PROPOSAL FOR A COORDINATED RESEARCH PROGRAMME

(Revision after approval by CCSS and contacts with potential participants)

1. Proposed Title of Programme

Fission Product Yield Data Required for Transmutation of Minor Actinide Nuclear Waste.

2. Introduction

This CRP was proposed (working paper INDC/P(95)-18) and endorsed at the 20th meeting of the International Nuclear Data Committee (INDC) in 1995. An IAEA Consultants Meeting (Vienna, 17-18 October 1996) reviewed the transmutation concepts and yield requirements and defined the scope and tasks of this CRP. Following a recommendation of the INDC, the proposed goal of this CRP has been coordinated with the efforts of the NEA International Evaluation Cooperation in the field of transmutation of waste.

3. Scientific Background

3.1. Transmutation concepts

Several concepts for transmutation of nuclear waste have been proposed, using classical thermal or fast fission reactors as incinerators, or accelerator driven systems. These concepts are being studied with regard to their feasibility, neutron economics, environmental safety, etc. For these studies, nuclear data including fission yields are required.

Details on the transmutation systems and the yield requirements are given in **Appendix 1**. The yield requirements in summary: for thermal reactors, only thermal fission yields; for fast reactors, yields for typical fast reactor spectra with an extrapolation formula up to 20 MeV; for accelerator driven systems, fission yields up to 150 MeV.

Fission yields are needed, in all systems, for the calculation of: neutron economy, reactor kinetics, decay heat and inventory (burnup, toxicity, loss of reactivity). For minor actinides they are also needed for feasibility studies. The minor actinides considered depend on the studies performed: from about 10 important ones (Np-237 to Cm-245) to about 100 from Rn-222 to Lr-258 (for details see **Appendix 1**).

3.2. New approach to evaluation of fission yields

Users doing calculations in the field of nuclear transmutation have to be able to obtain, from evaluations, **fission yields for any desired fissioning nuclide at any desired energy up to 150 MeV**. This requires a new approach to fission yield evaluation.

For the development and realization of this new approach to fission yield evaluation, it has to be borne in mind that for certain targets, fission yield measurements are impossible, and for other targets, measurements at certain (higher) energies are at least extremely difficult. Therefore it is necessary to develop, from relatively few measurements, **fission yield systematics** to estimate the yields over a wide range of fissioning nuclides and the energy range from thermal to 150 MeV. The accuracies of these estimates will of course be poorer where experimental data are lacking. However, for many of the fissioning nuclides considered, namely those present in only small quantities, the accuracy requirements are not very high.

For the **development of the nuclear model** for the yield systematics, the following points have to be considered:

- Existing empirical models for charge, mass and energy distributions have to be further developed and modified.
- Measurements of neutron induced fission yields for certain targets at several energy points are needed to derive the systematics and model parameters.
- Results from charged particle induced fission and photofission (where measurements are often easier), leading to the same compound nuclei as the corresponding neutron induced fission, could provide valuable information for the development of the systematics.
- Due to multiple chance fission, measured yield distributions at higher energies result from a mixture of fissioning nuclides, which has to be accounted for in the systematics.

3.3. Existing fission yield data

Evaluated data are not available for the required energy range. The current data situation can be summarized as follows:

- Energy dependent data exist only up to 14 MeV neutron energy.
- Yield files are available only for thermal and fast neutron fission, for some targets also for spontaneous and 14 MeV neutron induced fission.
- Yield sets for minor actinides are incomplete.
- There are no tools yet available to allow the calculation of yields at all energies from 14 to 150 MeV neutron energy (~ 20-150 MeV excitation energy).

Existing **experimental data** are insufficient for energies above thermal and practically non-existent above 20 MeV. Further measurements are indispensable. Since these are easier and more frequent for the ’major’ actinides, these have to be included in the development of the systematics.

4. Scientific scope and proposed programme goals

The **goal of the CRP** is to develop fission yield systematics and nuclear models as a tool for an evaluation of energy dependent fission yields up to 150 MeV. A computer code will be developed/adapted that will allow the calculation of fission yields for any given actinide at any desired neutron energy, although with varying accuracy.

In order to start the work in the CRP effectively, participants of the preparatory consultants' meeting who are interested in participating in the CRP, have agreed to do the following **preparatory work**:

- Collect all available experimental data for neutron, photon and charged particle induced fission and review them for drafting recommendations of further measurements required for the CRP work.
- Work out proposals for the presentation of the results and final publication.

