



STATUS AND PERSPECTIVES OF ISTC PROJECT #2578

**“TRANSMUTATION OF RADIOACTIVE NUCLEAR
WASTE – PRESENT STATUS AND REQUIREMENT FOR
THE PROBLEM-ORIENTED NUCLEAR DATA BASE”**

AND FOLLOW-UP PROPOSALS

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Proposals

The following topics from above mentioned could be developed by our team:

★ Accumulation of Rare Earth nuclides in ADS and their influence on overall ADS neutronics and safety

★ Improvement of nuclear models at intermediate and high energies

★ Development of models for investigations related to radiation damage of structural materials

★ Investigation of proliferation resistance issues of advanced fuels

★ **System Analysis of Nuclear Energy Development**



Proposals. Accumulation of RE nuclides

Why rare earth elements?

ANS meeting, Washington DC, November 17-21, 2002

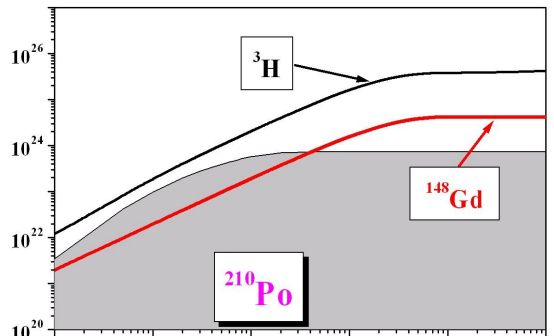
“¹⁴⁸Gd Production Cross Section Measurements for Accelerator Target Facilities”, *Karen Corzine, Eric Pitcher, Matt Devlin (LANL), Nolan Hertel (Georgia Tech) p.542*

“The activity level of ¹⁴⁸Gd is small, but it encompasses almost two thirds of the total dose burden in the LANSCE facilities based on present yield estimates.”

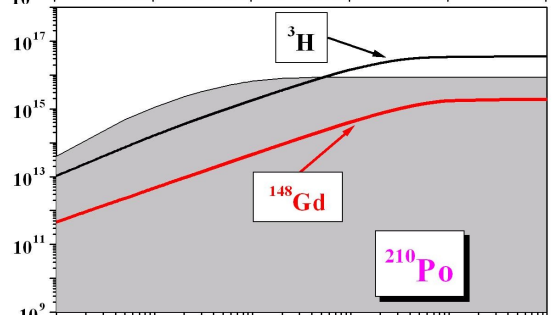


Proposals. Accumulation of RE nuclides

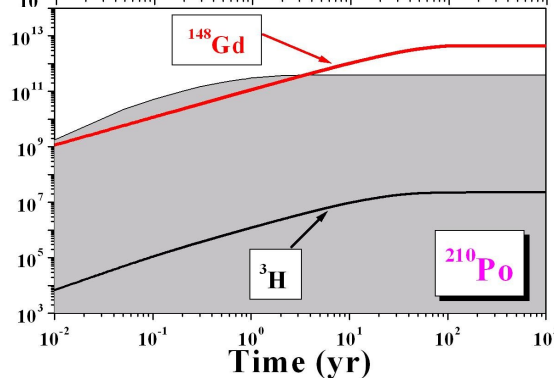
Inventory (at.)



Activity (Bq)



Toxicity (ALI)



