UT-BATTELLE

ORELA STATUS BRIEFING

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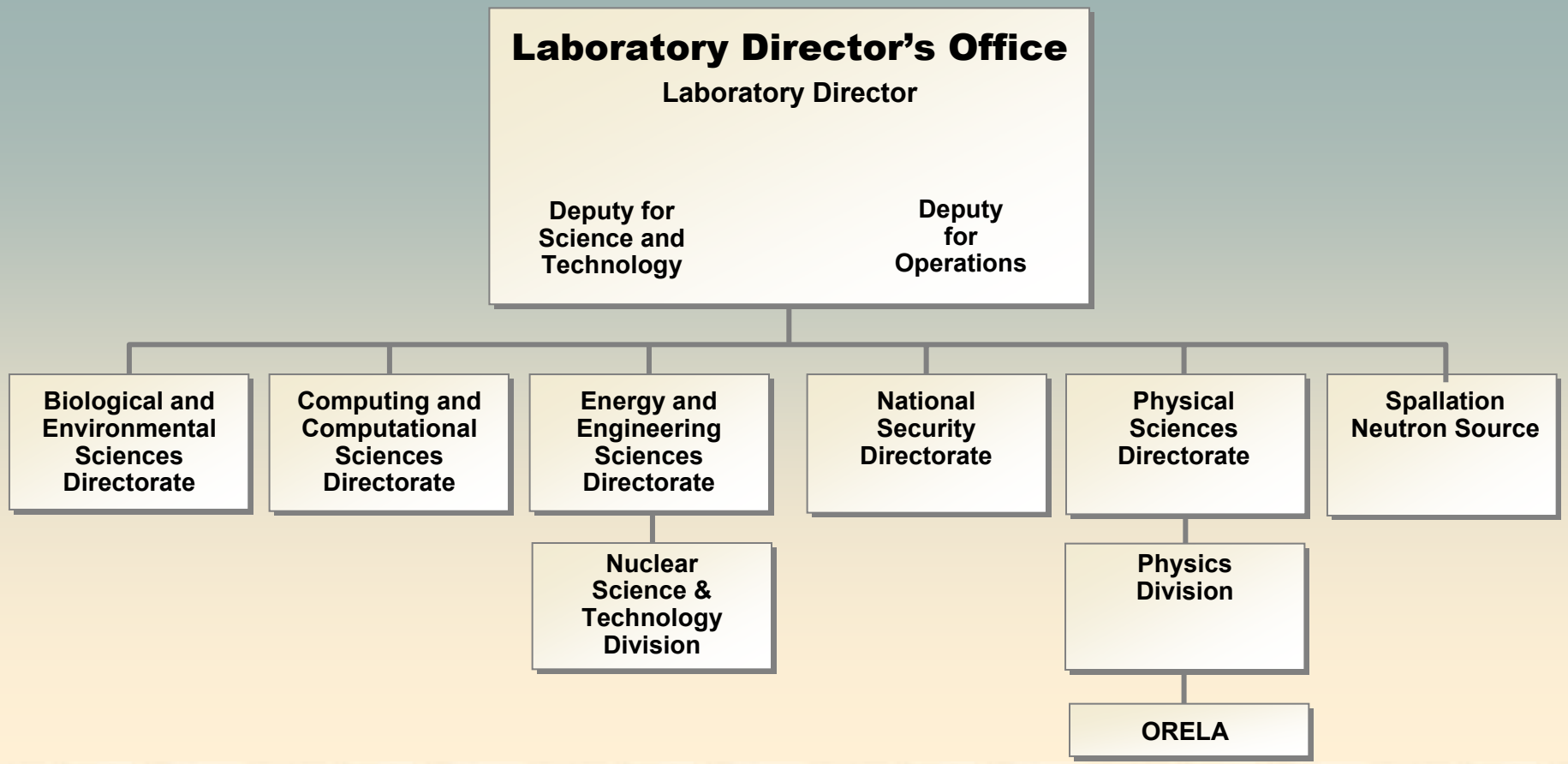
CSSG Meeting
September 16, 2005

OAK RIDGE NATIONAL LABORATORY
U. S. DEPARTMENT OF ENERGY

Presentation Outline

- ORELA Overview
- ORELA Importance for Neutron Cross-Section Measurements in the Resolved Resonance Region
- Facility Status
- Improvement Plan
- Summary

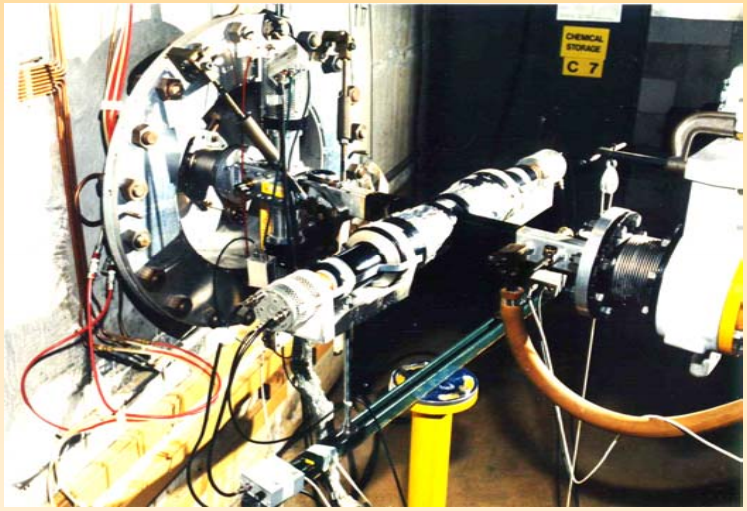
ORELA Position in ORNL Organization



What is ORELA?

