NE 155/255, Fall 2019

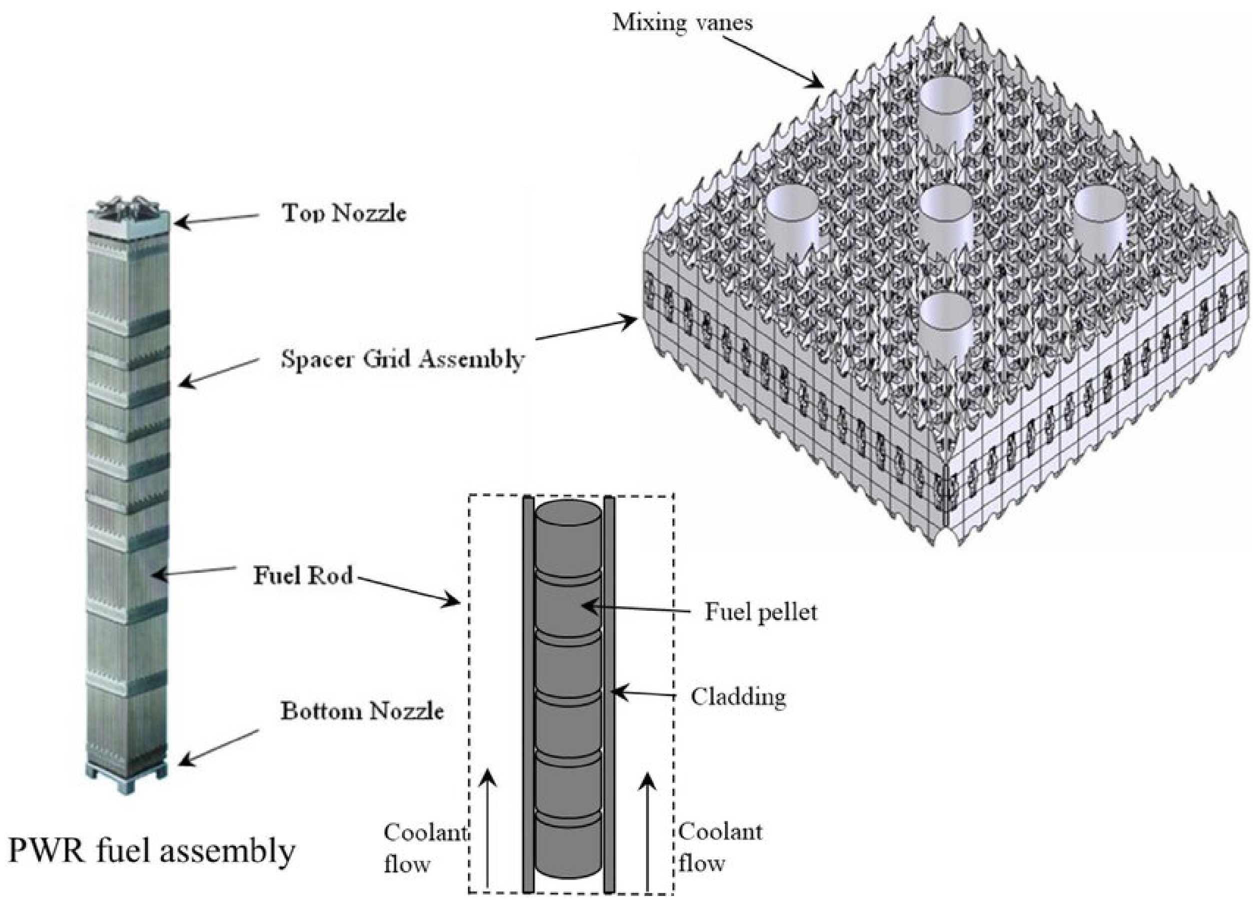
Solution Context and Tools

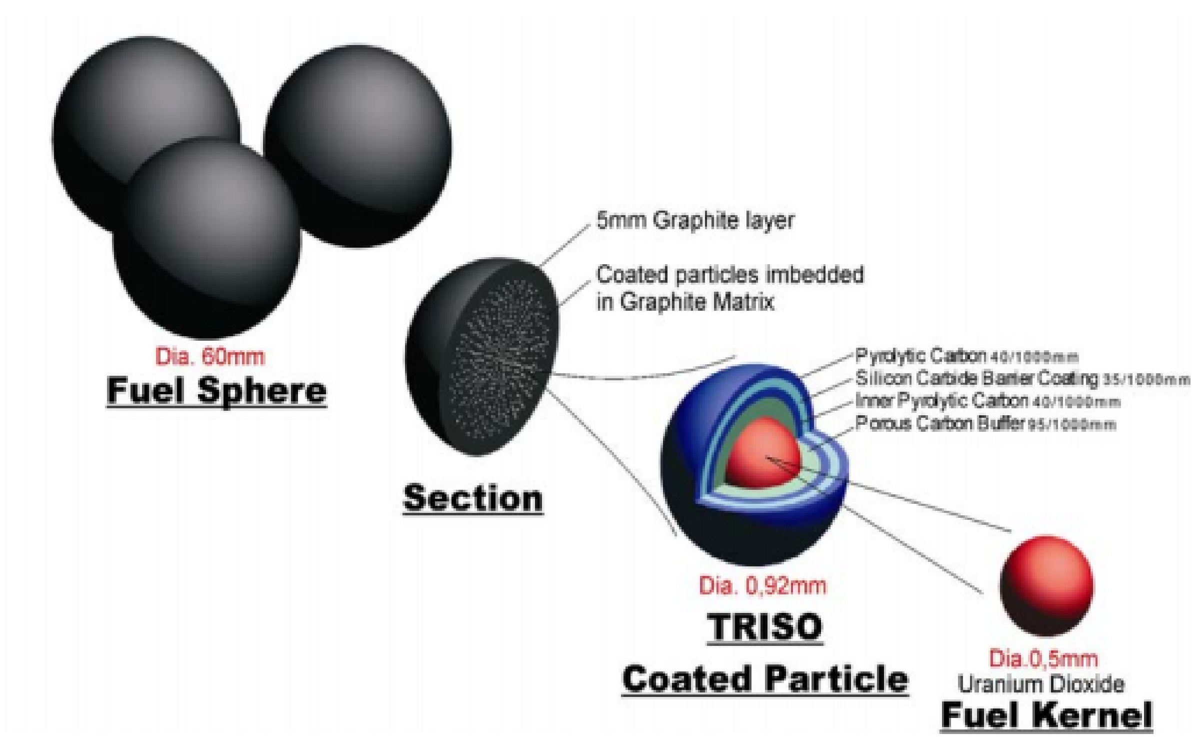
September 23, 2019

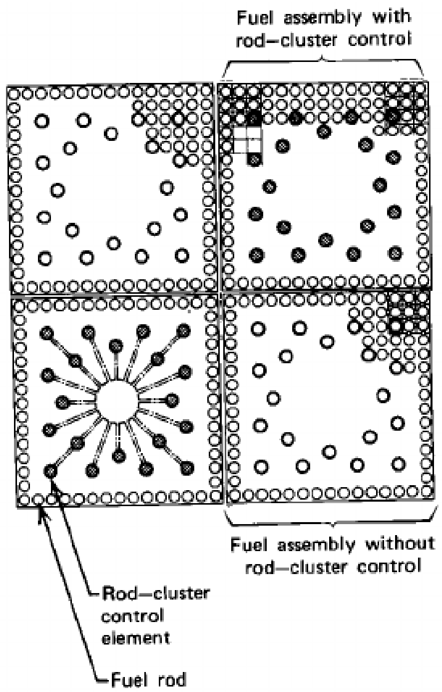
We've started looking a little bit at how to play around with the transport equation. To venture much farther in thinking about solving the transport equation, it helps to remember what we're applying it to and some other bits of information that we use.

As mentioned, we'll mostly focus on reactors in this class. A nuclear reactor is a three-dimensional structure consisting of complicated geometrical shapes made of variety of materials.