The tasks to be performed during the CRP are:

4a Study the problem of multiple chance fission at higher energies and find solutions how to account for it in systematics and calculated yields.
4b Study the differences between neutron and charged particle induced and photofission reactions, the possibility of and corrections needed for their combined use in systematics.
4c Study cascade and evaporation models used for higher energies, together with the models developed during the previous CRP:
4d Goverdovsky's model for the energy dependence of yields,
4e Wahl's mass and charge distribution models, and
4f Rudstam's isomeric yield model.
Elaborate the necessary adaptions of models and parameters.
4g Analysis of the experimental data for neutron, photon and charged particle induced fission with respect to their use in the development of the above models.
4h Performance of selected key measurements.
4i With the results of all these studies, develop systematics for the dependence of fission yields on (Z,A) of fissioning nuclides and neutron energies up to 150 MeV.
4j Recommend a specific computer program (possibly that of A. Wahl after adaption) and parameter database for use in actual yield evaluations.

Further tasks:

4k Evaluation of further reference yield sets and yields for monitor fission products.

4l Checks for discrepancies among evaluations.

4m Assessment of accuracy of applied transmutation calculations.

5. Participating institutes

The following institutes have shown their interest in participation and could make valuable contributions to this CRP:

Belarus (INP, Minsk): V. Maslov (contract)
China (CNDC, Bejing): Liu Tingjin (contract)
France (CEA Cadarache): F. Storrer (agreement)
Germany (Uni. Mainz): H.O. Denschlag (agreement)
Japan: contact A. Hasegawa (JAERI/INDC member)
The Netherlands (ECN Petten): A. Koning (agreement)
Russia (IPPE, Obninsk): A.A. Goverdovsky (contract)
Sweden (Uppsala Uni.): G. Rudstam (agreement)
Ukraine (Inst. Nucl. Res.): Y. Kibkalo (contract)
U.K. (BNFL Sellafield): R. Mills (agreement)
U.S.A. (LANL): W.B. Wilson (agreement)
(Washington Uni.): A.C. Wahl (agreement)

Possible task assignments to participants and details on their contributions are suggested in **Appendix 2**.

6. Implications for the future

(a) Estimated duration of the programme: 4 years, starting in November 1997.

(b) Co-ordination meetings planned:

1st Co-ordination meeting: November 1997
2nd Co-ordination meeting: autumn 1999
3rd Co-ordination meeting: autumn 2001

7. Estimated programme costs

(a) for research contracts (per annum):

3 contracts, US$ 4,000 each = US$ 12,000

(b) For meetings:

3 RCMs at an estimated cost of US$ 21,000 (current value)

(c) Summary of estimated costs (in US$):

Year	Contracts	RCM
1997		21,000
1998	12,000	
1999	12,000	21,000
2000	12,000	
2001	12,000	21,000
Total	**48,000**	**63,000**

Total cost of CRP 1997-2001: US$ 111,000

8. Action requested of the committee

Approve the programme in principle and consider individual proposals as they are received.

9. Brief summary for inclusion in the Agency's Bulletin

The goal of the CRP is to develop tools for the evaluation of fission yields for any actinide at any neutron energy from thermal up to 150 MeV. To achieve this goal, relevant theories will be studied, systematics of fission yields covering all actinides and neutron energies up to 150 MeV developed, existing models for mass, charge and energy distributions of fission yields adapted to the needs, and computer programs developed that allow the calculation of the desired yields.

Appendix 1

Transmutation Concepts

Fission yields for fissionable nuclides constituting the reactor fuel are needed, in all systems enlisted below, for the calculation of:

- neutron economy
- reactor kinetics
- decay heat
- inventory (burnup, toxicity, loss of reactivity)

<u>Thermal reactors</u>

In thermal reactors, transmutation by neutron capture is the dominant process, and the capture and (subsequent) decay products are incinerated by fission. Thermal fission yields, which are sufficiently well known, are used in the calculations.

<u>Fast reactors</u>

In fast reactors, all actinides are incinerated by fission. The nuclides to be considered are very much the same as in thermal reactors, and the fission yields up to 14 MeV neutron energy are well known. The CRP will address the development of an extrapolation formula that is valid up to 20 MeV.

<u>Accelerator driven systems</u>

These systems use spallation reactions induced generally by high energy (about 1 GeV) protons from an accelerator. Particles including neutrons up to high energies (>20 MeV) are emitted in the first stage (intranuclear cascade phase and pre-equilibrium phase) of the spallation reaction, while most of the low energy (<20 MeV) neutrons are emitted in the second (evaporation/deexitation) stage. These neutrons induce further spallation reactions in thick targets.

Accelerator driven systems using thermal neutrons

This concept uses Th-232 and U-233 as fuel (minor actinides see below). The extended extrapolation formula developed for fast reactors (see above) will also be applied to these nuclides up to 20 MeV.

Accelerator driven systems using fast neutrons

For these concepts, fission yields as a function of neutron energy are needed **from thermal energy to 150 MeV** for all fissionable nuclides given for all other systems above.