- **O**ak **R**idge **E**lectron **L**inear **A**ccelerator
  - Perform neutron cross-section measurements
  - Generate electrons that strike a target (Ta) and produce neutrons via bremstrahlung and photoneutron reactions
  - Neutrons directed down various flight paths to cross-section measurement stations

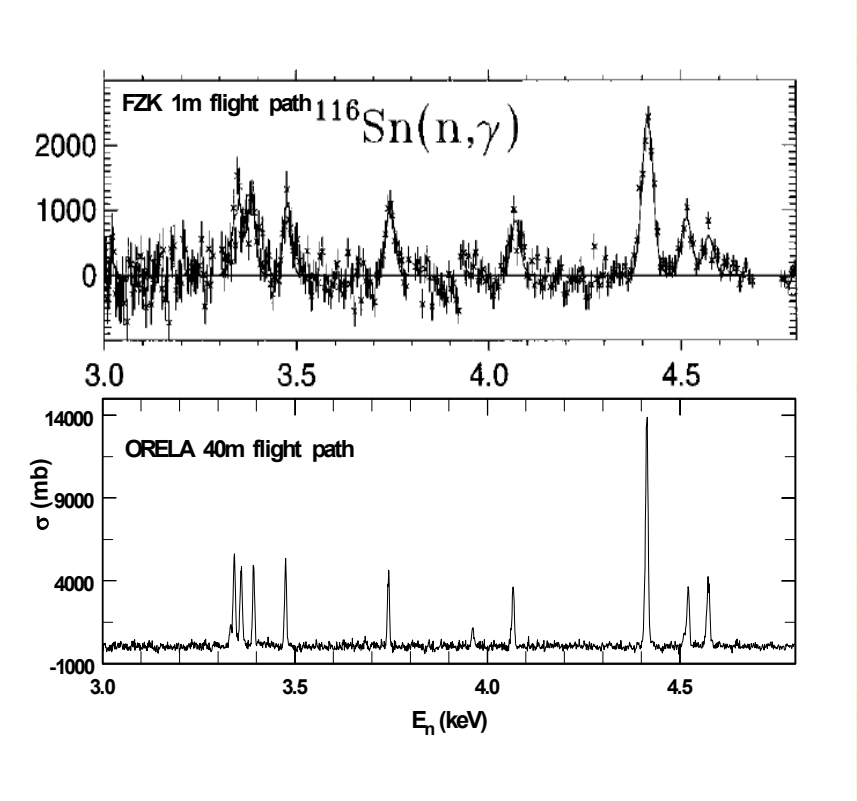
- Important features
  - **Unique measurement facility in U.S.**
  - **High flux (10^{14} n/sec) => gram-sized, affordable samples**
  - **Excellent resolution (Δt=4-30 ns) => good S/N facilitates better evaluations**
  - **"White" neutron spectrum from E_n ~ 0.01 eV - 80 MeV => reduces systematic uncertainties**
  - **Measurement systems well understood => very accurate data.**
  - **Simultaneous measurements => (n,γ), (n,α), (n,n'), and σ_{total} experiments at the same time on different beam lines**



ORELA is Major Contributor to DOE Science and Nuclear Missions

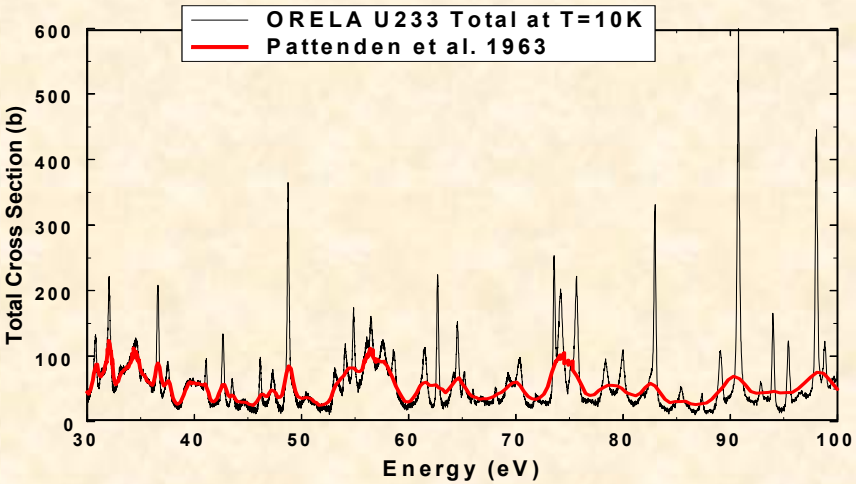
- ORELA provides high-resolution neutron measurements in the low to intermediate energy ranges—important for current and emerging nuclear applications
- Measurement experience coupled with ORELA capabilities has established ORNL as leading evaluation center for resolved and unresolved resonance regions
- Over past 30 years, ORELA measurements have contributed to ~80% of U.S. Evaluated Nuclear Data File (ENDF/B) evaluations