Pb-Bi target
Proton beam: 1 GeV,
10 mA*

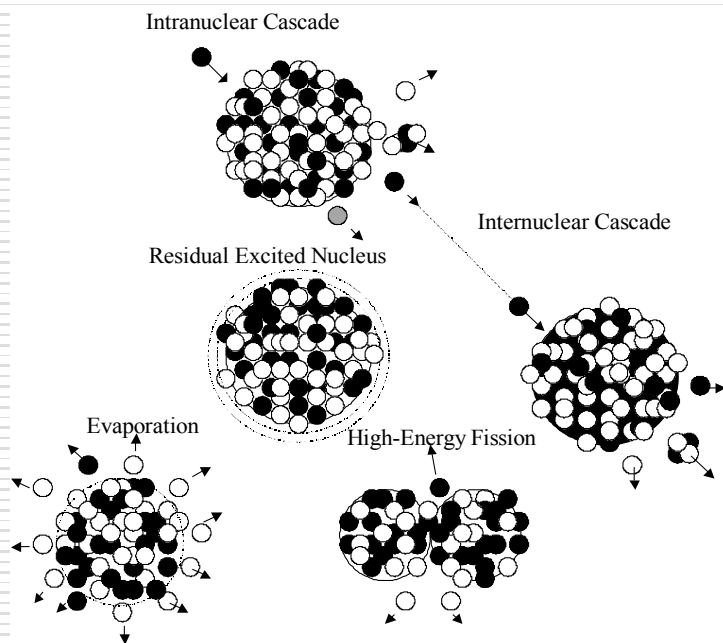
M.Saito, A.Stankovsky,
V.Artisyuk, Yu.Korovin,
A.Shmelev, Yu.Titarenko,
Radiological Hazard of Spallation
Products in Accelerator-Driven
System, *Nuclear Science and
Engineering*, **142** (2002) p.22-36



Proposals. Accumulation of RE nuclides

Characteristics of the predecessors of RE alpha-emitters accumulated in various targets irradiated by 1.6 GeV protons

On Mechanism of Rare Earths' Accumulation



Characteristics of predecessor	Target		
	Tungsten	Lead	Uranium
Fragment: ^{146}Sm			
Yield (at/p)	8.3×10^{-4}	2.1×10^{-4}	4.3×10^{-5}
$\langle Z \rangle$	70.0	76.7	88.0
$\langle A \rangle$	174.2	193.8	222.1
$\langle E_{\text{exc}} \rangle$	342.6	582.4	1005.3
Fragment: ^{148}Gd			
Yield (at/p)	3.4×10^{-3}	8.8×10^{-4}	8.7×10^{-5}
$\langle Z \rangle$	70.5	77.6	89.5
$\langle A \rangle$	175.2	194.3	223.9
$\langle E_{\text{exc}} \rangle$	314.1	551.3	979.2

*Probability to have an excitation energies around 1 GeV (uranium case) is much less than few hundred MeV (tungsten case) needed to evaporate enough nucleons and finally produce RE isotopes. It gives an additional argument that **rare earths are the final fragments of evaporation process from excited state after intranuclear cascade reaction***

Proposals. Accumulation of RE nuclides

Current Status

In view of insufficient experimental data on their yield in ADS target materials, computer simulation remains to be of importance.

Computer codes reveal a large discrepancy particularly in the region of Rare Earths.

Improvement of the models for high energy interactions is a must.



Proposals. Accumulation of RE nuclides



PROJECT PROPOSAL

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I. Summary Project Information

1. Project Title and Taxonomy

Full title: "Analysis of Spallation Products' effect on the Accelerator- Driven Systems' safety and adjacent fuel cycle "

Short title: "Analysis of Spallation Products' effect on the ADS safety "

Technology area: FIR-FUC, FIR-FUE, FIR-MOD, FIR-REA, FUS-HSF, FIR-NSS

Category of technology development: Applied investigations



Proposals. Accumulation of RE nuclides

The project necessitates

Review of available experimental data focusing rare earth accumulation in spallation targets;
The improvement of existing (cascade-preequilibrium-evaporation) and development of new nuclear models to meet the agreement with experimental data available;

Scoping neutronics studies with available data to outline the domain of rare earth effect on neutronics;

Identification of rare earth nuclides with high potential effect on ADS neutronics through trial calculations with nuclear data available for nuclides with similar nuclear properties;

Formation of evaluated nuclear data files for identified important nuclides.

As an important outcome, the project brings

The domain of beam (energy and current) and target (composition and dimensions) parameters sensitive to rare earths accumulation from the viewpoint of nuclear safety;

Recommendation of requirements to the accuracy of the rare earths' nuclear data;

Elaboration on and development of benchmark model with addition of spallation products for calculational analysis with use of various codes and nuclear databases.



