Nuclear Data Pipeline

David Brown

Workshop on Nuclear Data for Reactor Antineutrino Measurements (WoNDRAM), ONLINE

21-24 June 2021

Brookhaven National Laboratory

U.S. DEPARTMENT OF ENERGY

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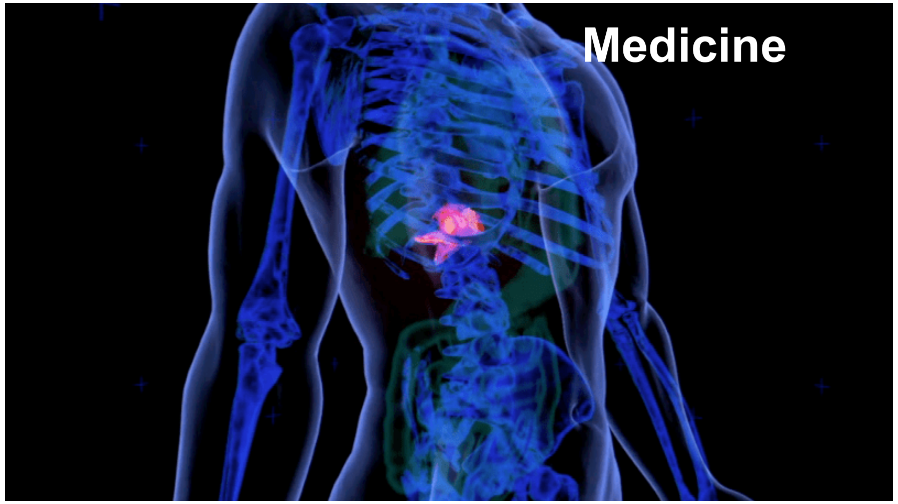
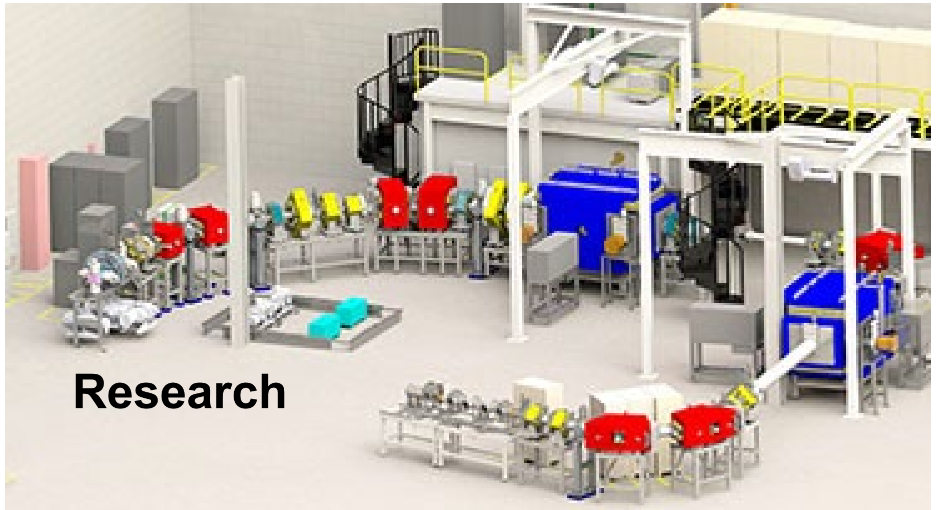
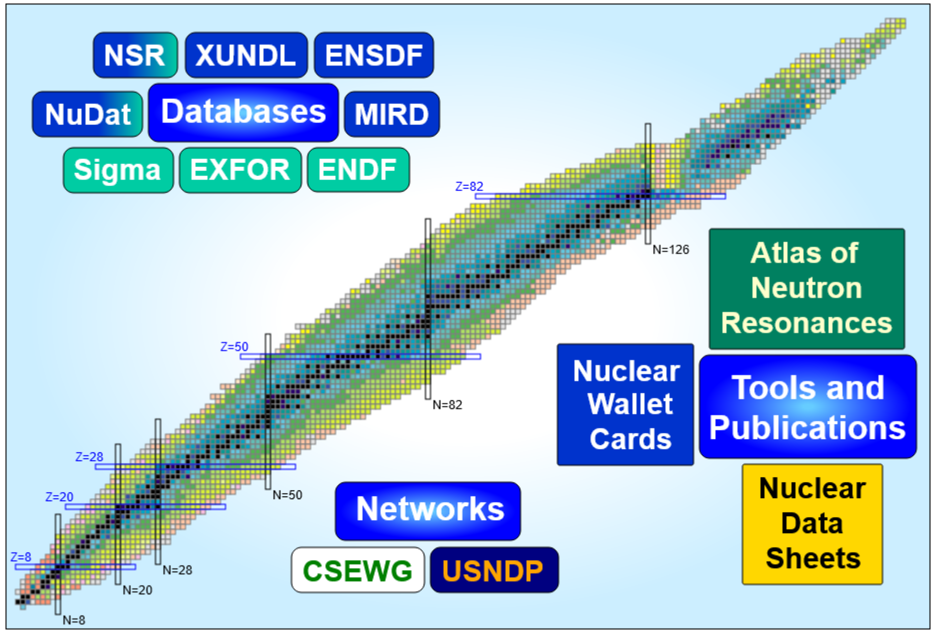
Nuclear Data Stakeholders