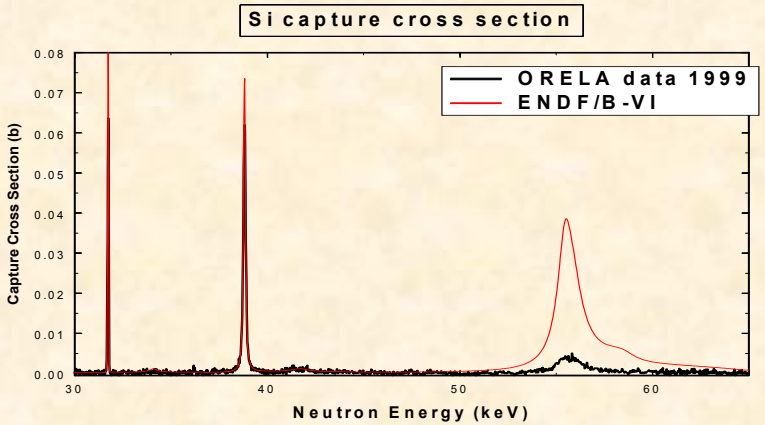
Energy Resolution Comparison for ^{116}Sn Capture Measurements taken at ORELA and Karlsruhe

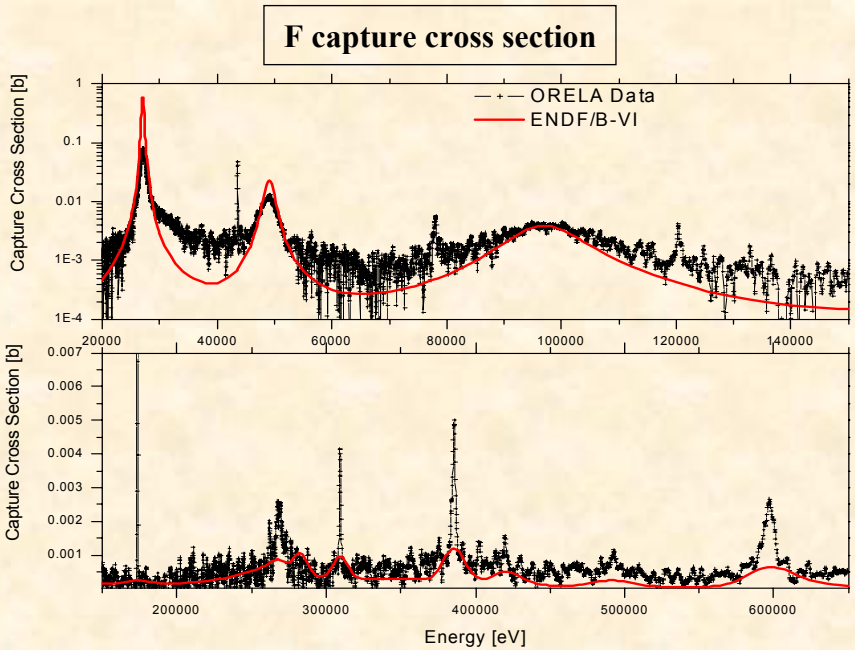


Data Improvements from ORELA Measurements

- Improvements in nuclear data capabilities are needed to keep pace with advances in computational methods development—translates to optimized nuclear applications
- Unique measurement capabilities are essential for providing accurate and improved cross section data for nuclear applications
- Recent ORELA measurements have removed large neutron sensitivity found in older cross-section measurements and identified missing resonances



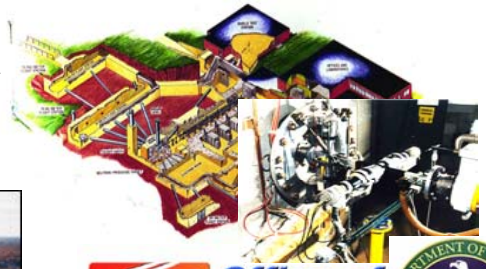




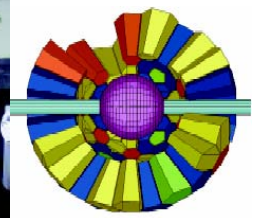
DOE Office	Application Benefit from Improved ORELA Cross-Section Data
SC	(n, γ) and (n, α) measurements and cross-section data for nuclear astrophysics
DP	Constituents of concrete storage vaults, Cl processing in Pu salts, emergency response technologies, stockpile stewardship
EM	Si, O, Al, Fe in glass, concrete & soil mixtures for fissionable material storage, WIPP salt
NE	Fluorine data required for fuel enrichment & product conversion, GEN-IV fuel cycle, advanced accelerator targets
RW	Transportation and storage packages, YMP tuff
NR	Naval fuel cycle operations; space reactor applications

