IAEA-RC-1003.1

TWG-FR/127

LIMITED DISTRIBUTION

WORKING MATERIAL

Research Coordination Meeting of the Coordinated Research Project on

"Analytical and Experimental Benchmark Analyses of Accelerator Driven Systems"

hosted at the

Belarus National Academy of Sciences in Minsk

by the

Joint Institute of Power Engineering and Nuclear Research "SOSNY"

5 – 9 December 2005

Reproduced by the IAEA
Vienna, Austria, 2006

CONTENTS

INTERNATIONAL ATOMIC ENERGY AGENCY

Technical Meeting (Research Co-ordination Meeting) of the Coordinated Research Project (CRP) on "Analytical and Experimental Benchmark Analyses of Accelerator Driven Systems"

hosted at the

Belarus National Academy of Sciences in Minsk

by the

Joint Institute of Power Engineering and Nuclear Research "SOSNY"

Meeting Report

INTRODUCTION AND BACKGROUND

The Technical Meeting hosted at the Belarus National Academy of Sciences in Minsk by the Joint Institute of Power Engineering and Nuclear Research “SOSNY” from 5-9 December 2005 was the kick-off Research Coordination Meeting (RCM) of the IAEA Coordinated Research Project (CRP) on “*Analytical and Experimental Benchmark Analyses of Accelerator Driven Systems (ADS)*”.

The CRP had received proposals for research agreements and contracts from scientists representing the following 25 institutions: Centro Atomico Bariloche, SCK CEN Mol, Instituto de Pesquisas Energéticas e Nucleares São Paulo, Joint Institute of Power Engineering and Nuclear Research SOSNY Minsk, China Institute of Atomic Energy, CEA Cadarache, CNRS Paris, FZ Rossendorf, FZ Karlsruhe, Budapest University of Technology and Economics, Politecnico di Torino, Japan Atomic Energy Agency, Nuclear Research and Consultancy Group (NRG) Petten, Pakistan Institute of Nuclear Science and Technology, AGH-University of Science and Technology Krakow, Institute of Atomic Energy Otwock/Swierk, ITEP Moscow, MEPHI Moscow, Kurchatov Institute, JINR Dubna, Universidad Politécnica de Madrid, CIEMAT Madrid, Royal Institute of Technology Stockholm, National Science Center “Kharkov Institute and Technology”, and Argonne National Laboratory). These institutions represent 18 IAEA Member States (i.e., Argentina, Belarus, Belgium, Brazil, China, France, Germany, Hungary, Italy, Japan, Netherlands, Pakistan, Poland, Russia, Spain, Sweden, Ukraine, USA), and one International Organization (JINR Dubna). The lsit of the CRP participants, including the names of the Chief Scientific Investigators (CSIs) and the contact email address are given in Table 1.

The **overall objective** of the CRP is contributing to the generic R&D efforts in various fields common to innovative fast neutron system development, i.e., heavy liquid metal thermal hydraulics, dedicated transmutation fuels and associated core designs, theoretical nuclear reaction models, measurement and evaluation of nuclear data for transmutation, and development and validation of calculational methods and codes. Ultimately, the CRP’s overall objective is to make contributions towards the realization of a transmutation demonstration facility.

The **specific objective** of the CRP is to improve the present understanding of the coupling of the ADS spallation source with the multiplicative sub-critical core.

As **outcome**, the CRP aims at advancing the efforts under way in the Member States towards the proof of practicality for ADS based transmutation by providing an information exchange and collaborative research framework needed to ensure that the tools to perform detailed ADS calculations, namely from the high energy proton beam down to thermal neutron energies, are available.

The CRP will address all major physics phenomena of the spallation source and its coupling to the sub-critical core. The participants will perform computational **and** experimental benchmark analyses using integrated calculation schemes and simulation methods. Apart from analytical benchmark exercises, the CRP will integrate some of the planned experimental demonstration projects of the coupling at power between a sub-critical core and a spallation source (e.g., YALINA Booster in Belarus and SAD at JINR, Dubna).

After the hosts’ welcome conveyed by Prof. Viacheslav I. Kushinov from the Joint Institute for Power and Nuclear Research - SOSNY, and by Academician Petr A. Vitiaz**,** First Vice-Chairman of the National Academy of Sciences of Belarus, the self-introduction by the participants and the selection of Dr. Hamid Aït-Abderrahim (SCK•CEN, Mol) as chairperson, the Scientific

Secretary of IAEA's Technical Working Group on Fast Reactors (TWG-FR) summarized scope, objectives and implementation plan of the CRP.

The estimated duration of the CRP is 5 years. Following the establishment, during 2004, of the international CRP team by putting in place research agreements and contracts, and after convening this kick-off research RCM, the implementation plan of the CRP foresees three more RCMs (in 2007, 2008, and 2009, respectively), and the publication of the final report in 2010.

OBJECTIVES OF THE KICK-OFF RCM

The objectives of the 1st RCM of the CRP were to

— Review the status of analytical and experimental work performed in the participants' organizations in the field of transmutation R&D

— Agree upon the topical areas to be covered by the CRP, including the identification of the experiments to be considered for the experimental benchmark exercises

— Identify lead organisations among the CRP participants for each of the topical areas

— Propose, discuss and agree upon the various analytical and experimental benchmark exercises to be performed within the framework of the CRP

— Produce an agreed upon definition of detailed tasks as well as work plans and deadlines for completing the agreed upon analytical and experimental benchmark exercises

— Identify interest and participants in each benchmark task

— Clarify responsibilities for competing tasks

RESULTS OF THE RCM

The meeting discussed 17 different benchmark exercise proposals. Table 2 provides a summary of the proposals, describing with the help of a few key words the proposed benchmark's topic, indicating the institution that proposed it and the tally of institutions expressing interest (X mark) and potential interest (? Mark). Out of these proposals, the meeting decided to retain (at least for a first stage of the CRP) 7 benchmark exercises, which are summarized in Table 3. In some cases, the retained benchmark exercises are pooling together and/or consolidating proposals that are aimed at similar objectives.

1. YALINA Booster

This benchmark exercise comprises measurements and analyses of various YALINA Booster configurations.

2. Spallation target

This benchmark will deal with spallation target parametric studies including experimental validation.

3. High Energy Particles and Shielding

These benchmark exercises are centred on the FEAT and TARC experiments performed at CERN. For the former, the benchmarks will focus mainly on energy dependence and source efficiency issues; for the latter on the analysis of neutron fluence and ^{99}Tc transmutation experimental data. SAD shielding simulation studies will also be part of this CRP topic.

4. Analytical and Numerical Benchmarks

Both analytical and numerical benchmarks will be defined for kinetics problems of source driven sub-critical systems. The former will deal with simplified configurations that can be tackled by purely analytical approaches, while the latter will address solutions to kinetics problems of source driven sub-critical systems obtained by numerical methods.

5. KUCA

This CRP topic comprises benchmarks defined around Kyoto University's Critical Assembly (KUCA). Currently, KUCA is equipped with a 14 MeV DT neutron source. Since 2002, the Fixed Field Alternate Gradient (FFAG) Accelerator project is being implemented at Kyoto University, which consists in the construction of a ~1 μA current proton accelerator with beam energy in the range 20 to 150 MeV, and in experimental programmes at KUCA for ADS R&D (i.e., sub-critical configurations in KUCA driven by spallation targets that would utilize the FFAG accelerator beam). The benchmarks will comprise experimental and analytical analyses of both 14 MeV DT source and ~1 μA, 150 MeV proton beam induced spallation source experiments.

6. KIPT

These benchmark exercises will be centred on the neutron source facility planned at the Kharkov Institute for Theoretical Physics (KIPT). This facility is an electron accelerator based neutron source for ADS R&D. The benchmarks will comprise design analyses for the KIPT neutron source facility, and calculation vs. experiment comparisons for the target design.

7. ADS Performance

The objective of these benchmark exercises is twofold: the validation of ADS calculations of the performance of ADS (e.g., transmutation capabilities), and the validation of burnup methodologies and codes. An important aspect of these benchmark exercises is the experimental validation.

CONCLUSIONS, RECOMMENDATIONS AND ACTIONS

During the discussion of the various benchmark exercises, the meeting agreed that it was important that the CRP participants be aware that the value of the benchmark analyses will be greatly enhanced if their results would allow providing general recommendations with regard to the methodology (availability, state of validation, open issues, etc) for analysing external neutron driven sub-critical systems. As an example, the meeting discussed the type of general recommendations expected from the Yalina Booster benchmarks as far as space effects and the definition/interpretation of kinetic parameters are concerned.

Benchmark # 6 (KIPT) will cover two aspects: benchmarking and validating the methodology (in particular with regard to the target design), and design analyses of the coupled electron beam – sub-critical core facility.

The proposals made by the AGH-University of Science and Technology Krakow (benchmark exercises to validate the methodology used to calculate target activation) will be considered together with the JINR Dubna proposals (polonium activation of lead-bismuth targets) within the framework of the SAD benchmarks (Benchmark #3).

The proposal made by the Budapest University of Technology and Economics, BUTE (Monte Carlo and deterministic "energy coupling methodology") will be tested within the framework of the SAD shielding benchmark (Benchmark #3).

An important component of Benchmark #7 (ADS Performance) is the validation of burnup codes and procedures used for external neutron driven sub-critical systems. The meeting participants emphasised that a meaningful validation of these methods requires comparison with experimental data. Thus, an action item (see below) was defined to investigate the availability of experimental data in this area. The same applies for the IBR-30 benchmark exercise (also intended to be part of Benchmark #7): the availability of facility descriptions and experimental data has to be investigated.

The meeting established (see Table 4) an initial list of actions and activities for each of the 7 proposed benchmark exercises, including identifying the person primarily responsible (of course, in cooperation with the benchmark coordinator(s), see Table 3). It was agreed to have those items discussed and clarified/agreed by end of February 2006.

In addition, the following, more general action list was decided by the meeting participants:

— Clarify participation of Kyoto University as coordinator of Benchmark #5 (action on **K. Tsujimoto** who will provide the contact information and **A. Stanculescu** who will contact Kyoto University)

— The **benchmark coordinator(s)** agreed to deliver by **end of February 2006** the specifications of the respective benchmarks including data and codes to be used, the corresponding work programs (task lists, responsibilities, sharing of work) with intermediate milestones

— **A. Stanculescu** to organize a WWW based collaboration area for the CRP

— **V. Shvetsov** to provide detailed information about the availability of IBR-30 experimental data and its status (type of measurements, and ease of retrieving the experimental data)

— **H. Aït-Abderrahim** to inquire about the possibility of obtaining EFIT design data for consideration in Benchmark #7

— **H. Aït-Abderrahim** to inquire about the possibility of obtaining PROFIL and ARIAN experimental data for consideration in Benchmark #7

— **A. Stanculescu** to contact CEA (Jean-Paul Grouiller) about the possibility of obtaining PROFILE experimental data for consideration in Benchmark #7

— The **second RCM** is planned for March 2007.

TABLE 1.

Matrix of the proposed Benchmarks for CRP on "Analytical and Experimental Benchmark Analyses of Accelerator Driven Systems (ADS)"

Benchmark Proposals

				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
				IBR-30	**Shield SAD**	**YALINA Boost**	**Sp.Prod Po**	**Neut Yield**	**FEAT**	**TARC**	**ADS 800 MWth**	**KUCA 14 MeV/150 MeV**	**MARIA FP/MA Trans**	**Spall Targ charac**	**KIPT**	**Nuc.Data for MA**	**ADS Syst. Compar.**	**ADS Kin. Analitic. Bench**	**BU Codes Valid**	**MAKET Thick & thin target**
				JINR	JINR	JIPNR ANL KTH SCK-CEN	JINR AGH	Y. Korov	CERN/CIEMAT		JAEA	JAEA KUCA	IAE Otwock-świerk	ANL	ANL	KI	KI	PoliTo	FZK	ITEP
N°	**Institution**	**CSI**	**Country**																	
1	CNEA	Edmundo Lopasso	ARG																	
2	SCK-CEN	Hamid Aït	BEL			X			X	X		X		X				X	X	X
3	CNEN/IPEN/CEN	José Rubens	BRA			X	X	X						X		?		X	X	
4	NAS/JIPNR	Anna Kiyavitskaya	BYL			X			X	X			X		X					
5	CNNC/CIAE	Haihong Xia	CPR			X			X	X										
6	CEA	Christine Chabert	FRA								X									
7	CNRS	Annick Billebaud	FRA			X														
8	FZR	Klaus Noack	GER																	
9	FZK	Cornelis Broeders	GER		X	X	X	X	?	?		?		X		?	X	X	X	X
10	BUTE	Sandor Feher	HUN		?	X			X	X		?								
11	PoliTo	Piero Ravetto	ITA			X												X		
12	JAEA	Hiroyuki Oigawa	JPN			X			X	X	X	X		X						
13	NRG	Dírceau F. da Cruz	NEL			X			X	X		X							X	
14	PAEC/PINSTECH	Masood Iqbal	PAK			X					X	X			X					
15	AGH-UST	Stefan Taczanowski	POL		?		X												?	
16	IAE	Marcin Szuta	POL		X	X	X			X			X	X		X			X	X
17	ITEP	Yuri Titarenko	RUS		X	X			X		X			X			X			X
18	MEPHI	Vladimir Gribkov	RUS																	
19	KI/MUCATEX	Leonid Ponomarev	RUS			X		X	X	X		X		X		X	X	X		
20	JINR	Valery Shvetsov	INT	X	X															
21	UPM	Alberto Abanãdes	SPA			X			X	X	X									
22	CIEMAT	Enrique Gonzalez	SPA	?	?	X	X		X	X	?	?							?	
23	KTH	Waclaw Gudowski	SWE	X	X	X			X	X		X			X				X	
24	KIPT	Nikolai Shul'ga	UKR	X		X									X	X		X		
25	ANL	Yousri Gohar	USA	X		X	?					X		X	X				X	
26	JINR	Vladimir Buttsev	INT		X		X													
	Total Interest			4	6	19	6	3	11	11	5	7	2	8	5	3	3	6	7	4
	Interest + Potential			5	9	19	7	3	12	12	6	10	2	8	5	5	3	6	9	4

Technical Meeting
First Research Coordination Meeting of the Coordinated Research Project on "Analytical and Experimental Benchmark Analyses of Accelerator Driven Systems (ADS)"

Hosted by the

Joint Institute of Power Engineering and Nuclear Research "SOSNY"

5 – 9 December 2005, Minsk, Belarus

Draft Agenda

Background

Plutonium recycling in fast reactors, as well as incineration/transmutation of minor actinides and long-lived fission products in various hybrid reactor systems (e.g., ADS) offer promising waste management options. Several R&D programs in various IAEA Member States are actively pursuing such options.

The Coordinated Research Project (CRP) on “Analytical and Experimental Benchmark Analyses of Accelerator Driven Systems (ADS)” is assisting - in line with IAEA’s statutory objective expressed in Article II – the IAEA Member States’ activities in the area of advanced technology development for utilization and transmutation of actinides and long-lived fission products by providing an international umbrella for information exchange and collaborative R&D to pool resources and expertise. The CRP is being implemented within the framework of IAEA’s Nuclear Energy Department’s Technical Working Group on Fast Reactors (TWG-FR), in response to expressed Member States’ needs and advice received from the TWG-FR.

The CRP will contribute to the generic R&D efforts in various fields common to innovative fast neutron system development, i.e., heavy liquid metal thermal hydraulics, dedicated transmutation fuels and associated core designs, theoretical nuclear reaction models, measurement and evaluation of nuclear data for transmutation, and development and validation of calculational methods and codes. Apart from analytical benchmark exercises, it will integrate some of the planned experimental demonstration projects of the coupling at power between a sub-critical core and a neutron source (YALINA Booster in Belarus, RACE in the USA, and SAD at JINR, Dubna).

The specific objective of the CRP is to improve the present understanding of the coupling of an external neutron source (e.g., a spallation source in the case of the ADS) with a multiplicative sub-critical core, and to validate methodologies and calculational tools for the simulation and analysis of such systems. As outcome, the CRP aims at advancing the efforts under way in the Member States towards the proof of practicality for “transmutation machines” (e.g., ADS based transmutation concepts) by providing an information exchange and collaborative research framework needed to ensure that reliable tools to perform the detailed analyses of sub-critical systems driven by external neutron sources are available.

The main thrust of the CRP is given by ADS. However, transmutation concepts based on sub-critical cores driven by other external neutron sources are not excluded – in particular as regards the experimental benchmarking activities of the CRP, since there are a series of experimental demonstration projects using non spallation targets [e.g., (D,D) or (D,T) neutron sources, and photon-neutron sources based on electron accelerators].

For ADS, the CRP will address all major physics phenomena of the spallation source and its coupling to the sub-critical core. In the case of detailed ADS calculations, these analyses extend from the simulation of the high-energy proton beam down to thermal neutron energies in the sub-critical core. The participants will perform computational *and* experimental benchmark analyses using integrated calculation schemes and simulation methods.

The output from the CRP will be a final IAEA technical report summarizing the considered analytical and experimental benchmark exercises, and concluding on the validation status of integrated calculation and simulation schemes for transmutation concepts (e.g., ADS). It will also identify remaining open issues and R&D needs, and indicate a possible role for the Agency in the future. The CRP results will also be published in peer-reviewed journals and presented at international conferences.

The present meeting is the kick-off research coordination meeting (RCM). The main objectives for this kick-off RCM are as follows:

- Review the status of analytical and experimental work performed in the participants' organizations in the field of transmutation R&D
- Agree upon the topical areas to be covered by the CRP, including the identification of the experiments to be considered for the experimental benchmark exercises
- Identify lead organisations among the CRP participants for each of the topical areas
- Propose, discuss and agree upon the various analytical and experimental benchmark exercises to be performed within the framework of the CRP
- Produce an agreed upon definition of detailed tasks as well as work plans and deadlines for completing the agreed upon analytical and experimental benchmark exercises
- Identify interest and participants in each benchmark task
- Responsibilities for competing tasks
- Establish an outline and responsibilities for completion of the final IAEA technical report that will report the results of the CRP.

The estimated duration of the CRP is 5 years. It is planned to convene in 2007 and 2008 the 2nd and 3rd RCMs, respectively, to review progress to technical work and IAEA technical report preparation, and identify needed improvements and/or modifications to the tasks and/or work plans, also considering the status of the experimental programmes that will be considered within the scope of the CRP. The 4th (probably final) RCM is planned for 2009. This RCM will review the status of the technical work and perform an overall review of the CRP results, provide the final input to and finalize the draft of the IAEA technical report, identify open issues and R&D needs to resolve them, as well as the possible role of the Agency in doing this.

Meeting Agenda
Monday, 5 December 2005

1. Welcome by "SOSNY" and by IAEA
2. Self-introduction by participants
3. Selection of Chairperson and Rapporteur
4. Scope and objectives of the CRP (IAEA)
5. Review the status of analytical and experimental work performed in the participants' organizations in the field of transmutation R&D

Tuesday, 6 December 2005

6. Characteristics of ongoing and planned coupling experiments, possibilities and potential for inclusion into the CRP's work scope as experimental benchmark exercises
7. Presentation and discussion of the various proposals for CRP benchmark exercises (analytical and experimental)

Wednesday, 7 December 2005

8. Discussion of the various proposals for CRP benchmark exercises (analytical and experimental)
9. Review of the nuclear data and libraries that the participants plan to use
10. Review of the codes that the participants plan to use
11. Proposal, discussion and agreement upon the analytical and experimental benchmark exercises to be performed within the framework of the CRP (including benchmarks using the ADS User Library under development by the IAEA)

Thursday, 8 December 2005

12. Determine interest and participation in each benchmark exercise
13. Produce an agreed upon list of detailed tasks, as well as work plans and deadlines for the completion of the agreed upon tasks
14. Agreement on the CRP's Leading Scientific Investigator
15. Agreement on responsibilities for competing tasks
16. Agreement on the outline and responsibilities for completion of the final IAEA technical report that will report the results of the CRP

Friday, 9 December 2005

17. Final discussion and drafting of the RCM report

LIST OF PARTICIPANTS

Research Coordination Meeting of the CRP on
"Analytical and Experimental Benchmark Analyses of Accelerator Driven Systems (ADS)"

The Joint Institute of Power Engineering and Nuclear Research "SOSNY", Minsk, Belarus
5-9 December 2005

BELARUS

Ms. Anna KIYAVITSKAYA
Joint Institute for Power and Nuclear Research
JINPR-SOSNY
Academy of Sciences
220109 Minsk
BELARUS
Tel/Fax: ++375 17 299 47 12
Tel.: ++375 17 299 45 12
E-mail: anna@sosny.bas-net.by

Mr. Andrey FOKOV
Joint Institute for Power and Nuclear Research
JINPR-SOSNY
Academy of Sciences
220109 Minsk
BELARUS
Tel: +
E-mail: andrey@sosny.bas-net.by

Mr. Yurii FOKOV
Joint Institute for Power and Nuclear Research
JINPR-SOSNY
Academy of Sciences
220109 Minsk
BELARUS
Tel: + 375 17 299 43 33
E-mail: fokov@sosny.bas-net.by
Yurii_Fokov@tut.by

Mr. Anatoly KHILMANOVICH
Joint Institute for Power and Nuclear Research
JINPR-SOSNY
Academy of Sciences
220109 Minsk
BELARUS
E-mail: kholmanov@dragon.bas-net.by

Mr. Viacheslav KUSHINOV
Joint Institute for Power and Nuclear Research
JINPR-SOSNY
Academy of Sciences
220109 Minsk
BELARUS
E-mail: v.kushinov@sosny.bas-net.by

Mr. Christina ROUTKOVSKAIA
Joint Institute for Power and Nuclear Research
JINPR-SOSNY
Academy of Sciences
220109 Minsk
BELARUS
Tel: +
E-mail: chris@sosny.bas-net.by

Mr. Ivan SERAFIMOVICH
Joint Institute for Power and Nuclear Research
JINPR-SOSNY
Academy of Sciences
220109 Minsk
BELARUS
E-mail: burvi@tut.by

BELGIUM

Mr. Hamid AIT-ABDERRAHIM
Belgian Nuclear Research Center SCK•CEN
Boeretang 200
B-2400 Mol
BELGIUM
Fax:++32 14 321 529
Tel.: ++32 14 33 22 77
E-mail: haitabde@sckcen.be

BRAZIL

Mr. José Rubens MAIORINO
Instituto de Pesquisas Energéticas e Nucleares – IPEN
Av. Lineu Prestes
2242-Cidade Universitaria USP
05508-000 - São Paulo - SP
BRAZIL
Fax: ++55 11 3816 9423
Tel: ++55 11 3816 9111
E-mail: maiorino@net.ipen.br

CHINA

Mr. Haihong XIA
China Institute of Atomic Energy (CIAE)
Department of Nuclear Physics
P.O. Box 275(80)
102413 Beijing
CHINA
Fax: ++86 10 693 57787
Tel.: ++86 10 693 58798 and
(++86 136 910 123 75)
E-mail: xiahh@iris.ciae.ac.cn

FRANCE

Ms. Christine CHABERT
CEA Cadarache DEN/DER/SPRC/LEDC
13108 Saint Paul Lez Durance Cedex
FRANCE
Fax: ++33 4 42 25 75 95
Tel.: ++33 4 42 25 37 92
E-mail: christine.chabert@cea.fr

Mr. Gilbert GRANGET
CEA Cadarache DEN/DER/SPRC/LEDC
13108 Saint Paul Lez Durance Cedex
FRANCE
Fax:
Tel.: ++33 4 42 25 75 91
E-mail: gilbert.granget@cea.fr

Mr. Francois-Rene LECOLLEY
LPC CAEN
6, Boulevard du Marchal
14050 CAEN Cedex
FRANCE
Tel: +33 231 452 545
Fax: +33 231 452 549
E-mail: fr.lecolley@lpccaen.in2p3.fr

GERMANY

Mr. C.H.M. BROEDERS
Institut fuer Reaktorsichercheit (IRS)
Forschungszentrum Karlsruhe
Technik und Umwelt GmbH
Postfach 3640
76021 Karlsruhe
GERMANY
Tel.: ++49 7247 822 484
Fax: ++49 72 47 82 3718
E-mail: broeders@irs.fzk.de

Mr. Noack KLAUS
Forschungszentrum Rossendorf
Institute of Safey Research
Postfach 51 01 19
0314 Dresden
GERMANY
Tel: +49 351 260 3239
Fax: +49 351 260 3440
E-mail: K.Noack@fz-rossendord.de

HUNGARY

Mr. Maté SZIEBERTH
Institute of Nuclear Techniques
Budapest University of Technology and Economics
Muegyetem rkp. 9
H-1111 Budapest
HUNGARY
Fax: ++36 14 631 954
Tel.: +36 1 463 1633
E-mail: szieberth@reak.bme.hu

ITALY

Mr. Piero RAVETTO
Politecnico di Torino
Dipartimento di Energetica
Corso Duca degli Abruzzi, 24
10129 Torino
ITALY
Fax: ++39 0 11 554 4499
Tel.: ++39 0 11 564 4443
E-mail: piero.ravetto@polito.it