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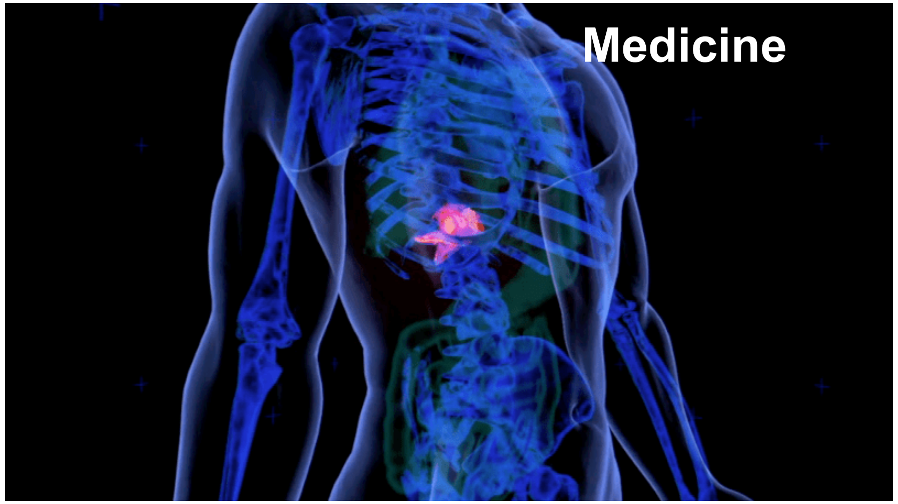
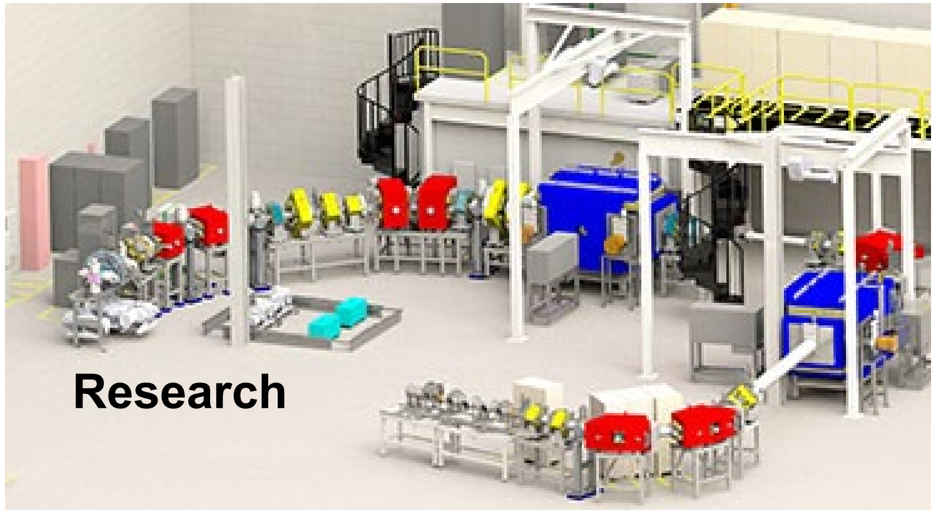
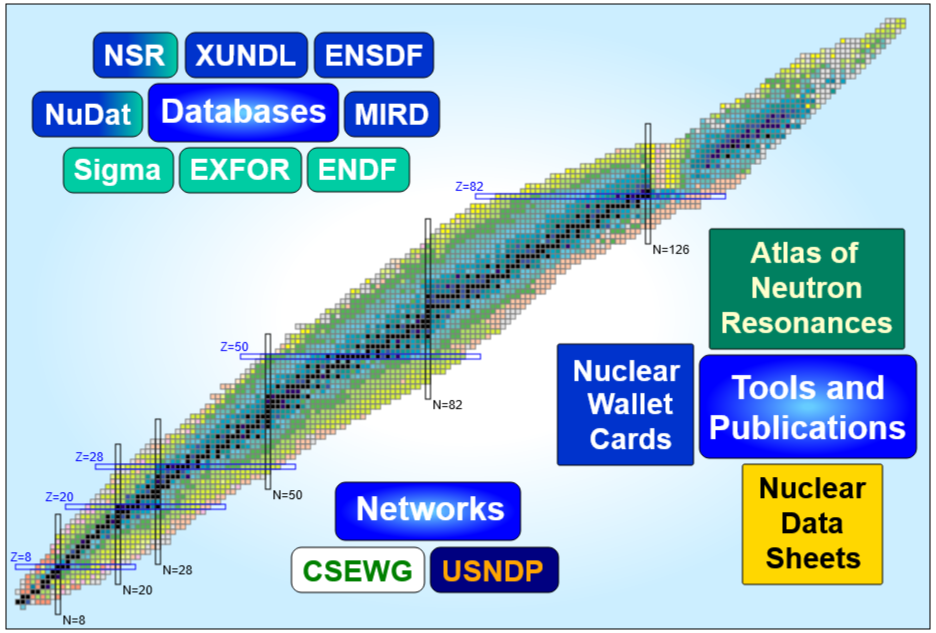
Nuclear Data Developers







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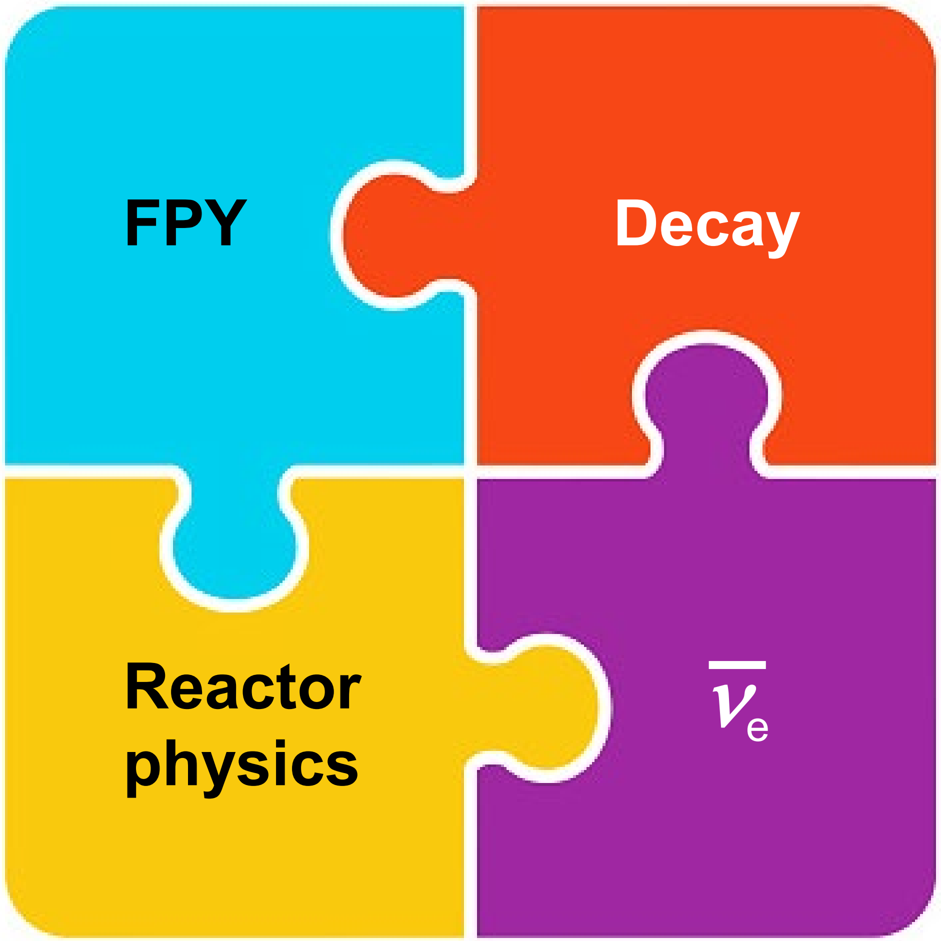
Common traits of stakeholders/developers

- Complex multifaceted (multiphysics!) problems
  - Need reactor physics, FPY, decay data, neutrino physics, etc.
- Domain specific expertise
  - Have expertise in nuclear decay data, fission theory, big data, etc.
- Domain specific resources
  - Have access to accelerator, reactor, detector system, HPC, etc.
- Our specific capabilities often are unique and can benefit many others

By joining forces, we leverage these capabilities for the greater good



Many software packages rely on embedded nuclear data

- Reactor design, simulation and licensing codes.
- Nuclear waste and repositories.
- Radiation spectroscopy, dose, detectors and shielding.
- Defense and CTBTO.