Data Support for DOE Nuclear Applications

ORELA



LANSCE

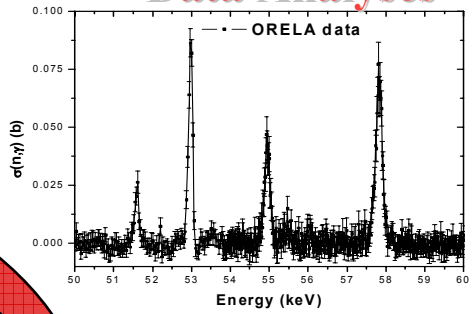


Office of Science
U.S. DEPARTMENT OF ENERGY

NNSA
National Nuclear Security Administration

Basic Science

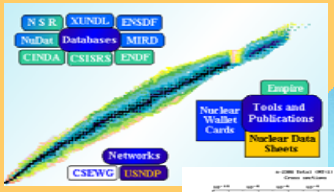
Data Analyses

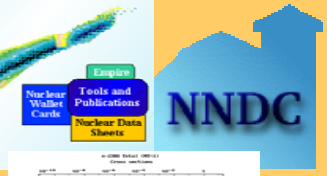


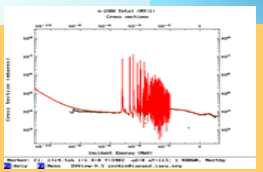
Cross-Section Evaluations

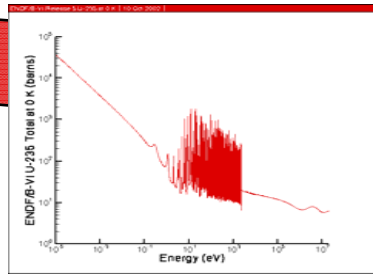
Applications

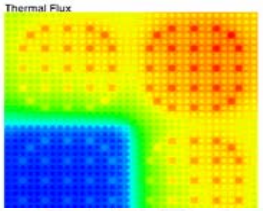
Evaluated Nuclear Data Files (ENDF/B)

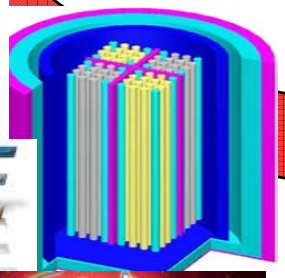












SCALE

MCNP

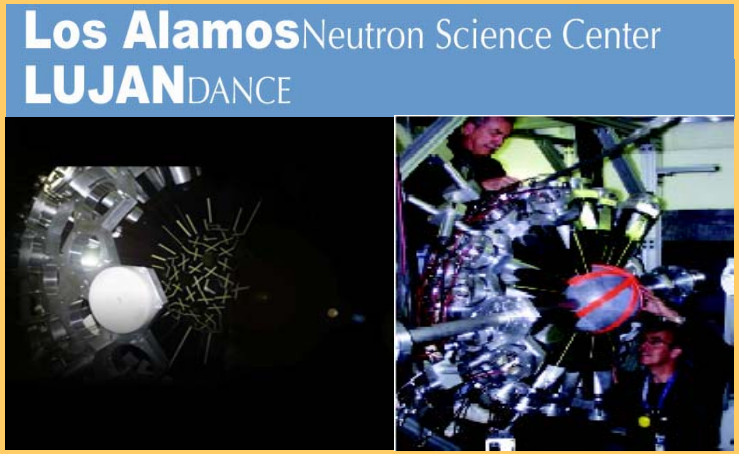
VIM

AMPX NJOY

PREPRO MC²2

Computational modeling

Complementary U.S. Cross-Section Measurement Facilities for Supporting Nuclear Applications



Neutron Cross-Section Measurements in Resolved Resonance Region

- Neutron flux is important but alone cannot guarantee accurate measurements
- Neutron energy resolution importance
  - Resolve resonances in order to obtain reliable average resonance parameters. These are important to perform the analysis of the unresolved energy range and statistical model calculations
  - Resolved resonances help to identify and disentangle isotopic impurities in the sample
  - Resolved resonances are important for self-shielding and multiple-scattering calculations

