# **Overview of Nuclear Data**

Michal Herman National Nuclear Data Center Brookhaven National Laboratory



a passion for discovery



Office of

## Nuclear Data Program Link between basic science and applications



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# Who needs nuclear data? and what for?

### Basic science (physics)

- testing theoretical models
- designing experiments
- analyzing experimental data

### Astrophysics

origin of elements

### Nuclear power

- reactors R&D
- fuel cycle
- operation safety
- radiation shielding
- waste disposal and transmutation

### Nuclear medicine

- radioisotope production
- dose calculation
- radiotherapy
- diagnostics
- National/homeland security
  - device R&D
  - stockpile stewardship
  - criticality safety
  - nuclear forensics
  - detecting illicit trafficking of nuclear materials
- Industrial applications



# **USNDP** mission

The mission of the United States Nuclear Data Program (USNDP) is to provide current, accurate, authoritative data for workers in **pure** and **applied** areas of nuclear science and engineering. This is accomplished primarily through the compilation, evaluation, dissemination, and archiving of extensive nuclear datasets. The USNDP also addresses gaps in the data, through targeted experimental studies and the use of theoretical models.



### Dissemination

### **Experiments**

### Archival Evaluation/ Theory Compilation



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# **Components of Nuclear Data**

	Structure	Reactions	
Bibliographical	NSR		
Compilation	XUNDL	EXFOR	
Evaluated	ENSDF	ENDF/B	





### **Experiments**

Using external facilities ~15% of USNDP effort



Needs continuous coverage Backlog needs to be dealt with

Ultimate nuclear data product combines experiment with theory, links basic science with applications, includes modeling and covariances, high added value!



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**Evaluation**/

hedry

## Objectives

- Experiments form the basis of what we do and we also contribute.
- Compilation reaction and nuclear structure data in NSR, EXFOR and XUNDL databases.

	Structure & Decay	Reactions
Bibliographical database	NSR >214,000 publications	
Compilation	XUNDL	EXFOR
databases	5,622 datasets	20,400 experiments
Evaluated	ENSDF	ENDF/B-VII.I
libraries	3,256 isotopes	14 sub-libraries

- Evaluation/Theory nuclear structure and reaction data for ENSDF and ENDF/B databases.
  - Advance nuclear reaction modeling; uncertainty quantification.
  - Maintain/develop nuclear data formats and data verification codes.
- Archival of nuclear data (maintaining classic library, gradually scanning it into electronic files, securing electronic files).
- Dissemination of nuclear physics data using up to date technology..







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# Interaction between ND libraries (ENSDF)









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# Interaction between ND libraries (ENDF)









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Experimental Nuclear Data Program











# Why USNDP Needs Experimental Program (on a small scale)?

- Perform measurements targeting specific needs
- USNDP is in unique position to identify deficiencies in nuclear data
- Faster response in remedying deficiencies in database
- Stronger link between data community and research groups
  - Maintain USNDP staff current with advancing experimental techniques
  - Promoting nuclear data awareness within research community
- Combined evaluation and experimental research opportunities
- Attract new talents to nuclear data program



# **USNDP-BLIP Decay Data Collaboration**

Brookhaven Linear Isotope Producer (BLIP) Important medical isotopes requiring new measurements of decay data produced at BLIP



Shipped to world's largest γ-ray array Gammasphere (100 HPGe detectors) for high-precision γ-ray spectroscopy





# Starting point : <sup>82</sup>Rb for Cardiac PET



# **Preliminary Analysis Very Promising**



# **Promising New PET isotope**



Nuclear Physics (NP)

# Significant effort into production of <sup>72</sup>Se

725e	735e	74Se
8.40 D	7.15 H	STABLE
1: 100:00%	E-100.0096	0.09%
71Ar	72Aa	73As
6130 H	26.0 m	80.30 D
£ 100.008	8: 100.00%	1. 100.00%
70Ce	710e	720e
STABLE	11:43D	STABLE
20.57%	1:400:00%	27.45%

#### May 2014

#### Growing the Tool Box for Medical Imaging: The Selenium-72/Arsenic-72 Generator

Researchers from Los Alamos National Laboratory and the University of Missouri have designed a new source of a valuable imaging isotope. The Science

Bombarded with charged particles, chemical elements undergo conversion ("transmutation") into small amounts of other elements. Such accelerator induced isotope formation has enabled new methodologies of making self-contained delivery systems for the radioisotope <sup>72</sup>As for future clinical applications.

#### The Impact

Positron emission tomography (PET) is a powerful technique to image lesions and biological processes using radioactive (positron emitting) isotopes. Researchers from Los Alamos National Laboratory (LANL) and the University of Missouri developed a new method to obtain a source for a radioisotope that allows for the tracking of biological processes with longer localization times: the selenium-72/arsenic-72 generator may provide clinicians with new 26 hour half-life in-vivo tracers for diagnostics and the study of diseases.

#### Summa



1.E.1

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### Decay data is ancient !!