The Nuclear Data Pipeline

70+ years of nuclear data measurements available

An ongoing effort of more than 50 years.
Many tools and approaches developed
Still room for improvement

These are collected, processed, separated and shipped

In a convenient and usable form

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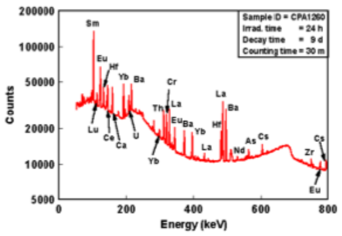
The Nuclear Data Pipeline

Working together, we get the highest quality data to all users

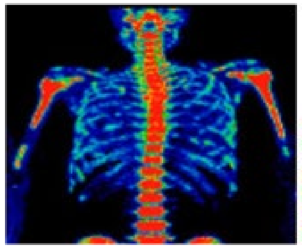
security



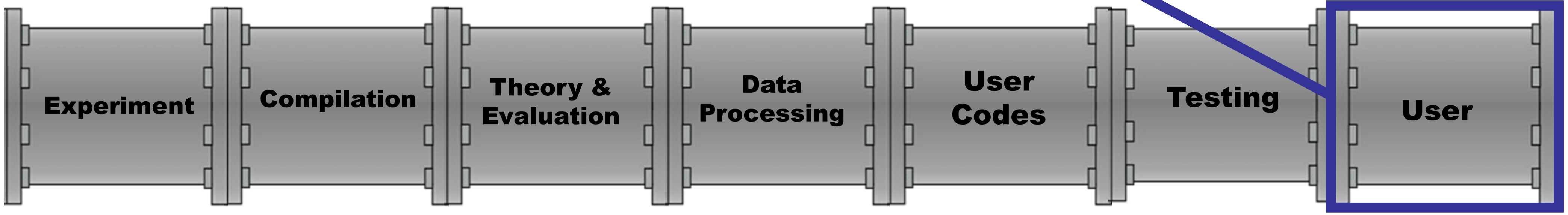
science

FRIB

isotopes

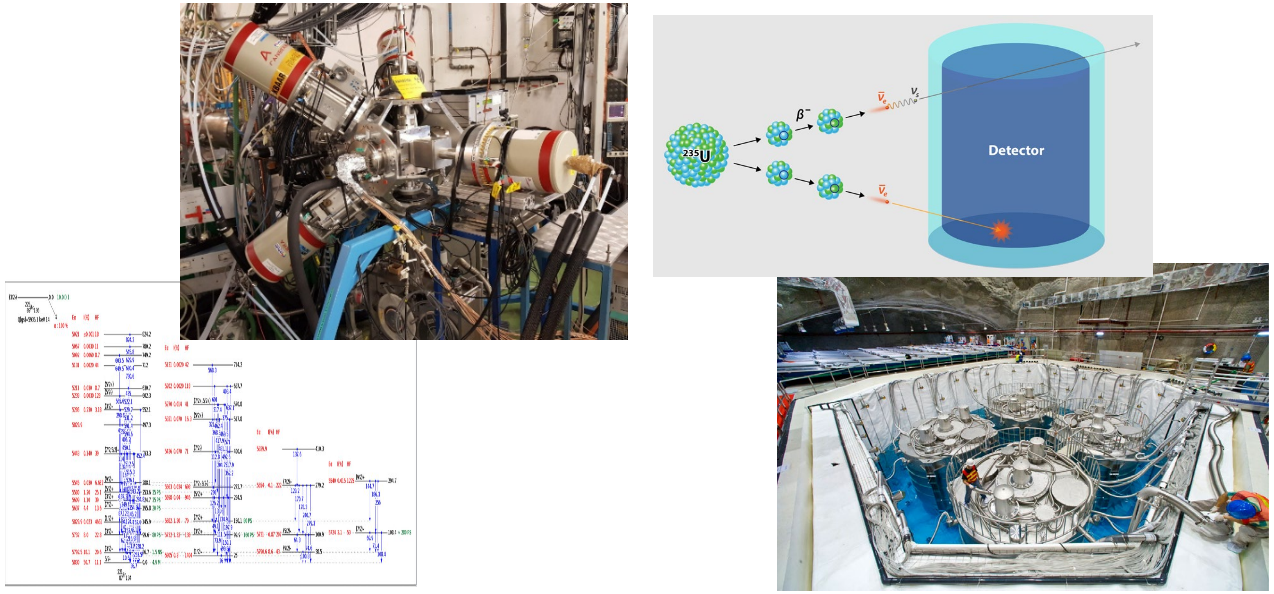


energy

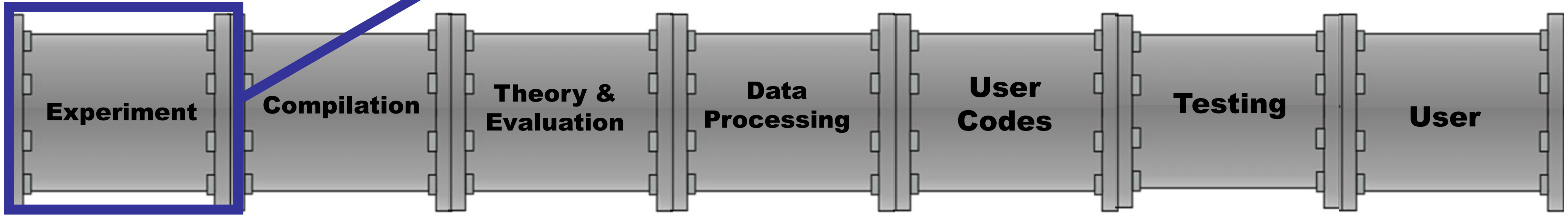


The Nuclear Data Pipeline

It all begins with experiments



It is important that "all" aspects of an experiment be preserved in the event that the the experiment needs to be reanalyzed in the future



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Nuclear Instruments and Methods in Physics Research A 390 (1997) 95–154

ELSEVIER

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH
Section A

Measurement of β^--decay intensity distributions of several fission-product isotopes using a total absorption γ-ray spectrometer

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[a] *Department of Physics, University of Idaho, Moscow, ID 83844-2341, USA*
[b] *Retired, Idaho National Engineering Laboratory, Idaho Falls, ID 83415-2114, USA*
[c] *Idaho National Engineering Laboratory, Idaho Falls, ID 83415-2114, USA*

Received 6 June 1996

Abstract

A total absorption γ-ray spectrometer coupled to the ^{252}Cf-based INEL ISOL facility has been used in a program of systematic study of the distributions of β^--decay intensities of fission-product radionuclides. Cascade-summed γ-ray spectra measured with the system have been compared with the spectrum simulated from the corresponding decay schemes, as a test of the completeness and correctness of these schemes. New β^--decay intensity distributions have been deduced for the decay of these radionuclides. Radionuclides which have been studied in this manner include ^{89}Rb, ^{90g}Rb, ^{90m}Rb, ^{91}Rb, ^{93}Rb, ^{93}Sr, ^{94}Sr, ^{94}Y, ^{95}Sr, ^{95}Y, ^{138g}Cs, ^{138m}Cs, ^{139}Cs, ^{140}Cs, ^{141}Cs, ^{141}Ba, ^{142}Ba, ^{142}La, ^{143}Ba, ^{143}La, ^{144}Ba, ^{144}La, ^{145}Ba, ^{145}La, ^{145}Ce, ^{146}Ce, ^{146}Pr, ^{147}Ce, ^{147}Pr, ^{148}Ce, ^{148}Pr (2.0 min), ^{148}Pr (2.27 min), ^{149}Pr, ^{149}Nd, ^{151}Pr, ^{151}Nd, ^{152}Nd - ^{152}Pm (4.1 min.), ^{153}Nd, ^{153}Pm, ^{154}Nd, ^{154}Pm (1.7 min), ^{155}Nd, ^{155}Pm, ^{156}Pm, ^{157}Pm, ^{157}Sm, ^{158}Sm, and ^{158}Eu.