Proposals. Improvement of nuclear models at intermediate and high energies

Nowadays, a lot of efforts is directed to improve:

CEM model at LANL

INCL4 model at CEA Saclay & Univ. of Liège

However...



Proposals. Improvement of nuclear models at intermediate and high energies

New version of IEAF-2005 activation library will be released soon*

682 files including 70 files for nuclides in 1st isomeric state and 5 files for nuclides in 2nd isomeric state ($T_{1/2} \geq 10$ min.)

Nuclides: from $Z=1$ up to $Z=84$ (1-H-1 – 84-Bi -210)

Energy: up to 1 GeV

Evaluations in the energy region 150 MeV – 1 GeV were performed in INPE Obninsk

** Intermediate Energy Activation File, In the framework of collaboration with Forschungszentrum Karlsruhe Institut für Reaktorsicherheit*



Proposals. Improvement of nuclear models at intermediate and high energies

Criteria for analysis of various INC/Preequilibrium/evaporation models

Basis: all the available in EXFOR experiment data on interactions of neutrons and protons with materials at the energies up to 1 GeV

* Deviation criteria analysis by means of:

$$H = \sqrt{\frac{1}{N} \sum_{i=1}^N \left(\frac{\sigma_i^{\text{exp}} - \sigma_i^{\text{cacl}}}{\Delta \sigma_i^{\text{exp}}} \right)^2}$$

$$F = 10 \sqrt{\frac{1}{N} \sum_{i=1}^N \left(\lg \sigma_i^{\text{exp}} - \lg \sigma_i^{\text{calc}} \right)^2}$$

* Correlation matrix analysis



Proposals. Improvement of nuclear models at intermediate and high energies

Deviation criteria analysis

Target nuclei range (ascending of ^A)	Recommended models
1-H-1 - 2-He-4	MCNPX interpolation tables & evaluation
3-Li-6 - 10-Ne-22	ISABEL/ Dresner
11-Na-23 - 13-Al-27	INCL4/Dresner
12-Mg-28 - 27-Co-55	CASCADE/INPE
29-Cu-56 - 28-Ni-59	Bertini/ Dresner
26-Fe-60 - 40-Zr-89	CASCADE/INPE
38-Sr-90 - 54-Xe-124	INCL4/ Dresner +
50-Sn-125 - 75-Re-181	CASCADE CEM2K
72-Hf-182 - 84-Po-210	CASCADE/INPE