JAPAN

Mr. Kazufumi TSUJIMOTO
Japan Atomic Energy Agency (JAERI)
Transmutation Experimental Facility Group
Tokai-mura, Naka-gun
Ibaraki-ken 319-1195
JAPAN
Tel: +81 29 282 6436
Fax: 81 29 282 5671
E-mail: tsujimoto.kazufumi@jaea.go.jp

NETHERLANDS

Mr. Dírceu F.da Cruz
Nuclear Research and Consultancy Group (NRG)
Fuels, Actinides and Isotopes
P.O. Box 25
1755 ZG Petten
NETHERLANDS
Fax: + 31 224 56 84 90
Tel: +31 224 56 41 03
E-mail: dacruz@nrg-nl.com

Mr. Alfred HOGENBIRK
Nuclear Research and Consultancy Group (NRG)
Fuels, Actinides and Isotopes
P.O. Box 25
1755 ZG Petten
NETHERLANDS
Fax: +
Tel: +31 224 56 4399
E-mail: hogenbirk@nrg-nl.com

PAKISTAN

Mr. Masood IQBAL
Nuclear Engineering Division
Pakistan Institute of Nuclear Science & Technology
(PINSTECH)
P.O. Nilore
Islamabad
PAKISTAN
Tel.: +92 51 220 7264
Fax: +92 51 929 0275
E-mail: masood@pinstech.org.pk

POLAND

Mr. Marcin SZUTA
Institute of Atomic Energy
PL-05-400 Otwock/Swierk
POLAND
Tel.: +48 22 718 0023
Fax: +48 22 779 3888
E-mail: elasg@cyf.gov.pl

Mr. Jerzy JANCZYSZYN
AGH-University of Science and Technology
Faculty of Physics and Applied Computer Science
Al. Mickiewicza 30
30-059 Krakow
POLAND
Tel: +48 12 6174733
Fax: +48 12 6340010
E-mail: Janczyszyn@novell.ftj.agh.edu.pl

RUSSIA

Mr. Vladimir BUTSEV
JINR (Joint Institute for Nuclear Research)
Frank Laboratory of Neutron Physics
141980 Dubna
Moscow Region
RUSSIAN FEDERATION
E-mail: Butsev@jinr.ru

Mr. Vladimir GRIBKOV
Moscow Physical Society
Dense Magnetized Plasma Laboratory
Moscow
RUSSIAN FEDERATION
E-mail: gribkov@yahoo.com

Mr. Boris KOCHUROV
Head of Reactor Phys. Laboratory
ITEP
Moscow
RUSSIAN FEDERATION
E-mail: boris.kochurov@itep.ru

Mr. Alexander POLANSKI
JINR (Joint Institute for Nuclear Research)
Frank Laboratory of Neutron Physics
141980 Dubna
Moscow Region
RUSSIAN FEDERATION
E-mail: polanski@jinr.ru

Mr. Leonid PONOMAREV
RRC “Kurchatov Institute” and
MUCATEX, Research Coordinative Center on the
Problem of Muon Catalyzed Fusion and Exotic Quantum
Systems
Ul. Rogova, 9-2
123098 Moscow D-98
Russian Federation
Tel: +7 095 947 2772
Fax:
E-mail(s): leonid@mucatex.msk.ru
mucatex.leonid@g23.relcom.r

Mr. Valery SHVETSOV
JINR (Joint Institute for Nuclear Research)
Frank Laboratory of Neutron Physics
141980 Dubna
Moscow Region
RUSSIAN FEDERATION
Tel: +7 096 21 62925
Fax: +7 096 21 65429
E-mail: shv@nf.jinr.ru

Mr. Yury E. TITARENKO
State Science Center of the Russian Federation
Institute of Theoretical and Experimental Physics
B. Cheremishkinskaya, 25
Moscow, 117259
RUSSIAN FEDERATION
Fax: ++7 095 127 0543
Tel.: ++7 095 123 6383
E-mail: Yury.Titarenko@itep.ru

Mr. Igor TRETIYAKOV
Research and Development Institute of Power
Engineering (RDIPE)
P.O. Box 788
Moscow 101000
RUSSIAN FEDERATION
Tel.:
Fax:
E-mail: tretjakov@nikiet.ru

1.

SPAIN

Mr. Alberto PENA
Universidad del Pais Vasco/Euskal Herriko
Unibertsitatea (UPV/EHU)
Faculty of Engineering
C/Alameda de Urquijo s/n. 48013 Bilbao-Bizkaia
SPAIN
Tel: +34 94 601 4275
Fax: +34 94 601 4159
E-mail: alberto.bandres@ehu.es

Mr. Enrique M. GONZÁLEZ-ROMERO
Division of Nuclear Fission
Department of Energy
CIEMAT
Avda. Complutense, 22
E-28040 Madrid
SPAIN
Fax: ++34 91 346 6576
Tel.: ++34 91 346 6118
E-mail: enriques@ciemat.es

SWEDEN

Mr. Waclaw GUDOWSKI
AlbaNova University Centre
Visiting address: Roslagtullsbacken, 21
Post address: SE-106 91 Stockholm
SWEDEN
Fax: ++46 8 5537 85 8465
Tel: ++46 8 55 37 82 00
Mobile : ++46 73 656 0 887
E-mail: wacek@neutron.kth.se

Mr. Carl-Magnus PERSSON
AlbaNova University Centre
Visiting address: Roslagtullsbacken, 21
Post address: SE-106 91 Stockholm
SWEDEN
Fax: ++46 8 5537 85 8465
Tel: ++46 8 55 37 82 04
Mobile : ++46 70 65 348 74
E-mail: calle@neutron.kth.se

UKRAINE

Mr. Sergiy FOMIN
Akhiezer Institute for Theoretical Physics
National Science Center "Kharkov Institute and Technology"
1, Akademicheskaya str.
Kharkov 61108
UKRAINE
Tel: +38 057 335 65 21
Fax: +38 057 335 2683
E-mail: sfomin@kipt.kharkov.ua

UNITED STATES OF AMERICA

Mr. Yousry GOHAR
Argonne National Laboratory
Technology Development Department
Building 362
9700 South Cass Avenue
Argonne, IL 60439
USA
Fax: ++1 630 252 4007
Tel.: ++1 630 252 4816
E-mail: gohar@anl.gov

IAEA

Mr. Alexander STANCULESCU
Nuclear Power Technology Development Section
Division of Nuclear Power
Fax: +43 1 26007 or 43 1 2600 29598
Tel: ++43 1 2600 22812
E-mail: A.Stanculescu@iaea.org

Joint Institute for Power&Nuclear Research – Sosny
National Academy of Sciences of Belarus

“RCM of the CRP **”Analtical and Experimental Benchmark Analyses of Accelerator Driven Systems”**

5-9 December 2005, Minsk, Belarus,

“EXPERIMENTAL INVESTIGATIONS on ADS AT SUB-CRITICAL FACILITIES OF JOINT INSTITUTE FOR POWER AND NUCLEAR RESEARCH-SOSNY OF THE NATIONAL ACADEMY OF SCIENCES OF BELARUS”

V. Bournos[1], C. Routkovskaia[1], I. Serafimovich[1], H.I. Kiyavitskaya[1], Yu. Fokov[1], A. Fokov[1], S. Mazanik[1], A. Adamovich[1], T. Korbut[2], A. Koulikovskaya[1],A. Khilmanovich[2], B. Martsinkevich[2] , S. Chigrinov

1 Joint Institute for Power&Nuclear Research – Sosny
National Academy of Sciences of Belarus

2 Stepanov’ Institute of Physics National Academy of Sciences of Belarus

Republic of Belarus

JOINT INSTITUTE FOR POWER AND NUCLEAR RESEARCH - SOSNY

Joint Institute for Power&Nuclear Research – Sosny
National Academy of Sciences of Belarus

Sub-critical facility YALINA (in belarussian means fir tree):
1 – neutron generator; 2 - Ti^3H (Ti^2H) target system; 3 - sub-critical assembly, 4 - gamma-spectrometer

Joint Institute for Power&Nuclear Research – Sosny
National Academy of Sciences of Belarus

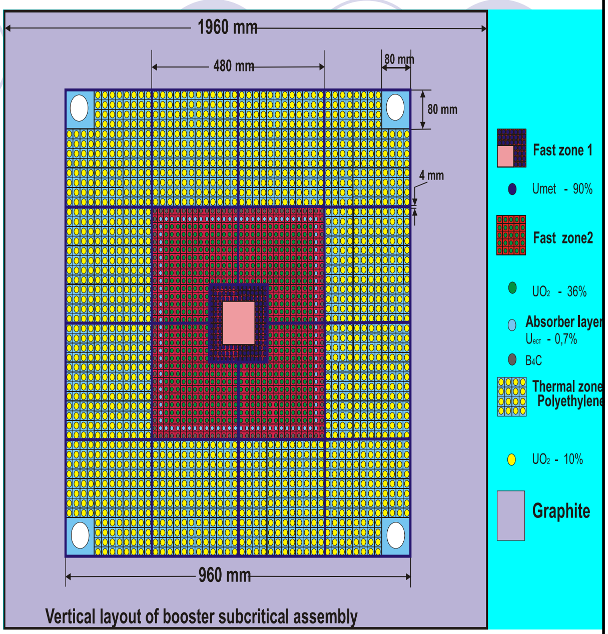
Booster sub-critical assembly YALINA-B. Design and parameters.

YALINA-Booster consists of:

- **lead target located at the core center;**
- **booster zone arranged of lead subassemblies with fuel pins (metallic and dioxide uranium fuel of 90% and 36% enrichment by ^{235}U) inserted into them,**
- **thermal neutron spectrum zone with fuel pins EK-10 (UO_2 of 10% enrichment) in polyethylene subassemblies,**
- **radial and axial reflectors,**
- **biological shielding.**

Keff = 0,975 – 0,98
Booster zone (Keff= 0,60):
48x48x50cm
FUEL: X_5=90% U met.
X5=36% UO_2
F(E_n >0,1 MeV)~10**9 n/(cm^2 s)
moderator Pb
Load (kg) U_5–62.8;U_8 -54.5

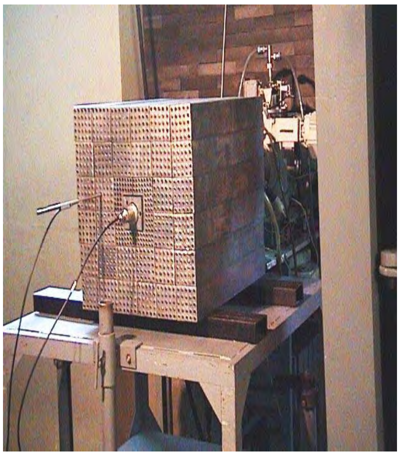
Intermediate zone
thickness, cm 3
material Umet (X_5=0,7%) + B_4C
moderator Pb
load (kg) U_5 – 0.23; U_8 - 31.8
Thermal zone (Keff= 0,95)
thickness, cm 24
fuel : X_5 =10% UO_2
Moderator polyethylene
reflector graphite
F(th):
Ti^{3}H –target ~ 10^9 n/(cm^{2}s)
Load (kg) U_5 – 8.5; U_8 -72.6
multiplication factor 50
Total load (kg) U_5 ~ 71; U_8 - 167



Vertical layout of booster subcritical assembly

Joint Institute for Power&Nuclear Research – Sosny
National Academy of Sciences of Belarus

Booster zone of the sub-critical assembly



Lead subassembly of booster zone

Joint Institute for Power&Nuclear Research – Sosny
National Academy of Sciences of Belarus

- Booster and thermal zones are coupled each other by one-directional way of coupling due to the **"valve" zone**, where thermal neutrons escaping from thermal zone are absorbed, to maintain the required level of sub-criticality that is to ensure the safe operation of the installation.

  Such peculiarity of the core structure allows:
- **essentially increase the importance of the external neutron source,**
- **generate fission pulses being many times shorter and intensive than those at conventional reactor systems,**
- **to carry out the experiments for study of the peculiarities of nuclear waste transmutation in conditions of fast and thermal neutron spectra**,
- to study kinetics of such systems by pulse mode of external neutron source (neutron generator) operation.

Joint Institute for Power&Nuclear Research – Sosny
National Academy of Sciences of Belarus

Main characteristics of YALINA-Booster

Neutron producing target	
Material	Pb
Side dimension, mm	80×80 ×648
Density of lead, g/cm^3	11,34
Maximum beam current, mA	12

Main characteristics of YALINA-Booster

Configuration	Rectangular parallelepiped
Booster zone (region 1)	
Fuel pins number	132
Average content of ^{235}U in fuel pin	259,8
Fuel pins spacing, mm	11,43

Main characteristics of YALINA-Booster

Fuel pin configuration	Cylindrical
Fuel pin outer diameter, mm	7
Cladding thickness, mm	0,2
Cladding material	Stainless steel (X18H10T)
Fuel composition	U_{met}
Density of fuel composition, g/cm^3	18,7
Fuel enrichment by ^{235}U, %	90

Booster zone (region 2)

Fuel composition	**UO_2**
Fuel density, g/cm3	**9,8**
Fuel enrichment by 235U, %	**36**
Fuel pin configuration	**Cylindrical**
Fuel pin number	**575**
Average content of 235U in fuel rod, g	**49,5**
Fuel pin outer diameter, mm	**7**
Cladding material	**Stainless steel (X18H10T)**
Cladding thickness, mm	**0,2**
Fuel pins' spacing, mm	**14**
Number of experimental channels	**1 channel with diameter 12 mm**

Intermediate (absorbing) zone	first layer, next to booster zone
Number of absorbing rods	**108**
Rod material	**U_{met}^{nat}**
Rod diameter, mm	**7**
Cladding thickness, mm	**0,2**
Uranium density, g/cm^3	**18,7**
Uranium isotopic content, %: ^{235}U / ^{238}U	**0,715 / 99,285**
Intermediate (absorbing) zone	**second layer, near thermal zone**
Number of absorbing rods	**116**
Absorber material	**B_4C**
Density, g/cm3	**1,2 – 1,3**
Isotopic content of boron, %: - $^{10}B/^{11}B$	**20 / 80**

Thermal zone

Moderator	Polyethylene
Moderator block side dimension, mm	80 x 80 x 48
Number of blocks in subassembly (in length)	12
Subassembly total length, mm	576
Subassembly active part length, mm	500
Diameter of holes for fuel rods location, mm	11
Fuel pins' spacing, mm	20
Fuel pin diameter, mm	10
Cladding thickness, mm	**1,5**

Thermal zone

Cladding material	Aluminum alloy(CAB)
Fuel composition	UO2 + Mg
Fuel density, g/cm3	5,172
Average material content in fuel pin, g	
^{235}U	7,76
^{238}U	69,84
^{16}O	10.45
Mg	8,95
Fuel pins number	1140 - 1180

Reflectors

Radial:	
Material	**Graphite / borated polyethylene**
Thickness, mm	**250 / 50**
Axial :	
Material	**borated polyethylene**
Thickness, mm	**100**

YALINA-Booster

- Start-up was performed in June 2005.
- Following the rule of safe behavior of multiplication factor at each step of fuel loading into the core the load process was stopped when keff approached ~0.98.

- *The program of the experimental investigation:*

1 - development of methods of sub-criticality level monitoring,
2 - measurement of long-lived fission products and minor-actinides transmutation rates,
3 - experimental study of sub-critical systems kinetics,
4 - measurements of spatial distribution of neutron flux density,
5 - time behavior of neutron flux depending upon neutron pulse parameters ….

and

YALINA team welcomes new ideas!

During the start up procedure the following experimental measurements were performed:

- Neutron yield from D,D-target (2×10^{10} n/s);
- Axial distribution of neutron flux density and spectral indices $^{235}U/^{232}Th$, $^{235}U/^{238}U$ in experimental channel of booster zone EC1 (by fission chambers) at starting moment without uranium fuel and absorbers.
- Radial distribution of fission density in the assembly without uranium fuel and absorbers.
- The effect of “valve” zone (B_4C) in the assembly without uranium fuel.
- Radial distribution of neutron flux density in thermal zone of unloaded assembly with and without “valve” zone (B_4C) depending on source neutron energy.

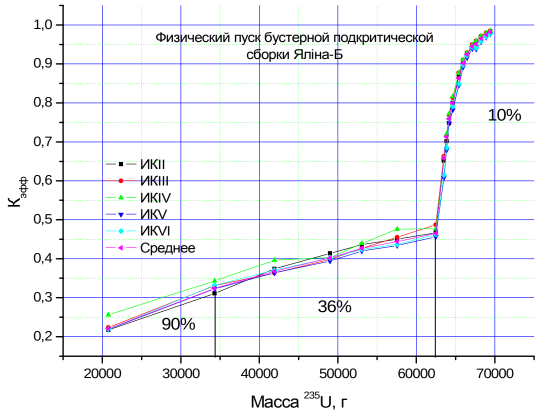
During the start up procedure the following experimental measurements were performed:

- Spatial distribution of neutron flux density in vicinity of experimental channel EC1.
- Initial state (before start up) counts number N0 in four channels located in graphite reflector at the corners of the assembly and in two additional channels located in thermal zone.
- k_{ef} and extrapolated critical mass throughout the process of fuel load (with application of reciprocal count method and Gozani method).
- The effect of thermal zone configuration (rectangular or cylindrical) on $k_{eff.}$
- Axial distribution of neutron flux density in the experimental channels of thermal zone (k_{ef} ~0.98).
- Determination of reactivity worth of fuel pins and control rods.

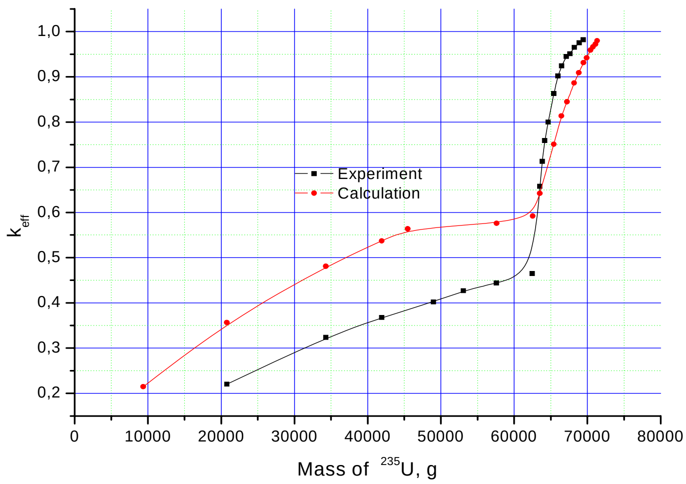
During the start up procedure the following experimental measurements were performed:

- Reactivity effect due to the presence of lead target.
- Neutron spectra measurements (fast – by fission chambers with ^{232}Th (threshold of fission reaction ~1.2 MeV) and ^{238}U (~ 0.9 MeV), thermal – ^{235}U).
- Radial distribution of thermal neutron flux density with application of activation detectors (reaction $^{115}In(n,\gamma)\ ^{116}In$.
- The effect of borated polyethylene shielding on subcriticality level of the assembly.

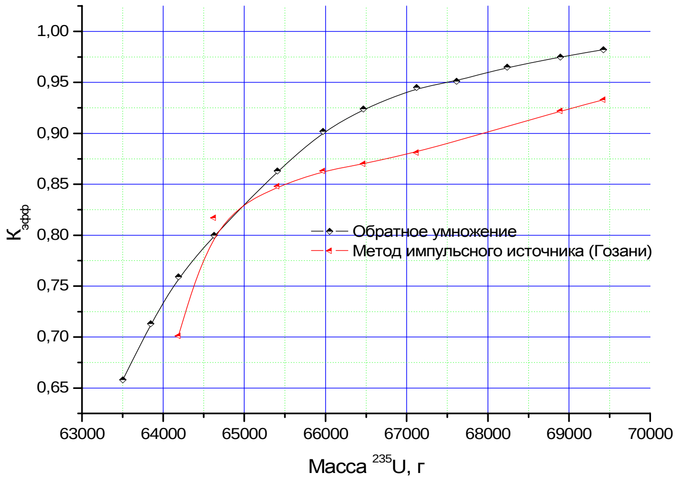
k_{eff} of YALINA-Booster assembly versus mass of loaded ^{235}U measured by means of Reciprocal Count Method during start-up procedure



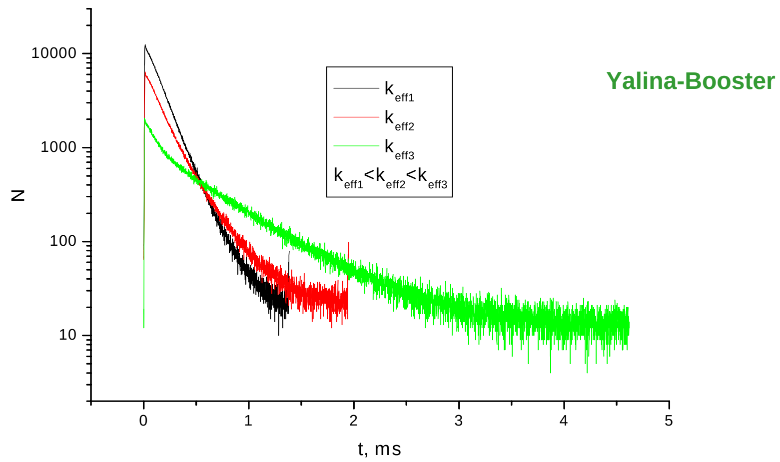
Experimentally measured (by Reciprocal Count Method) and calculated (MCNP-4B) code k_{eff} depending upon the mass of loaded ^{235}U



The results of k_{eff} start-up experimental measurements with application of Reciprocal Count Method and Pulse Neutron Source Method (Gozani)



Characteristic curves of neutron flux density decay (the central channel of thermal zone) with neutron producing target located in center of the assembly



Results of the experiments

- **A satisfactory agreement of measured and calculated YALINA-Booster characteristics ,**
  - **subcriticality level, neutron flux density etc.**
- **The preliminary experiments have proved that the procedure of fuel load into the YALINA-Booster core was chosen to be appropriate.**

Results of the experiments

- **Starting from $k_{eff} \approx 0.8$ the reactivity changes control was performed additionally by means of PNS methods that gave rise to reliability of the measurement of such important characteristics.**
- **Due to the experience gained during maintenance and operation of YALINA facility with thermal neutron spectrum a lot of know how was used during YALINA-Booster facility design and set-up that made possible to improve it's maintenance and operation characteristics.**

Subjects of IP EUROTRANS

- DM2 ECATS aims to provide validated experimental input from relevant experiments on the coupling of an accelerator, a target and a sub-critical blanket in order to assist the design of XT-ADS and European Facility for Industrial Transmutation (EFIT).
- These experiments should provide design input on the dynamics and experimental techniques of such a coupled system with feedback effects, together with shielding, safety and licensing issues.

WP2.1 : Qualification of sub-criticality monitoring and of the core power/beam current relationship

Task 2.1.2: YALINA Zero power experiments

- **Coordinator : A. BILLEBAUD (CNRS)**
- **Participating Organisations : P1 FZK, P6 CIEMAT, P8 CNRS, P13 ENEN(KTH, Chalmers University), P23 NRG P28 SCK-CEN**
- **External Partners : JIPNR Sosny**

Subtask 2.1.2.1: Core definition and characterisation in YALINA

- **To define the most suitable configurations in view of the objective 2.1**
  - The time constant of the system should be optimised to best reflect the conditions of XT-ADS and EFIT.
  - The spatial zoning should be designed to represent closest XT-ADS and EFIT conditions in terms of neutronic characteristics and to allow an easy transferability of the results to DM1.
  - Special attention should also be given to the choice of possible detector locations and types.

Best reflect the conditions of XT-ADS and EFIT

- Once the basic configuration is identified and implemented, an experimental characterisation of the core will be carried out.
- Calibration of the sub-critical level by a reference technique (e.g. the PNS Area technique) is envisaged together with a rigorous follow-up of the subsequent changes of the configuration to allow a continuous traceability of the actual sub-critical level to the sub-critical level determined by the reference technique.
- To further characterise the core, spatial traverses and spectrum indices are needed.