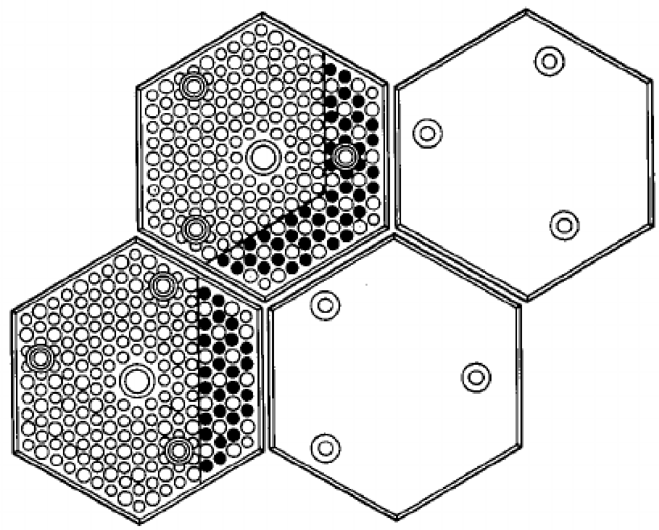
- A unit cell usually consists of a fuel rod, gap, cladding and corresponding moderator. It is usually surrounded by similar cells. A fuel rod consists of fuel pellets.
- A fuel assembly usually consists of several hundred fuel rods (fuel cells).
- A reactor core consists of several hundred fuel assemblies.
- Fuel assemblies and fuel rods are usually arranged in square or hexagonal lattice.
- Instead of fuel pellets, the fuel could be in the form of coated fuel particles (TRISO particles).
- Coated fuel particles could be arranged into fuel compacts or pebbles (pebble bed reactor).