Neutron Cross-Section Measurements in Resolved Resonance Region

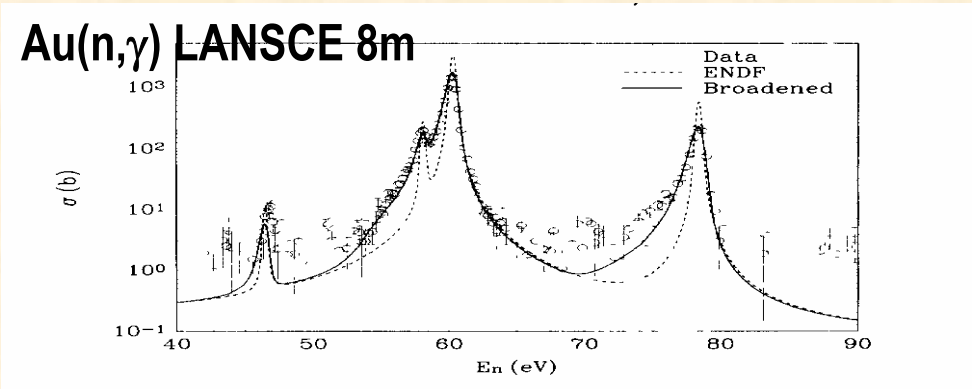
- Flight path length, the longer the better
- Pulse width of the neutron burst, the shorter the better:
  - Typically fixed with spallation sources (tens of ns to hundreds of ns)
  - Linac sources can vary pulse width (1ns up to tens of ns)
- Source moderation distance
  - Uncertainty of the creation location of the neutron inside the target/moderator configuration impacts resolution
  - ORELA is an undermoderated source with relatively small neutron production target
    - ORELA source: radius = 7.6 cm and height = 3.7 cm
    - n_TOF source: radius = 40 cm and height = 80 cm
  - Spallation sources are usually optimized for thermal neutron flux, this requires large moderators
    - The moderation effect puts tails on resonances due to delayed neutron emission
    - Hinders resolution of closely spaced resonances
    - Produces background in unresolved energy range which cannot be corrected. This effect is on the order of 16% at 20 keV (Coceva et al. 2002) for n_TOF and can not be estimated quantitatively

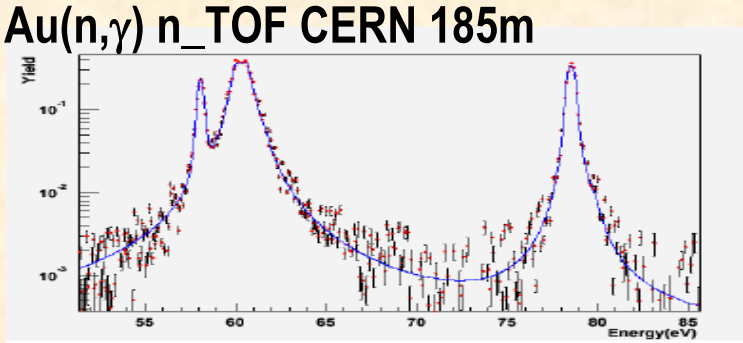
Cross Section Measurement Capabilities

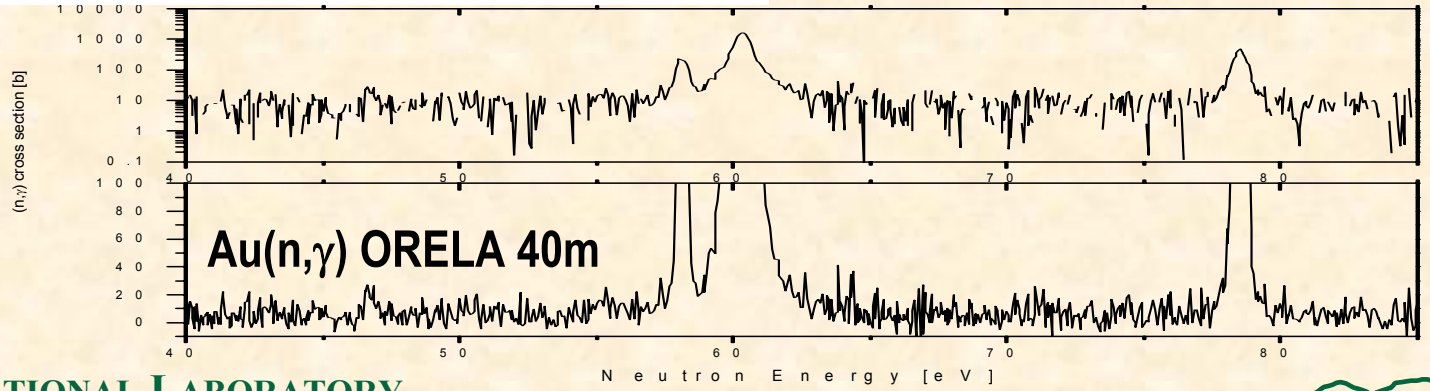
Facility Parameters	United States				Europe	
	ORELA	LANSCE	IPNS	RPI	GELINA	n_TOF
Source	e^- linac	p spallation	p spallation	e^- linac	e^- linac	p spallation
Particle E (MeV)	140	800	450	>60	120	20000
Flight Path (m)	10-200	7-55	~6-20	10-250	8-400	185
Pulse Width (ns)	2-30	125	40	15-5000	1-2000	7
Max Power (kW)	50	64	6.3	>10	11	45
Rep Rate (Hz)	1-1000	20	30	1-500	Up to 900	0.278-0.42
Best Intrinsic Resolution (ns/m)	0.01	3.9	2.0	0.06	0.0025	0.034
Neutrons/s	1×10^{14}	7.5×10^{15}	8.1×10^{14}	4×10^{13}	3.2×10^{13}	8.1×10^{14}