Decay data for 48 fission products.

Seminal work for reactor decay heat and antineutrino calculations.

130 citations in Google Scholar

Beta intensity uncertainties information is incomplete.

BETA DECAY ENERGIES AND
STRENGTH FUNCTION DETERMINATIONS
OF NEUTRON RICH ISOTOPES IN
THE A = 91 - 100 REGION

by

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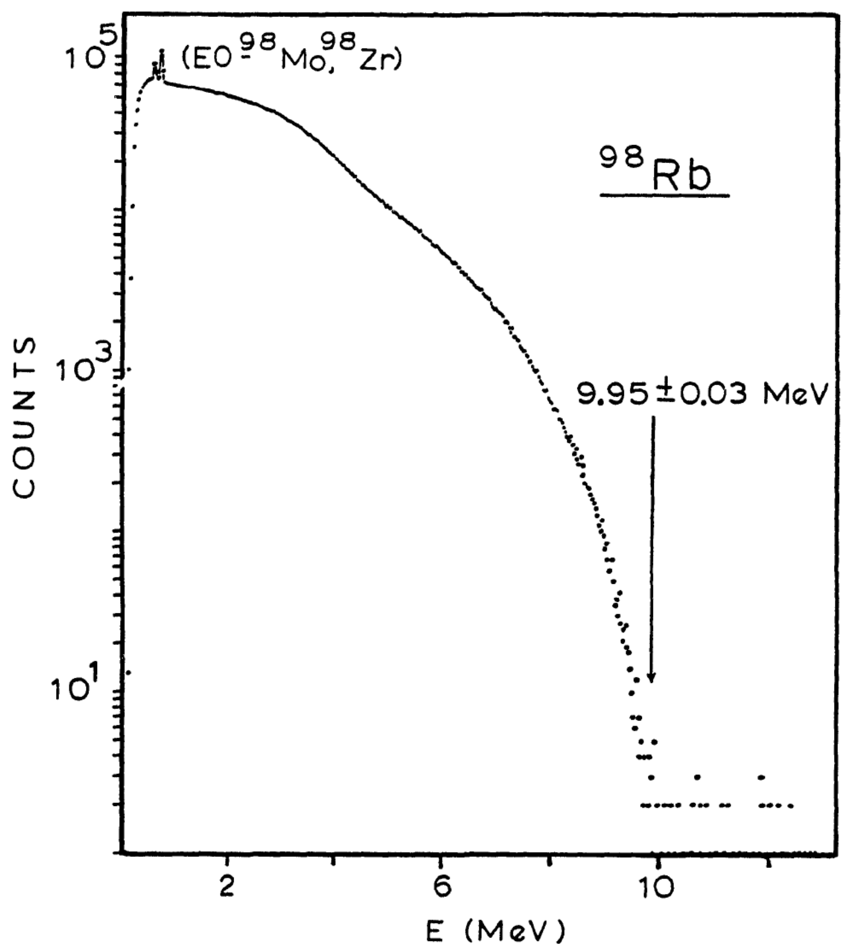
A thesis submitted to the
Faculty of Graduate Studies and Research
in partial fulfillment of the requirements
for the degree of Doctor of Philosophy

Foster Radiation Laboratory
McGill University, Montreal
Quebec, Canada



Precise beta spectra measurements of about 20 fission products at BNL's reactor.

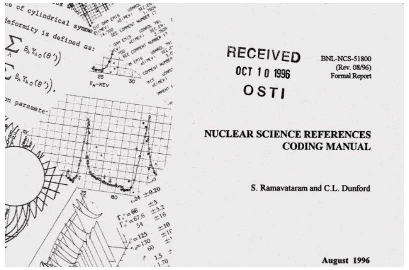
Data was never recovered.

The Nuclear Data Pipeline

Data is compiled into databases

Archive: Seek "abandoned" data and archive it before it is lost

Nuclear Science References (NSR):
229,594 nuclear physics articles indexed according to content. 3,714 articles added in FY18 from 80 journals.

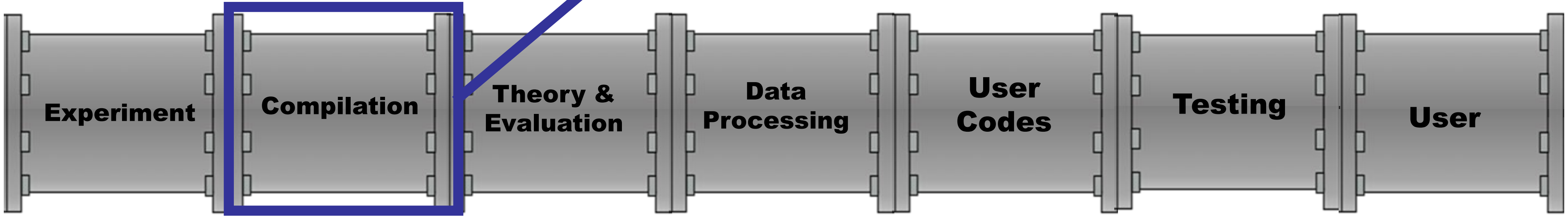


EXFOR: Compiled nuclear reaction data, originally only for neutron-induced. Data from 130 articles added in FY18.

XUNDL: Compiled nuclear structure and decay data. Data from 325 articles added in FY17.

For our purposes, focus is on decay and FPY.

- Decay data mainly compiled in XUNDL (as structure data)
- FPY data in EXFOR (as reaction data)



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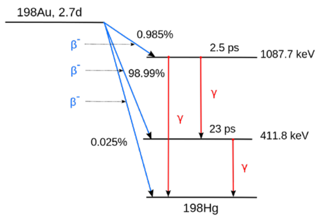
The Nuclear Data Pipeline

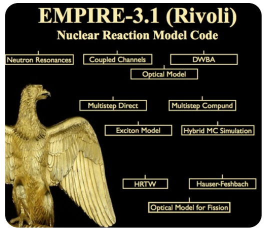
Evaluate data by combining all information into recommended values

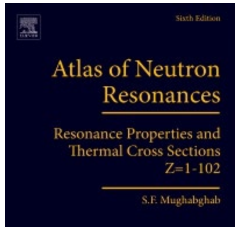


ENSDF: Recommended nuclear structure and decay data for all 3,325 known nuclides.

