Accelerator Transmutation of Waste
Challenges and Needs

P.J. Finck

October 30, 2000

Outline

- The waste issue
- Transmutation fundamentals
- Transmutation approaches
- The ATW technologies
- Issues, challenges, and needs: current R&D plans

The Waste Issue

- By 2015, the US will have generated 72000 tons of Spent Nuclear Fuel (SNF)
- The Yucca Mountain repository is making progress, but critics point to three issues:
  - Long term toxicity
  - Licensing difficulties
  - The “Plutonium mine”
- Under certain conditions, SNF transmutation would:
  - Reduce demands on current repository
  - Reduce the need for a further repository

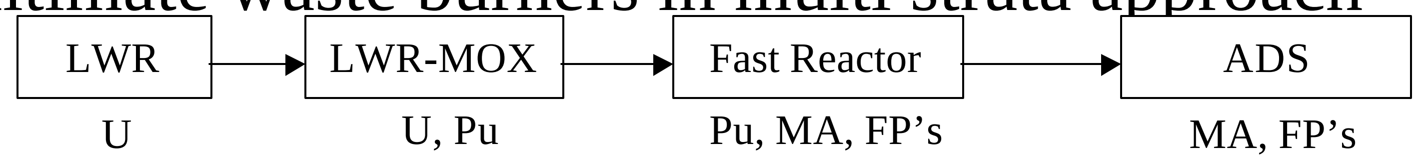
Conditions: high degree of transmutation
low losses and robust waste forms
low costs

Transmutation Fundamentals

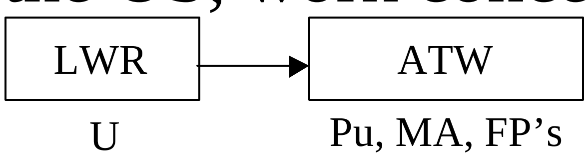
- Long lined fission products (Tc-99; I-129): capture neutrons, prefer low energy
- Pu's and Minor Actinides: need to favor fission over capture
  - Use of fast neutrons (i.e. fission spectrum)
- Cheapest source of fast neutrons: fast reactors (accelerator driven or critical)

Background on Accelerator Driven Systems

- Systems rediscovered in early 90's as "Energy Amplifier"
  - Thorium Cycle, Lead-Bismuth (LBE) Target and Coolant
  - Claimed safety advantages and flexibility
- In Europe and Japan, systems have evolved towards ultimate waste burners in multi strata approach