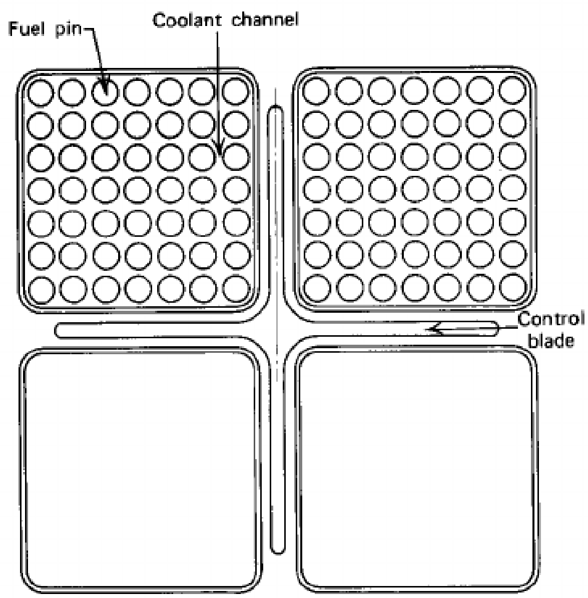

Mixing vanes
Top Nozzle
Spacer Grid Assembly
Fuel Rod
Bottom Nozzle
Fuel pellet
Cladding
Coolant flow
Coolant flow
PWR fuel assembly


Dia. 60mm
Fuel Sphere
5mm Graphite layer
Coated particles imbedded in Graphite Matrix
Section
Pyrolytic Carbon 40/1000mm
Silicon Carbide Barrier Coating 35/1000mm
Inner Pyrolytic Carbon 40/1000mm
Porous Carbon Buffer 95/1000mm
Dia. 0,92mm
TRISO
Coated Particle
Dia.0,5mm
Uranium Dioxide
Fuel Kernel