Minor actinides

Altogether, fission yields are needed as a function of neutron energy from thermal energy to 150 MeV, for the calculations enlisted at the beginning of this part as well as for feasibility studies. The minor actinides considered depend on the studies performed: those listed in the table below are from a NEA survey [1], whereas a LANL study [2] gives about 100 from Rn-222 to Lr-258. The importance of minor actinide yields depend on their relative concentration.

The table below gives a survey of the energy ranges of fission yields as used in transmutation calculations for various transmutation concepts according to [1].

Yields used in transmutation calculations

	Thermal		Accelerator driven systems		
Nuclide	reactor	fast reactor	thermal	fast	overall
Th-232			0-20 MeV	0-150 MeV	0-150 MeV
U-233			0-20 MeV	0-150 MeV	0-150 MeV
U-235	thermal	fast, 0.1-20 MeV		0-150 MeV	0-150 MeV
U-238		fast, 0.1-20 MeV		0-150 MeV	0-150 MeV
Np-237		fast, 0.1-20 MeV		0-150 MeV	0-150 MeV
Pu-238	thermal	fast, 0.1-20 MeV		0-150 MeV	0-150 MeV
Pu-239	thermal	fast, 0.1-20 MeV		0-150 MeV	0-150 MeV
Pu-240		fast, 0.1-20 MeV		0-150 MeV	0-150 MeV
Pu-241	thermal	fast, 0.1-20 MeV		0-150 MeV	0-150 MeV
Pu-242		fast, 0.1-20 MeV		0-150 MeV	0-150 MeV
Am-241		fast, 0.1-20 MeV	0-20 MeV	0-150 MeV	0-150 MeV
Am-242	thermal	fast, 0.1-20 MeV	0-20 MeV	0-150 MeV	0-150 MeV
Am-242m	thermal	fast, 0.1-20 MeV	0-20 MeV	0-150 MeV	0-150 MeV
Am-243		fast, 0.1-20 MeV	0-20 MeV	0-150 MeV	0-150 MeV
Cm-243	thermal	fast, 0.1-20 MeV	0-20 MeV	0-150 MeV	0-150 MeV
Cm-244		fast, 0.1-20 MeV	0-20 MeV	0-150 MeV	0-150 MeV
Cm-245	thermal	fast, 0.1-20 MeV	0-20 MeV	0-150 MeV	0-150 MeV
other					0-150 MeV

References

[1] 'Overview of Physics Aspects of Different Transmutation Concepts', report NEA/NSC/DOC(94)11, 1994.
[2] Calculation by W.B.Wilson, LANL, private communication by T.R. England to M. Lammer; results included in working paper INDC/P(95)-18.

Appendix 2

Envisaged distribution of tasks among potential participants

It has to be borne in mind that only a restricted number of participants will be selected by the IAEA on the basis of the submitted agreement/contract proposals and their expected activities during the duration of the CRP.

Survey of possible task assignments to participants

The numbers of tasks given in the table correspond to those assigned to the tasks listed in section 4.

Participant	File	Measurements		Theory/models						Evaluation		Other		
		4g	4h	4a	4b	4c	4d	4e	4f	4i	4j	4k	4l	
Denschlag		x			x									
Goverdovsky		x	x				x			x	x			
Kibkalo				x	x	x	x			x	x			
Koning		x	x			x								x
Liang	CENDL											x	x	
Maslov				x	x	x	x			x	x			
Mills	UKFY/ JEFF										x		x	
Rudstam			x						x					
Storrer													x	x
Wahl	fractional yields	x						x		x	x			
Wilson	ENDF/B		x			x					x			x

Details of the tasks assigned to participants

Evaluators of fission yield files

W.B. Wilson: ENDF/B fission yield file (together with T.R. England); also: model calculations; applied transmutation calculations.

R.W. Mills: UKFY = JEF(F) yield file (link to NEA); also: analysis of measurements, file intercomparisons.

Liang (together with Liu T.): CENDL file; also: correlations and covariances; reference yield sets; monitor fission products.

A.C. Wahl: evaluation of (fractional independent yields; the obtained charge distribution parameters are used in the other evaluations.

Development of nuclear models and systematics

A.C. Wahl: models for mass and charge distributions; systematics for energy dependence and fissioning nuclide; computer programs to calculate any desired yield distribution.

A.A. Goverdovsky: model and systematics for energy dependence of yields; yield measurements up to 30 MeV;

G. Rudstam: model for isomeric yield ratios;

V. Maslov, Y. Kibkalo (not fixed/contacted yet): theoretical analysis and calculations: models for high energy fission, multichance fission, charged particle induced and photo-fission; (cooperation) systematics for energy dependence.

Other CRP tasks

H.O. Denschlag: analysis of experiments, comparison of neutron, charged particle induced and photofission.

A. Koning: high-energy fission measurements, theory and models; expert for transmutation (applied), link to NEA task force.

F. Storrer: yield files validation and intercomparison; transmutation expert (applied), link to NEA.