Proposals. Improvement of nuclear models at intermediate and high energies

Correlation matrix analysis for nuclei with A=4-210

$$D = \left| \frac{\sigma_i^{calc} - \sigma_i^{exp}}{\sigma_i^{exp}} \right|$$

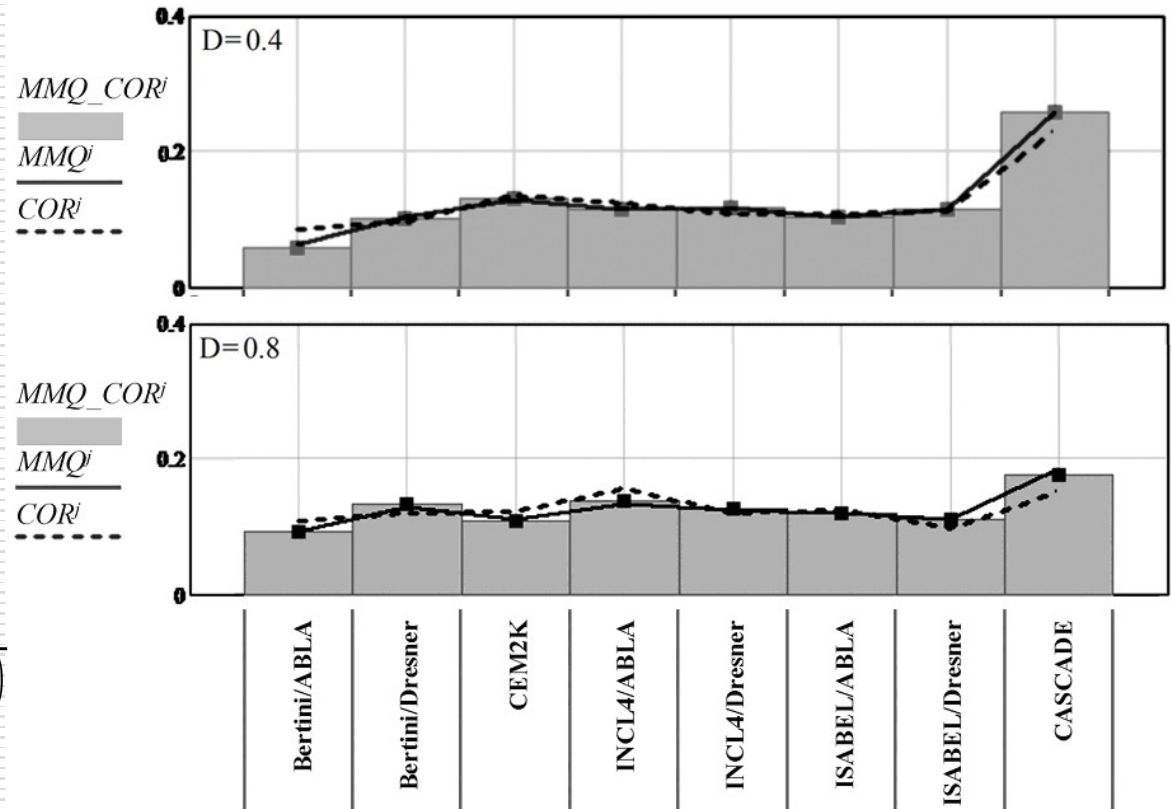
Least-squares method

$$MMQ_j = \sum_{k=1}^{k_{max}} \left(\sum_{i=1}^{i_{max}} (\sigma_{expik} - \sigma_{calcik})^2 \right)^{-1}$$

Correlation method

$$COR_j = \sum_{k=1}^{k_{max}} \frac{c \text{ var}(\sigma_{expk} \sigma_{calck})}{\text{stdev}(\sigma_{expk}) \text{stdev}(\sigma_k)}$$

$$MMQ_COR_j = MMQ_j * COR_j$$



Proposals. Improvement of nuclear models at intermediate and high energies

Correlation matrix analysis

Target nuclei range (ascending of A)	Recommended models
6-C-12 - 10-Ne-22	INCL4/Dresner
11-Na-23 - 13-Al-27	CEM2K
12-Mg-28 - 27-Co-55	CASCADE/INPE
29-Cu-56 - 28-Ni-59	ISABEL/ Dresner
26-Fe-60 - 40-Zr-89	CASCADE/INPE
38-Sr-90 - 54-Xe-124	CASCADE/INPE
50-Sn-125 - 75-Re-181	ISABEL/ ABLA
72-Hf-182 - 84-Po-210	CASCADE/INPE

CASCADE/INPE reveals high competitiveness !



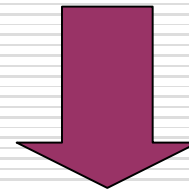
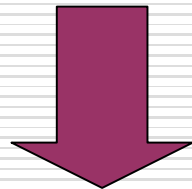
Proposals. Development of models for radiation damage studies

Models for Radiation Damage Calculations

The radiation damage characteristics might be calculated by using of NJOY code. It uses the NRT formulas for the calculation of the damage energy.