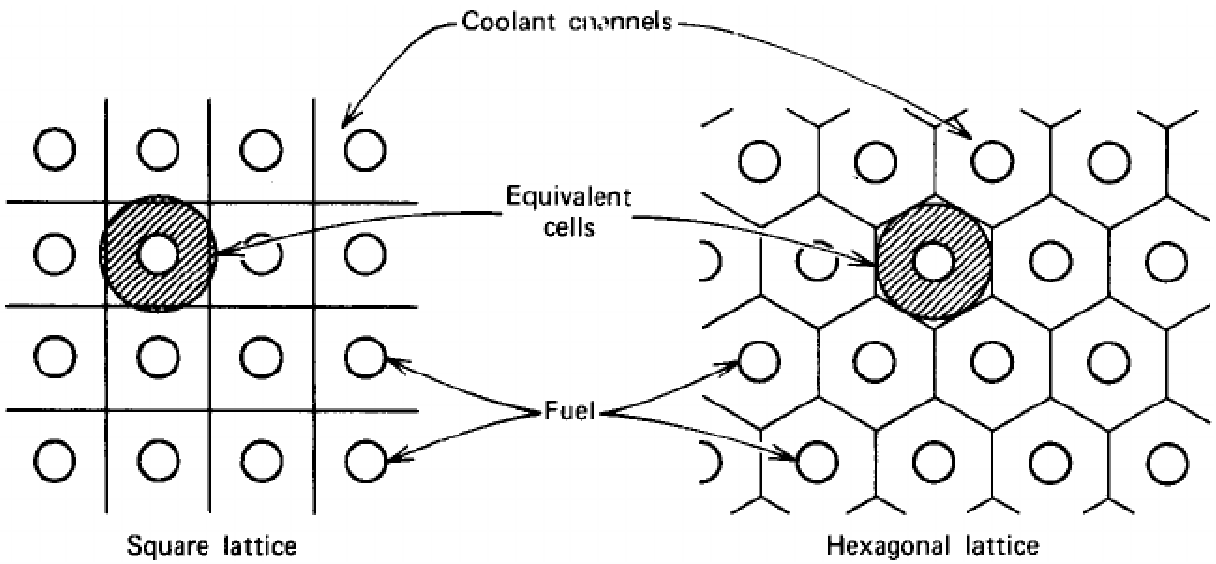


PWR assemblies


HTGR assemblies



BWR assemblies

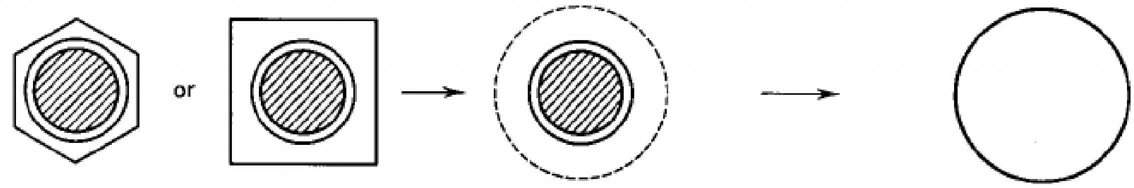


PWR Specs (from Appendix H of Nuclear Reactor Theory)

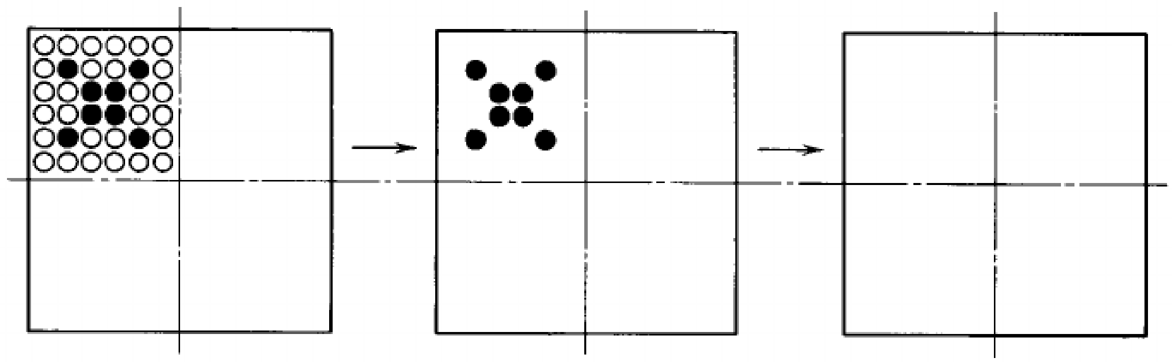
- $\sim$200 fuel assemblies
- Each assembly contains array of 17$\times$17 fuel rods
- 3.5 - 4 m tall, $\sim$3.5 m active diameter
- UO_2 fuel, H_2O moderator and coolant, Zircaloy clad
- $\sim$3% enrichment

BWR Specs (from Appendix H of Nuclear Reactor Theory)

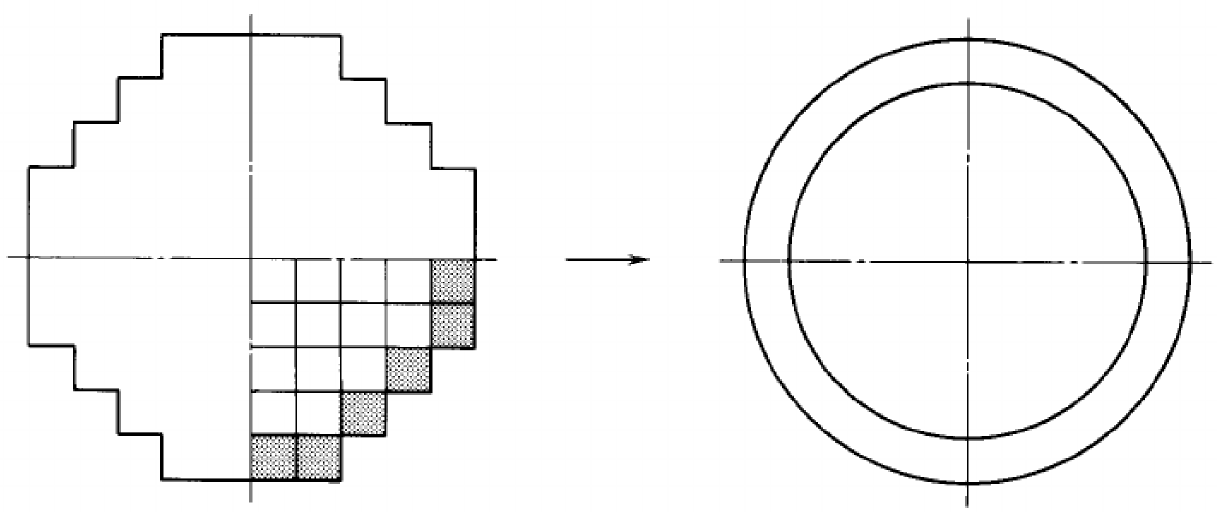
- $\sim$700 fuel assemblies
- Each assembly contains array of 8$\times$8 fuel rods
- $\sim$3.5 m tall, $\sim$3.5 m active diameter
- UO_2 fuel, H_2O moderator and coolant, Zircaloy clad
- $\sim$2.5% enrichment