- In the US, work concentrated on single stratum

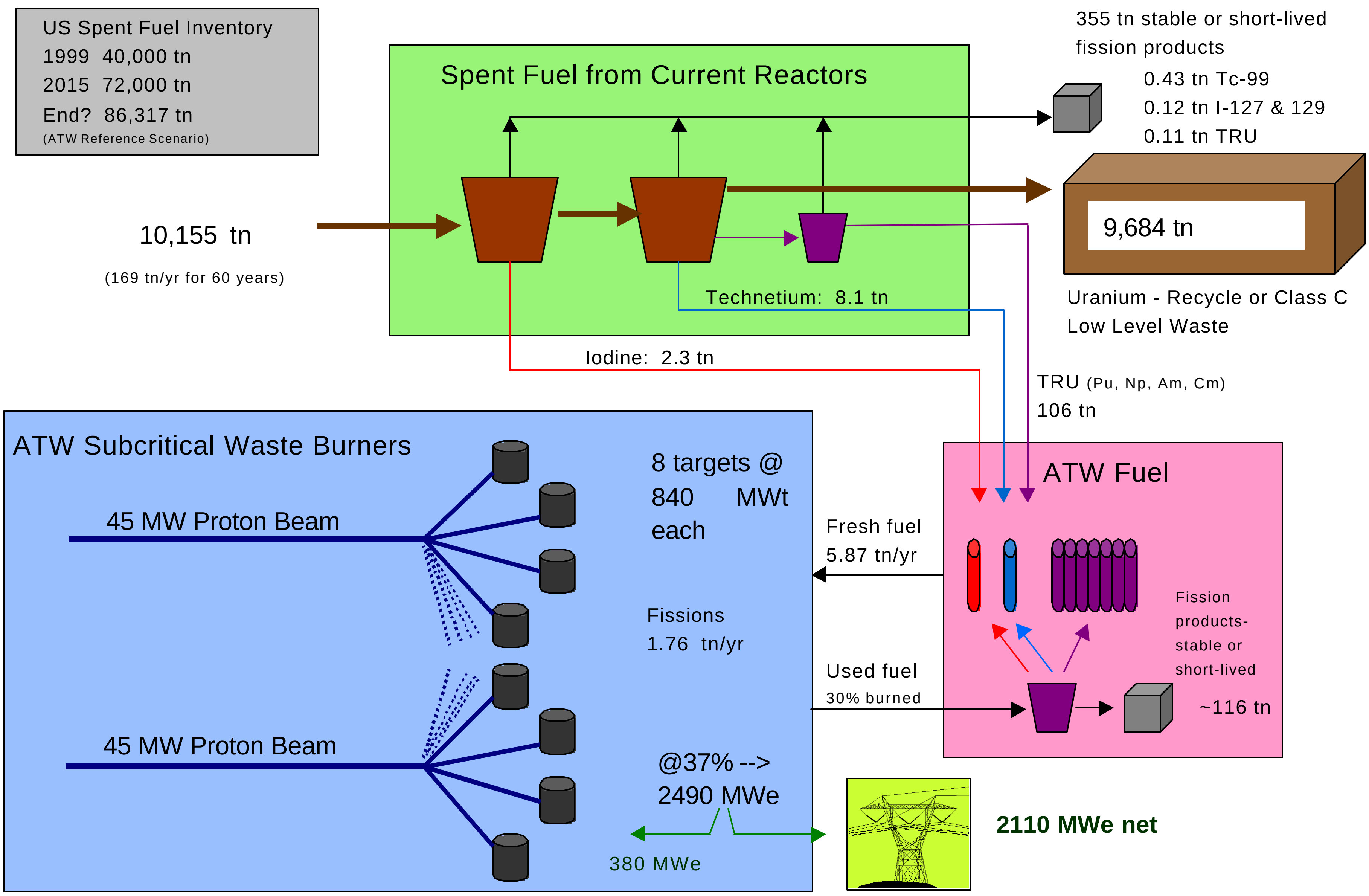


- Multi-strata approach is currently being considered

The ATW Technologies

- FY99: congress mandated a roadmap for development and deployment of the ATW
- Constraints
  - Once through cycle – ATW to “Burn” all Pu, MA, and FP’s
  - LINAC and LBE Technologies strongly preferred
- Major issues were identified:
  - Fuel: high burnup, non-fertile fuels
  - Separations: high through put, very low losses
  - Transmuter: design, performance, safety and control, operability
  - LINAC: size, reliability
- Six years science-based R&D plan
- Modest funding for FY00: 9 million