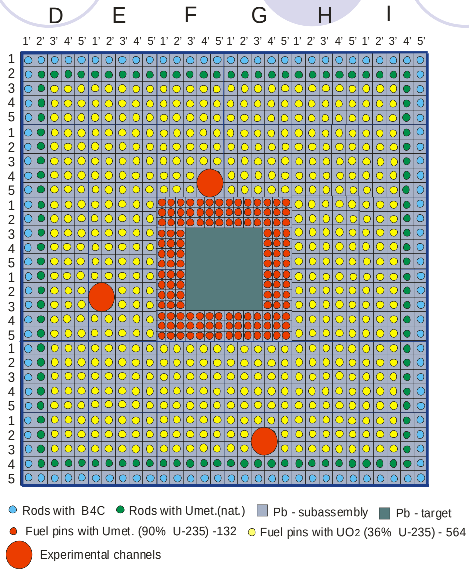
WP2.4 : Evaluation of licensing and commissioning aspects deduced from SAD, RACE and YALINA in view of the XT-ADS necessities

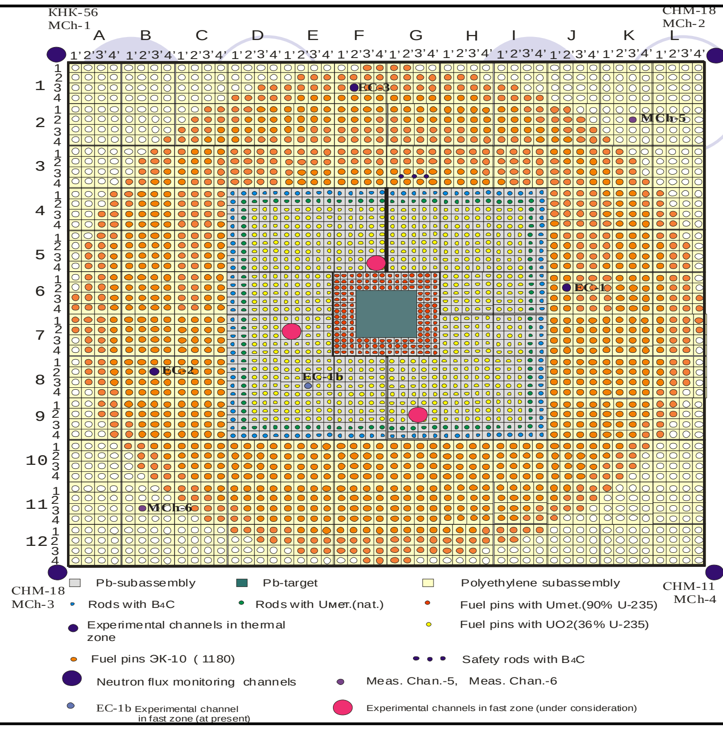
- **Coordinator : R. ROSA (ENEA)**
- **Participating Organisations : P1 FZK, P5 CEA, P11 EA, P12 ENEA, P13 ENEN(KTH)**
- **Task 2.4.3 : Extraction of knowledge from the licensing experiences gained in SAD, RACE and YALINA and transposition to the necessities of the XT-ADS design**
- **D 2.46 Report on licensing and commissioning aspects gained with YALINA experiments and transposition to the necessities of the XT-ADS design**

Yalina-IP-EUROTRANCE 1

- Modernization of neutron generator for the objectives of YALINA-IP EUROTRANS experiments
- Modernization of subcritical assembly and experiment infrastructure
  - location of 3 experimental channels in the fast zone to make possible the location of large fission chamber with diameter 32 mm;
  - laying the additional connection lines between subcritical assemblies room and control board room;
  - creation of the system for the measurements of current of deuterium ions incident to the target;
  - development of the system of on-line monitoring of neutron flux from the target.
- It will be necessary 20 small tritium targets with 45mm in diameter and 1 large tritium target with 230 mm in diameter to perform the experiments
- The expected duration of the experimental program including the experiments will be ~**22 months**.

Experimental channels in booster (fast) zone of the assembly at YALINA-IT-EUROTRANS





Yalina-IP-EUROTRANCE - II

- Extending of fast zone by replacement of inner row of polyethylene blocks of the thermal zone by one row of lead blocks (28) around the existing fast zone:
  - neutronics calculations including nuclear safety aspects for licensing issues preparation;
  - designing, manufacturing;
  - obtaining the necessary license and authorization
- Highly sensitive fission chambers (produced in Dubna, JINR) and electronic chains for additional experimental channels.

Yalina-IP-EUROTRANCE - II

- To gain keff ~0.95 and neutron generation time ~ 2 μs the creation of fast assembly will be necessary. It is quite probable that the appropriate amount of nuclear fuel will not be available to create a fast assembly (preliminary estimation).
- To get the answer, the appropriate calculation will be performed.
- The presented expenses and expected duration of the experimental programm can be corrected during the discussion.

Conclusion

The experimental facilities YALINA and YALINA-B allow to deliver valuable data in the following fields:

- validation of the experimental techniques for, e.g., sub-criticality monitoring,
- investigation of spatial kinetics of the sub-critical systems with external neutron sources,
- measurements of transmutation rates of fission products and minor actinides,
- neutron spectra measurement,
- safety research on sub-critical systems,
- technological applications such as, neutron activation analysis
- production of isotopes for calibration of gamma spectrometers etc.

SCK-CEN Proposal for CRP

Hamid Aït Abderrahim, Peter Baeten, Edouard Malambu, Thierry Aoust

Proposal based on YALINA

- As a CRP we propose experimental validation of core physics on basis of the YALINA experiments for static and kinetic parameters.
- Among the static parameters, ks, keff, fission-rate distributions and some spectral indices will be measured. Also kinetic parameters such as the delayed neutron fraction and the mean neutron lifetime are parameters intended to be measured.
- The most important point will remain the measurement of the subcriticality level with different kind of techniques subject to their own advantages and shortcomings.
- A comparison with calculations (for instance based on MCNPX associated with JEF 3.1 libraries) and analysis and understanding of discrepancies will be the final goal.
- Participation to other Numerical Benchmark is considered (Analytical Bench for kinetic methods, TRAC and Feat)

Core Analysis Tools For Use in the ADS CRP

MCNPX 2.5.0 (LANL) - our standard code for static core calculations

- Extends MCNP to multiple particles (n,γ,p,α,e,...) and physics models
- Nuclear data: LA150 (LANL), JEF 2.2, JEFF 3.1, ENDF/B-VI.8, ...
- ALEPH-DLG – in-house automated generation of multi-temperature MCNP(X) using NJOY 99.90 (soon upgraded to 99.112)

LAMBDA - calculating the adjoint weighted mean neutron generation time

- In-house developed procedure using a perturbation method to take into account the adjoint flux
- Automated user interface with any version of MCNP(X)

ALEPH – a Monte Carlo burn-up tool under development at SCK•CEN

- Couples MCNP(X) with an enhanced version of ORIGEN 2.2
- Flexible, efficient and easy to use

NUCLEAR SCIENCE AND ENGINEERING: **151**, 82–87 (2005)

Development of the CRISP Package for Spallation Studies and Accelerator-Driven Systems

S. Anefalos,* A. Deppman, and Gilson da Silva

Instituto de Física, Universidade de São Paulo, IFUSP
P.O. Box 66318 - CEP 05315-970, São Paulo, SP, Brazil

J. R. Maiorino and A. dos Santos

Instituto de Pesquisas Energéticas e Nucleares - IPEN, São Paulo, SP, Brazil

and

F. Garcia

Universidade Estadual de Santa Cruz, Bahia, Brazil

Received July 12, 2004
Accepted October 13, 2004

Abstract – *Power generation from nuclear reactors provides an almost inexhaustive power source due to the huge quantities of nuclear fuel existent in our planet, which guarantees its utilization for thousands of years. Interest has been shifted to the so-called hybrid reactors [accelerator-driven systems (ADS)] as an alternative technology for power generation and transmutation, thus requiring precise knowledge about nuclear structure and nuclear reaction characteristics. Research groups from Instituto de Fisica, Universidade de São Paulo and Brazilian Center for Research in Physics made a joint effort to develop a computer program, CRISP, to calculate the intranuclear cascade proprieties and the nuclear evaporation process, present in all nuclear reactions with energies above a few tens of mega-electron-volts, using Monte Carlo techniques. Some reaction channels were included in these programs, resulting in a more realistic representation of the processes involved, aiming at reactor physics studies and academic studies about hadron and meson properties in nuclear matter. Some results obtained with this code and a comparison with experimental data are presented. Although all these results are preliminary, they are very consistent with the available experimental data. Since the applicability of the CRISP package has a wide range of options, especially in ADS, some results describing the effectiveness of the code were achieved.*

I. INTRODUCTION

The incineration of transuranics (TRU) is being considered by using fast neutrons from a spallation source in a subcritical reactor waste burner,[1–3] taking into account that the fission cross section is much higher than the capture cross section at these energies for most TRU, transmuting therefore long-lived TRU in medium- or short-lived waste. Besides the incineration of TRUs and fission fragments, a coupled system consisting of a spallation source and a subcritical array of fuel may have a positive gain of energy (net energy/energy to operate the accelerator).[4,5] This fact has motivated innovative concepts of accelerator-driven reactors in which thorium can be used as fuel.[6] It is very important to know precisely the nuclear processes that lead to the spallation neutron source, including all the characteristics concerning spatial and energetic angular distribution, the spallation products, and neutron multiplicity. To obtain this information we can separate the process into two

*E-mail: spereira@if.usp.br

parts: intranuclear cascade (INC) and internuclear cascade. The first concerns the interaction between the projectile and the target, its subsequent INC, and evaporation/fission competition inside the nucleus. The second, the internuclear cascade, refers to the transport of these particles through matter. One powerful tool to tackle these problems is the Monte Carlo approach, which describes the nuclear reactions at intermediate and high energies. The traditional Monte Carlo calculations consider the INC as a sequence of individual interactions along their tracks and assuming that all the other particles inside the nucleus are motionless objects.[7–9] These models do not take into account the local density fluctuations during the cascade process or the variability of the occupation numbers of levels below the Fermi level during the reaction. At present, the INC process is performed with a realistic time-sequence approach in which all particles inside the nucleus can participate in the cascade and the nuclear density fluctuations are naturally taken into account during the cascade. Another characteristic is the fact that the variations of the occupation number of each single particle level are considered as a function of time, and a more realistic Pauli blocking mechanism can be introduced. None of the existing models have effectively used this feature. Also, the evaporation/fission competition process was usually oversimplified by the assumption that only neutron evaporation is relevant in comparison with the fission channel, which is at variance with recent developments in this area.[10] Taking i account only the evaporation of protons and alpha particles, the fissilities of actinides and pre-actinides are correctly predicted. This model for evaporation/fission and the corresponding software is described in Ref. 11.

II. THE CRISP PACKAGE

The Liège INC model[12] (INCL4) and LAHET (Ref. 13) are two examples of equivalent codes, but they also have huge differences between them. The INCL4 utilizes a diffuse nuclear surface, corresponding to a Woods-Saxon density distribution and a time-dependent approach with collisions well separated in space and time. The stopping time is defined as the time of separation between two phases in the INC, chosen arbitrarily. The collision process is divided into two stages. On the other hand, the LAHET code system utilizes two INC models, the Bertini INC model[7] and the ISABEL INC model.[14] The Bertini model, the default option in the LAHET code, has a target nucleus as a continuum where the particle will collide with a nucleon after a mean free path chosen randomly. The time in which the cascade process stops is determined by comparing the energy of the nucleons with a fixed parameter. If the energy is lower than this parameter, the cascade is stopped. The CRISP package discussed here utilizes an algorithm that describes a many-body INC and evaporation/fission competition process, considering dynamic evaluation of the fermionic multicollisional process and the possibility of neutron, proton, and alpha particle evaporation.[15,16] The fission process can also occur and compete with the evaporation process. Other reaction mechanisms have been included, such as Pauli blocking, the formation of many nucleonic resonance, and the shadowing effect, the last two being important reaction channels for photoabsorption. One important issue in the Monte Carlo calculations for nuclear reactions at intermediate energies is the correct simulation of Pauli blocking. In the modern codes, the variations of the levels occupation numbers during the INC are not considered in a realistic way, but the Pauli principle is usually incorporated by means of statistical approaches. As a consequence, violations of this principle occur, clearly seen in the occupation numbers of low-energy levels, in negative excitation energies of the residual nucleus and in the so-called nuclear boiling. In the CRISP model, we included the time sequence characteristics of the MCMC code[17] and the evaporation/fission competition process model of the MCEF code.[11,18] Also, we improved the code by including the following:

1. excitation of the nucleonic resonance heavier than the Delta
2. initial nuclear ground state construction according to the Fermi model and Pauli principle
3. more realistic Pauli blocking mechanism
4. nucleon-nucleon (NN) single-pion production channel.

The Pauli blocking mechanism is accounted for by dividing the phase-space into cells and by imposing the condition that each can be occupied by only one particle. The cell corresponds to a quantum level, which is determined according to the Fermi gas model. In this approach, due to spin and isospin degrees-of-freedom of the nucleons, we can accommodate up to four nucleons on each level. The cell's availability for the final state particles is verified after the analysis of each possible interaction between different particles in the nucleus. If all secondaries can be placed at the correct levels, the interaction is allowed; otherwise, it is blocked. This procedure must be performed at every stage of the cascade and also on the construction of the initial ground state nucleus. The Pauli exclusion principle is incorporated in our model by ensuring that at any step in the INC calculation, the number of nucleons at any level will not be greater than the limit allowed by this principle. One of the main advantages of this method, compared to those adopted by similar approaches,[12,19,20] is the elimination of unphysical results such as the violation of the Pauli principle or the spurious depletion of the Fermi sphere, which shows up in the form of spontaneous nuclear boiling,[12] leading to the impossibility of keeping the nucleus stable for long durations (or many cascade interactions).

Also, the incorrect determination of the occupation numbers and the use of arbitrary cascade stopping-time parameters could result in events with negative excitation energy. With the CRISP package, we eliminate these undesirable effects and their unphysical consequences and propitiate a more realistic description of the cascade process, allowing the repopulation of the Fermi sphere by any nucleon inside the nuclear volume during the INC. With these improvements, a physical, energetic criterion for stopping the INC calculation was established; i.e., the stopping takes place when all the bound nucleons do not have enough energy to escape from the nucleus. Another implementation is the NN single-pion production reaction. Pion production in NN collisions is an important process in intermediate-energy nuclear physics. This reaction is especially relevant if one is interested in neutron or proton multiplicities, since the creation/emission of pions is directly related to the excitation energy of the residual nucleus. The channels that are present in the CRISP code are as follows:

1. $p + p \rightarrow p + n + \pi^+$
2. $p + p \rightarrow p + p + \pi^0$
3. $n + p \rightarrow nn\pi^+ + pp\pi^-$.

It is important to note that all the NN pion cross sections utilized came from experimental data for NN → NNπ reactions for beam energies from 300 MeV to 2 GeV (Ref. 21). The NN single-pion production threshold is ~300 MeV, and two-pion production occurs at ~1000 MeV. The last reaction channel is in an implementation stage.

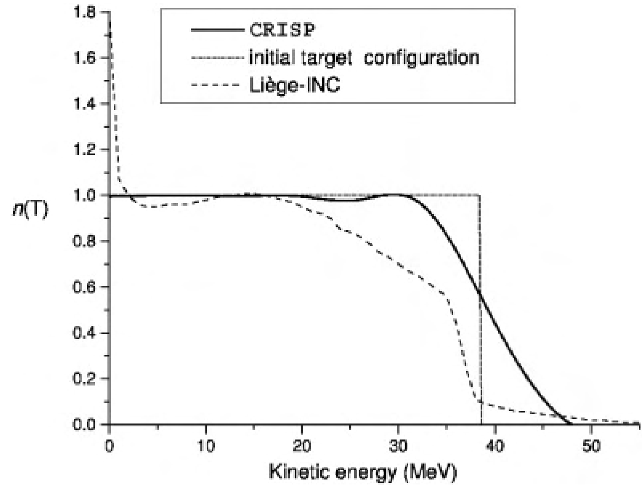


Fig. 1. Occupation number as a function of the level of energy.

III. PREVIOUS RESULTS

One of the most common problems found in the Monte Carlo calculations of nuclear reaction is related to the Pauli blocking mechanism. This problem has been solved, and some of the consequences are shown in Fig. 1, where the occupation number of levels at different energies, as calculated by our code and by the Liège model, are plotted. The CRISP package does not violate the Pauli principle with occupation number outcomes greater than unit. The Liège model instead violates the Pauli principle by allowing more than one fermion at the same level.

TABLE I

Neutron Multiplicities in Proton-Induced Reactions on Pb Nuclei Compared with the CRISP Predictions and Those from Other Models[12]

Neutron Energy	Experiment[a]	CRISP	INCL4 KHSv3p	TIERCE Cugnon	LAHET Bertini	LAHET ISABEL	LAHET Bertini-preq
Pb E_p = 800 MeV							
0 to 2 MeV		4.24	3.3	4.9	5.61	5.13	5.37
2 to 20 MeV	6.5	6.36	6.8	6.9	8.63	6.63	7.12
>20 MeV	1.9	2.06	2.5	2.2	1.75	1.92	2.13
Total		12.7	12.5	14.0	16.0	13.7	14.04
Pb E_p = 1200 MeV							
0 to 2 MeV		4.65	3.4	5.8	6.35		6.02
2 to 20 MeV	8.3	6.98	8.1	8.9	11.44		9.86
>20 MeV	2.7	2.47	3.1	2.8	2.45		2.83
Total		14.1	14.7	17.4	20.2		18.7

[a]Proton-induced reactions on Pb nuclei.

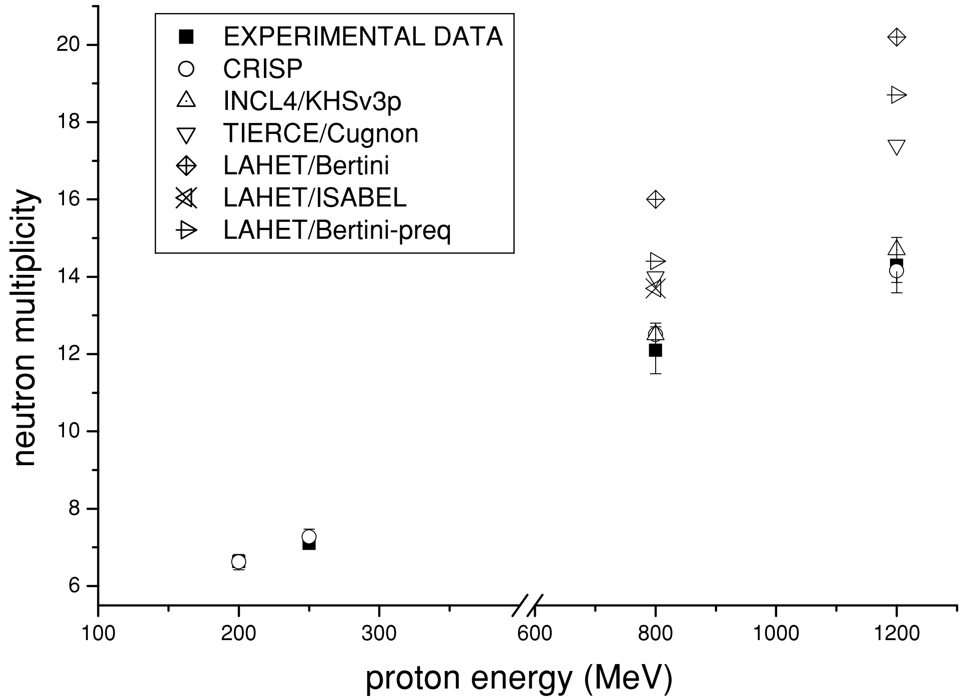


Fig. 2. Neutron multiplicities in ^{208}Pb for 200- to 1200-MeV protons. The CRISP result is compared to the ICRU database (data for 200 and 250 MeV) (Ref. 22) and Ref. 12.

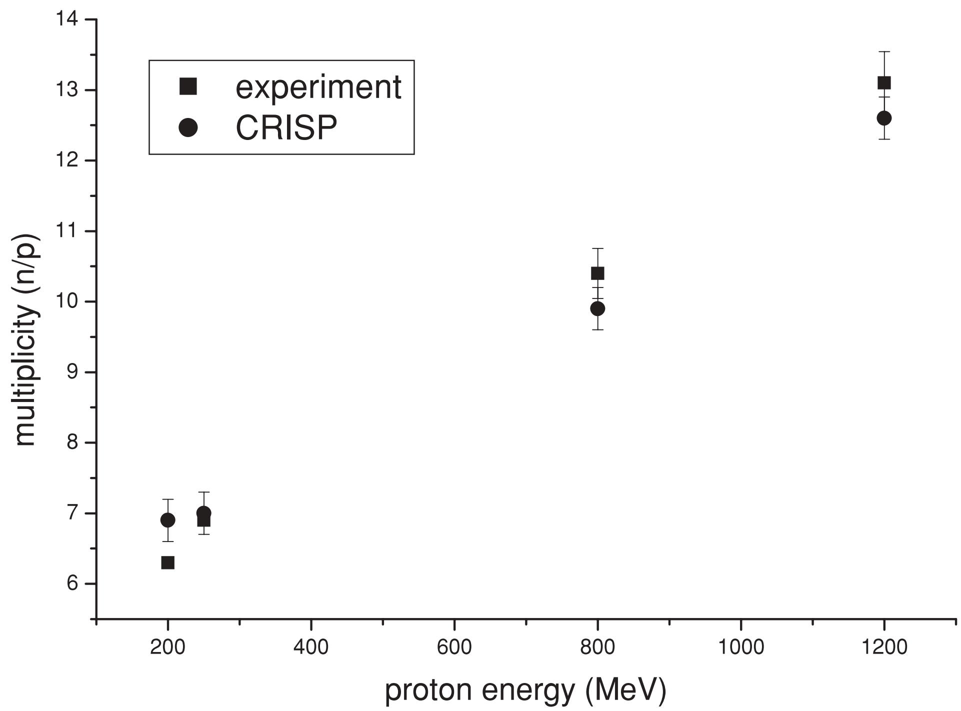


Fig. 3. Neutron multiplicities in ^{184}W for 200- to 1200-MeV protons. The CRISP result is compared to the ICRU database (data for 200 and 250 MeV) (Ref. 22) and Ref. 23.

In Table I, neutron multiplicities for proton-induced reactions on Pb at different intervals of energy are given. Our model predictions agree very well with the cascade neutrons ($E \geq 20$ MeV) and the evaporation neutrons (2 to 20 MeV) (Ref. 12). Also in Table I, the CRISP results are compared with those obtained with other models.

In Fig. 2 one can see the neutron multiplicity obtained after the INC and the evaporation/fission competition process, initiated by the interaction of a proton with the ^{208}Pb nucleus. The results are compared with those given by the International Commission on Radiological Units and Measurement (ICRU) database and Ref. 12. One may observe that our results are qualitatively and quantitatively in good agreement with the experimental data. This may be attributed to the correctness of the INC and evaporation/fission calculations, since the neutron multiplicities of the secondary particles depend on the characteristics of both processes.

These results are important for applications such as the studies on accelerator-driven systems (ADSs). More high-energy simulations are being performed to obtain and compare multiplicity results up to a few giga-electron-volt energy protons. Similar results are plotted in Fig. 3 for ^{184}W. The results are in agreement with the experimental values.

Concerning proton production in proton-induced reactions, we also obtained very good results when comparing our predicted values with other evaporation models, as shown in Table II.

IV. CONCLUSIONS

In this work we presented results obtained with the CRISP package for proton-nucleus reaction at intermediate and high energies. This package was obtained by the coupling of the MCMC and MCEF codes, with the introduction of some improvements, such as a better Pauli blocking mechanism, the formation of a nuclear ground state according to the Fermi model with respect to the Pauli principle, the introduction of the most relevant resonant excitation, deexcitation for nucleon photoabsorption, and the NN single-pion production channel. We described some of the consequences resulting from these modifications and presented a few results of interest for ADS development. The results on neutron multiplicities and energy distribution are consistent with the experimental data at different proton energies. More detailed calculations are being performed to study other features of proton-nucleus reactions and with different targets.

TABLE II

Neutron and Proton Multiplicities in Reactions Induced by 1.2-GeV Protons on Pb*

Particle Multiplicity	CRISP	INCL4 Dresner[24]	INCL4 KHSv3p (Ref. 25)
$nE < 2$ MeV	4.65	3.70	3.41
$2 < nE < 20$ MeV	6.98	7.31	8.12
$nE > 20$ MeV	2.47	3.12	3.17
$pE < 20$ MeV	0.9	1.05	0.7
$pE > 20$ MeV	2.73	2.48	2.53

*The results calculated by CRISP are compared with two evaporation models coupled with INCL4 (Ref. 12).

ACKNOWLEDGMENTS

We are thankful to FAPESP, CNPq, and CAPES (Brazilian agencies) for their support.

REFERENCES

1. B. W. LEWIS, AECL-968, Atomic Energy of Canada Ltd. (1952).

2. H. KATSUTA et al., *Proc. 2nd OECD/NEA Information Exchange Mtg. Actinide and Fission Product Separation and Transmutation*, Argonne, Illinois, November 11–13, 1993 (1993).

3. K. FURUKAWA et al., "The Combined System of Accelerator Molten Salt Breeder (AMSB) and Molten Salt Converter Reactor (MSCR)," *Proc. Japan-U.S. Seminar Thorium Fuel Reactors*, Naora, Japan, October 1982 (1982).

4. C. RUBBIA and J. A. RUBIO, CERN/LHC/96-11(EET), CERN (1996).

5. C. RUBBIA et al., CERN/AT/95-44(ET), CERN (1995).

6. C. D. BOWMAN et al., "Nuclear Energy Generation and Waste Transmutation Using an Accelerator-Driven Intense Thermal Neutron Source," *Nucl. Instrum. Methods A*, **320**, 336 (1992).

7. W. H. BERTINI, "Low-Energy Intranuclear Cascade Calculation," *Phys. Rev.*, **131**, 1801 (1963).

8. V. S. BARASHENKOV et al., "A Cascade-Evaporation Model for Photonuclear Reactions," *Nucl. Phys. A*, **231**, 462 (1974).