ENDF: Recommended particle transport and decay data, with a strong emphasis on neutron-induced reaction data

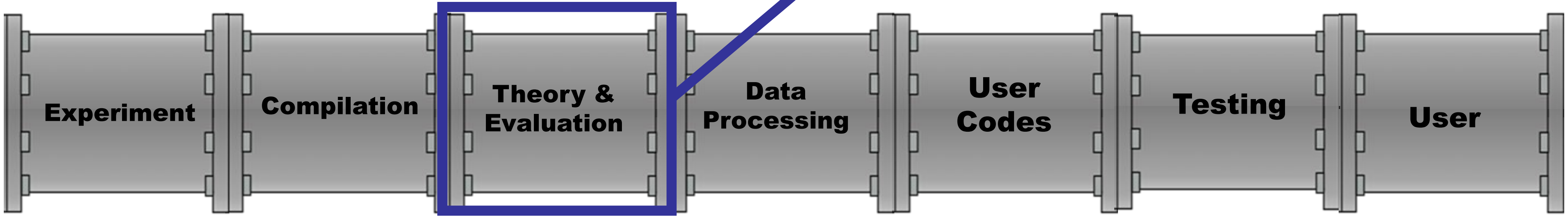
Atlas of Neutron Resonances: 6th edition of the famed successor to BNL-325, contains neutron resonance parameters, thermal cross sections and average resonance parameters.





Reactor source data & FPY handled well by ENDF library project.

Decay data usually goes ENSDF -> ENDF and can be accelerated



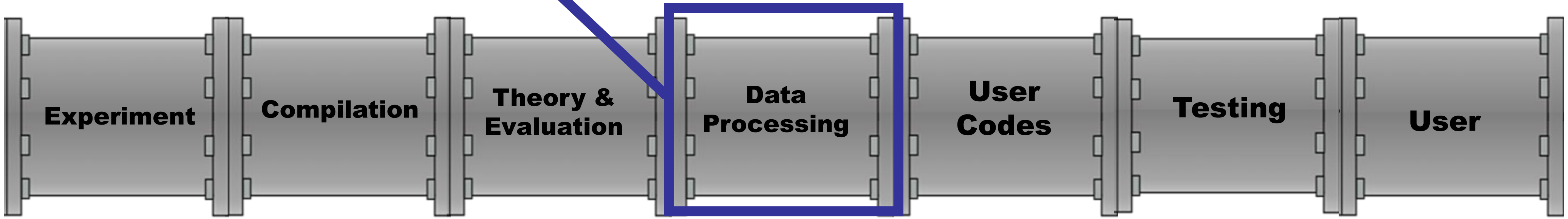
The Nuclear Data Pipeline

Delivering Data to Codes

Processing: Prepare data for use in application codes. US develops NJOY, AMPX and FUDGE.

Quality Assurance: The NNDC's ADVANCE nuclear data continuous integration system ensures the quality of data by automatically testing each ENDF evaluation as soon as it is changed.

Occasionally a new kind of data may require a new format & processing capability



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The Nuclear Data Pipeline

Delivering Data to Codes

Often times, getting data to users is as easy as linking the processed data files

GEANT4 A SIMULATION TOOLKIT

scale Nuclear Systems Modeling & Simulation

MCNP6

PHITS

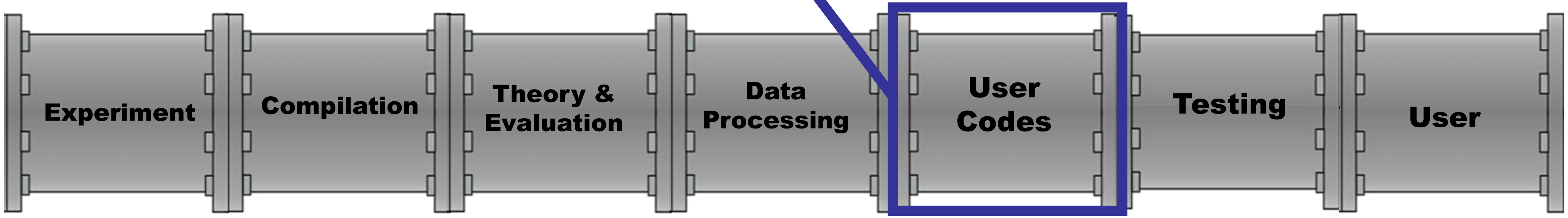
TRIPOLI 4®

Mercury

OpenMC

FLUKA

Depending on nature of new physics, codes may need extension



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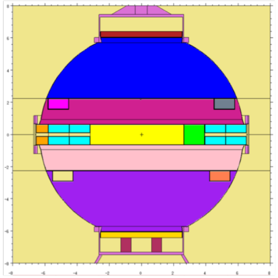
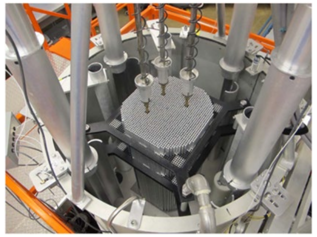
The Nuclear Data Pipeline

Testing the implementation



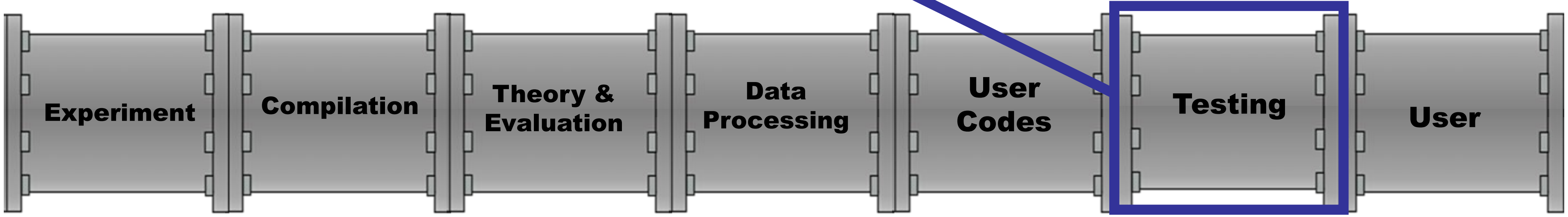


Validation: Test data in simulations of non-trivial, but well understood, nuclear systems. Integrated test of

- Evaluated nuclear data
- Nuclear data processing codes
- Transport codes

We can't test the antineutrino spectra directly, but we can rigorously test the components that are needed to compute it:

- SFCOMPO for decay/FPY
- ICSBEP/IRPhEP for reactor performance
- What else?