Neutron Cross-Section Measurements in Resolved Resonance Region

- ORELA, LANSCE and IPNS:
  - ORELA has very good neutron energy resolution but the penalty will be a lower neutron flux.
  - LANSCE and IPNS have higher n-flux per burst but inferior resolution.
  - ORELA is an undermoderated n-source whereas LANSCE and IPNS are highly moderated sources. This can have severe consequences for the resolution of resonances.







Neutron Cross-Section Measurements in Resolved Resonance Region

- Interplay between facility characteristics, isotope/nuclide specific parameters, and Doppler broadening determine resolution capability
- Example: ^{241}Pu measured at 20 m flight path length
  - Average resonance spacing ~0.9 eV
  - Maximum energy for which resonances can be resolved:

Sample Temp (K)	ORELA (20 m, 8 ns)	LANSCE (20 m, 125 ns)	IPNS (20 m, 80 ns)
300	600 eV	400 eV	300 eV
70	1000 eV	400 eV	300 eV

U.S. Cross Section Measurement Capabilities

- Historically, ORELA and LANSCE have served as the primary source of measured cross-section data for U.S. ENDF/B
- ORELA and LANSCE are complementary facilities: LA-UR-90-4355
  - LANSCE provides accurate data at "high energies" (MeV and higher)
  - ORELA fills the "data gap" with detailed energy resolution from eV to MeV range—intermediate energy range
- ORELA capability unmatched in resonance region

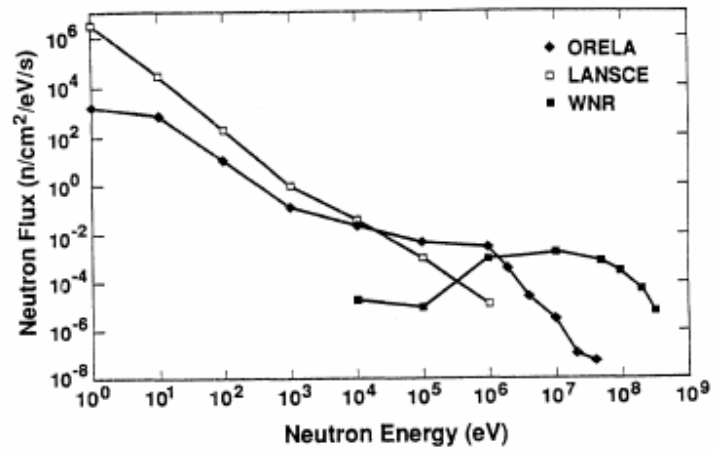


Fig. 11. Neutron flux as a function of neutron energy for the resolution profile RP1 (Fig. 7) and for the three facilities: ORELA, LANSCE, and WNR, as they presently exist (A-plot).

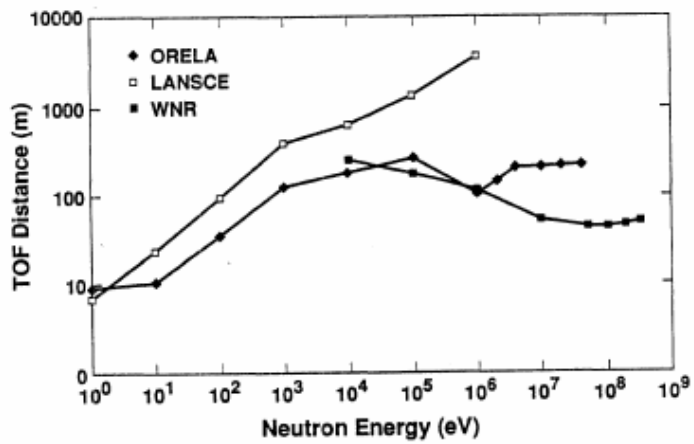


Fig. 12. TOF distance as a function of neutron energy for the resolution profile RP1 (Fig. 7) and for the three facilities: ORELA, LANSCE, and WNR, as they presently exist (A-plot).