(a) Fuel–cell homogenization

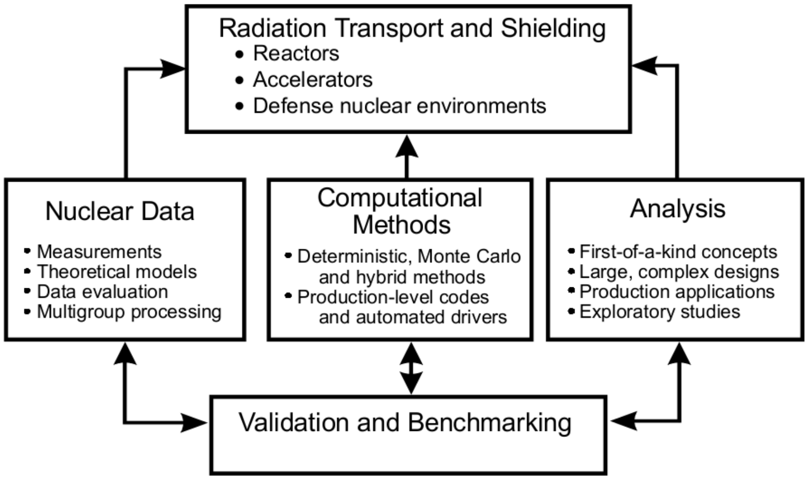


(b) Fuel–assembly homogenization



(c) Core homogenization

Solution Context and Data

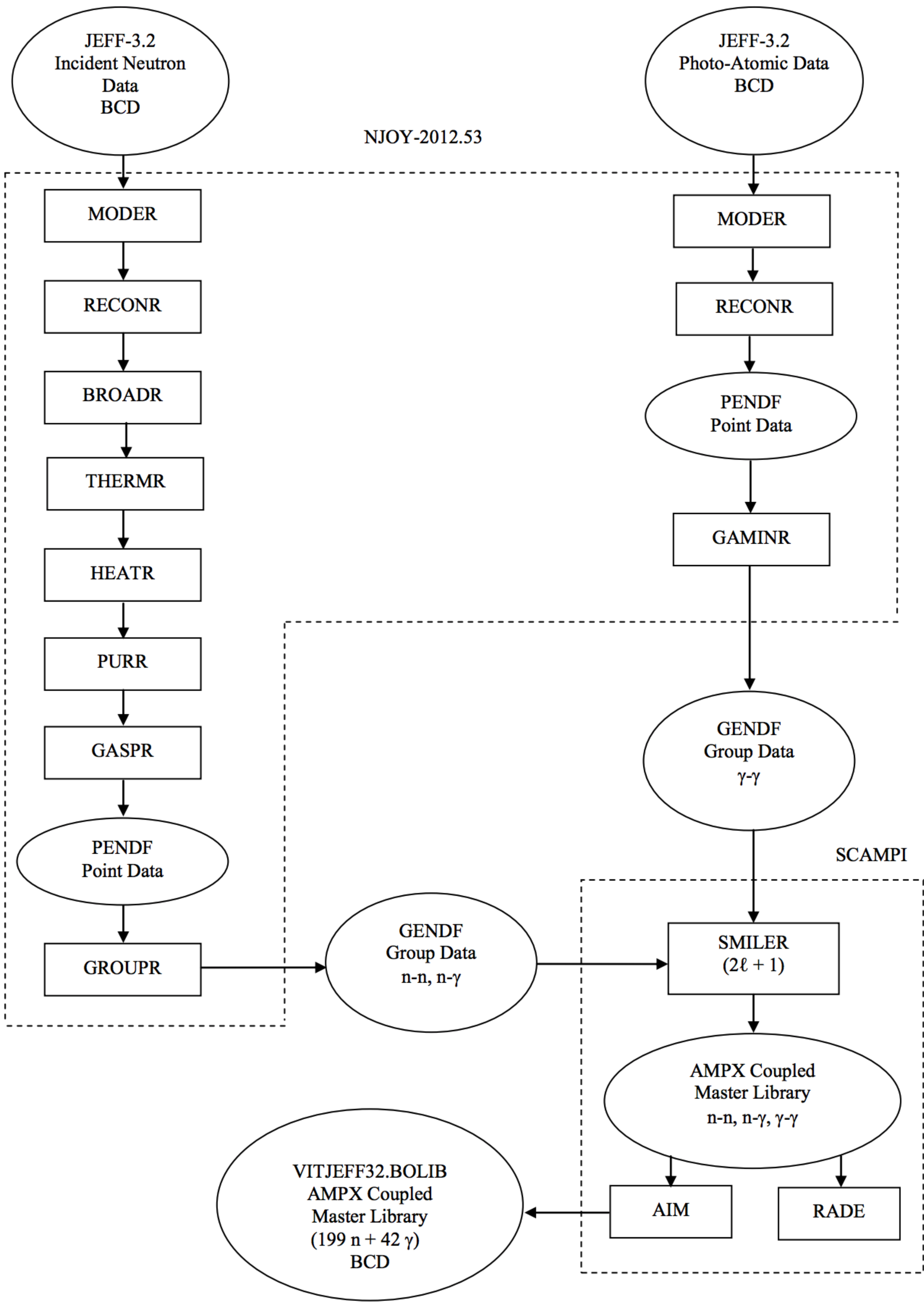


We have many different types of geometries and physics going on with the systems we're interested in. However, we take the same fundamental approach no matter what. Each component is incredibly important, but let's take a moment to talk about **nuclear data**.

We need a description of all of the physical interactions happening inside a nuclear reactor that we can use in our equation. An *evaluated nuclear data file* is a collection of various data enabling to reconstruct, for each isotope, its cross-section's