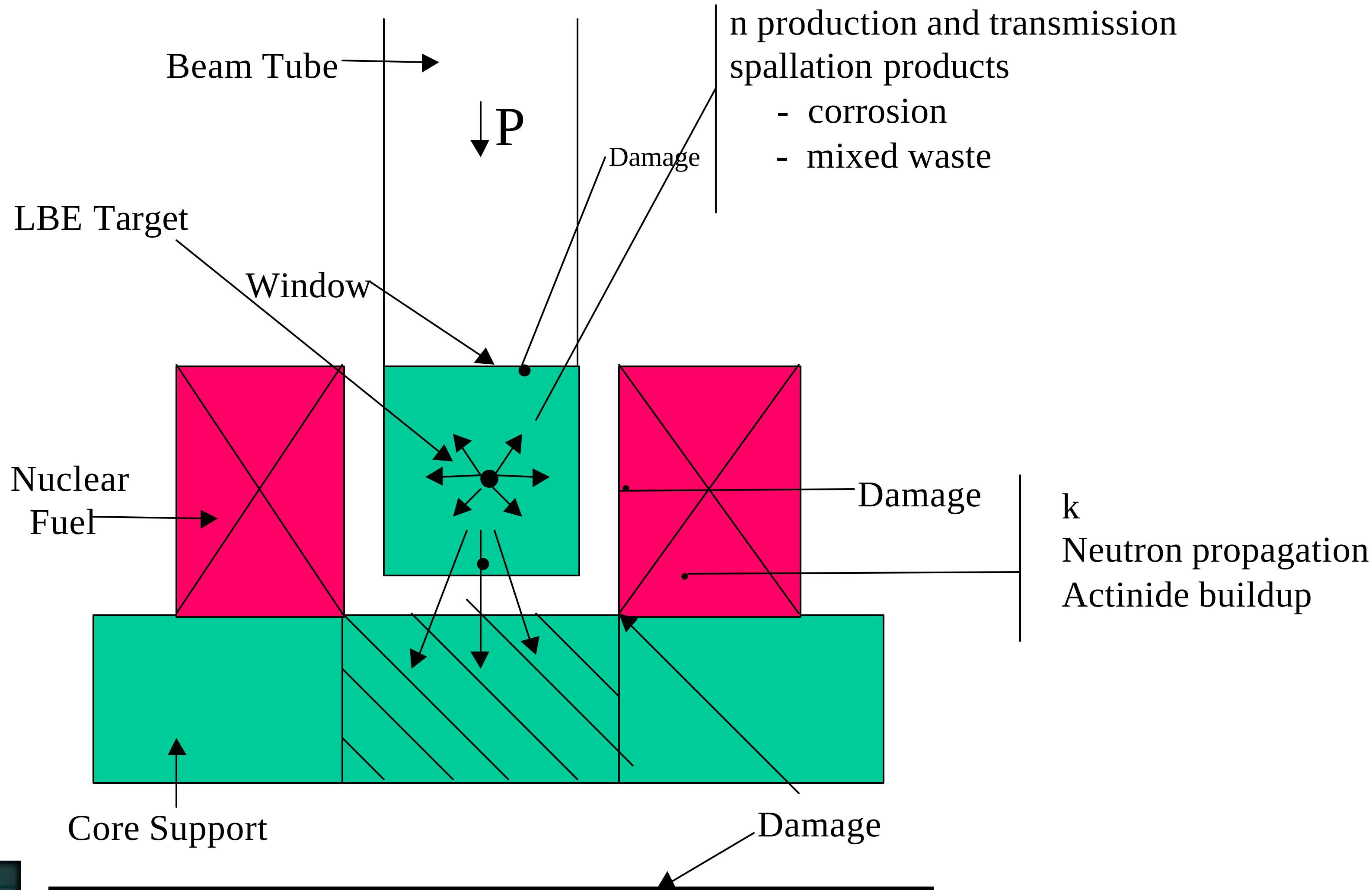
ATW Plant Sized to Process 10,155 Tonnes of Spent Fuel
(based on average composition of Reference Scenario spent fuel)



Some Major Issues

- Accelerator:
  - Intensity and energy
  - Reliability
- Separations:
  - Large quantities of hot materials
  - High purity (99.9%)
- Fuels:
  - Fabrication
  - Behavior (burnup, damage)
- Target:
  - Design
  - Materials
  - Neutron and spallation products production
- Transmuter:
  - Design
  - Control
  - Safety (including decay heat)
  - Physics (k-eff, neutron propagation, actinide buildup, damage and gas production)

Major Issues - Physics



Damage Issues

- Major engineering concern (lifetime, safety, costs)
- Due to: - displacements of atoms
  - helium and hydrogen production
- Behavior sufficiently well known for low energy particles
  - correlations (NRT)
- Very large uncertainties at higher energies
- Plan integral tests (LANSCE, etc)
- Plan for a more systematic microscopic approach