But such calculation is not correct for:

- the light secondary ions at the energies, where electronic loss is not proportional to $E^{1/2}$
- the case of noticeable difference between Z and A for the secondary ion and material
- compounds



The IOTA (Ion Transport in Materials) has been developed



Proposals. Development of models for radiation damage studies

The code ***IOTA*** was developed to obtain the total number of primary defects created in materials, the displacement cross-section and the space defect distribution. The simulation of the ion movement in the media is performed **with the help of the different approaches:**

- ***binary collision approximation (BCA)***
- ***Monte Carlo method.***

The experimental data for ion stopping power are used for the calculation. Besides that, the special edition of the ***IOTA*** code allows to consider the inelastic nuclear interactions of the primary protons with materials. It uses the inelastic displacement cross-sections calculated with the help of the intranuclear cascade evaporation model for a wide number of materials



Proposals. Proliferation resistance



PROJECT PROPOSAL

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I. Summary Project Information

1. Project Title and Taxonomy

Full title: "Proliferation resistance issues of advanced fuels with increased fraction of light even uranium isotopes U-234"

Short title: "Proliferation resistance "

Technology area: FIR-FUC, FIR-FUE, FIR-MOD, FIR-REA, FUS-HSF, FIR-NSS

Category of technology development: Applied investigations



Proposals. Proliferation Resistance

Basic Ideas

Critical mass of U-234 is almost **order of magnitude** less than that of 20% enriched Uranium;
Significant amounts of U-234 expected to appear in Thorium-Uranium fuel cycle and in advanced fuel cycles supplemented with transmutation of Minor Actinides (through decay of Pu-238 - the dominant isotope in the isotopic mix at equilibrium cycle)

Basic Requirements

Preparation of evaluated nuclear data files for identified important nuclides.

Main Outcomes

Evaluation of proliferation resistance properties of U-234 doped fuels
Recommendation to fuel form and details of out-of-reactor fuel management.