9. Y. YARIV and Z. FRANKEL, "Intranuclear Cascade Calculation of High Energy Heavy Ion Collisions: Effect of Interactions Between Cascade Particles," *Phys. Rev. C*, **24**, 488 (1981).

10. A. DEPPMAN et al., "Photofissility of Actinide Nuclei at Intermediate Energies," *Phys. Rev. Lett.*, **87**, 182701 (2001).

11. A. DEPPMAN et al., "A Monte Carlo Method for Nuclear Evaporation and Fission at Intermediate Energies," *Nucl. Instrum. Methods B*, **211**, 15 (2003).

12. A. BOUDARD et al., "Intranuclear Cascade Model for a Comprehensive Description of Spallation Reaction Data," *Phys. Rev. C*, **66**, 044615 (2002).

13. R. E. PRAEL and H. LIECHTENSTEIN, "User Guide to LCS: The LAHET Code System," LA-UR-89-3014, Los Alamos National Laboratory (1989).

14. Y. YARIV and Z. FRANKEL, "Intranuclear Cascade Calculation of High-Energy Heavy-Ion Interactions," *Phys. Rev. C*, **20**, 2227 (1979).

15. A. DEPPMAN et al., "The MCEF Code for Nuclear Evaporation and Fission Calculations," *Comput. Phys. Comm.*, **145**, 385 (2002).

16. S. B. DUARTE et al., "Cluster Approach to Intranuclear Cascade for Relativistic Heavy-Ion Collisions," *Phys. Rev. Lett.*, **49**, 536 (1982).

17. M GONÇALVES, S. DE PINA, D. A. LIMA, W. MILOMEN, E. L. MEDEIROS, and S. B. DUARTE,"Many-Body Cascade Calculation for Photonuclear Reactions," *Phys. Lett. B*, **406**, 1 (1997).

18. A. DEPPMAN et al., "Photofissility of Heavy Nuclei at Intermediate Energies," *Phys. Rev. C*, **66**, 067601 (2002).

19. J. CUGNON, C. VOLANT, and S. VUILLIER, "Improved Intranuclear Cascade Model for Nucleon-Nucleus Interactions," *Nucl. Phys. A*, **620**, 475 (1997).

20. J. CUGNON and P. HENROTTE, "The Low-Energy Limit of Validity of the Intranuclear Cascade Model," *Eur. Phys. J. A*, **16**, 393 (2003).

21. B. J. VERWEST and R. A. ARNDT, "NN Single Pion Production Cross Sections Below 1500 MeV," *Phys. Rev. C*, **25**, 1979 (1982).

22. A. LETOURNEAU et al., "Neutron Production in Bombardments of Thin and Thick W, Hg, Pb Targets by 0.4, 0.8, 1.2, 1.8 and 2.5 GeV Protons," *Nucl. Instrum. Methods B*, **170**, 299 (2000).

23. ICRU 2000 Nuclear Data for Neutron and Proton Radiotherapy and for Radiation Protection, Report 63, International Commission on Radiological Units and Measurements (2000).

24. L. DRESNER, ORNL-TM-196, Oak Ridge National Laboratory (1962).

25. A. R. JUNGHANS, M. DE JONG, H. G. CLERC, A. V. IGNATYUK, G. A. KUDYAEV, and K. H. SCHMIDT, "Projectile-Fragment Yields as a Probe for the Collective Enhancement in the Nuclear Level Density," *Nucl. Phys. A*, **629**, 635 (1998).

For The Analytical and Experimental Benchmark Analyses of ADS CRP
Dec 5-9, 2005, Minsk

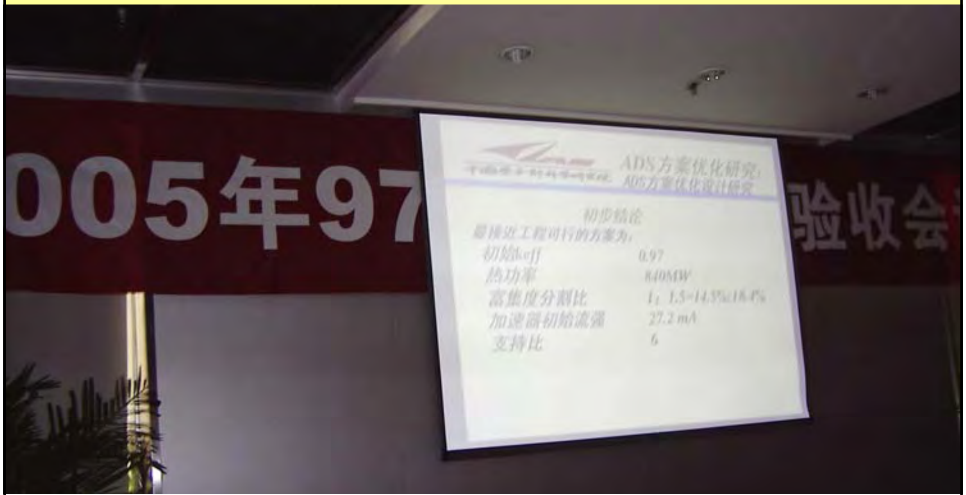
The Introduction of Researches on ADS In China

Xia Haihong
China Institute of Atomic Energy

Introduction

- The conceptual study of ADS had lasted for about five years and ended in 1999 in China
- From then a five years R&D program has been launched supported under Major state Basic Research Program,973

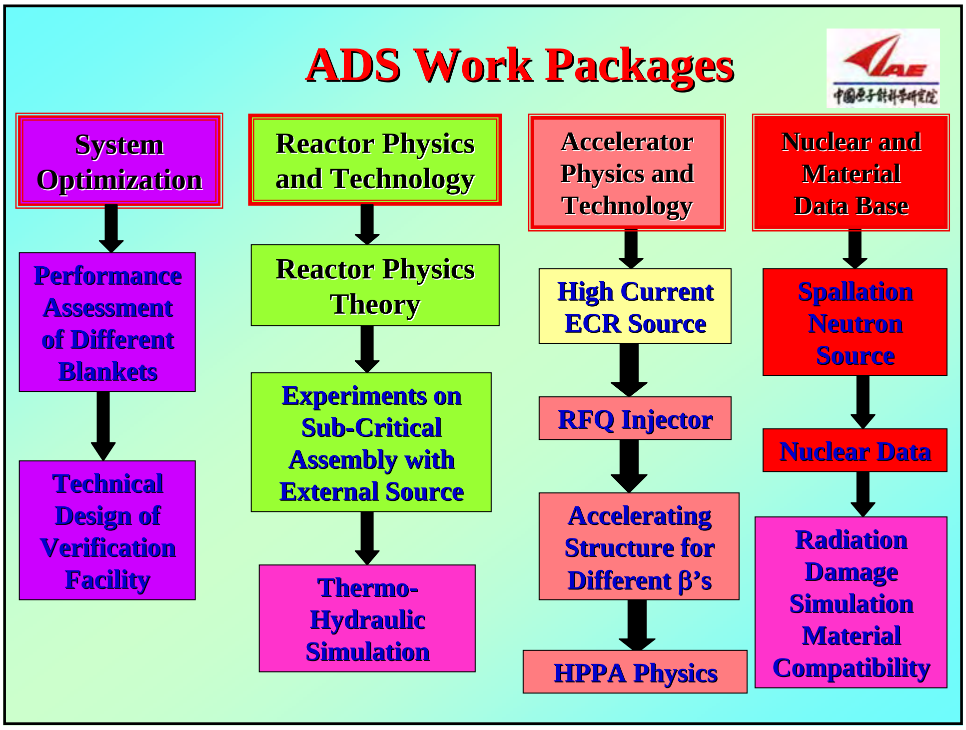
Introduction

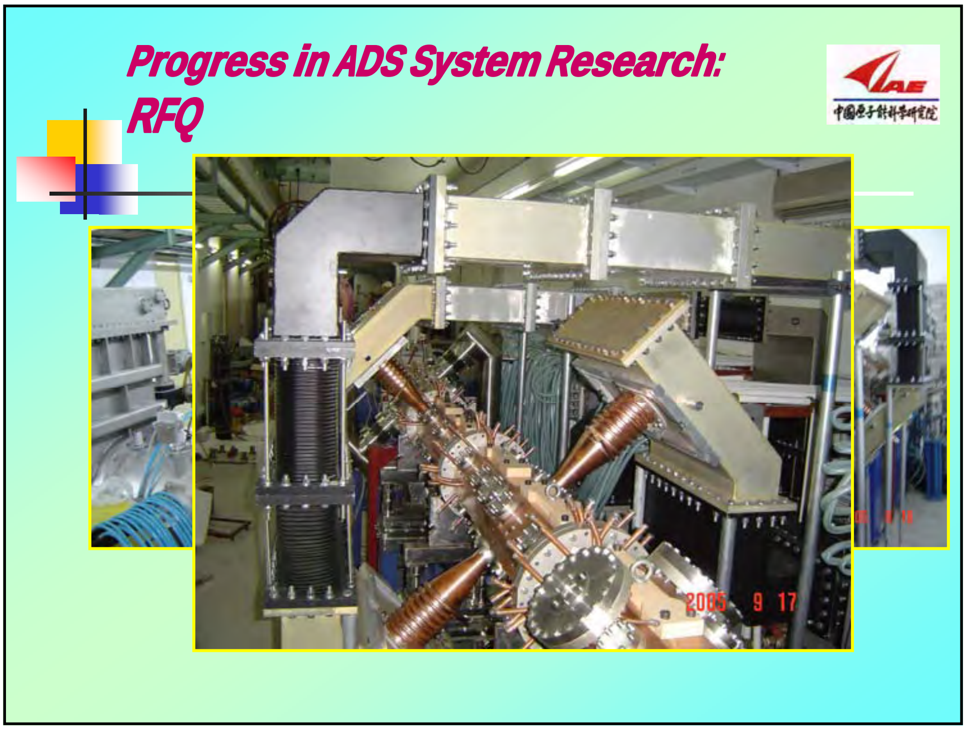


After 5 years hard work
China ADS Project passed the national review successfully at the end of October, 2005

In last September
the third Asia ADS workshop was successfully held in Beijing

In the last years the scientific and technical exchange and cooperation with foreign research Institutions in different aspects are of really a great help to our work


ADS Work Packages
System Optimization
Performance Assessment of Different Blankets
Technical Design of Verification Facility
Reactor Physics and Technology
Reactor Physics Theory
Experiments on Sub-Critical Assembly with External Source
Thermo-Hydraulic Simulation
Accelerator Physics and Technology
High Current ECR Source
RFQ Injector
Accelerating Structure for Different β's
HPPA Physics
Nuclear and Material Data Base
Spallation Neutron Source
Nuclear Data
Radiation Damage Simulation Material Compatibility


Progress in ADS System Research: RFQ

Ion Source and RFQ

Progress in ADS System Research: Neutron Data Evaluation

Neutron induced reaction data for

$^{50,52,53,54,nat}Cr$, $^{54,56,57,58,nat}Fe$,

$^{58,60,61,62,64,nat}Ni$, $^{63,65,nat}Cu$,

$^{90,91,92,94,96,nat}Zr$, $^{180,182,183,184,186,nat}W$,

$^{204,206,207,208,nat}Pb$, ^{209}Bi,

$^{230,231,232,233,234}Th$,

$^{232,233,234,235,236,237,238,239,240}U$,

$^{236,237,238,239,240,241,242,243,244,246}Pu$。

Progress in ADS System Research: Neutron Data Evaluation

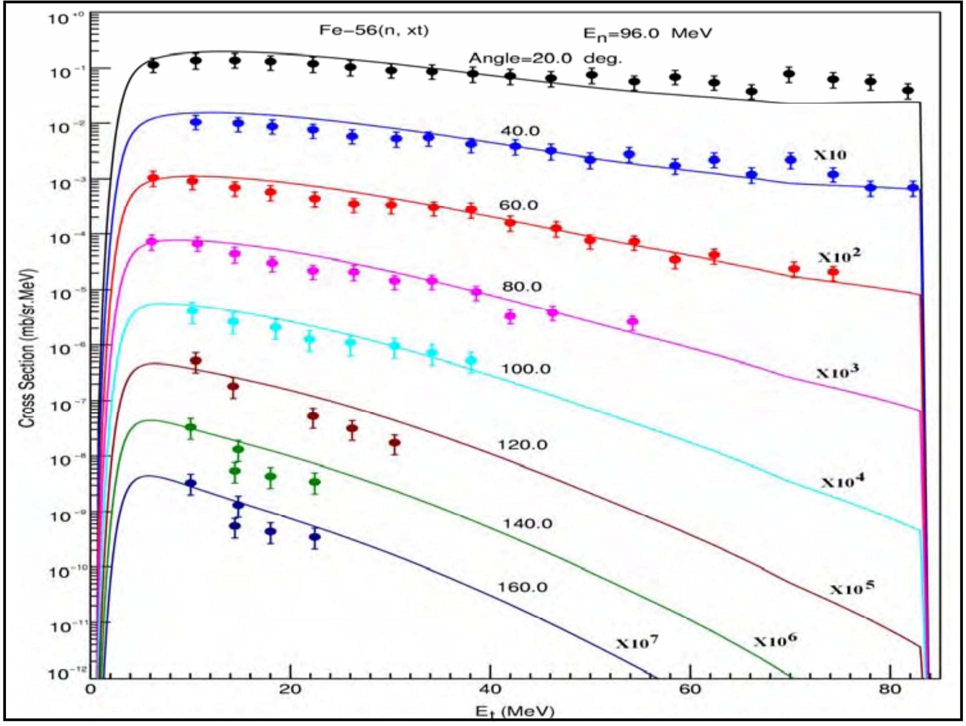
Proton induced reaction data for

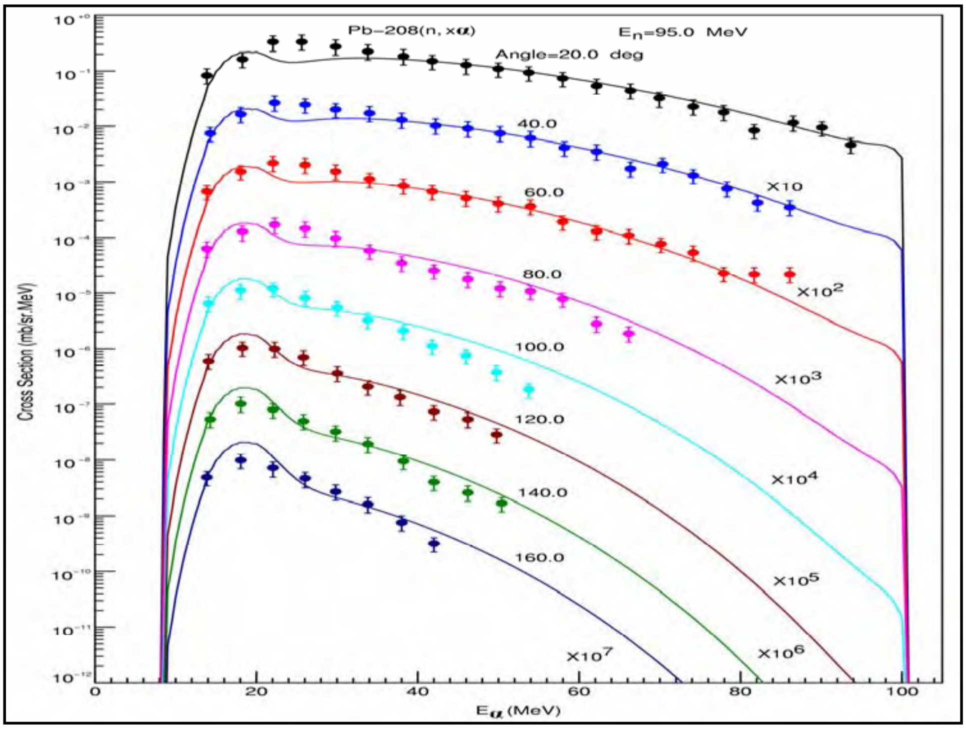
^{54,56,57,58}Fe, ^{58}Ni, ^{63,65}Cu,

^{180,182,183,184,186}W,

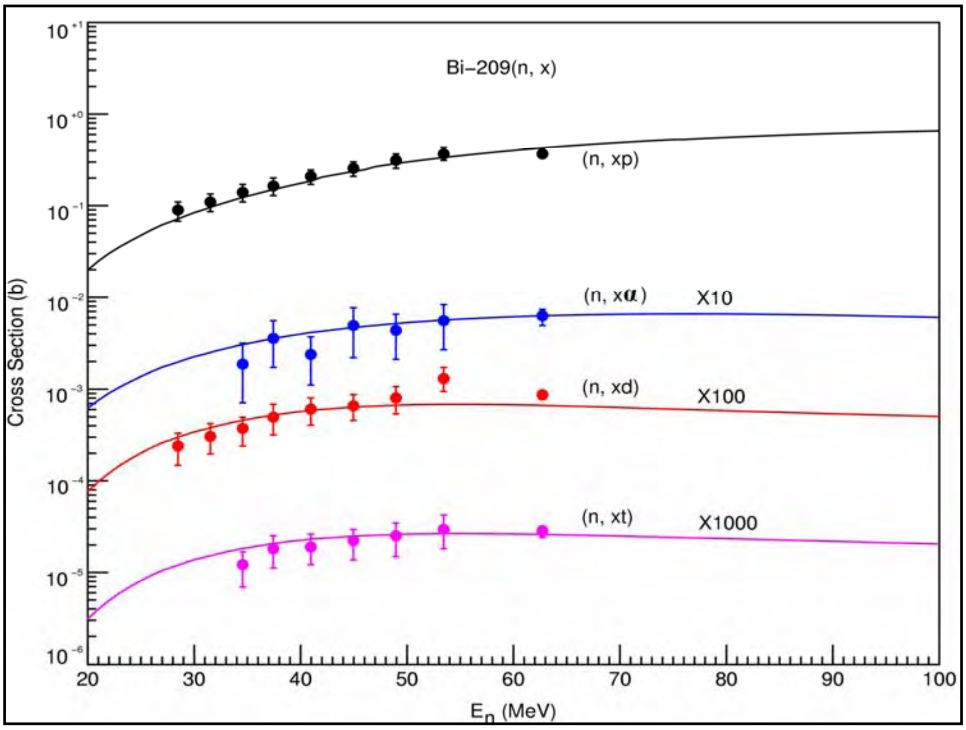
^{196,198,199,200,201,202,204}Hg

^{204,206,207,208}Pb, ^{209}Bi。

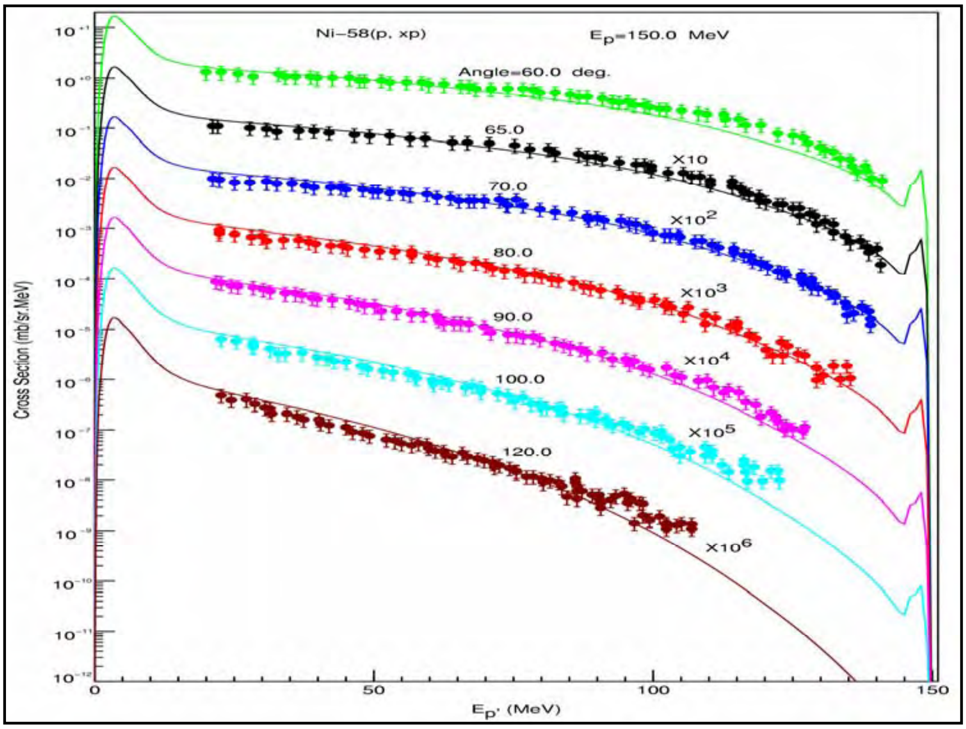


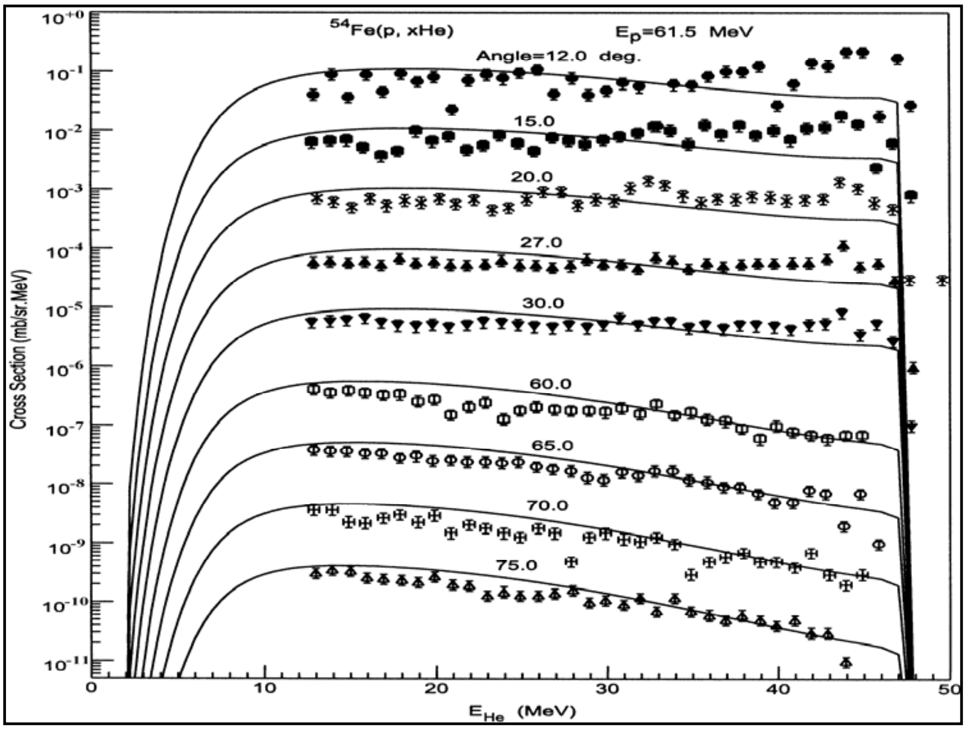


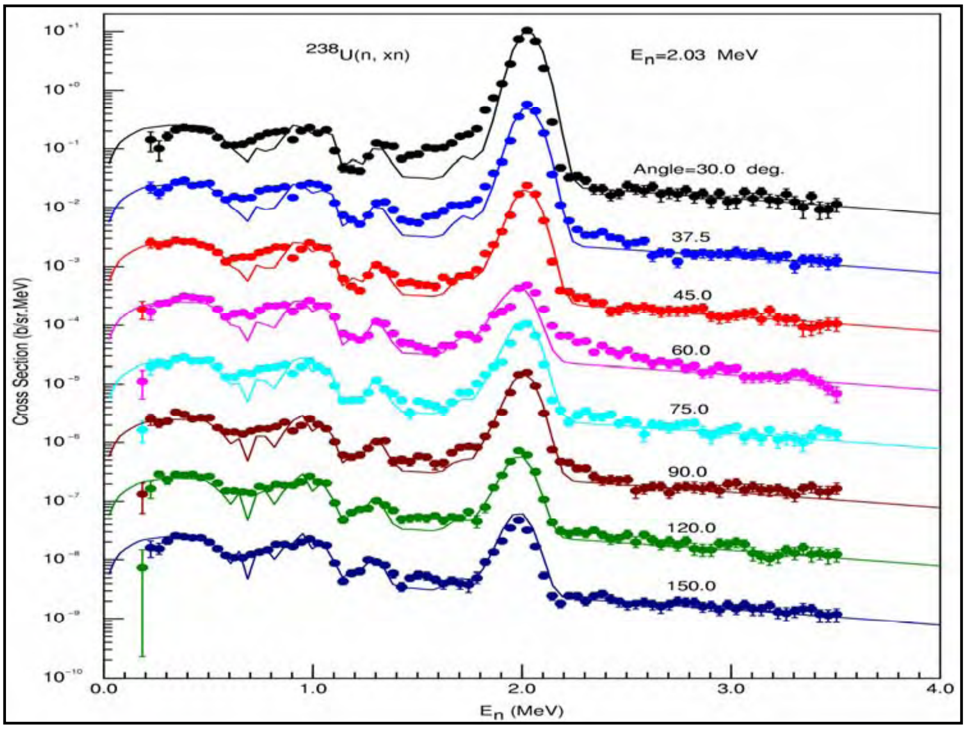
Pb-208(n, xα)
En=95.0 MeV
Angle=20.0 deg
40.0
60.0
80.0
100.0
120.0
140.0
160.0
X10
X10²
X10³
X10⁴
X10⁵
X10⁶
X10⁷
Cross Section (mb/sr.MeV)
Eα (MeV)