Neutronics

$$F = S\ f^{*}\ \frac{1}{1 - k_{eff}}\ \ x\ldots$$

f *: Source energy; geometry; core composition

K eff: Actinide cross sections; composition; geometry
actinide buildup

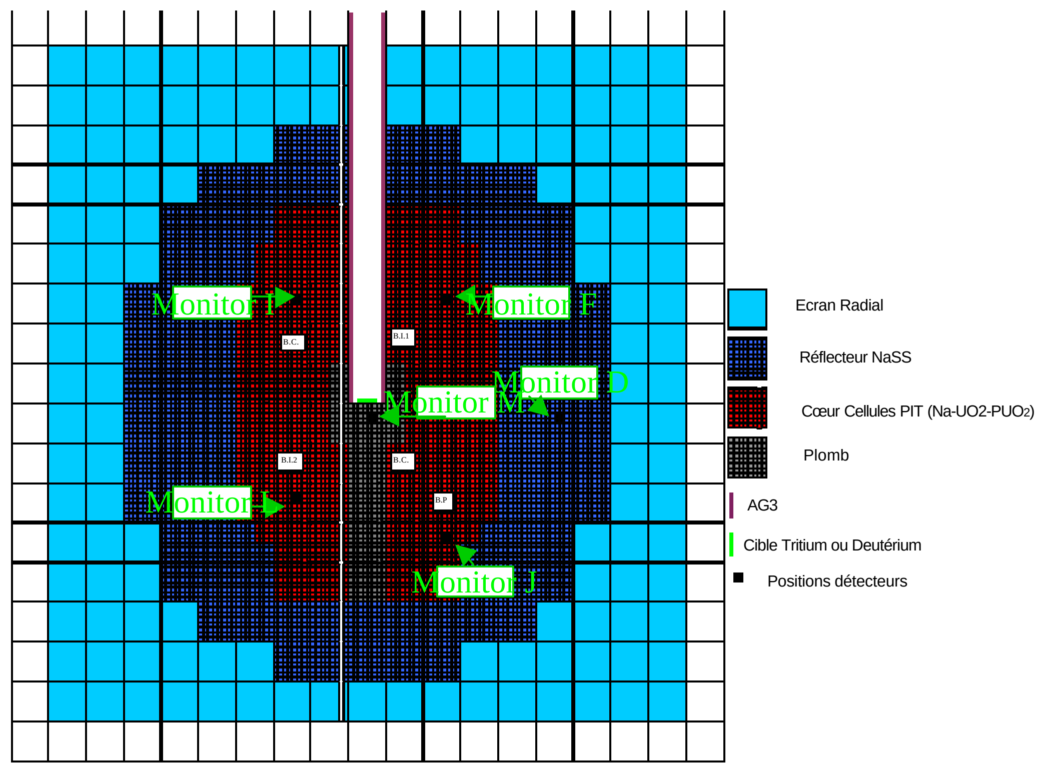
S: Neutron production; angular distribution; spectrum

Sensitivities to Cross Sections Below 20 MEV

- Used sensitivity analyses to calculate uncertainties and contributions for the following parameters:
  - K_{eff}
  - MAX (DPA)
  - Peak power
  - Reactivity coefficients
  - Source importance
- "Reasonable" nuclear data uncertainties and co-variances were estimated.
- Physics of spallation process and sub-critical system are quite well decoupled. Here, we consider only the sub-critical system.

MUSE

- Collaborate with French to obtain experimental data on subcritical cores (Static, Dynamic)
- MASURCA Facility, D-D and D-T sources
- Currently mocking up MOX Cores:
  - –Na coolant, Pb Target
  - –Pb coolant, Pb Target
  - –Gas coolant, W target
- Preliminary results confirm that current codes/data are adequate
- Propose to continue program in ZPPR:
  - –More representative fuel
  - –Spallation source



Major Parameters and Issues in MUSE

- Data and code validation: Study and analysis of experimental configurations using different cross section data sets and system of codes. Analysis of experiments with different neutron diffusing media placed around the source and different levels of subcriticality.
- External source effectiveness: The F^*, defined as the ratio of the importance of the external source neutrons to the importance of fission neutrons, is a key parameter in the optimization of an ADS system. It allows to improve the energy balance and to provide optimized neutron importance distribution.
- Instability and decoupling effects: The presence of a buffer zone at the center of the system decouples the neutrons inducing instability effects. Higher eigenmodes and eigenvalues evaluations through static and time-dependent (dynamic) measurements helps the understanding of these phenomena.

MUSE Analysis Results

Experimental Configuration	Measured Experimental Reactivity	Monte Carlo Calculation ENDF/B-VI	Deterministic Transport ENDF/B-VI	Deterministic Transport JEF2.2
Reference	-112 ± 60	+ 666 ± 23	+1342	+327
Subcritical Level 3	-1579 ± 90	-812 ± 30	-50	-1053
Subcritical with Pb buffer	-5687 ± 120	-4564 ± 28	-4268	-5398
Subcritical with Na buffer	-5893 ± 120	-4977 ± 26	-4232	-5270

Actinide Build Up

- Large uncertainties in higher actinides capture and fission cross sections
- Results in uncertainties:
  - k eff at beginning of cycle
  - burnup swing
- Require:
  - microscopic measurements
  - integral measurements (sample irradiations)
  - better measurement techniques
  - re-evaluations

OECD/NEA Benchmark for ADMAB

- Objectives
  - To resolve the discrepancies observed in the previous benchmark exercise
  - To check the performance of reactor codes and nuclear data for ADS employing non-conventional fuels
- Specifications
  - 377MWt LBE-cooled accelerator-driven MA burner
  - Nitride fuel (minor actinides) diluted with Zr, (TRU,Zr)N
  - RZ model
  - Specified spatial and energy distributions of spallation neutron source
  - Specified initial compositions
    - Start-up cycle composition
    - Equilibrium cycle composition