## 1968

ENERGY LEVELS IN <sup>72</sup>Ge FROM THE DECAYS OF <sup>72</sup>Ga AND <sup>72</sup>As

#### DAVID C. CAMP

Lawrence Radiation Laboratory, University of California, Livermore, California<sup>†</sup>

Received 24 June 1968

1.E.1:3.A

Nuclear Physics A162 (1971) 481-496; C North-Holland Publishing Co., Amsterdam Not to be reproduced by photoprint or microfilm without written permission from the publisher



#### DECAY OF 72 As TO THE LEVELS OF 72 Ge

A. C. RESTER 1, J. H. HAMILTON and A. V. RAMAYYA

Physics Department 11, Vanderbilt University, Nashville, Tennessee 37203

and

NOAH R. JOHNSON Oak Ridge National Laboratory <sup>111</sup>, Oak Ridge, Tennessee 37830

# Preliminary Analysis of As-72 Decay



- Excellent statistics for known transitions
- Already identified many new transitions
- Significant revision of the decay properties









	Structure & Decay	Reactions
Bibliographical	NSR	
database	>214,000 publications	
Compilation	XUNDL	EXFOR
databases	~5,600 datasets	~20,400 experiments

- Groundwork for any evaluation
- Preserves multibillion \$\$\$\$ investment in nuclear experiments over a century
- Often goes beyond the publication



## Components of Nuclear Data program

Compilation

	Structure	Reactions	
Bibliographical	NSR		
Compilation	XUNDL	EXFOR	
Evaluated	ENSDF	ENDF/B	





### Bapaninanis

### Evaluation/ Theory

Ultimate nuclear data product combines experiment with theory links basic science with applications includes modeling and covariances high added value!



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### **Reaction data:**

**EXFOR** (compiled) **ENDF** (evaluated)

### **Structure data:**

XUNDL (compiled) ENDSF (evaluated)



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### **Structure data:**

XUNDL (compiled) ENDSF (evaluated)



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# Nuclear structure and decay data evaluated: ENSDF compiled: XUNDL

#### 16.991 D 19 0.0 5/2+ 103Pd 46Pd57 **Nuclear Structure (ENSDF)** 100 Logft O(qs)=543.1 keV 8 E: 100 % 5/2+ 0.00400 5.1 536.8 masses 241.9 443.8 properties of nuclear levels 497.1 energies 0 spins & parities 0 magnetic moments 0 357.4 62.4 half-lives 317.7 357.5 3/2-4.4E-4 10.5 295 deformations decay modes 0 intensities (branching ratios) conversion coefficients ... radiation properties 9/2+ 93 53.3 Contributed by members of the Nuclear Structure \_7/2+ 99.90 39.7 39.7 and Decay Data Network (NSDD), 1/2-0.05 STABLE 0.0 103<sub>Rh</sub>58 under auspices of the IAEA.



### ENSDF's seminal role in science & applications

The only Nuclear Structure database that is

updated continuously

contains information for all nuclei and all nuclear level

properties & radiations

No viable alternative exists in the world!





### Structure data: XUNDL (compiled) ENDSF (evaluated)



### Nuclear reaction data evaluated: ENDF/B

- energy-dependent reaction cross sections
- energy and angular distributions of reaction products
- energy-angle distributions
- neutron resonance param.
- neutron multiplicities
- isomeric cross sections ...





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# Contents of the ENDF/B (sub)libraries

No.	NSUB	Sublibrary	Short	VII.1	VII.0	<b>VI.8</b>
		name	name			
1	0	Photonuclear	g	163	163	-
2	3	Photo-atomic	photo	100	100	100
3	4	Radioactive decay	decay	3817	3838	979
4	5	Spont. fis. yields	s/fpy	9	9	9
5	6	Atomic relaxation	ard	100	100	100
6	10	Neutron	n	423	393	328
7	11	Neutron fis.yields	n/fpy	31	31	31
8	12	Thermal scattering	tsl	20	20	15
9	19	Standards	std	8	8	8
10	113	Electro-atomic	e	100	100	100
11	10010	Proton	р	48	48	35
12	10020	Deuteron	d	5	5	2
13	10030	Triton	t	3	3	1
14	20030	<sup>3</sup> He	he3	2	2	1



# Most users never see ENDF data

ENDF data are most often used as data tables that implement collision physics in application codes

Users don't see them but they can't live without them!





ATLAS detector muon system,

**Energy Deposition** 

simulated in GEANT4

-20

0

20

40

40

20

-20

40

<u></u> 0



"Neutron carwash" radiation detector



PHITS model of J-PARC spallation source



NY Center for Computational Science



SCALE model of INL Advanced Test Reactor May 27-19, 2015

Supernovae are the site of r-process nucleosynthesis

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### Overview of structure and reaction databases

	ENSDF structure	ENDF/B reactions
Scope	global	driven by applications
Updating	frequent/continuous	separate releases
Geography	world-wide	national/regional
Source	experiment	experiment & theory
Extrapolation	no	yes
Format	ENSDF	ENDF-6
Validation	n/a	extensive



# Other popular USNDP products



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# Nuclear Reaction Theory in Nuclear Data Evaluation

Experiments never cover whole energy range and all reaction channels



### Nuclear theory ND is a major user and developer of nuclear modeling



# Room for improvement



- ENDF (reaction data)
  - Elimination of compensating errors targeted differential and semi-integral experiments, and better physics in evaluations
  - Gaps in the ENDF/B neutron sub library
  - No US activation file
  - No US dosimetry library
  - No alpha sub-library in ENDF/B-VII.1
  - Limited covariances, lack of cross-reaction and crossmaterial correlations, no covariances for fission product yields
  - No uncertainties for delayed nu-bar
  - Lack of high-energy proton library enabling scoping studies for isotope production



# Room for improvement



- ENSDF (structure and decay data)
  - Poorly known decay schemes for many medical isotopes and generally for fission products
  - Total lack of covariances
  - Continuous spectra not allowed within current format
  - TAGS data difficult to incorporate in current format
  - Disconnect between structure information and fission yields (i.e. isomeric levels)
  - No theory
  - No information on neutrinos, antineutrinos
  - Evaluation priority not driven by applications



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