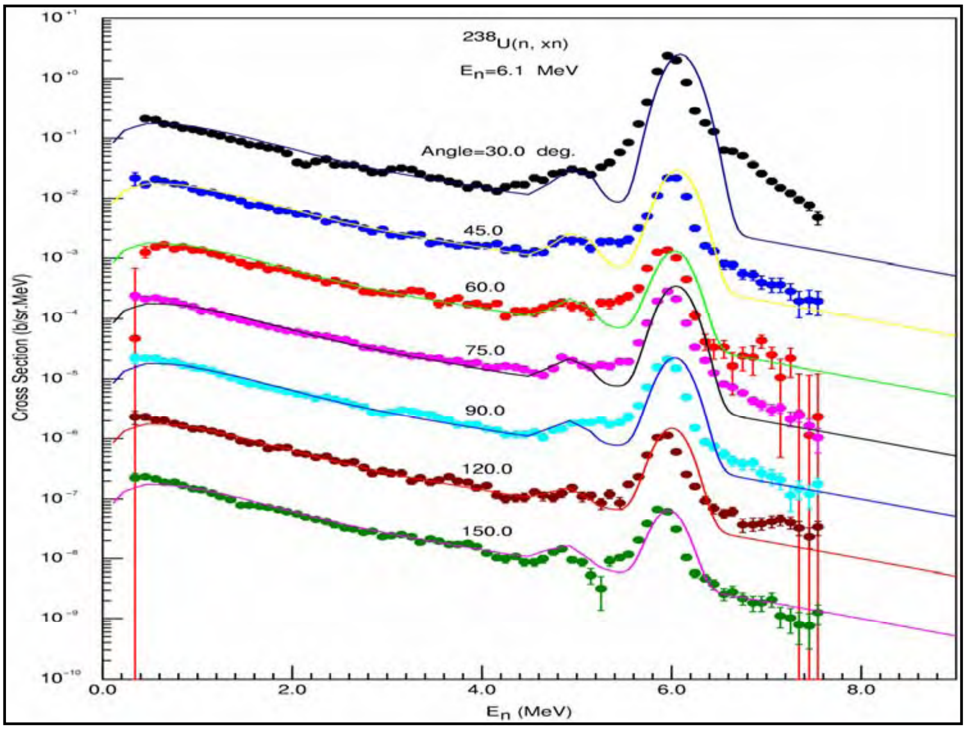
Bi-209(n, x)
(n, xp)
(n, xα)
X10
(n, xd)
X100
(n, xt)
X1000
Cross Section (b)
En (MeV)


Ni–58(p, xp)
Ep=150.0 MeV
Angle=60.0 deg.
65.0
X10
70.0
X10²
80.0
X10³
90.0
X10⁴
100.0
X10⁵
120.0
X10⁶
Cross Section (mb/sr.MeV)
Ep' (MeV)

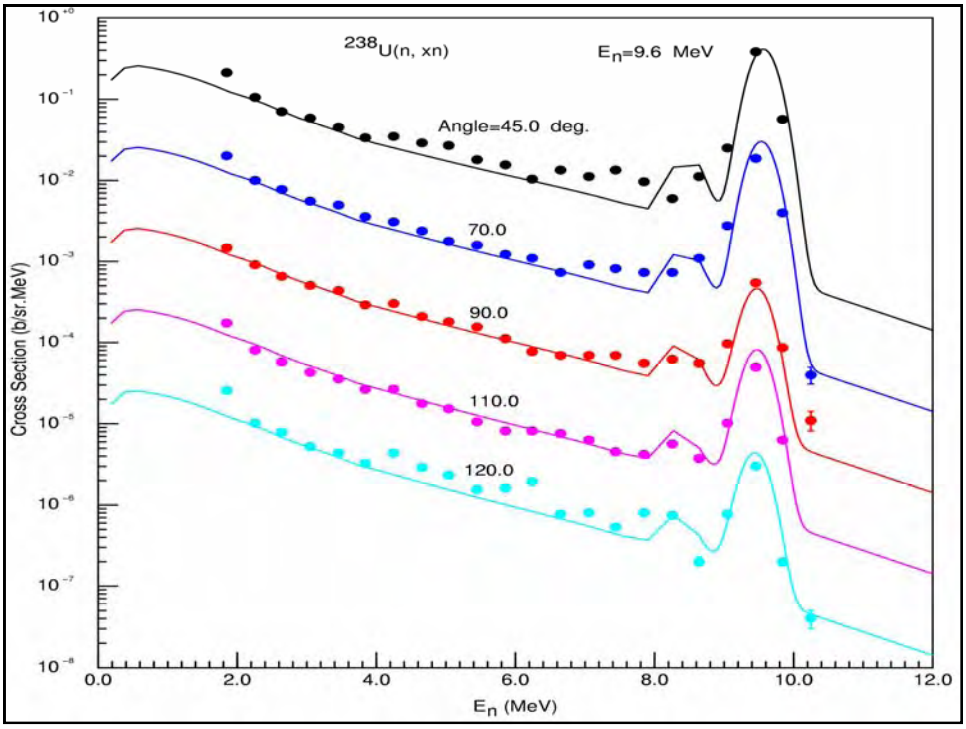

⁵⁴Fe(p, xHe)
Ep=61.5 MeV
Angle=12.0 deg.
15.0
20.0
27.0
30.0
60.0
65.0
70.0
75.0
Cross Section (mb/sr.MeV)
EHe (MeV)



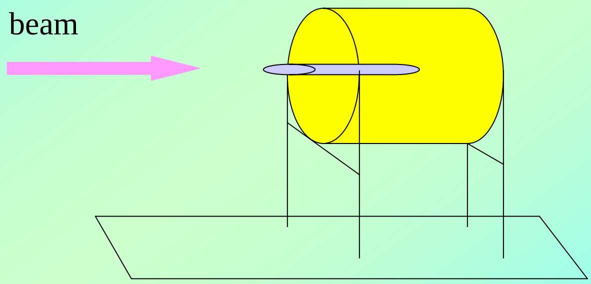
^{238}U(n, xn)
E$_n$=2.03 MeV
Angle=30.0 deg.
37.5
45.0
60.0
75.0
90.0
120.0
150.0
Cross Section (b/sr.MeV)
E$_n$ (MeV)



^{238}U(n, xn)
E$_n$=6.1 MeV
Angle=30.0 deg.
45.0
60.0
75.0
90.0
120.0
150.0
Cross Section (b/sr.MeV)
E$_n$ (MeV)



Progress in ADS System Research: Sub-critical Physics



The Venus 1 Layout

Arrangement of the core

Source/Buffer

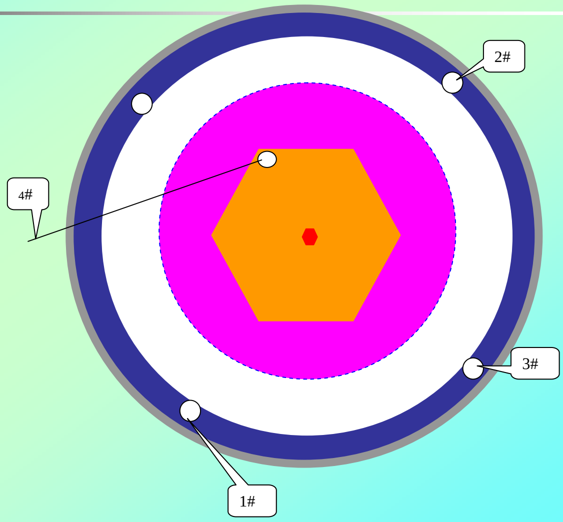
Driven Zone

Active Zone

Reflector

Shielding

1#，2#-BF3
3#，4#-3He

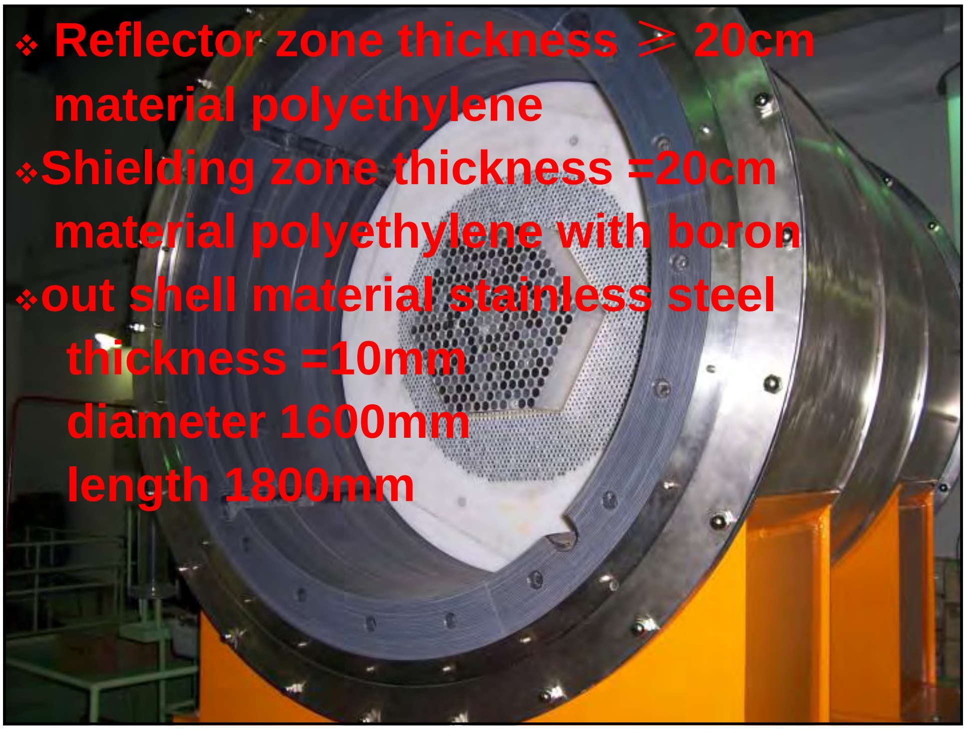


Natural uranium Fuel element

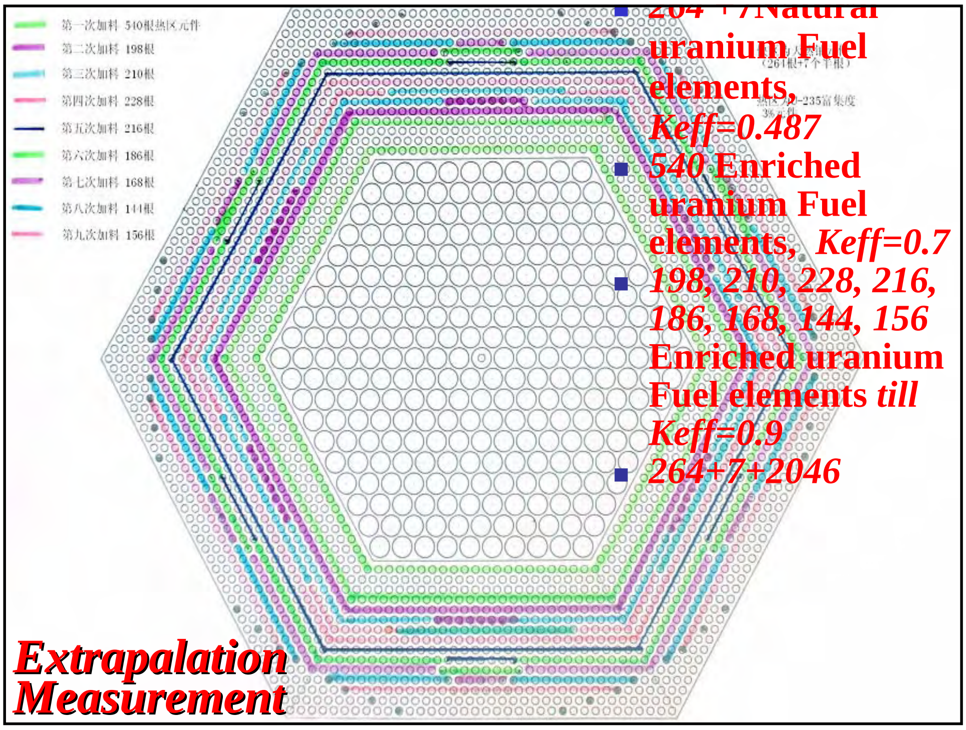
- **diameter Φ 22mm(20mm)**
- **container Aluminum 1mm**
- **activity length 1000mm**
- **density 18.6g/cm^3**
- **a fuel element weight 6.2kg.**

Enriched uranium 3% (weight %)UO_2 Fuel element

- diameter Φ 8mm(6.5mm)
- container Zr 0.65mm
- activity length 702mm
- density10.5 g/cm³
- a fuel element weight 0.25kg.



The first fuel element was loaded on 2005.7.18

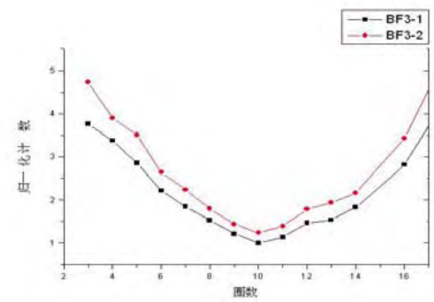


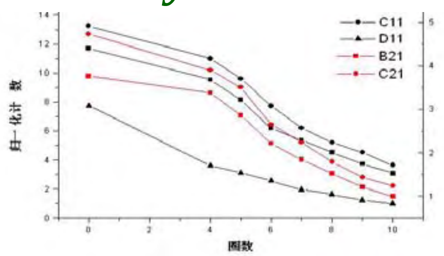
- 264 +7Natural uranium Fuel elements, *Keff=0.487*
- 540 Enriched uranium Fuel elements, *Keff=0.7*
- *198, 210, 228, 216, 186, 168, 144, 156* Enriched uranium Fuel elements *till Keff=0.9*
- *264+7+2046*

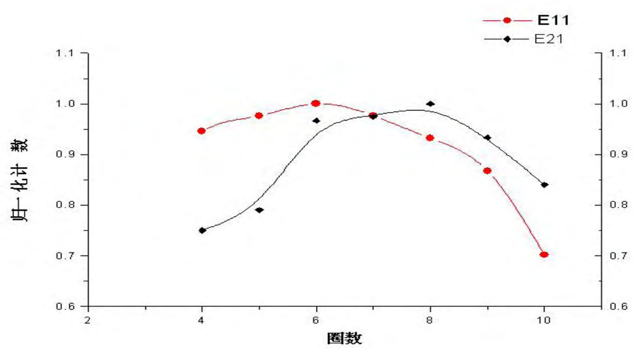
Extrapalation Measurement

The Venus 1 coupled with 300 kV pulsed neutron generator

Primary Results







Different Neutron Source

Red：

Am-Be, 10^5 n/s

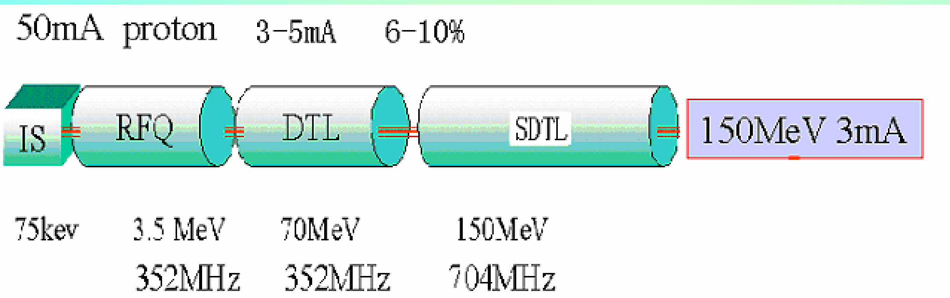
Black：D-T, 10^9-10^{10}n/s

Consideration in near future

A moderate style multi-purpose verification system is under consideration. In the conceptual study, we consider:

- **Low energy accelerator (150MeV/3mA proton linac)**
- **MW swimming pool light water sub-critical reactor**

The Venus Ⅱ Program



150 MeV, 3mA Accelerator

CONCLUSION

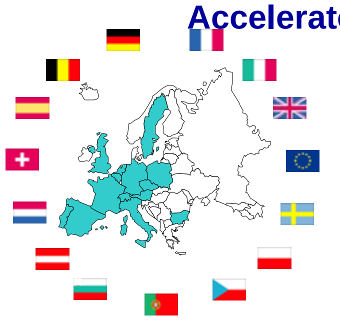
For long term and sustainable nuclear energy development, ADS is an good option in fuel circulation. ADS has been started to develop with a rather moderate project in China and is still in the early stage. The goal for our ADS research is to establish the scientific and technological foundation for the future development of ADS step by step.

中国原子能科学研究院
CHINA INSTITUTE OF ATOMIC ENERGY

Thank you!

Overview on DM2/ECATS program as proposed in the frame of the Integrated Project EUROTRANS

EURopean Research Programme for the TRANSmutation of High Level Nuclear Waste in an Accelerator Driven System



G. GRANGET
&
EUROTRANS/DM2 Team

Minsk,
December, 2005

FI6W-CT-2004-516520: Integrated Project on European Transmutation (EUROTRANS)

SUMMARY

1. Introduction (European roadmap, existing facilities : their necessary modifications and their ability to answer the DM1 specifications)
2. RACE
3. YALINA
4. SAD
5. WORKPACKAGES Introduction

FRAMEWORK

- European roadmap for transmutation by ADS dedicated systems
- Physic studies
- From MUSE to XT-ADS

Best use of existing facilities : TRADE, RACE, YALINA, SAD

After MUSE :

- Sub-criticality measurement technics
- Static and dynamic behaviour of an ADS (at power)
- Power/current relationship
- High energy protons and neutrons
- Shielding and safety issues

For DM1/DESIGN :

Experimental data are required for the design of XT-ADS and EFIT

- Qualification of sub-criticality monitoring
- Validation of the generic behaviour of an ADS in a wide range of sub-critical levels, sub-criticality safety margins and thermal feedback effects
- Start-up and shut-down procedures, instrumentation validation and specific dedicated experimentation
- Interpretation and validation of experimental data, benchmarking and code validation activities

FI6W-CT-2004-516520: Integrated Project on European Transmutation (EUROTRANS)

For DM1/DESIGN :

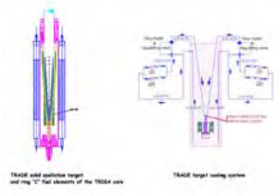
Experimental data are required for the design of XT-ADS and EFIT

- Qualification of the proton beam reliability and the beam transport line
- Pb-Bi or Pb spallation target design in association with relevant proton beam and the effects of spallation residues including that of polonium
- Qualification of the impact of the high energy protons and the fast neutron flux on the damage of structure and shielding issues
- Safety and licensing issues of the different components as well as the integrated system

SIXTH FRAMEWORK PROGRAMME

TRADE :

Target design



Experimental tools : Piccolo-Micromegas, Fast rabit, oscillator

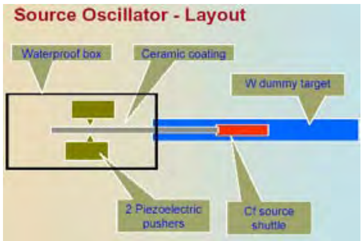
Benchmarking

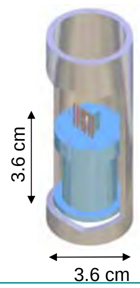
Confi guration	Keff				
	ANL	CEA	CNRS	ENEA	Mean value
1a	1.01167	1.01113	1.00801	1.00717	1.00950
1b	1.05463	1.05341	1.04965	1.05136	1.05226
1c	0.96867	0.96985	0.96758	0.96563	0.96793

SIXTH FRAMEWORK PROGRAMME

RACE-T (underway) :

- Complete experimental plan in 2005 (as previously defined)
- Final configuration MSA/MSM (with generator in center)
  - ½ week
- All configuration PNS
  - 4 weeks
- All configuration Cf oscillator
  - 1 week
- All configuration absorber oscillator
  - 1 week
- All configuration fission rate traverses
  - 3 weeks
- SC2, SC3 fast rabbit traverses
  - 2 weeks
- 1 generator dedicated to PNS, 1 generator dedicated to fission traverses and fast rabbit, and 1 generator dedicated to PNS in Texas leaving 1 as a spare
- 12 weeks total experimentation before end of 2005





RACE :

RACE Project Accelerators

Texas--1.8m long, 20 MeV

ISU--2.2 m long, 25-30 MeV

- 1-2 kW beam power with current electron gun and modulator/Klystron
- Relatively compact
- Reliable off-the-shelf components
- Easy to operate
- Flexible output characteristics

FI6W-CT-2004-516520: Integrated Project on European Transmutation (EUROTRANS)

Option Summary

Power	Energy	Target	Source
1.6 kW	20 MeV	W/Cu	2E12 n/s
1.6 kW	20 MeV	DU	5E12 n/s
1.6 kW	25 MeV	DU	7.5E12 n/s
25-30 kW	25-30 MeV	DU	6E13 to 1.2E14 n/s

Power Increase

- With the same accelerator fitted with a high current electron gun and the L modulator and larger klystron, the beam power will be increased to 20-30 kW owing to increases in peak beam current, repetition rate and beam pulse length.
- With the 25 MeV guide, the neutron yields are increased by ~1.5 times for both cases
- All essential equipment is available at IAC

25 MeV Acclerator Guide

2.2 meters

Targets

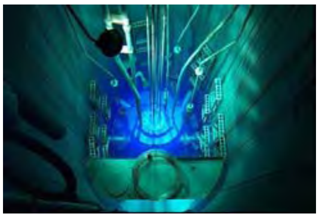
- With our current tungsten-copper target (the target used in the ISU RACE experiments is a 3.5" long by 2.75" diameter cylinder of 75% W, 25% Cu alloy) the neutron yield is ~2 x 10^{12} n/s
- With the DU target planned for Texas reactors, the yield rises to ~5 x10^{12} n/s at a beam power of 1.6 kW

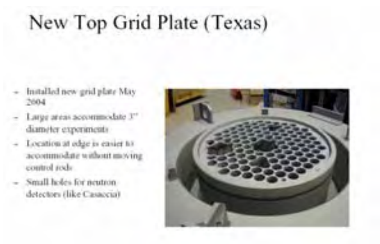
FI6W-CT-2004-516520: Integrated Project on European Transmutation (EUROTRANS)

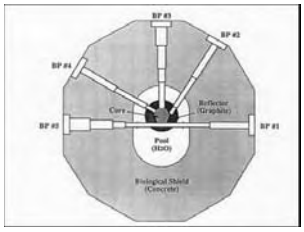
SIXTH FRAMEWORK PROGRAMME

UT RACE

- 1 MW TRIGA (around 10 years old)
- Plan is to ship linac to UT in early 2005
- First experiments in Spring/Summer 2005
- Target will be at periphery of core (through existing beam port)
- Possible to inject at center, but not designed yet
- k variable as desired







FI6W-CT-2004-516520: Integrated Project on European Transmutation (EUROTRANS)

SIXTH FRAMEWORK PROGRAMME

TAMU RACE

- Also 1 MW TRIGA, but in a rectangular grid
- Fuel type is 70% enriched with erbium as burnable poison (UT is 20% enriched)
- Use spent fuel perhaps to build a very flexible dedicated assembly

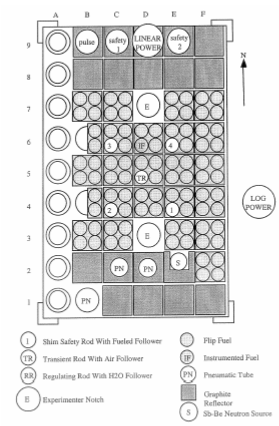


Fig. 2. FLIP core configuration.

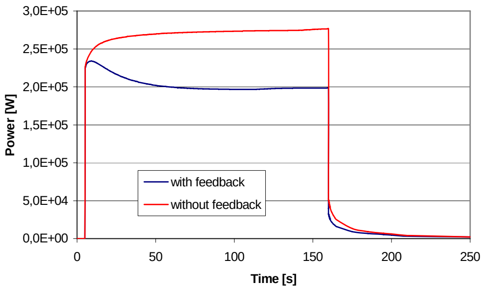
FEEDBACK EFFECTS :

$$-\rho = q\frac{S\phi^*}{P}$$

In this equation ρ can be considered :

•ρ(t) without feedback

•ρ(t, P) with feedback



To deduce reactivity from this curve, feedback effects must be checked by specific experiments.