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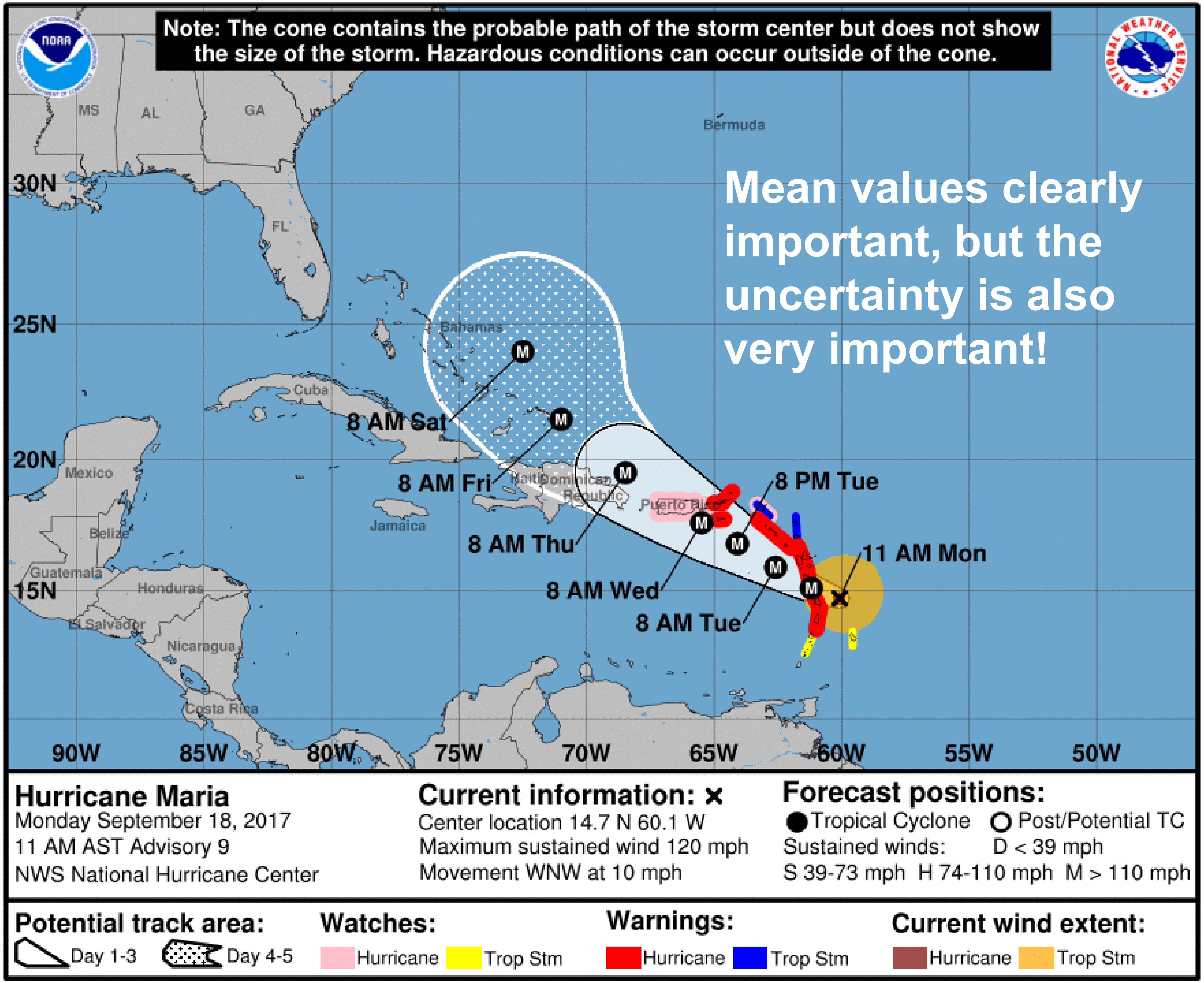


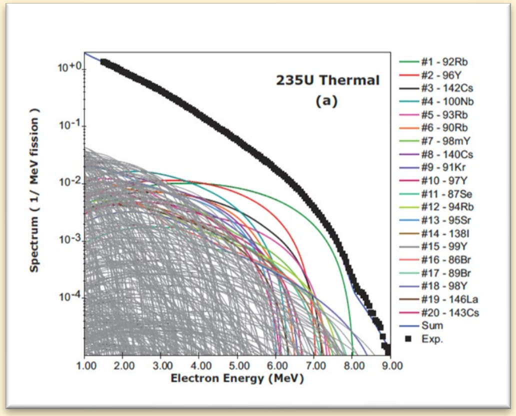
Note: The cone contains the probable path of the storm center but does not show the size of the storm. Hazardous conditions can occur outside of the cone.
Mean values clearly important, but the uncertainty is also very important!
MS
AL
GA
FL
Bermuda
Bahamas
Cuba
Mexico
Belize
Guatemala
Honduras
El Salvador
Nicaragua
Costa Rica
Jamaica
Haiti
Dominican Republic
Puerto Rico
30N
25N
20N
15N
90W
85W
80W
75W
70W
65W
60W
55W
50W
8 AM Sat
8 AM Fri
8 AM Thu
8 AM Wed
8 AM Tue
8 PM Tue
11 AM Mon
Hurricane Maria
Monday September 18, 2017
11 AM AST Advisory 9
NWS National Hurricane Center
Current information: ×
Center location 14.7 N 60.1 W
Maximum sustained wind 120 mph
Movement WNW at 10 mph
Forecast positions:
Tropical Cyclone
Post/Potential TC
Sustained winds: D < 39 mph
S 39-73 mph H 74-110 mph M > 110 mph
Potential track area:
Day 1-3
Day 4-5
Watches:
Hurricane
Trop Stm
Warnings:
Hurricane
Trop Stm
Current wind extent:
Hurricane
Trop Stm

The Nuclear Data Pipeline

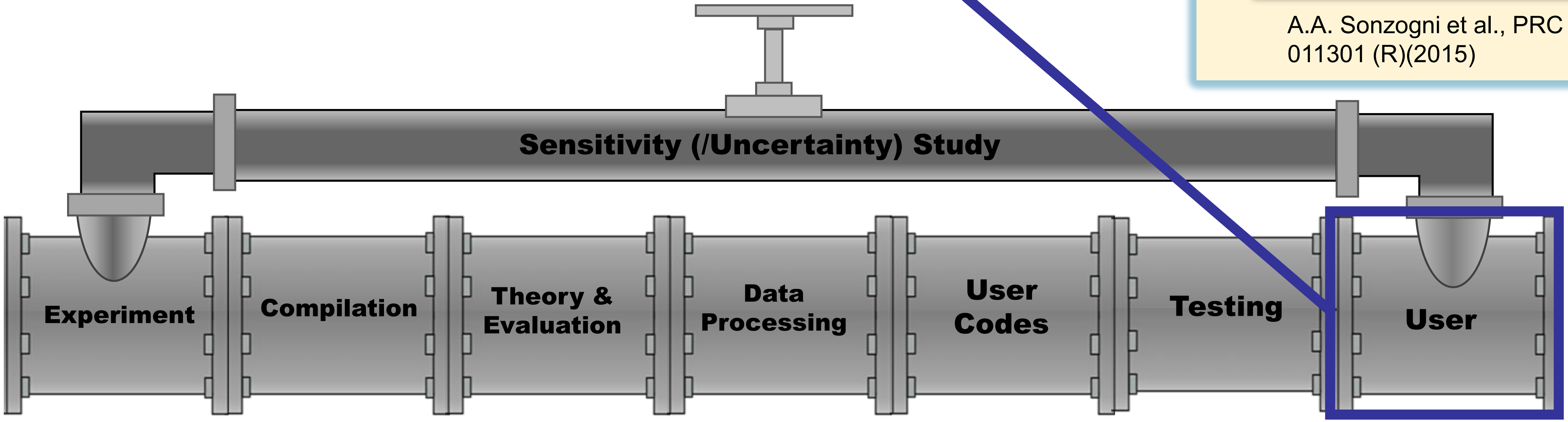
Users determine impact of input distributions on applied quantities, and identify data required to reduce uncertainty.