- general information
- resonance parameters
- angular distribution for emitted particles
- energy distribution for emitted particles
- energy-angle distribution for emitted particles
- thermal neutron scattering law data
- radioactivity and fission-product yield data
- multiplicities for radioactive nuclide production
- cross-sections for radioactive nuclide production

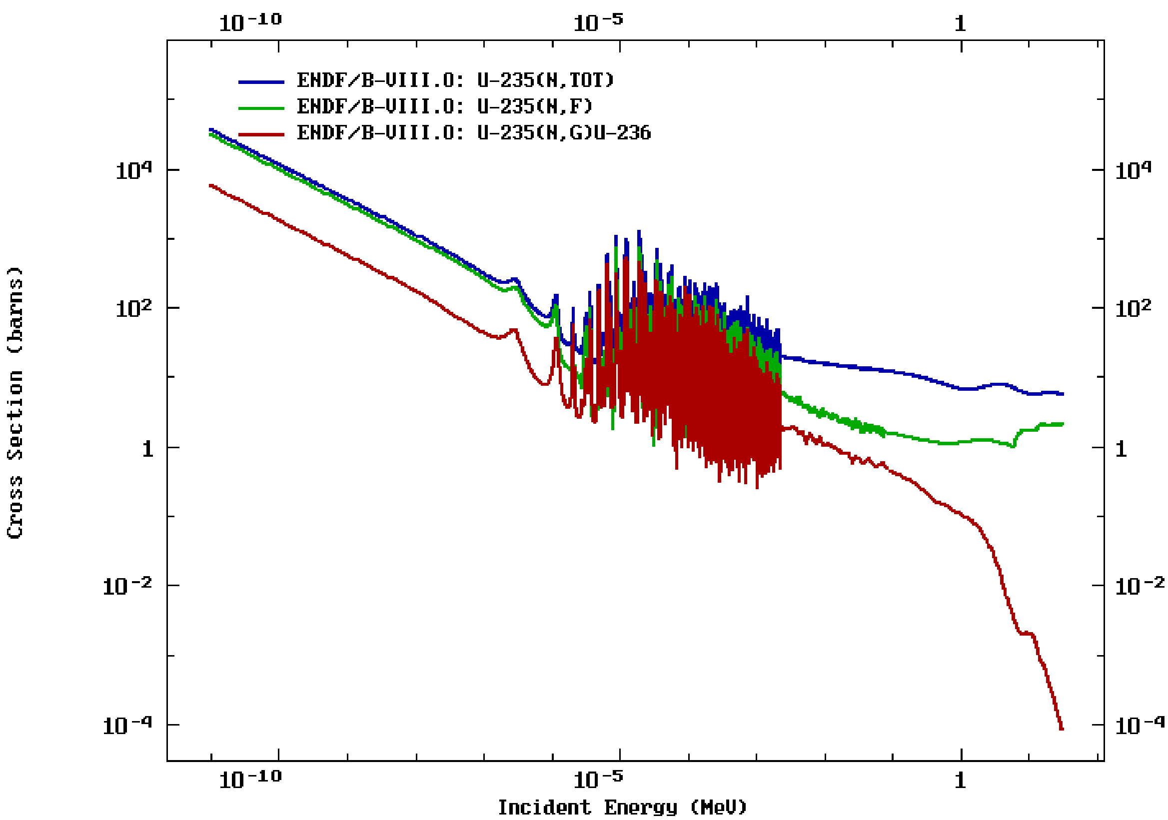
There are many evaluations coming from various countries such as: USA, Europe, Japan, Russia, China, . . . Getting from experimental data (what we have of it) + theory (however accurate that is) to data that can actually be used in a code is no small feat. And, that process is sort of a mess...

