactors
- Overlaps with other fields

Dave Brown
Focus Areas

Nuclear Data Pipeline

Measurement → Compilations → Evaluations → Processing → Validation → Application

Focus Areas:
- Nuclear Data Pipeline
- Experimental Facilities
- Databases
- Modeling
- Applications

WANDA 2022 High Energy Ion Interactions & Secondary Production Session

Ken LaBel, Ramona Vogt, Michael Smith
Experimental Facilities

- Numerous facilities used for measurements

TAMU REF

LBNL BASE

BNL NSRL

BNL SEUTF

MSU FSEE

ARUNA

Association for Research at University Nuclear Accelerators
Experimental Facilities

- UCL (Belgium)
- GANIL (France)
- CERN (Switzerland)
- PSI (Switzerland)
- RADEF (Finland)
- GSI (Germany)
- HPTC (Netherlands)
- KVI (Netherlands)
- LNS (Italy)

- Numerous facilities used for measurements
Experimental Facilities

- Beam demand significantly outstrips availability

Ken LaBel
Experimental Facilities

BNL AGS

- Reusing accelerators could meet *some* user needs

also ... dormant SC360 cyclotron
Provision Knoxville TN

coordinate re-use
Experimental Facilities

- Higher beam energies needed to reach sensitive volumes

Limited availability

Ken LaBel
**Experimental Facilities**

- **Unique, time-limited opportunity** to obtain critical **high-energy data**

He, C, Si, and Fe (3 – 50 GeV) $\rightarrow$ C, Al, and Fe targets

Complete before EIC

[Image of experimental facilities including RHIC, STAR, PHENIX, LINAC, NSRL, EBIS, Booster, AGS]

Daniel Cebra
Experimental Facilities

- Larger beam size capability needed to irradiate larger circuits/systems

• Old approach: batch mode
• Growing trend:
Compilations, Databases, Dissemination

Francesca Luoni

1786 data from 110 peer-reviewed publications

- User-generated compilation of reaction data
Compilations, Databases, Dissemination

Cross Section Measurement Database

**Galactic Cosmic Rays (GCR)**

- Protons $\rightarrow$ Fe nuclei $\sim 100$ MeV/n – 50 GeV/n
- Peaks: H, He, C, O, Si, Fe $\quad Z = 1, 2, 6, 8, 14, 26$

**NUCDAT (50,000 entries)**

Health Physics 103, 640, 2013.

- Others have private data collections

will be included in GSI-ESA-NASA database
Compilations, Databases, Dissemination

- Data sharing has been challenging for Space Electronics community

- proprietary
- security
- formats
- different systems
- operating funds

Ken LaBel    Ramona Vogt   Michael Smith
• EXFOR & ENDF reaction data do not cover range of energies / species
### Compilations, Databases, Dissemination