Common Issues: Credibility and availability of input distributions, methods for disentangling correlated reactions, methods for identifying required experiments.

Proper uncertainties enable sensitivity studies



A.A. Sonzogni et al., PRC 91, 011301 (R)(2015)



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Some takeaways

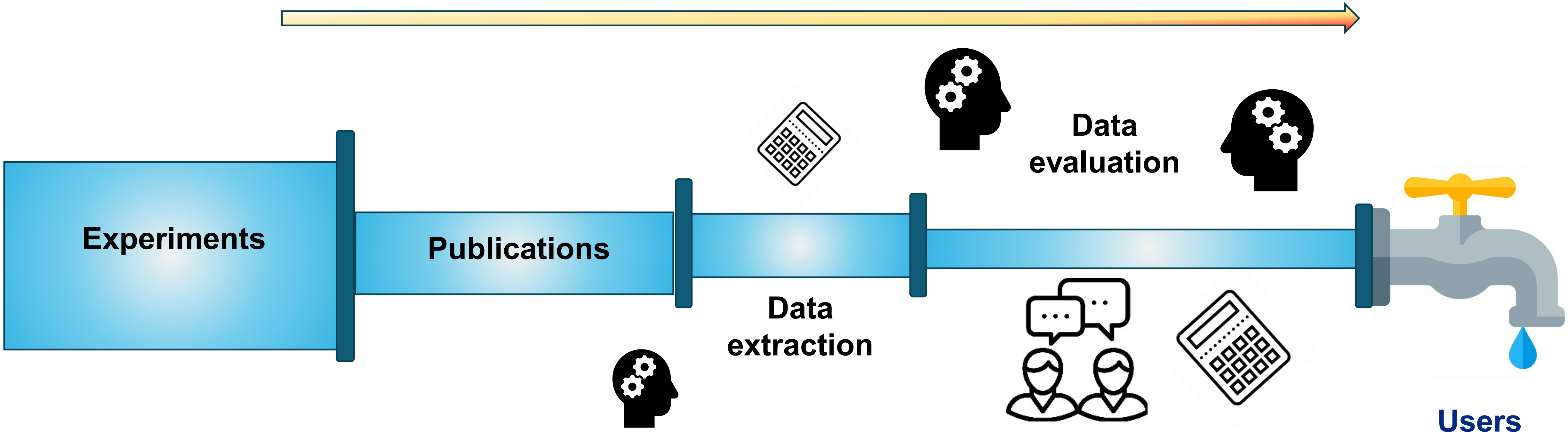
- All segments of the pipeline have a purpose and are essential.
- There must be communication & cooperation between all segments
- Uncertainties/Covariances are EVERYONE'S job, not just the evaluator

It is often quite easy to focus on your small piece of the puzzle and miss the bigger picture

Nuclear Data Pipeline Issues

Nuclear Data Pipeline

Current timeline of about **5 – 10 years**



Our product's impact is limited by:

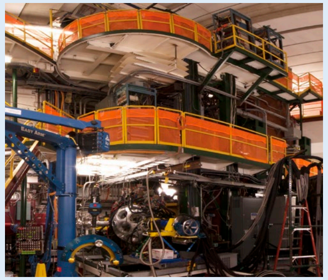
- Outdated methods and formats.
- Extracting data from articles should not be done by humans these days.
- Publications only contain a portion of all data measured.

Modernization of USNDP database has started with the recently funded ENSDF Modernization effort!

Let's leverage this effort to fix the rest!

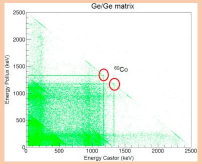
Current Low Energy Nuclear Physics Data Status

Data collection



Data storage

Data artifacts



Processed data

Analysis software

ROOT
Data Analysis Framework

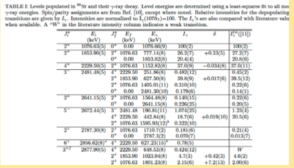
GEANT4
A SIMULATION TOOLKIT

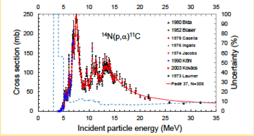
Simulation

Dissemination of Processed Results

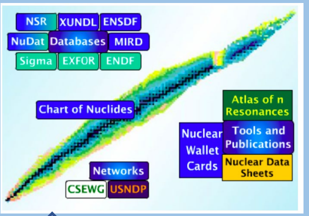
arXiv.org

50 YEARS PHYSICAL REVIEW C





Nuclear Databases



- Only a small fraction of experiments are fully preserved. These continue to increase in cost and complexity.
- There is **NO** centralized mechanism for data sharing, resulting in
    - Potential for repeating experiments
    - Data that goes unanalyzed
    - Less resources to plan experiments
    - No opportunity for reproducibility
- Data program parses published tables and digitizes graphs.