FI6W-CT-2004-516520: Integrated Project on European Transmutation (EUROTRANS)

RACE ABILITY :

•Reactor (100 kW with cooling system for feedback effect, Reference critical state, safety rods)

•Target (30 kW with cooling system)

•Powerful electron current for beam trip simulation

$\Lambda/\beta = 14.\ 10^{-3}$

SIXTH FRAMEWORK PROGRAMME

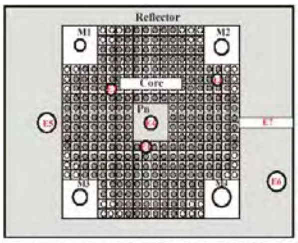
YALINA

YALINA Neutrons source characteristics

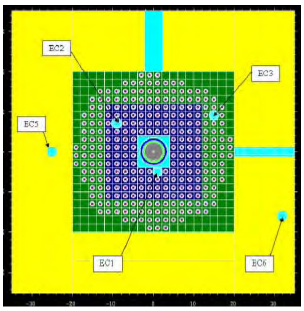
Deuteron energy		100 – 250 keV
Beam current		1 – 12 mA
Pulse duration		0.5 – 100 μs
Pulse repetition frequency		1 – 10000 Hz
Spot size		20 – 30 mm
(d,t)-target	Maximum neutron yield	$1.5 - 2.0 \cdot 10^{12}$ ns^{-1}
	Reaction Q-value	17.6 MeV
(d,d)-target	Maximum neutron yield	$2.0 - 3.0 \cdot 10^{10}$ ns^{-1}
	Reaction Q-value	3.3 MeV

FI6W-CT-2004-516520: Integrated Project on European Transmutation (EUROTRANS)

SIXTH FRAMEWORK PROGRAMME



Uranium-polyethylene subcritical assembly



EC	Λ/β_{eff} [10^3]
EC1	22.2±0.4
EC2	20.4±0.7
EC3	19.6±0.3
EC5	22.0±0.8
EC6	22.1±0.04

The view of "Bare" assembly (280 fuel pins) with lead blocks in the middle part instead of polyethylene ones. There are no measurement channels and fuel load map is somewhat different with respect to reference core.

The view of middle part of the assembly (part of polyethylene blocks were replaced by lead ones)

SIXTH FRAMEWORK PROGRAMME

YALINA ABILITY :

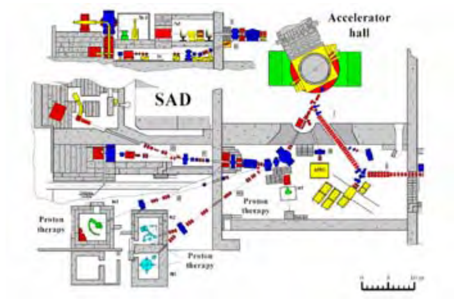
- Zero power subcritical medium (very easy to modify for physics experiments, with lead, variable neutrons spectrum)
- Simulated target
- Ion current for beam trip simulation and Power/Current relationship validation

Starting $\Lambda/\beta = 20.\ 10^{-3}$,

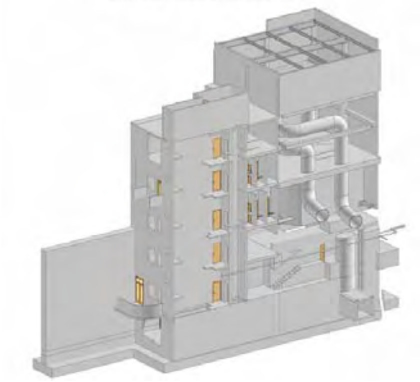
Smaller for YALINA-BOOSTER configuration

Intermediate spectrum between RACE and EFIT

SAD



Building for SAD facility



FI6W-CT-2004-516520: Integrated Project on European Transmutation (EUROTRANS)

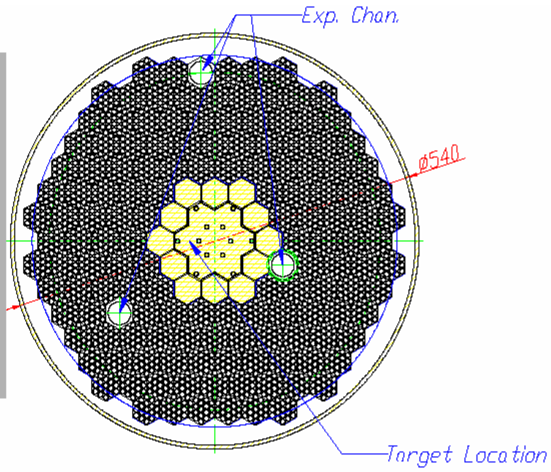
SAD 660 MeV PROTON BEAM :

Main characteristics of proton beam for SAD

Intensity of the extracted proton beam:	3.2 μA (1.997·10^{13} protons/s)
Beam emittance:	$\Sigma_x = \pi(5.1 \pm 2.3)\text{cm}\cdot\text{mrad}$ $\Sigma_y = \pi(3.4 \pm 1.4)\text{cm}\cdot\text{mrad}$
Time structure	
Fast extraction	
Frequency	250 Hz
FWHM	20 μs
Number of protons in pulse	0.8·10^{11}
Slow extraction	
Frequency	250 Hz
Pulse width	3500 μs
Beam microstructure	
Micro pulse FWHM	10 ns
Micro pulse period	70 ns

FI6W-CT-2004-516520: Integrated Project on European Transmutation (EUROTRANS)

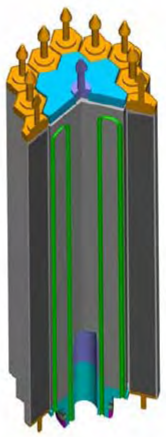
Number of cells for FAs	141
Number of loaded FAs	134
Number of loaded Pb prisms	7
fuel loading (UO_2-PuO_2)	396,9 kg
density of fuel	10,2 g/cm^3
PuO_2 content in fuel	29,5 % (w.)
U enrichment	0,7 % (^{235}U)
Height of fuel	58 cm



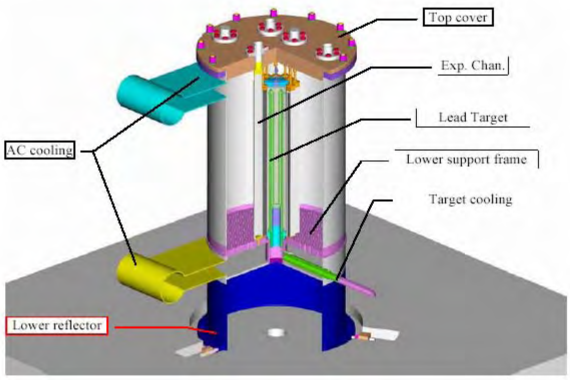
Layout of the SAD core (141 fuel assemblies x 18 fuel elements)

FI6W-CT-2004-516520: Integrated Project on European Transmutation (EUROTRANS)

Some SAD design details



Lead target section



SAD core section (fuel cassettes and reflector not shown)

SAD ABILITY :

- Subcritical system (Pu fuel, lead, air cooled)
- Solid Spallation target (air cooled)
- Proton beam line (beam trip simulation, shielding and safety issues)

$\Lambda/\beta = 0.2\ 10^{-3}$ (EFIT spectrum)

DOMAIN 2: Experiments on the Coupling of an Accelerator, a Spallation Target and a Sub-critical blanket

WP 2.1: Qualification of sub-criticality monitoring and of the core power/beam current relationship (RACE, YALINA, SAD)

P. BAETEN **1470 k€**

WP 2.2 Validation of the generic dynamic behaviour of an ADS in a wide range of sub-criticality levels and with consideration of thermal feedback effects (RACE, SAD)

M. SCHIKORR **1540 k€**

WP 2.3 Impact of high energy protons and neutrons, respectively on the target and structures and on shielding issues (SAD)

W. GUDOWSKI **2025 k€**

WP 2.4 Evaluation of licensing aspects deduced from SAD, RACE and YALINA in view of the XT-ADS necessities

R. ROSA **180 k€**

FI6W-CT-2004-516520: Integrated Project on European Transmutation (EUROTRANS)

SIXTH FRAMEWORK PROGRAMME

WP2.1 contains :

YALINA experiments

RACE-LP

SAD Start-up experiments

WP2.2 : RACE-HP

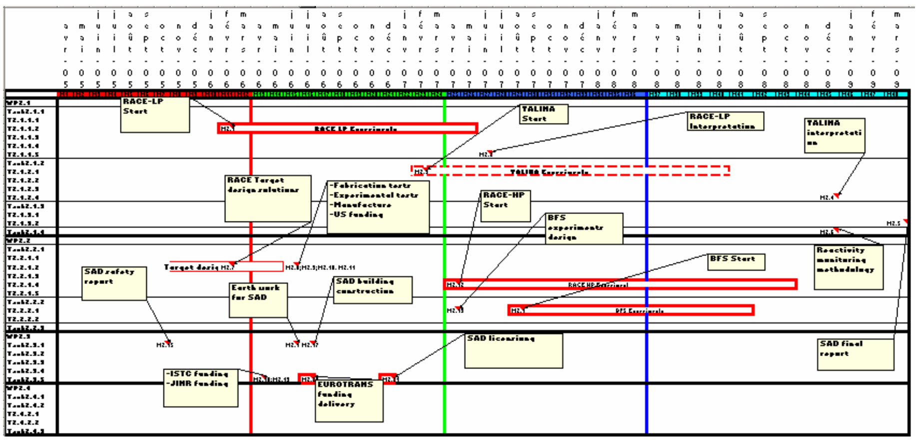
SAD/BFS and benchmarking

WP2.3 : SAD

WP2.4 : is related to all experiments

FI6W-CT-2004-516520: Integrated Project on European Transmutation (EUROTRANS)

SIXTH FRAMEWORK PROGRAMME



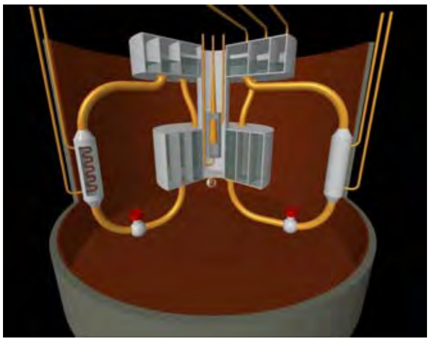
Proposal on BUTE contribution to the CRP

Coupling Monte Carlo and deterministic codes for ADS calculation
Monte Carlo simulation of neutron noise measurements

Máté Szieberth
Budapest University of Technology and Economics
Institute of Nuclear Techniques

Multiregional molten ADS

- The new concept
  - utilizes the spatial dependence of the spectrum;
  - increases the transmutational efficiency.
- Main features
  - the core is divided into separate regions
  - each region has a separate primary loop
  - loops are only neutronically and thermally coupled



- Goal: ADS calculation system for design and optimalization for transmutation
  - Fast burnup calculations
  - Precise calculation of the high-energy part

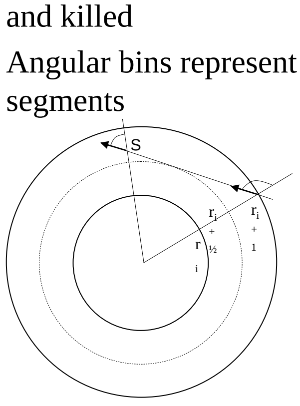
ADS calculation

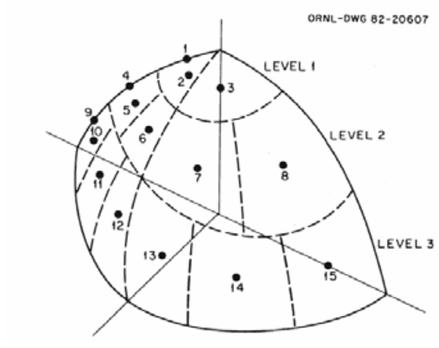
- Spallation and high-energy neutron transport based on physical models
  - Intra-nuclear cascade, pre-equilibrium model…
  - Only Monte Carlo transport is feasible
- Transport in the range of tabulated data (up to 20-200 MeV)
  - Deterministic methods are faster
- Coupling at the upper limit of data tables!
- Monte Carlo transport: MCNPX
  - Continuous energy 3D code +
  - High energy physical models
- Discrete ordinates transport: XSDRNPM
  - 1D discrete ordinates code
  - Part of the SCALE system
  - Easy to couple with depletion code

Budapest University of Technology and Economics (BUTE)

Source generation

- MCNPX calculation
- Neutrons scattering below the coupling energy are counted and killed
- Angular bins represent the segments





•Source is defined in discrete points
•Monte Carlo method is continuous in space
•Angular redistribution

IAEA CRP RCM, Minsk, 5-9 December 2005

Budapest University of Technology and Economics (BUTE)

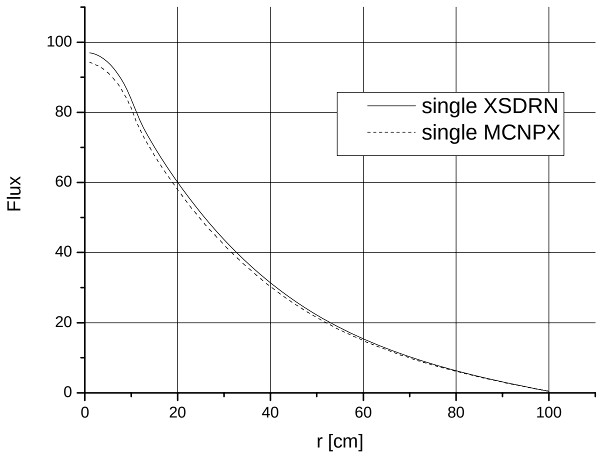
Test case

- Simple case for comparison of
  - Fully Monte Carlo and
  - Fully deterministic calculation
- Graphite cylinder (r = 1m)
- Isotropic source in the middle (r =10 cm)
- Source energy from 8.1873 MeV to 20 MeV

IAEA CRP RCM, Minsk, 5-9 December 2005

Budapest University of Technology and Economics (BUTE)

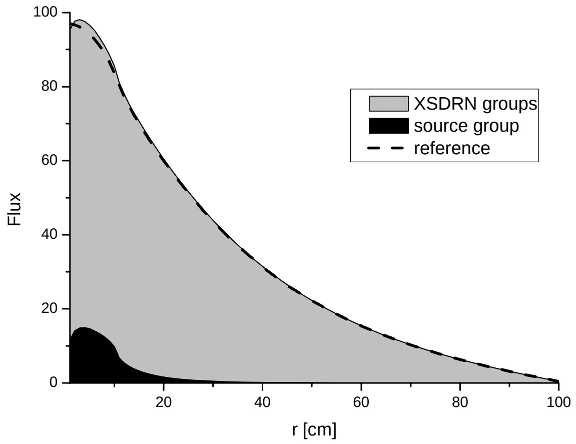
Calculations without coupling



IAEA CRP RCM, Minsk, 5-9 December 2005

Budapest University of Technology and Economics (BUTE)

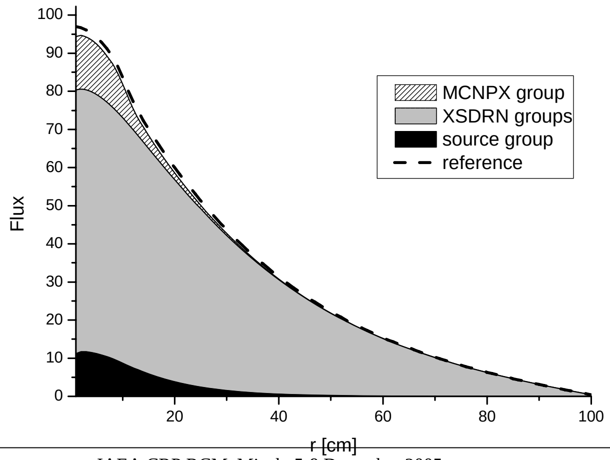
Coupling energy: 20 MeV



IAEA CRP RCM, Minsk, 5-9 December 2005

Budapest University of Technology and Economics (BUTE)

Coupling energy: 2.7 MeV



IAEA CRP RCM, Minsk, 5-9 December 2005

High energy reaction rates

- Required for correct burnup calculations
- No tabulated data → only analogous estimator
- Variance reduction:
  - Virtually increased total cross-section

$$\Sigma_t' = \Sigma_t + \Sigma^*$$

  - More collisions → improved statistics
  - Only the real part contributes to weight reduction

$$w_1 = \frac{\Sigma_t}{\Sigma_t + \Sigma^*} w \qquad w_2 = \frac{\Sigma^*}{\Sigma_t + \Sigma^*} w$$

Conclusions

- The energy based coupling of Monte Carlo and discrete ordinates codes is feasible, and can save computation time
- Can be integrated into burnup calculation scheme
- Dynamics calculation can be done with time-dependent deterministic code
- Other possible field of usage: shielding calculation for high energy sources (deep penetration problem)
- Useful for high energy, but validation can be done in any source driven system

Monte Carlo simulation neutron noise experiments

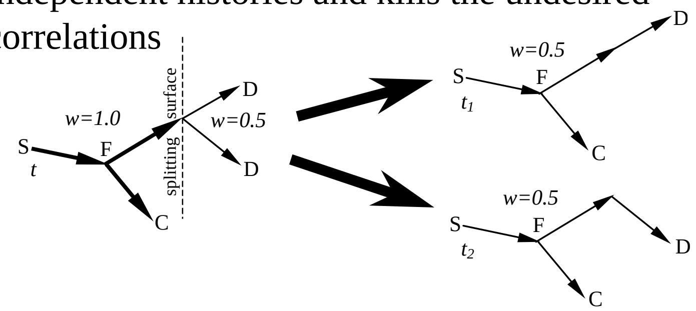
- Monte Carlo method is ideal for the simulation of stochastic processes
- Difficulties:

result influenced by higher moments	⟷	variance reduction
collective effects of particles (non-Boltzmann tally)	⟷	particle splitting methods

- Analogous MC can be used to avoid these problems
- Problem:
  - insufficient statistics of results

History splitting method

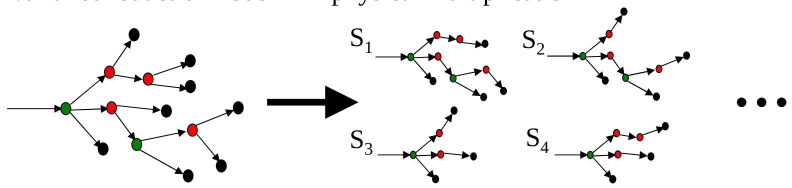
- Particle splitting methods give artificial multiplicity to the system and result in undesired correlations
- "History splitting" separates the split part into independent histories and kills the undesired correlations



History splitting

- Deconvolution: creation of subhistories
  - parent-branch, daughter-branches (b_i) and their weights (w_i) are stored for each variance reduction node
  - all possible subhistory are generated
- Rules of processing
  - each subhistory (S_i) has its own weight
  - subhistories are treated as independent histories

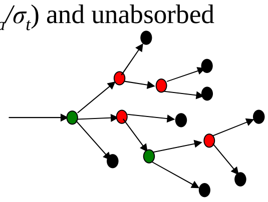
● variance reduction node ● physical multiplication ● termination



Budapest University of Technology and Economics (BUTE)

Applied variance reduction methods

- Alternative history control method instead of RR: switch back to analogue transport
- Splitting
  - Geometrical splitting
    - a particle is split into *n* pieces when enters a region with higher importance, $w=1/n$
    - played only when the particle enters a region for the first time
  - Implicit capture
    - the particle is split into absorbed ($w= \sigma_d/\sigma_t$) and unabsorbed ($w= 1-\sigma_d/\sigma_t$) parts
    - switched off below weight cutoff
    - limit for number of implicit captures on a track



IAEA CRP RCM, Minsk, 5-9 December 2005

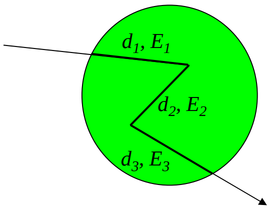
Detection with the track length estimator

- Aim: split every incoming particle into detected and undetected part
- Solution: track length estimator with implicit capture along the flight path
  - distance to next scattering is sampled *(d_i)*, capture excluded

$$w_{abs} = \sum_i \frac{\Sigma_a(E_i) - \Sigma_d(E_i)}{\Sigma_a(E_i)} \left(1 - e^{-\Sigma_a(E_i)d_i}\right) \prod_{j=1}^{i-1} e^{-\Sigma_a(E_j)d_j}$$

$$w_{det} = \sum_i \frac{\Sigma_d(E_i)}{\Sigma_a(E_i)} \left(1 - e^{-\Sigma_a(E_i)d_i}\right) \prod_{j=1}^{i-1} e^{-\Sigma_a(E_j)d_j}$$

$$w_{undet} = \prod_i e^{-\Sigma_a(E_i)d_i}$$



Effect of the weighted source events

- The history splitting changes the Poisson distribution of the source events
- Feynman-α: Y_∞ is not preserved, λ slightly biased
- The bias is not corrected yet, theoretical analyses are in hand

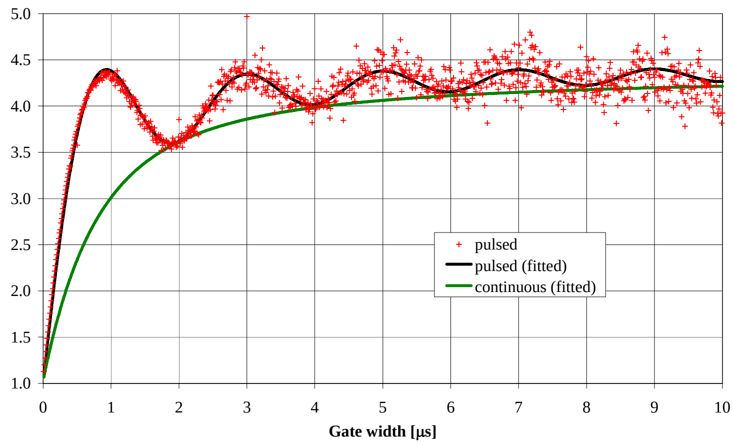
Preliminary calculations

- The method has been implemented in MCNP4C
  - additional subroutines
    - to collect data from variance reduction nodes
    - to generate subhistories when a history is finished
  - modifications to the physics model from MCNP-DSP
  - detection events are recorded (traveling time, t_t)
- Source time (t_s) is sampled for every subhistory
- Detection time ($t_d=t_s+t_t$) is determined and data is analyzed as a 'measurement' file

Budapest University of Technology and Economics (BUTE)

Results - pulsed Feynman-α

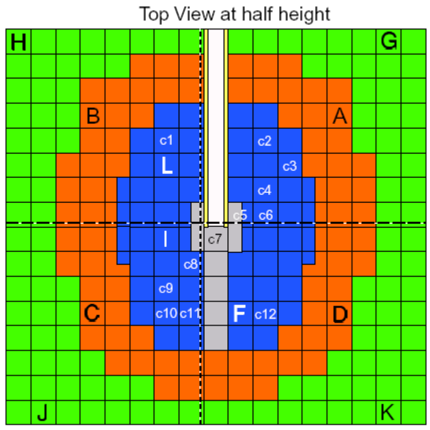
$$f(t,\bar{a}) = a_1\left(1-\frac{1-e^{-a_2 t}}{a_2 t}\right)+\frac{a_3}{t}\sin^2\frac{\pi t}{T}+1$$

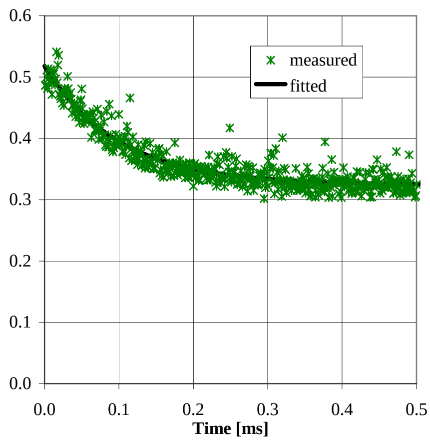


IAEA CRP RCM, Minsk, 5-9 December 2005

Budapest University of Technology and Economics (BUTE)

MUSE4 - autocorrelation





IAEA CRP RCM, Minsk, 5-9 December 2005

Budapest University of Technology and Economics (BUTE)

Comparison – number of histories and CPU time

Type of calculation	analogue	variance reduction
fast system	40,000,000	1,000,000
	188.69 min	11.5 min
thermal system	2,000,000	100,000
	415.05 min	30.82 min

IAEA CRP RCM, Minsk, 5-9 December 2005

Conclusions

- The application of particle splitting is possible with the help of the history splitting technique
- Variance reduction makes the simulation feasible for real systems

Activity in the field of source-driven systems at Politecnico di Torino

Politecnico di Torino,
Dipartimento di Energetica

Minsk 5-9/12/2005

Reactor physics models and methods

- Numerical methods for subcritical system dynamics

  - basic study of the physical features of space dynamics and limits of point models
  - adaptation of quasi-static schemes to source-driven problems
  - study of proper source adjoint problems
  - consistent definition of kinetic parameters

Minsk 5-9/12/2005

Reactor physics models and methods

- Numerical methods for subcritical system dynamics

  - development and validation of multi-point method

  - assessment and validation of methods and algorithms by analytical benchmarks (collaboration with B. Ganapol and E. Mund)

Minsk 5-9/12/2005

Reactor physics models and methods

- Interpretation of reactivity measurements

  - reconstruction of reactivity from flux measurements

  - study of spatial and spectral effects

  - investigation on tailored weighting techniques and source shape definitions to derive proper kinetic equations for pulsed experiments