ORELA Facility Status

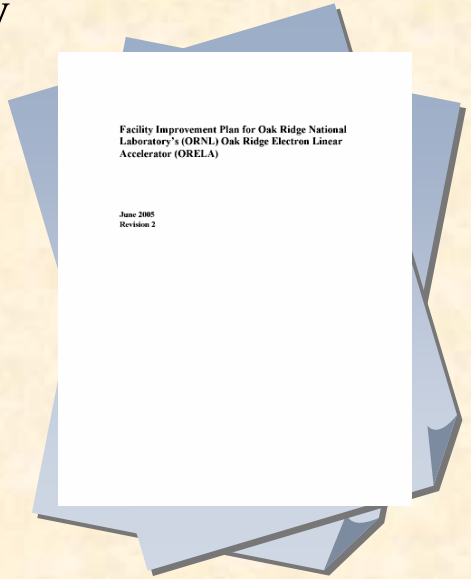
- Background (Pre 1990s)
  - In late 1960s, ORELA sponsorship split between Nuclear Energy and Nuclear Physics Programs under Atomic Energy Commission (AEC)
  - ORELA sponsorship passed to DOE Office of Science (SC) with demise of Fast Reactor Program in early 1980s
- 1990s to Present
  - SC is ORELA facility owner
  - ORELA provides data support for NNSA/NA-11 Nuclear Criticality Safety Program (NCSP)
- Current ORELA Nuclear Data Customers
  - DOE/SC and NNSA/NCSP
  - DOE Office Environmental Management (EM)—Criticality Safety Applications
  - DOE Office of Civilian Radioactive Waste Management (RW)—Burnup Credit (BUC) for transportation applications
  - DOE Nuclear Energy (NE)--NERI graphite measurements

ORELA Facility Status

- No single sponsor provides complete base funding for facility—support leveraged with different programs
- Advantages & Disadvantages
  - Sponsors benefit by receiving accurate cross-section measurements at reduced cost
  - Programmatic funds are used to support program-specific goals of sponsor—ORELA does not receive base funding to support major refurbishments and significant maintenance operations
- Beginning in FY2002, operational problems have plagued ORELA
  - Aging equipment
  - Electron gun malfunctions—unique guns manufactured in house
  - Inability to maintain adequate vacuum conditions in the accelerator
- ORELA availability and reliability has decreased—stagnating current and new measurements
  - 1 week of beam time in FY2004
  - Needed 2-3 months of beam time in FY2004

ORELA Facility Improvement Plan

- Facility refurbishments needed to increase ORELA reliability and maintain long-term operational readiness
- Improvement Plan
  - Immediate improvements: FY2006 & FY2007
  - Desirable improvements: FY2008—FY2010
- Side Notes
  - Institute for Reference Materials and Measurements (IRMM—Geel, Belgium) are in final stages of similar accelerator refurbishments
  - Partially completed refurbishments have restored operational reliability to more than 90%—Peter Rullhusen
  - Similar experience with refurbishments at RPI—Yaron Danon


Facility Improvement Plan for Oak Ridge National Laboratory's (ORNL) Oak Ridge Electron Linear Accelerator (ORELA)

June 2005
Revision 2

ORELA Facility Improvement Needs

Required for stable operation at any power level

Immediate improvement needs:

- **Electron gun program revival**
  - **Staff expertise needed**
- **Vacuum, cooling refurbishments**
- **Computer control of ORELA**
- **Thyratrons**

Improvements to avoid single-point failures:

- **Klystron**
- **Replacement target lift***
- **Remove positron target**

Required for 50 kW operation

Desirable improvements:

- **Add'l Thyratrons**
- **Add'l Klystrons**
- **Linac parts**

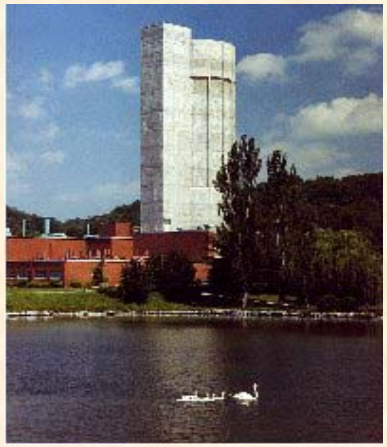
*No spare, 6 month downtime in case of failure.

ORELA Immediate Improvement Needs

- Electron Gun Program
  - Guns manufactured in-house—“off-the-shelf” guns cannot be used
  - Currently, ORELA does not have an inventory of parts needed to manufacture stable of guns
    - Expect ~1000 hours of operation/gun
    - Need inventory of 3-4 spare guns
- Vacuum System
  - New guard vacuum pumps
  - Vac-ion pumps,
  - Pump for target room
  - Improved rough pump system with broad measurement capabilities
- Cooling System
  - Improved temperature control
  - Increased heat removal capacity
  - Better control of coolant flow to individual sections of the accelerator