Average experiment costs ~1 million
~300 experiments into XUNDL alone every year

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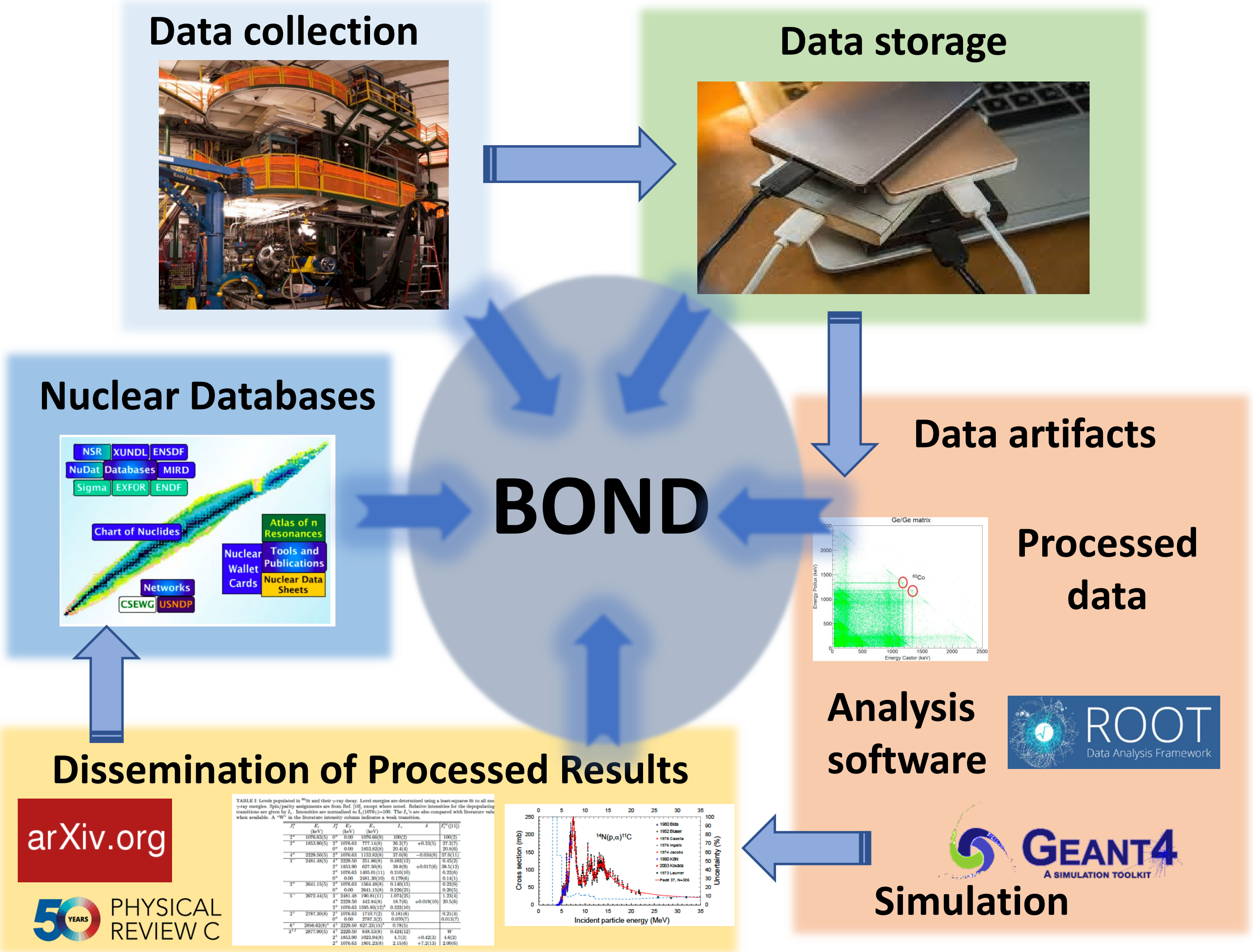
Brookhaven Open Nuclear Data (BOND)



BOND will ingest, document, and preserve data at each stage of an experiment

Major goals include :

- Establish repository of low-energy nuclear data at NNDC
- Implement FAIR principles
- Leverage RHIC/HP Data Computing Facility expertise
- Integrate NNDC in Data Management Plans
- Start with new facilities (i.e. FRIB)
- Work backwards to legacy data

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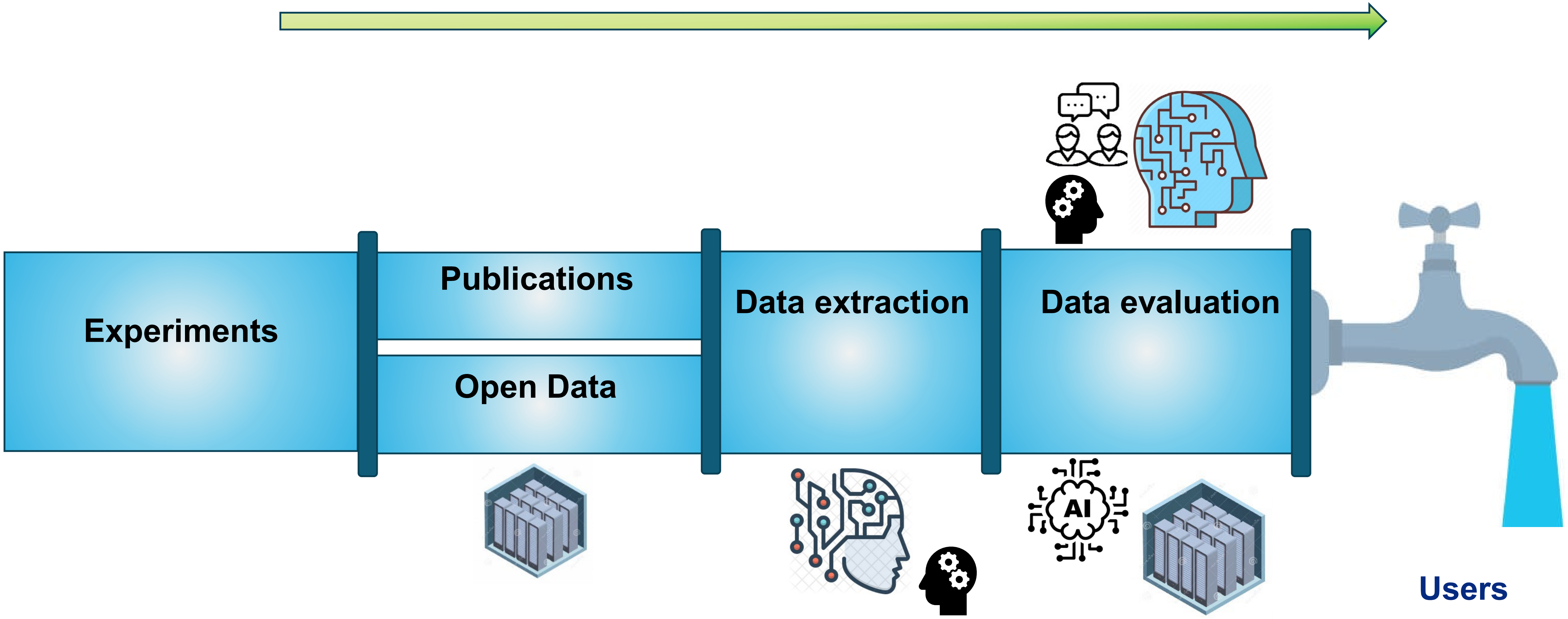
Average experiment costs ~1 million

~300 experiments into XUNDL alone every year

Nuclear Data Pipeline

Proposed timeline of about **1 – 2 years**



This new paradigm will address bottlenecks, ensure that results of expensive experiments are properly stored, and address stakeholders' feedback in a timely manner.

Final takeaways

- All segments of the pipeline have a purpose and are essential.
- There must be communication & cooperation between all segments
- Uncertainties/Covariances are EVERYONE'S job, not just the evaluator

- We are working to accelerate the pipeline
- Open data initiative can capture and preserve detailed experimental before it is lost to history