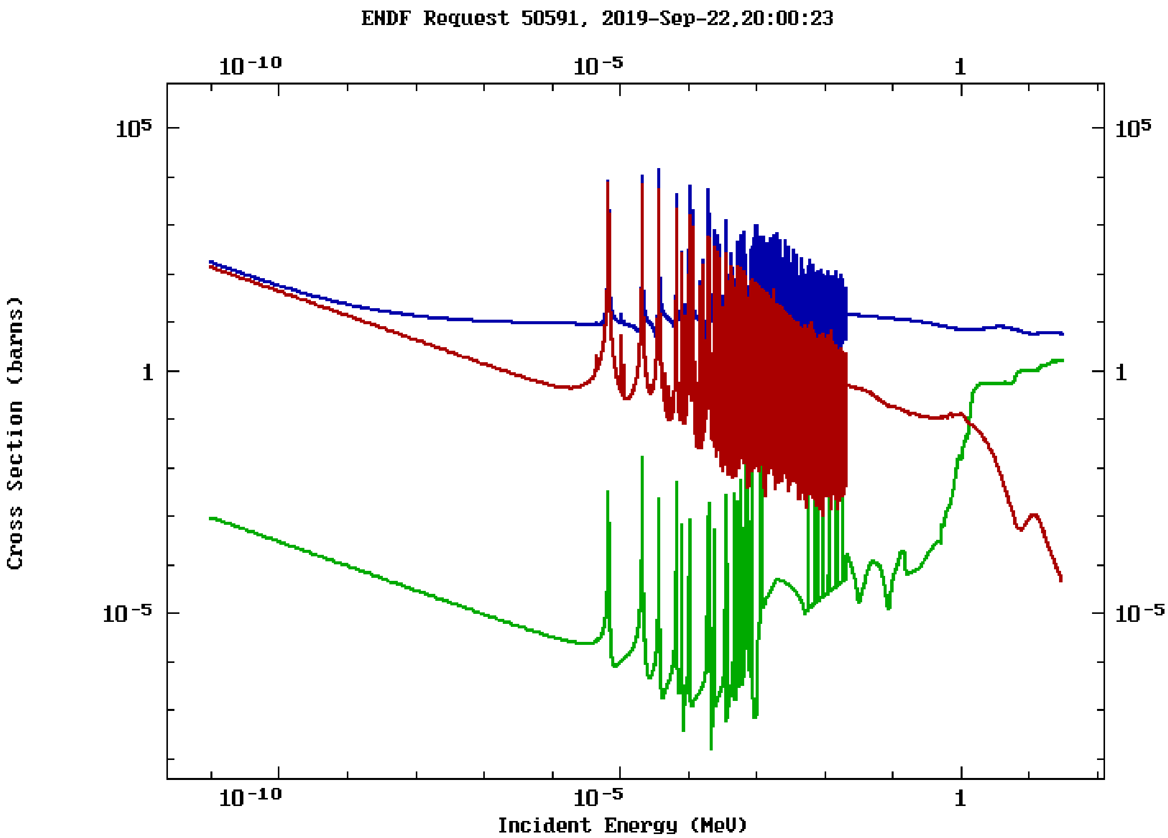

JEFF-3.2
Incident Neutron
Data
BCD
JEFF-3.2
Photo-Atomic Data
BCD
NJOY-2012.53
MODER
RECONR
BROADR
THERMR
HEATR
PURR
GASPR
PENDF
Point Data
GROUPR
MODER
RECONR
PENDF
Point Data
GAMINR
GENDF
Group Data
γ-γ
SCAMPI
GENDF
Group Data
n-n, n-γ
SMILER
(2ℓ + 1)
AMPX Coupled
Master Library
n-n, n-γ, γ-γ
VITJEFF32.BOLIB
AMPX Coupled
Master Library
(199 n + 42 γ)
BCD
AIM
RADE