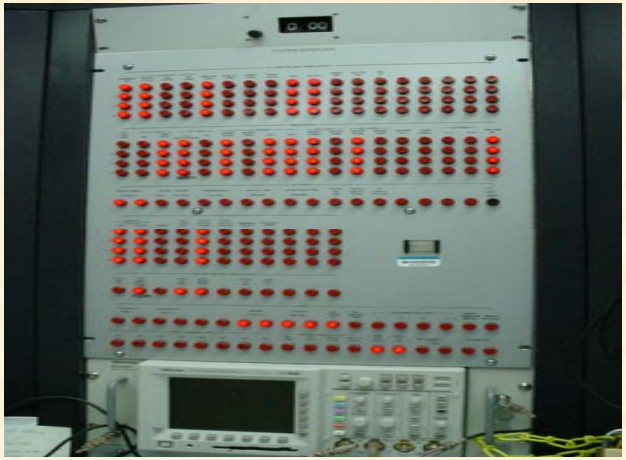
ORELA Immediate Improvement Needs

- Computer Control Improvements
  - Operator staff resources shared between Holifield Radioactive Ion Beam Facility (HRIBF) and ORELA
  - Cannot provide 24-hour manned operation at both facilities
  - Computer control with web capabilities needed for
    - Monitoring
    - Diagnosis
    - Adjustment and resetting of systems



HRIBF

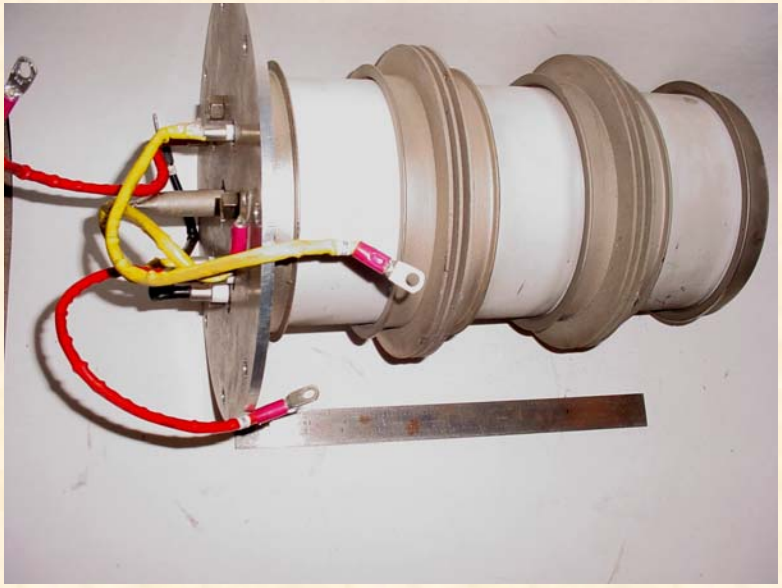
RF Control Panel



Interlock & View Panel

ORELA Immediate Improvement Needs

- Thyratrons and Klystrons
  - Have finite but unpredictable lifespan
  - Need to replace in near-term to maintain reliable service
  - All spare klystrons have been used—no inventory of spare klystrons



Thyratron

Klystron

ORELA Immediate Improvement Needs: Improvements to Avoid Single-Point Failures

- Target Lift
  - Lift has been in service for more than 30 years in very high radiation environment (ORELA Target Room)
  - ORNL does not have spare target lift
  - Target lift failure:
    - minimum 6 month down time to acquire new lift and complete repairs
    - Not off-the-shelf item—must fabricate new lift
  - ORNL Physics Division planning measurements that will require access to target room and use of target lift system—reliability of target lift operation unknown
- Remove Positron Target
  - Located behind ORELA target—no longer needed
  - Requires operational cooling systems because of beam interception
  - Removal is needed to prevent shutdown maintenance of these systems that are located in the ORELA target room

ORELA Improvement Schedule
Immediate Improvements

Task	Milestone
FY 2006	
Electron gun refurbishment program	
Produce & test operable electron gun	12/1/2005
Produce 3-4 spare guns	6/1/2006
Complete vacuum, cooling refurbishments	12/1/2005
Restart ORELA operation	12/15/2005
Implement computer control of ORELA	9/30/2006
FY 2007	
Acquire spare target lift	7/1/2007
Remove positron target	9/30/2007
Procure & install additional thyratrons and klystrons	9/30/2007

ORELA Improvement Schedule
Desirable Improvements

Task	Milestone
FY 2008	
Procure & install thyratrons for 50 kW operation	9/30/2008
Initiate procurement & installation of additional klystrons for 50 kW operation	9/30/2008
FY 2009	
Initiate procurement & installation of LINAC parts for 50 kW operation	9/30/2009
Procurement & installation of additional klystrons for 50 kW operation	9/30/2009
FY 2010	
Complete procurement & installation of LINAC parts for 50 kW operation	3/1/2010
Complete procurement & installation of additional klystrons needed for 50 kW operation	6/1/2010
Qualify ORELA for 50 kW operation	9/30/2010

ORELA Briefing Summary

Accomplishments/Capabilities	Issues
• 30+ years performing detailed energy-resolution cross-section measurements • Data contributions to multiple nuclear programs • Contribution to significant number of ENDF evaluations • Continued need to support current and emerging nuclear applications • ORELA Workshop (July 2005) established technical community endorsement and importance of facility capabilities	• Reduced availability & reliability • Pending NCSP, EM, and RW cross-section measurements

Actions

- Implement improvement plan to re-establish ORELA operation and restore reliability
- Perform pending cross-section measurements