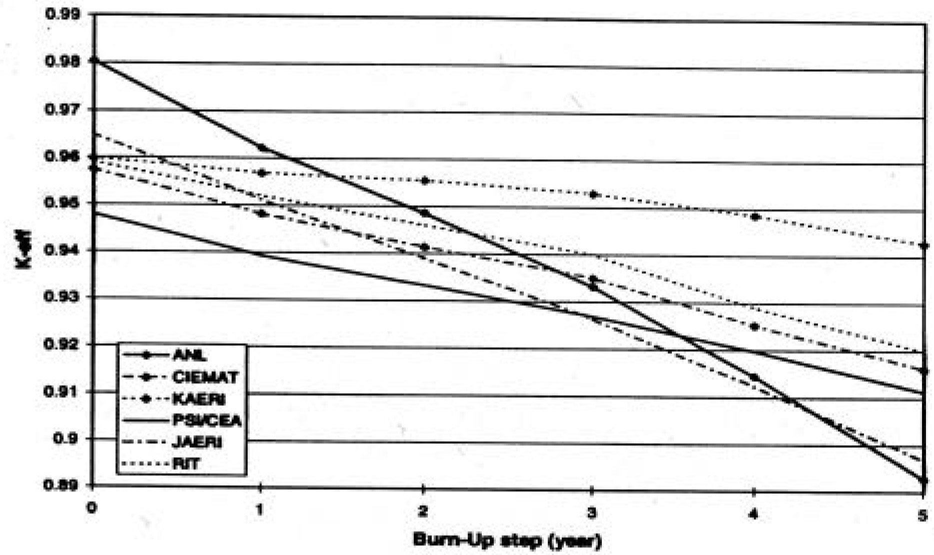


Figure 2. k_{eff} variation with burn-up in start-up core

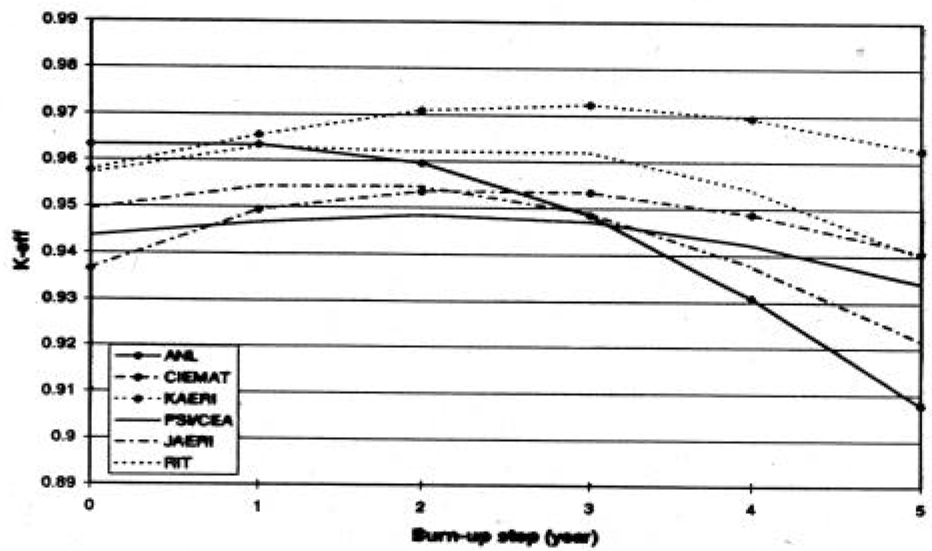


Figure 3. k_{eff} variation with burn-up in equilibrium core

Decay Data

- Major safety concern
- Uncertainties increase significantly with atomic mass
- No sensitivity studies available
- Measurement techniques are cumbersome

Top Level Needs

Data	Justification	Accuracy
Neutron Production in Spallation Reaction: Yield, Spectrum, Angular Distribution	- **System Dimensions** - **System Design** - **Cost** - **Lifetime**	**20%**
Isotopic Distribution of Spallation products	- **Corrosion** - **Waste Issues**	**30 to 50%**
Gas Production Damage rates	- **System Lifetime** - **Fuel Lifetime**	**30 to 50%**
Actinide principal cross sections	- **System Safety** - **Transmutation Performance** -	**5 to 50%**
Actinide Decay Data	- **System Safety**	**10%**

Top Level Needs (cont.)

Integral Experiment	Justification	Accuracy
Core Physics	- Safety - Performance	Few percent
Spent Fuel Isotopics	- Performance	5 to 10 %
Target Physics	- Performance	Few percent
Materials and Fuels Irradiation Tests	- Performance - Lifetime	30 to 50%