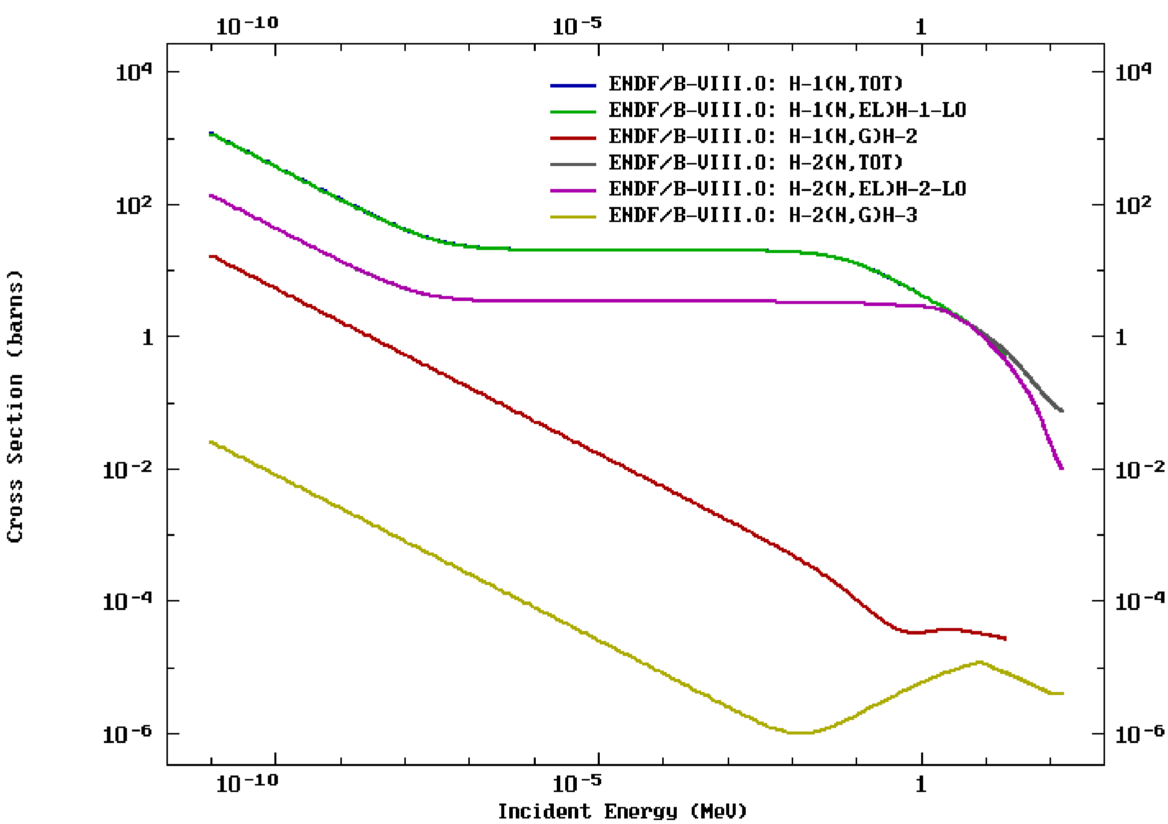
The NJOY manual is approximately 800 pages.

We won't go through all of this, but it's important to have context about what this is and how confusing it can be. There is a lot of data and many formats. In computation you will pretty much only need to interface with ENDF and its equivalents.

The data that we use is complicated, and can be quite different depending on the application we're interested in. Let's look at some. All plots shown here were generated with the NNDC ENDF project at `https://www.nndc.bnl.gov/exfor/endf00.jsp`




ENDF Request 50591, 2019-Sep-22,20:00:23
Cross Section (barns)
Incident Energy (MeV)
10^{-10}
10^{-5}
1
10^{5}
10^{-5}


ENDF/B-VIII.0: H-1(N,TOT)
ENDF/B-VIII.0: H-1(N,EL)H-1-L0
ENDF/B-VIII.0: H-1(N,G)H-2
ENDF/B-VIII.0: H-2(N,TOT)
ENDF/B-VIII.0: H-2(N,EL)H-2-L0
ENDF/B-VIII.0: H-2(N,G)H-3
Cross Section (barns)
Incident Energy (MeV)
10^{-10}
10^{-5}
1
10^{4}
10^{2}
10^{-2}
10^{-4}
10^{-6}

Physics Impacts

We are often able to use knowledge about the physics to inform method development or, at the very least, choose which methods are more appropriate given our physics.

For example, you may notice is how, in particular, fast and thermal reactor physics differ. We often need different codes to deal with LWRs and FRs.

Many of the assumptions employed in traditional LWR methods do not apply:

- Lack of a 1/E energy spectrum as a basis for the calculation of resonance absorption.
- Upscattering resulting from the thermal motion of the scattering nuclei may be neglected.
- Inelastic, (n, 2n), and anisotropic scattering are quite important.
- Long mean free paths imply global coupling. That is, local reactivity effects impact the entire core.
- The energy range where neutrons induce fission and the energy range where the fission neutrons appear strongly overlap.

Other physics considerations have high priority in FR methods:

- Detailed energy modeling for resonance structure (core/reflector).
- Transport and anisotropy effects are more important at high energy.

In general, a distinct set of physics analysis and core design tools with tailored assumptions have been and are being developed for FR analysis.