Minsk 5-9/12/2005

Reactor physics models and methods

- Transport effects in source-driven experiments
  - study of basic phenomena
  - evaluation of limits of diffusion theory referring to reference configurations
  - study of propagation phenomena in pulsed experiments (recent work for analytical benchmarks): investigation of model and numerically induced phenomena

Minsk 5-9/12/2005

Physics models and methods for molten-salt reactors

- Development of models to account for flow of fissile material
- Construction of proper kinetic models (point and quasi-statics) and definition of kinetic parameters
- Coupling of neutronics with thermal and fluid-dynamics equations (on-going work)

Minsk 5-9/12/2005

Benchmarks in neutron kinetics and system dynamics: motivations

- Methods were developed for classic reactors
- The physical situation in ADS is very different
  - High neutron energy
  - Source dominance

Minsk 5-9/12/2005

Validation of dynamic simulation tools: three step process

- Validation of models
- Validation of numerical procedures
- Qualification of simulation tools

Minsk 5-9/12/2005

Validation of models: analytical benchmarks

- Analytical benchmarks
  - Closed-form solutions for reference problems
  - No discretizations, full error control
  - Separate model and numerically induced effects
  - Full comprehension of physical phenomena
  - Determination of limitations of approximate models (diffusion vs. transport, anisotropy effects, definition of kinetic parameters …)

Minsk 5-9/12/2005

Validation of numerical procedures: analytical and numerical benchmarks

- Analytical benchmarks
  - Verification that equations are adequately solved
- Numerical benchmarks: comparisons among codes
  - Assess accuracy and efficiency of algorithms
  - Establish code performance
  - Evidence possible shortcomings

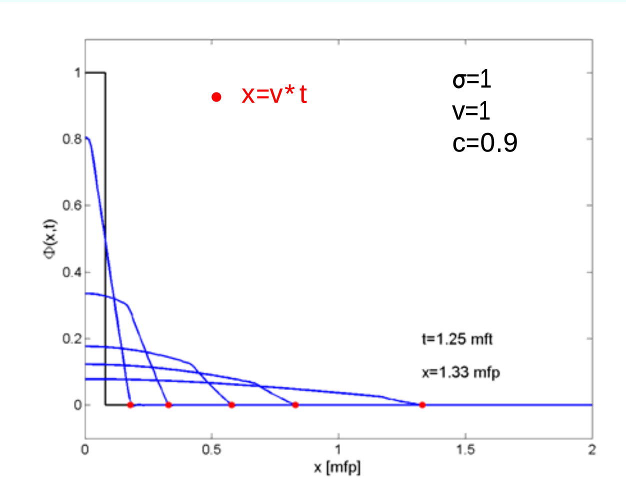
Minsk 5-9/12/2005

Qualification of simulation tools: experimental benchmarks

- Experimental benchmarks
  - Establish limits of validity of computational tools
  - Validation of nuclear data

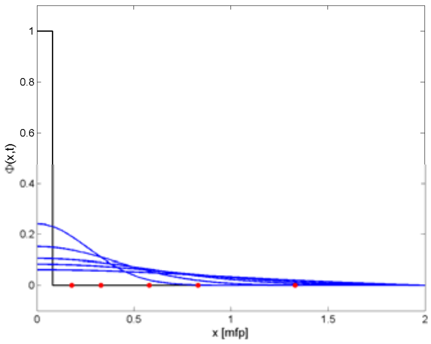
Minsk 5-9/12/2005

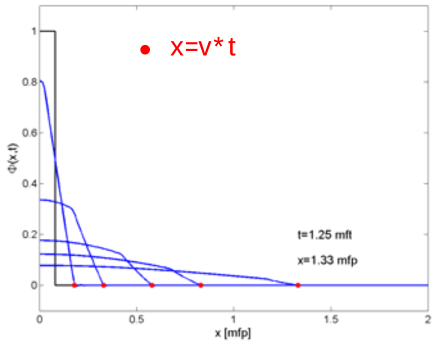
Space asymptotic method: propagation of a source pulse



Minsk 5-9/12/2005

Propagation of a source pulse: asymptotic method vs. diffusion

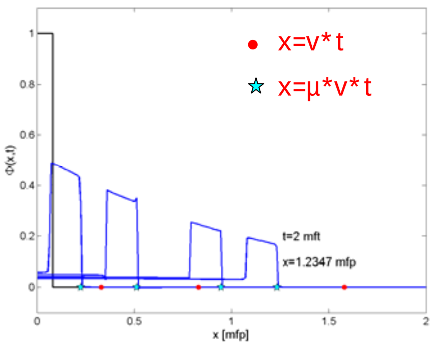


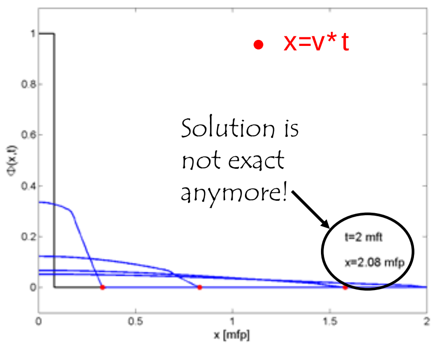


Diffusion is totally inadequate to describe this phenomenon

Superposition of real exponential ⇔ Propagation at infinite speed

Propagation of a source pulse: asymptotic method vs. P_1

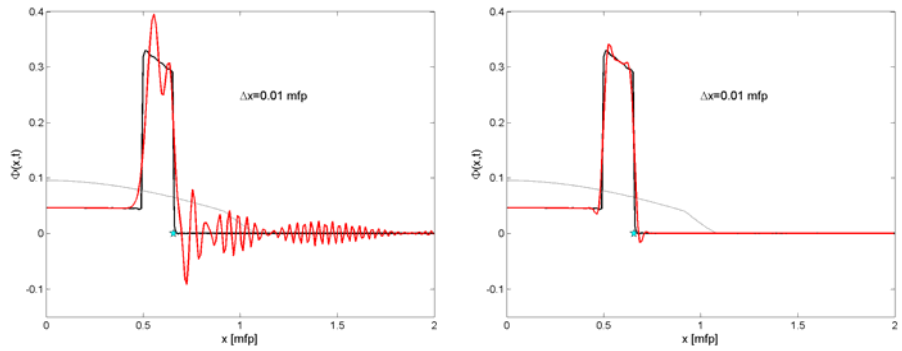




P_1 presents a wave-like propagation of the uncollided part + forward collided part of the pulse

Propagation of a source pulse: P_1 vs. S_2

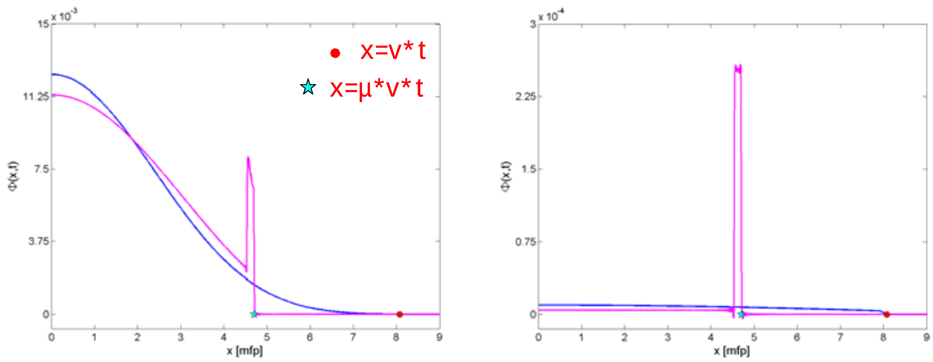
Since P_1 and S_2 in 1D are equivalent, comparison are made to evidence the effect of spatial discretization of S_2



☆ x=μ*v*t

Minsk 5-9/12/2005

Propagation of a source pulse: asymptotic method vs. P_1 (influence of c)

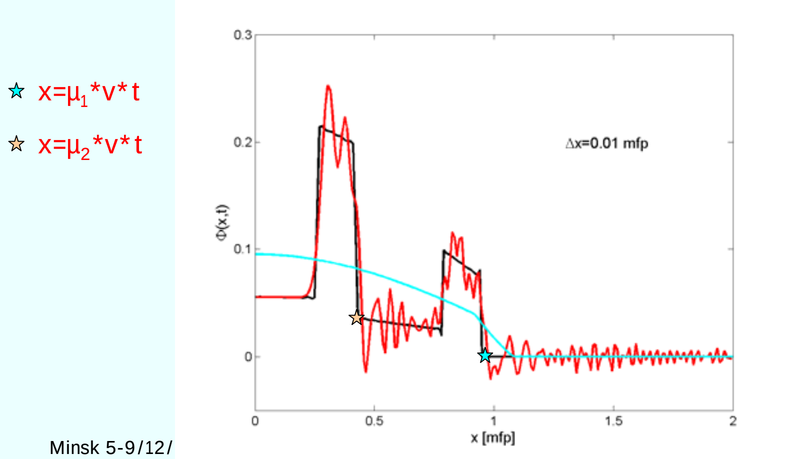


c=0.9 c=0.1

Minsk 5-9/12/2005

Solution of the S_4 problem - DD

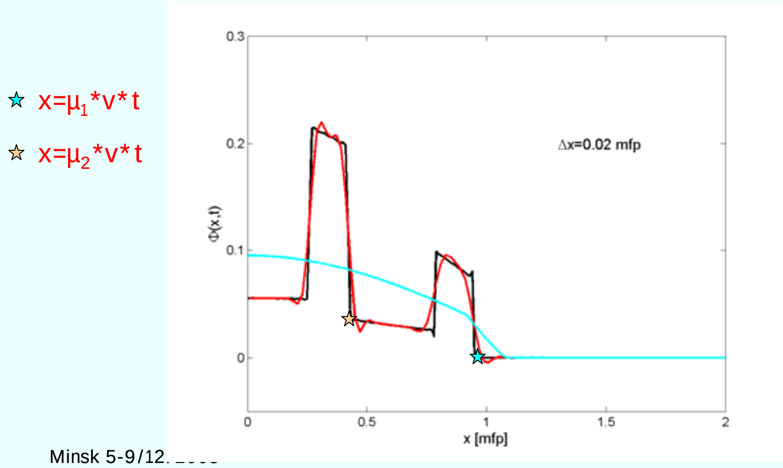
Influence of space discretization → numerically-induced oscillation



Minsk 5-9/12/

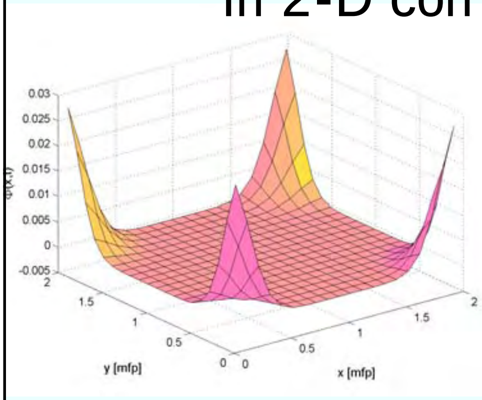
Solution of the S_4 problem - LD

Influence of space discretization → smoothening of oscillation with linear discontinuous



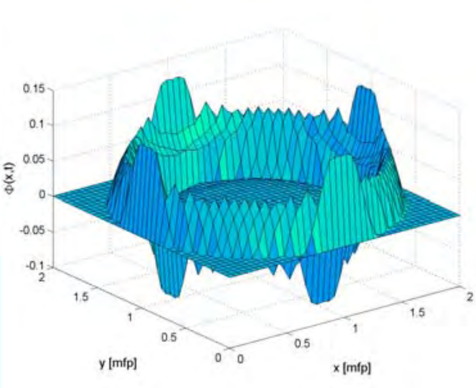
Minsk 5-9/12.

Solution of P_1-S_2 models in 2-D configurations



S_2

P_1



Minsk 5-9/12/2005

Research Project on Accelerator-driven Subcritical System Using FFAG Accelerator and Kyoto University Critical Assembly

K. Mishima, T. Misawa, H. Unesaki, C. Pyeon, C. Ichihara, M. Tanigaki, Y. Mori, S. Shiroya & M. Inoue
Research Reactor Institute, Kyoto University,Kumatori, Osaka 590-0494, Japan

Y. Ishi & S. Fukomoto
Mitsubishi Electric Corporation

Outline of Present Project for ADS at Kyoto University Research Reactor Institute

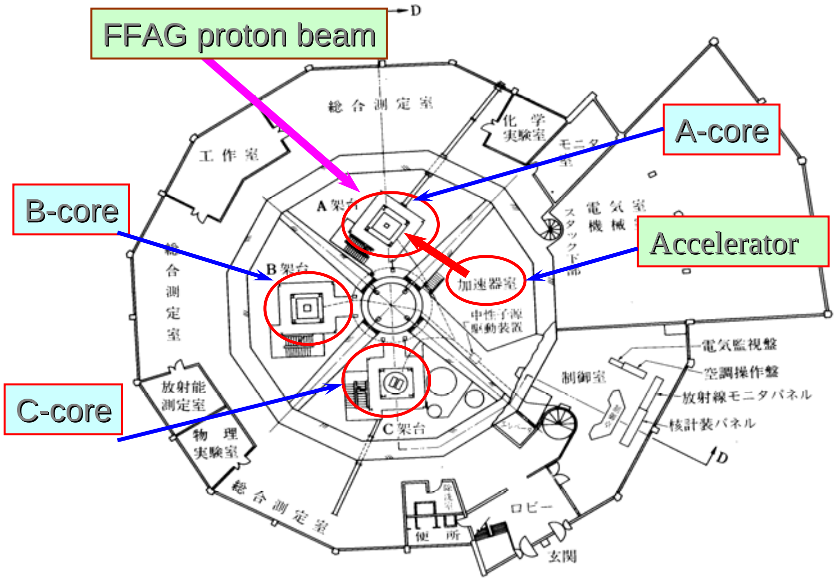
- This project titled "**new FFAG accelerator development for ADS research**" was started from 2002 and it is financially supported by Ministry of Education and Technology (MEXT) for innovative reactor development.
- New **FFAG** (Fixed Field Alternate Gradient) accelerator that can produce proton beam of about 1 micro-A current with arbitrary energy from 20 to 150 MeV will be constructed.
  - including R&D of FFAG accelerator
- The proton beam from FFAG will be introduced into a core of KUCA to generate high-energy neutrons by bombarding heavy metal such as tungsten.
- Basic research for ADS will been conducted at KUCA.

KUCA

(Kyoto University Critical Assembly)

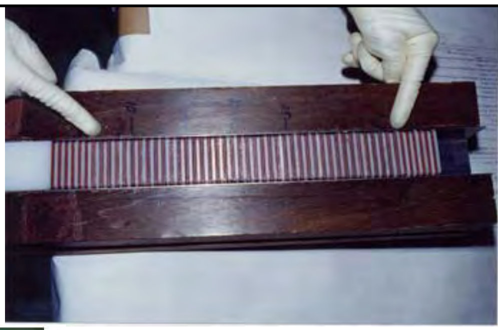
- First Criticality: Aug. 1974
- Only one critical assembly owned by university in Japan
- Maximum power: 100 W (short time 1kW)
- Accelerator to produce 14MeV neutron by DT reactions is equipped.

Cross Sectional View of KUCA Building



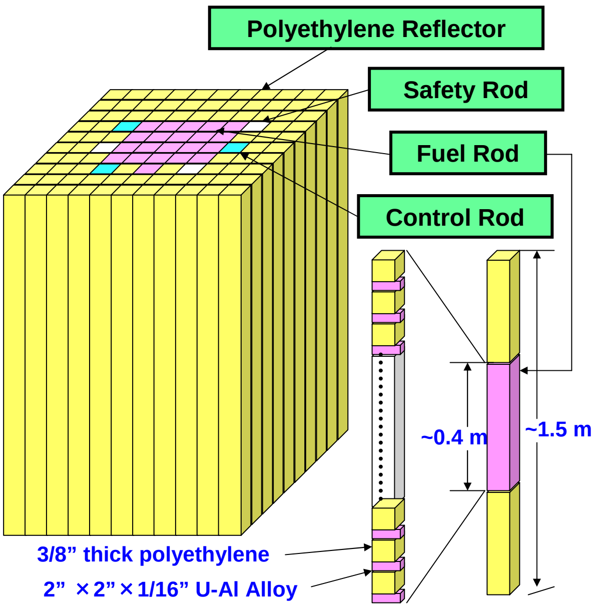
Fuel Cell

fuel plate +
polyethylene plate

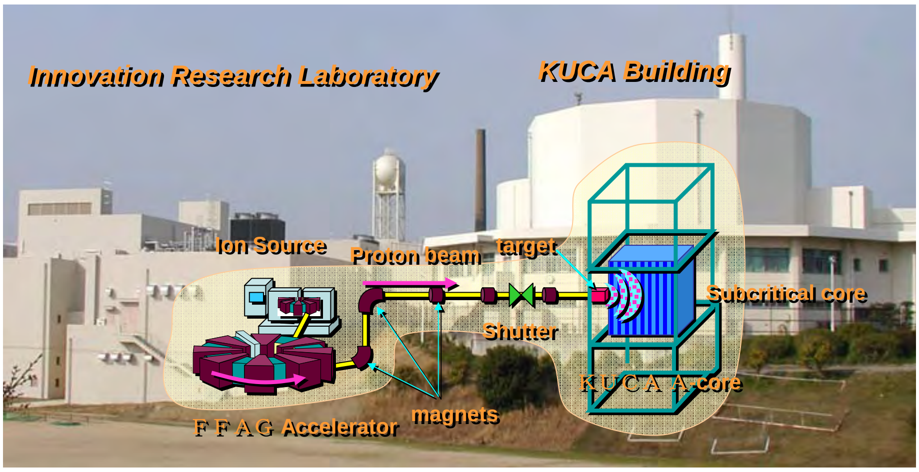


A-Core View

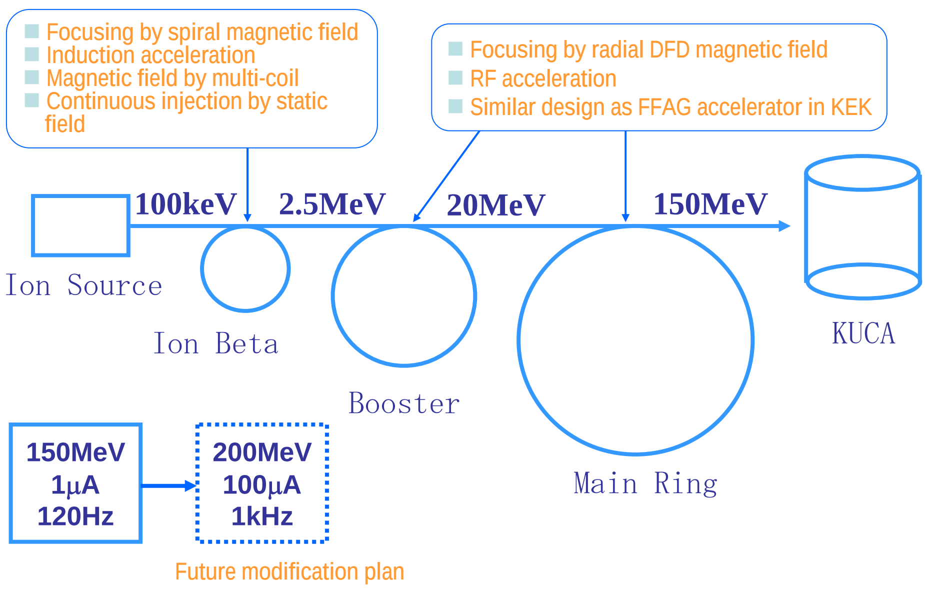
Image of the KUCA A-core



Concept of FFAG-KUCA Experiment on ADSR

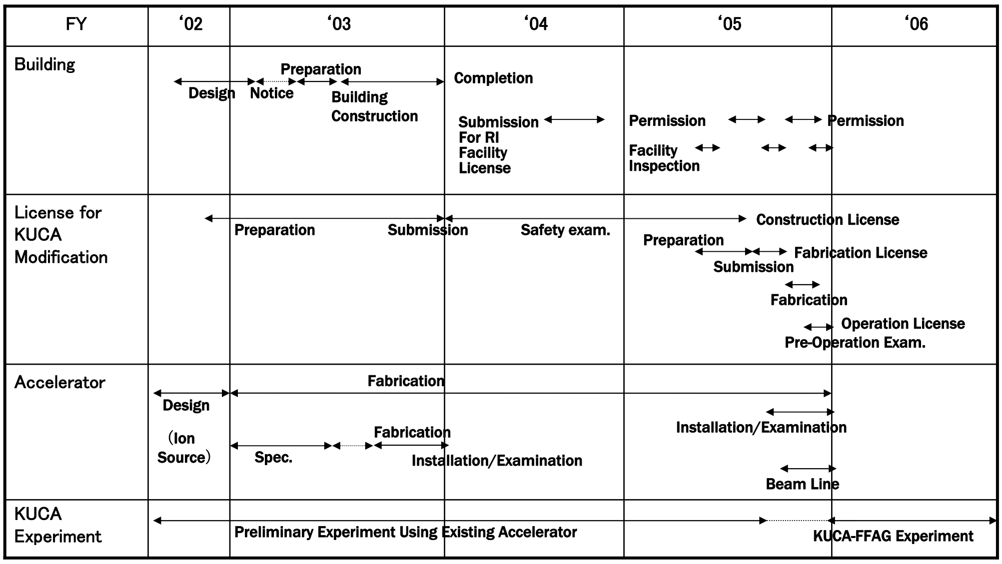


Configuration of FFAG Accelerator Complex



KART & LAB Schedule

September 16, 2005

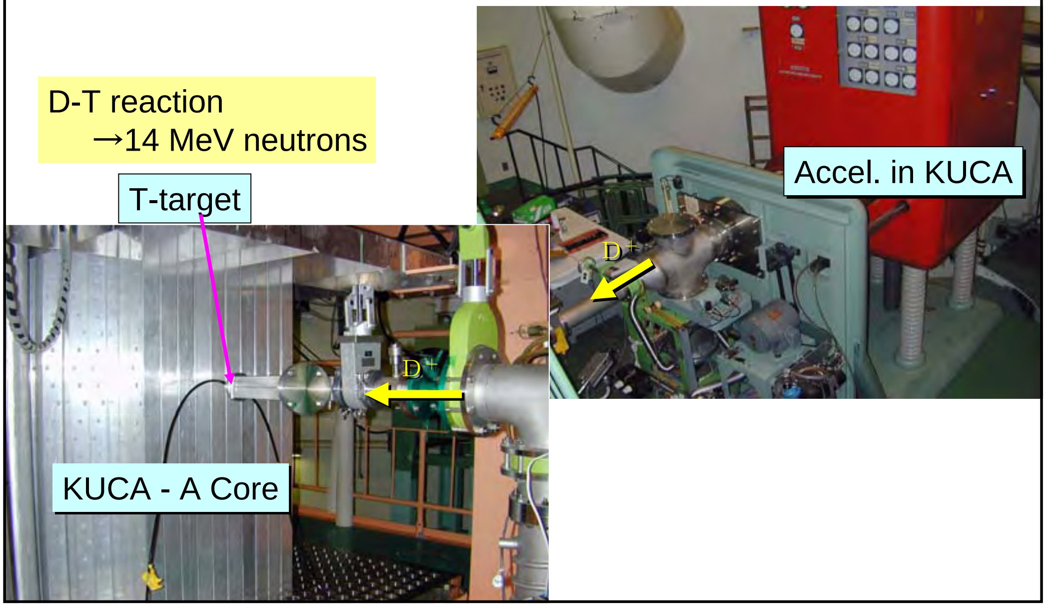


Present ADS research at KUCA

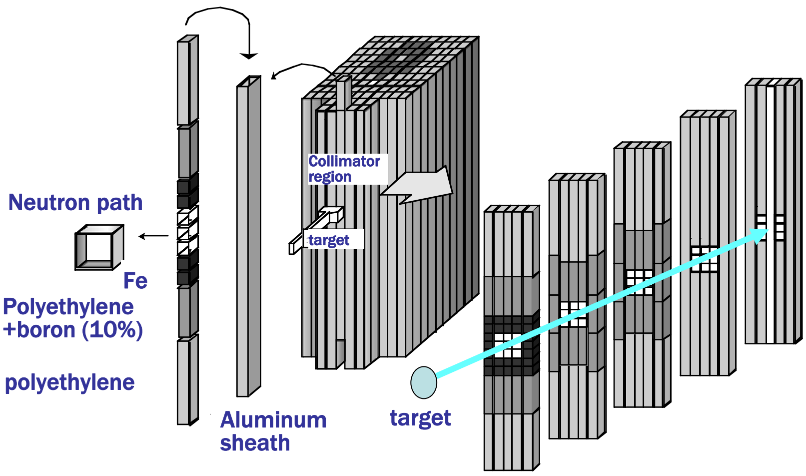
- Neutron flux distribution measurement in subcritical state
  - Optical fiber detector
  - Foil or wire activation method
- Neutron spectrum measurement
  - unfolding method by irradiation of with several foils.
  - unfolding method by recoil proton with a liquid scintilator (NE213)
- Neutron noise analysis for ADS with pulsed neutrons to determine various core parameter.
- Subcriticality measurement
  - Pulsed neutron method
  - Noise analysis method
  - modified neutron source multiplication method
- Analysis of experiments with Monte Carlo code (MVP, MCNP, and MCNPX) and other deterministic transport codes.