Proposals. System Analysis of Nuclear Energy Development

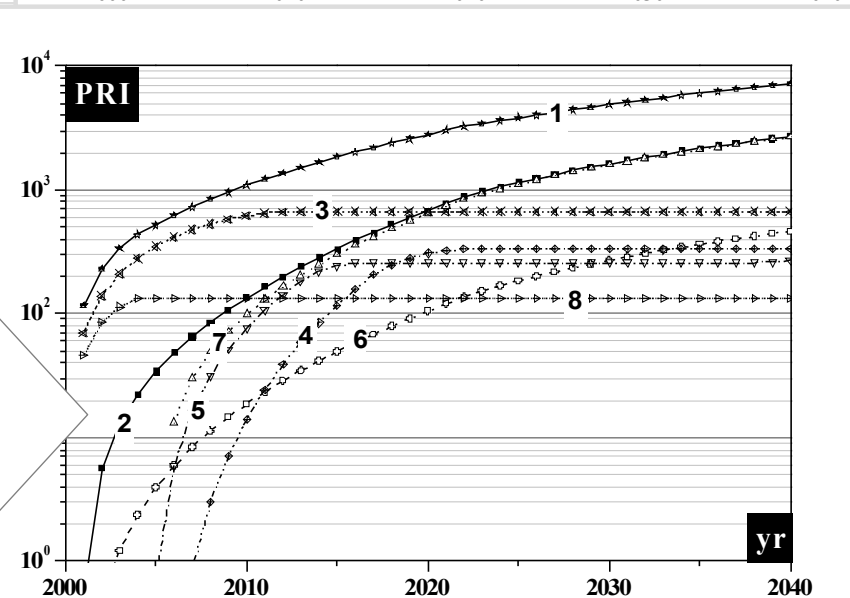
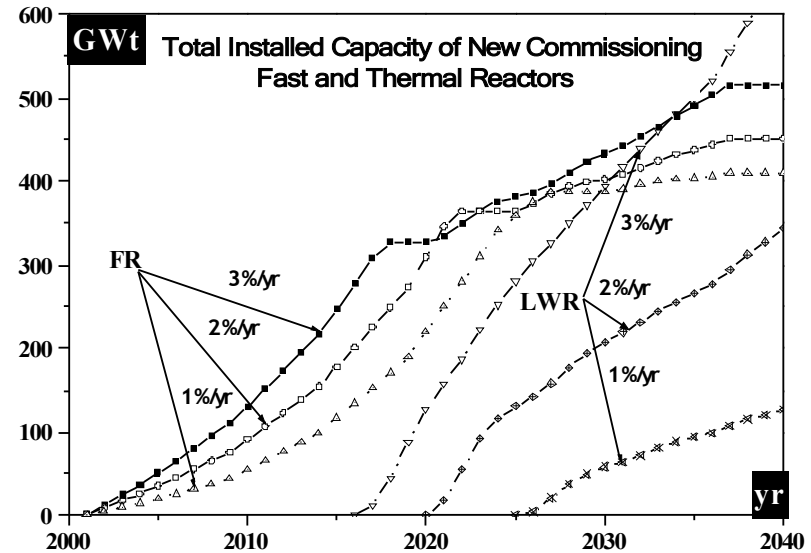
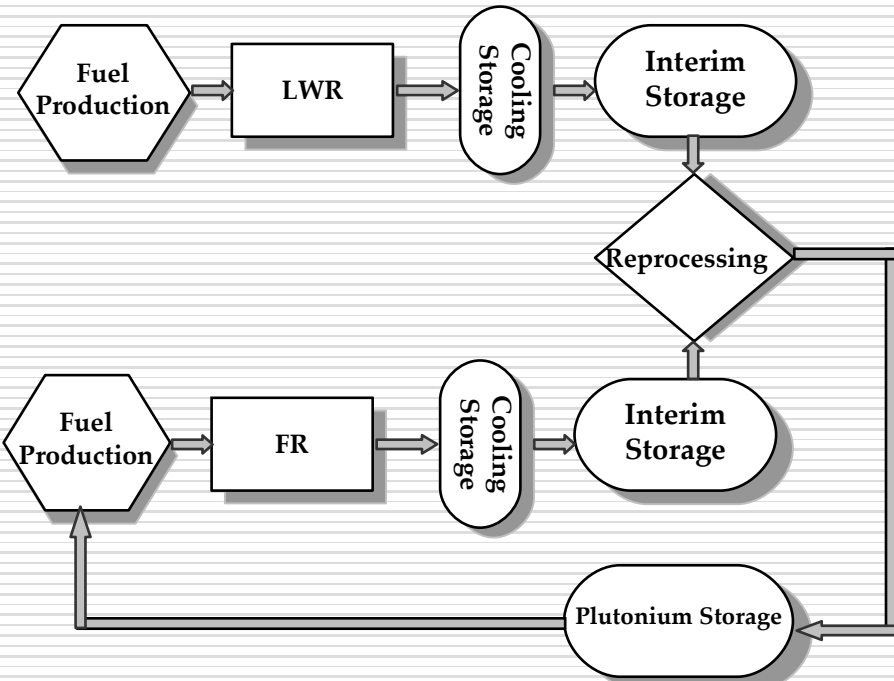
Optimization of the nuclear power structure and strategy of fissile materials management in the regional and global NFC from the economics, nonproliferation and waste management viewpoint.

- **MESSEGE V**
- **DESAE**
- **SIMPACT**
- **ENPEP**
- **a couple of INPE models**



Proposals. System Analysis of Nuclear Energy Development

MINIMIZATION OF PROLIFERATION RISK EXPOSURE ON THE PHASE OF TRANSITION TO TWO-COMPONENT NUCLEAR POWER SYSTEM



Proliferation risk index:

- 1 - cumulative production
- 2 - MOX fuel
- 3 - storage of collected SNF
- 4 - storage of FR's SNF
- 5 - storage of LWR's SNF
- 6 - irradiation in FR
- 7 - reprocessing of SNF
- 8 - storage of

In the end...

Freeman DYSON

”The fundamental problem of the nuclear industry is not reactor safety, not waste disposal, not the dangers of nuclear proliferation, real though all these problems are.

The fundamental problem of the industry is that nobody any longer has any fun building reactors.

... The spirit of the schoolhouse did not prevail....

And so the really good reactors were never invented”.

Disturbing the universe. (p.104-106)
Harper and row publication (1979)



In the end...

**Thank You
for Your attention...**