#### Table 4: Accelerator Shielding Experiments in SINBAD (in bold are recent compilations)

<table>
<thead>
<tr>
<th>Title</th>
<th>Shielding material</th>
<th>Projectile</th>
<th>Measured quantity</th>
<th>Computer code input</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmission Through Shielding Materials of n &amp; γ Generated by 52 MeV p</td>
<td>C (&lt; 64.5 cm thick), Fe (&lt; 57.9 cm), H2O (&lt; 101 cm), concrete (&lt; 115 cm)</td>
<td>52 MeV protons on C target</td>
<td>NE213 scintillation</td>
<td>No</td>
</tr>
<tr>
<td>Transmission Through Shielding Materials of n &amp; γ Generated by 65 MeV p</td>
<td>concrete, iron, lead and graphite (10 to 100 cm thick)</td>
<td>65 MeV protons on Cu target</td>
<td>NE213 scintillation</td>
<td>No</td>
</tr>
<tr>
<td>TIARA 40 and 65 MeV Neutron Transmission Through iron, Concrete and Polyethylene</td>
<td>Fe (130 cm), concrete (&lt; 200 cm), polyethylene (up to 180 cm)</td>
<td>43 and 68 MeV protons on Li7 target</td>
<td>BC501A, Bonner ball, fission counters, TLD, SSNTD</td>
<td>No</td>
</tr>
<tr>
<td>ROESTI I and III</td>
<td>Fe and Pb (100 cm thick)</td>
<td>200 GeV/c positive hadrons (2/3 p, 1/3 n')</td>
<td>In, S, Al, C foils, RPL</td>
<td>Yes</td>
</tr>
<tr>
<td>ROESTI II</td>
<td>Fe (100 cm thick)</td>
<td>24 GeV/c protons</td>
<td>In, S, Al, C foils, RPL</td>
<td>Yes</td>
</tr>
<tr>
<td>RIKEN Quasi-monoenergetic Neutron Field (70-210 MeV)</td>
<td>air</td>
<td>70 – 210 MeV protons on Li</td>
<td>NE213 (TOF)</td>
<td>No</td>
</tr>
<tr>
<td><strong>HIMAC He, C, Ne, Ar, Fe, Xe and Si ions on C, Al, Cu and Pb targets</strong></td>
<td>C, Al, Cu and Pb targets</td>
<td>100-800 MeV/ nucleon He, C, Ne, Ar, Fe, Xe &amp; Si ions</td>
<td>NE213 &amp; NE102A scintillators</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>HIMAC/NIRS High</strong></td>
<td>Fe (up to 100 cm)</td>
<td>300 MeV/nucleon Neutron</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- SINBAD database can help space shielding and transport studies
Compilations, Databases, Dissemination

- Nuclear Data community could help these data efforts cooperate / coordinate / cross-link / evolve
Nuclear Reaction Modeling

• Some successes with phenomenological reaction models

DDFRG double differential fragmentation model (Norbury)
Nuclear Reaction Modeling

- Semi-empirical parameterizations are also valuable
Nuclear Reaction Modeling

• Tuning of models to data needed from 100 MeV/u – 1 GeV/u
Nuclear Reaction Modeling

Heavy Ion Reactions in RHI community

• Current reaction models in space community could benefit from > 20 yrs of theory advances in R H I community
Nuclear Reaction Modeling

- Opportunity to provide modeling support for shielding applications

FLUKA model of LHC

R. Garcia-Alia
Applications - Electronics

- Production of secondaries in electronic circuits need improved models

- Predict species, angles, energies

- High-energy testing needed for deep sub-micron electronics

- Measure for all relevant materials
Applications - Medical

Future: shrink spatial resolution by $10^2 - 10^3$
go to $\sim$GeV heavier ions
include improved physics models

Approach: **port to GPUs**
currently 200x faster than GEANT4

- Cancer therapy community developing HPC simulations that can benefit
  space human effects research
Applications - Modeling

- Space radiation transport studies detail sensitivity to nuclear data

Sensitivities

O, Mg, Si, Fe projectiles are critical

partial cross sections for p, n, alpha are important
• Space transport studies should explore synergies with RHI collisions

high net-baryon density physics

critical focus on light ion production
Applications – Spacecraft Design

- Spacecraft design needs accurate and reliable rad transport tools with relevant nuclear data for all particle interactions.

Uncertainties in space radiation environment & rad transport protect instruments.

Different requirements protect astronauts.

Non-ionizing energy loss rate for $^4$He

Insoo Jun

- MeV·cm$^2$/g
- Si bombardment MeV

- Nuclear Total
- Elastic
- Nonelastic
Final Comments

- **Electronics Effects** and **Human Effects** communities could benefit from enhanced collaboration with **nuclear physics** (and with each other)

- Numerous ties between the **Relativistic Heavy Ion community** and the **Space communities** should be **fostered and exploited** [reaction theory, RHIC measurements, transport simulations/light particle production]

- Coordinate **beam time requests** and **accelerator re-use** to best meet high demand for more experiments

- **Space community** could benefit tremendously from **expertise** in **Nuclear Data community** (databases, visualization, sensitivity tools, dissemination, archiving, model integration, ML approaches ...)

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