Preliminary Experiment

Using Existing KUCA-Acc. System

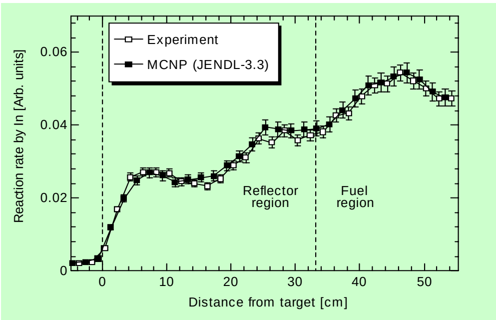


Experiment on the Optimization of Neutron Beam Collimator Geometry



Comparison of k-eff by experiments and calculation (MCNP)

JENDL-3.3		ENDF/B-VI.2	
Experiment $\rho_{exp\text{-}sub}$ (%$\Delta k/k$)	Calculation $\rho_{cal\text{-}sub}$ (%$\Delta k/k$)	Experiment $\rho_{exp\text{-}sub}$ (%$\Delta k/k$)	Calculation $\rho_{cal\text{-}sub}$ (%$\Delta k/k$)
-0.68 ± 0.03	-0.69 ± 0.03	-0.68 ± 0.03	-0.71 ± 0.03
-0.89 ± 0.04	-0.84 ± 0.03	-0.89 ± 0.04	-0.86 ± 0.03
-1.34 ± 0.07	-1.35 ± 0.03	-1.34 ± 0.07	-1.40 ± 0.03
-1.76 ± 0.05	-1.71 ± 0.03	-1.76 ± 0.05	-1.72 ± 0.03



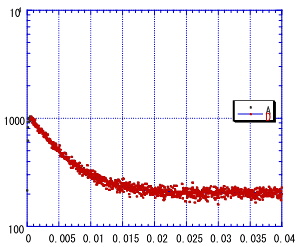
Reaction Rate Distribution of Indium wire
(experiments and calculation)

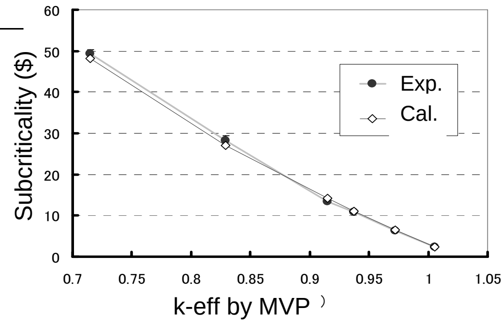
Reaction Rate by Fast Neutron

Irradiation position		Target	(15, Q) Without collimator	(15, K) With collimator
Reaction	Threshold (MeV)	Reaction rate	Reaction rate	Reaction rate
^{115}In (n, n') ^{115m}In	0.32	2.66×10^{-1}	6.14×10^{-2}	5.71×10^{-1}
^{46}Ti (n, p) ^{46}Sc	1.62			1.13
^{60}Ni (n, p) ^{60}Co	2.08	1.00	4.47×10^{-2}	5.38×10^{-3}
^{56}Fe (n, p) ^{56}Mn	2.97	2.96×10^{3}	1.39×10^{1}	9.50×10^{2}
^{27}Al (n, α) ^{24}Na	3.25	4.84×10^{-1}	7.29×10^{-3}	4.14×10^{-2}
^{48}Ti (n, p) ^{48}Sc	3.28			5.63×10^{-1}
^{24}Mg (n, p) ^{24}Na	4.93	9.83×10^{-2}	1.06×10^{-2}	5.71×10^{-2}
^{93}Nb ($n, 2n$) ^{92m}Nb	9.05			1.43
^{127}I ($n, 2n$) ^{126}I	9.22	4.55	3.66	
^{47}Ti (n, np) ^{46}Sc	10.69			1.05
^{49}Ti (n, np) ^{48}Sc	11.59			4.20×10^{-2}
^{58}Ni ($n, 2n$) ^{57}Ni	12.43	8.26×10^{-2}	1.14×10^{-3}	5.70×10^{-3}

Subcriticality Measurement by Pulsed Neutron Method

Optical Fiber Detector





Conclusion

- **ADS basic research has been carried out at KUCA combined with 14 MeV pulsed neutron accelerator**
  - neutron flux (reaction rate) distribution
  - fast neutron spectrm
  - neutron noise analysis
  - subcriticality
- **From 2006, new experiments at KUCA with a FFAG 150 MeV proton accelerator will be started.**

- **The experiment in KUCA will be suitable for benchmark problem in this CRP. However, official request from CRP will be needed to select as benchmark problem.**

KUCA (Kyoto University Critical Assembly)

- Multi-core type critical assembly (A-, B-, C-cores)
- The A-core that is used for ADS study is consisted of highly enriched uranium fuel plates, moderator plates (such as polyethylene, graphite and beryllium) and reflector plates.
- It can be loaded with natural uranium metal plates or thorium metal plates combined with fue17l and moderator plates.
- Neutron spectrum of the core can be changed by altering volume ration of fuel and moderator plates; thermal to epi-thermal neutron spectrum.
- Because of the limit of fuel plates, fast energy spectrum core can be partly simulated only in subcritical state.
- A Cock-Croft Walton type accelerator is installed at KUCA building to accelerate deuterium (D+) beam to generate 14 MeV pulsed neutrons by D-T reactions.

Research and Development Activities on Accelerator Driven Subcritical System in JAEA

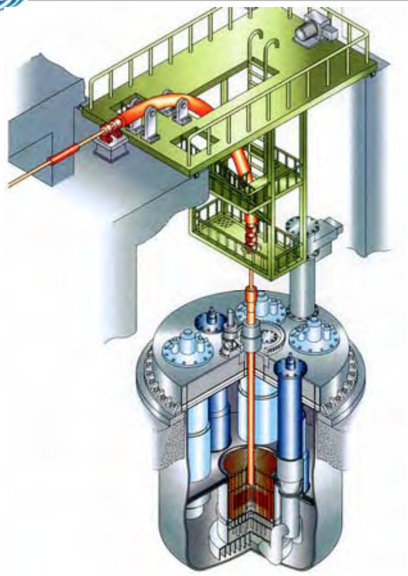
Kazufumi TSUJIMOTO
Japan Atomic Energy Agency

IAEA CRP meeting, Minsk, Belarus, December 5-9, 2005

Contents

- Design study of ADS in JAEA
- Calculation tools and libraries
- Future experimental program (TEF)
- Conclusion

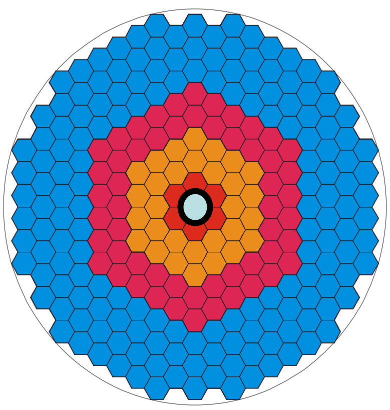
Reference Design of ADS



Conceptual view of 800MWth LBE-cooled ADS

- Proton beam : 1.5GeV ~30MW
- Spallation target : Pb-Bi
- Coolant : Pb-Bi
- Subcriticality : k_{eff} = 0.97
- Thermal output : 800MWt
- MA initial inventory : 2.5t
- Fuel composition :
  (MA+Pu)Nitride + ZrN
  Initial loading
  Zone-1 : Pu/HM = 30.0%
  Zone-2 : Pu/HM = 48.5%
- Transmutation rate :
  10%MA / Year (10 units of LWR)
- 600EPFD, 1 batch

Core Configuration of JAEA ADS



Target	7
Inner Fuel	30
Outer Fuel	54
Shield	162

Assembly pitch	233.9 mm
Assembly flat-to-flat distance	232.9 mm
Length of fuel assembly	3,740 mm
Effective fuel length	1,000 mm
Fuel pins／Assy	391
Fuel pin outer diam.	7.65 mm
Fuel pin pitch	11.48 mm

Calculation Tools

Static calculation code (deterministic code)

- **SLAROM, SRAC** : Cell calculation using collision probability method
- **DANTSYS** : Transport calculation
- **CITATION** : Diffusion calculation

Static calculation code (Monte Carlo)

- **MVP**, **MCNP** : Continuous energy Monte Carlo code
- **PHITS**, **MCNP-X** : High energy particle transport code

Burnup calculation

- **ATRAS** : Integral code system which consists of **SCALE**, **TWODANT**, **BURNER**
- **ABC-SC** : Integral code system which consists of **SLAROM**, **TWODANT**, **ORIGEN**
- **MVP-BURN** : Burnup code with MVP Montel Carlo code

Sensitivity calculation

- **SAGEP**, **SAGEP-BURN** : Sensitivity analysis using generalized perturbation theory

Nuclear Data Libraries

Nuclear data libraries (standard)

- **JENDL-3.3, ENDF/B-VI.8, JEFF-3.0 (3.1)**

  These libraries are available in deterministic and Monte Carlo calculations.

Nuclear data libraries (High energy)

- **JENDL-HE** : Neutron and proton up to 3GeV (JENDL/HE-2004 includes 66 nuclides)
- **LA150** : Neutron and proton up to 150MeV

  These libraries are available in high energy particle transport code (MCNP-X)

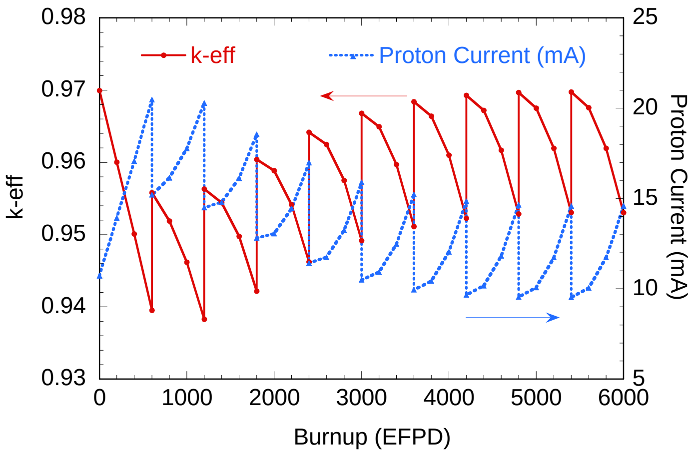
Preprocessing code

- **NJOY, TIMS**, etc.

Group constant for cell calculation

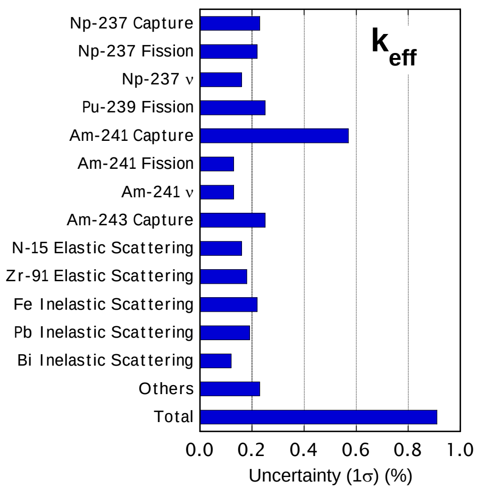
- **SLAROM** : JAERI Fast Reactor Group Constant Set (JFS-3), 70 and 73 group
- **SRAC** : SRAC library, 107 group

Neutronics of ADS : Burnup Characteritics



- k_{eff}: 0.97 – 0.94 ⇨ **Maximum beam : 1.5 GeV x 18 mA = 27 MW**
- **In this study, 30MW is adopted, though 20MW will be sufficient in the equilibrium cycle.**

Neutronics of ADS : Uncertainty Analysis



Sensitivity analysis was performed to evaluate Impact of uncertainties of nuclear data on neutronics parameters on ADS.

— Covariance data

JENDL-3.3 Covariance Data

^{52}Cr, ^{55}Mn, ^{56}Fe, ^{58,60}Ni, ^{90}Zr

Pu-239, -240, -241

New Evaluation Covariance Data (based on JENDL-3.3)

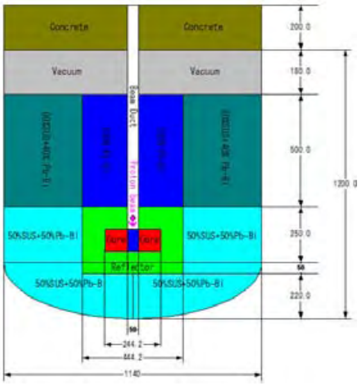
Np-237, Am-241, Am-243 : σ_f, σ_c, ν_p

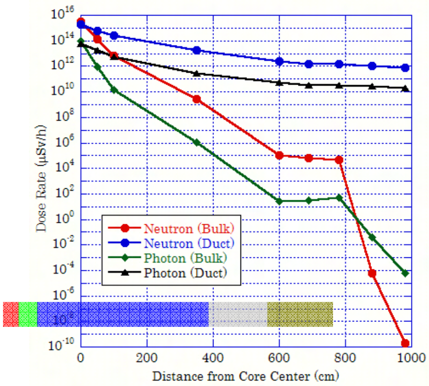
Pb-206, -207, -208, Bi-209 : σ_{in}

N-15 : σ_{el}

Pu-238, Am-242m, Cm-244 : σ_f, σ_c

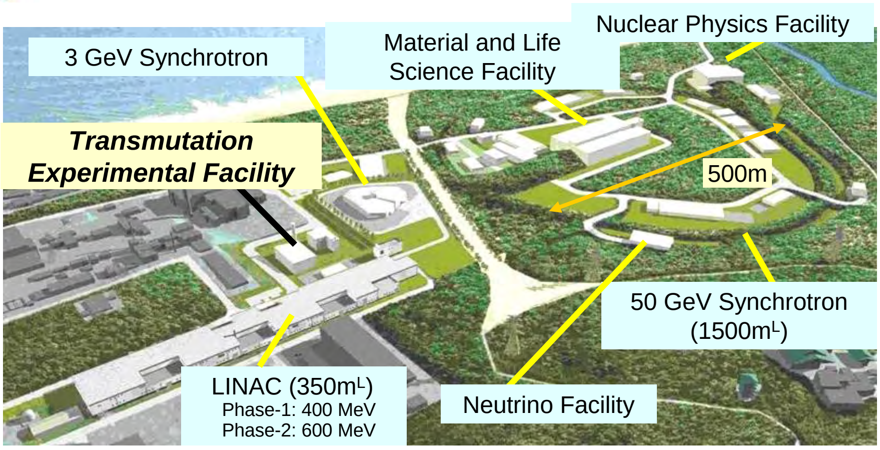
Neutronics of ADS : Shielding





- Streaming analysis was performed by MCNPX-2.5 code.
- Radiation dose and particle spectrum for activation analysis were obtained.
- Radiation dose by leaking neutron gives 20 order higher value than that of Bulk case (omitting beam duct).

J-PARC : Site Plan

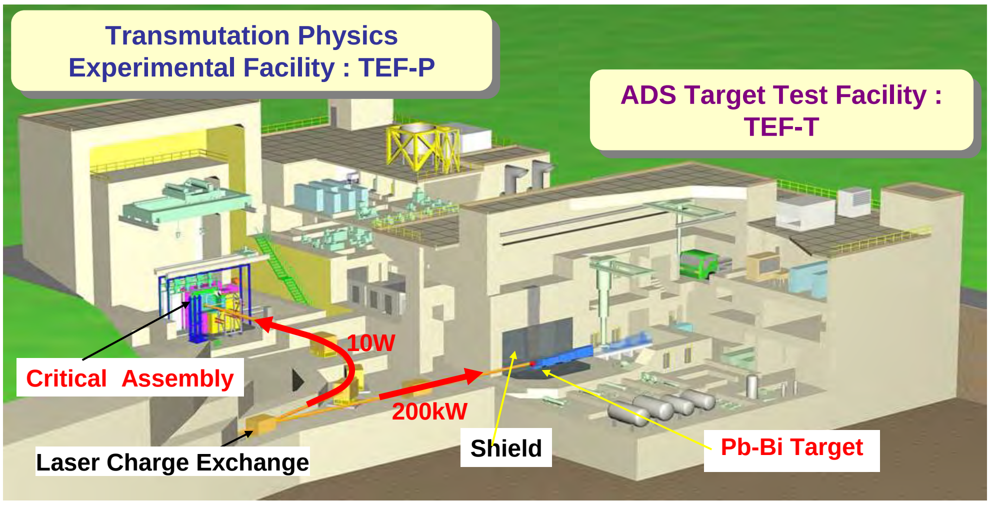


J-PARC : Japan Proton Accelerator Research Complex

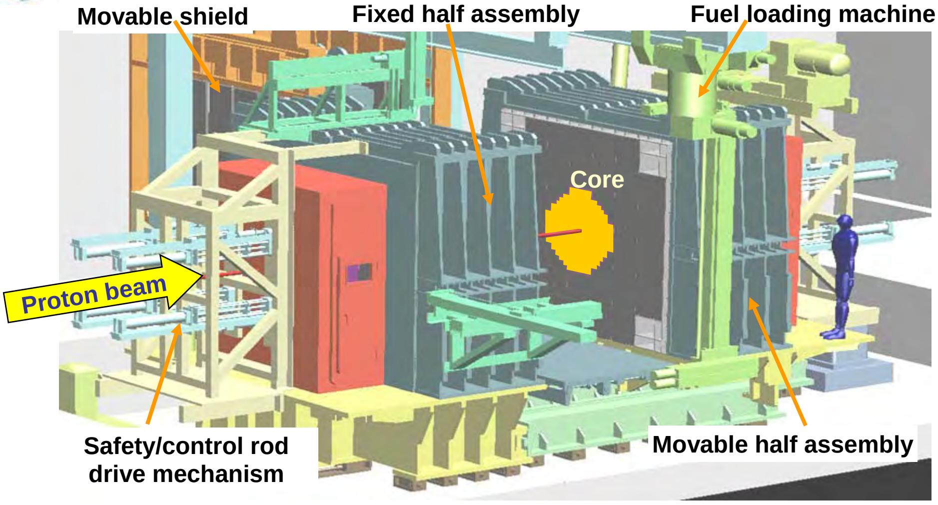
- **Construction of Phase-1 : 2001-2007 (except for some parts)**
- **Transmutation Experimental Facility and 600 MeV LINAC are in Phase-2.**

J-PARC : Status of Construction

Transmutation Experimental Facility (TEF)



Transmutation Physics Experimental Facility (TEF-P)



- Max. power : ~ 500W, Max beam : ~10 W (~10^{12}n/s)
- Experiments in critical state can also be performed.

Program Plan (preliminary)

- Check and Review (C&R) will be necessary to start TEF.
- Shortage of construction budget is anticipated.
- We are discussing the separation of TEF into two parts to reduce construction budget per year and to start basic experiment as early as possible:
  - Part-1 : TEF-P and a beam dump
  - Part-2 : TEF-T and 600 MeV SC-LINAC
- Part-1 will start from FY2008.

	Fiscal Year	2005 H17	2006 H18	2007 H19	2008 H20	2009 H21	2010 H22	2011 H23	2012 H24	2013 H25	2014 H26
	Milestone	▼Establishment of New Organization; ←→ C&R			▼Licensing of TEF-P			←→ C&R			
J-PARC	LINAC	180MeV			400MeV recovery					600MeV	
J-PARC	TEF	TEF-P	Design	Safety review	Construction					Commissioning	
J-PARC	TEF	Beam dump	Design		Construction					Commissioning	
J-PARC	TEF	TEF-T	R&D, Design							Construction	

Conclusion

- **Design study of ADS in JAEA**
  - As an analytical benchmark, we can propose a benchmark problem base on JAEA-ADS (Pb-Bi cooled tank-type ADS with 800MWth).
- **Future experimental program (TEF)**
  - Introduction of TEF facilities, TEF-P and TEF-T.
  - We are preparing "**Call for preliminary Letters of Intent for TEF**" and sent it during this year. We hope to get may preliminary LOI from all over the world.

IAEA CRP on ADS
The proposed NRG contribution

Alfred Hogenbirk
Productgroup Fuels, Actinides & Isotopes
NRG

Code/data validation

* Validate codes and data applied for simulation of
  - Transmutation potential
  - Dynamic behaviour

  of ADS
* Expected result: major step towards licensing and building demo facility for transmutation of MA and LLFP.

Analysis tool

* MCNP(X) (if required embedded in OCTOPUS)
* Efficient calculation of 3-D distributions of reaction rates
  – Flux
  – Power
  – Damage
  – etc.
* Exact (and fast) calculation of β_{eff}
* Interpolation of temperature-dependent cross sections

Nuclear data

* Nuclear data for MCNP(X) based on
  – JEFF-3.1
  – ENDF/B-VII
  – JENDL-3.3
  – And older releases of major evaluations
  – Comparison with IAEA ADS library will be made
* Validation of Pb data using YALINA booster zone

Framework of NRG’s contribution

* NRG’s activities adjacent to NRG’s contribution to EUROTRANS DM2 ECATS:
  – YALINA simulations

RCM on Analytical and Experimental Benchmark Analysis of Accelerator Driven System (ADS), Belarus, Minsk, 5-9 December 2005.

Project "Installation of a stand at the horizontal channel of the MARIA Research Reactor , Otwock-świerk, Poland, for the research of transmutation of minor actinides and fission products".

Marcin Szuta

Institute of Atomic Energy, Otwock-Świerk 05-400, Poland, mszuta@cyf.gov.pl

1. Significance of the project and relevance of the project to the CRP "Analytical and experimental Benchmark Analysis of ADS".

As a long range objective we would like to focus on management of the fuel economy in the sub-critical assembly of the accelerator driven system (ADS) in terms of long lived fission products (LLFP) and minor actinides (MA) transmutation.

Transmutation of the radioactive waste (RW) is an important element within the technical objective of the optimal management of the fuel economy in the sub-critical assembly of the accelerator driven system (ADS).

Analysis of possible ways of reduction of radioactive wastes by transmutation of radioactive long-lived fission products such as ^{99}Tc, ^{129}I and ^{135}Cs and by burning up of transuranic nuclides implies that the sub-critical assembly of the accelerator driven system should consist of three zones. The requirement of three zones comes out of the fact that each radioactive isotope to be reduced is to be located in a different spectrum of thermal, epithermal and high energy neutron fluxes. High flux thermal neutron environment ($\geq 10^{16}$ n/cm^3·s) is expected as the best way for the transmutation of most of the radioactive waste to stable or short-lived nuclides and for increasing the probability for fission such actinides as ^{237}Np and ^{238}Np.

The concept of ADS system for energy production and for transmutation is quite new to some extent and from this reason it requires many theoretical and experimental studies.

The research of transmutation is a very large area of study requiring a significant experimental and financial support, so it can be performed only within the international cooperation.

Specifically, the proposed research within this CRP requires important means, in terms of high-energy proton beams, spallation targets, sub-critical assembly, measurement instrumentation, post-irradiation characterisation and its testing and, of course, manpower for the interpretation of results, modelling observed phenomena, and programme management. The personal involved in the research is to be a skilled personal of international reputation in the field of energy production and transmutation and reactor physics computations.

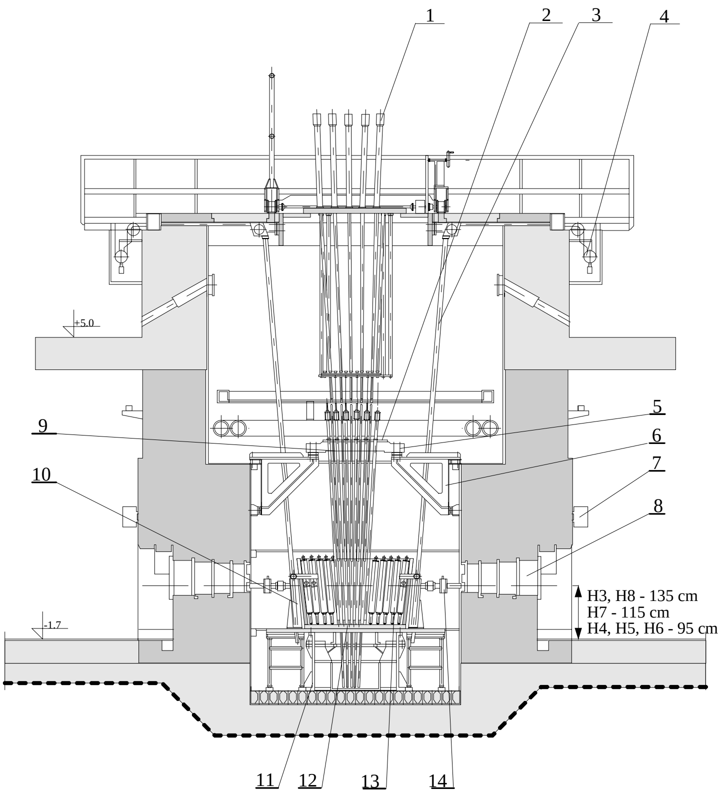
In order to analyse this topic experimentally, we propose to replace the expensive spallation source requiring accelerator by the neutron source obtained by converting the thermal neutron flux from the horizontal channel of the research reactor MARIA into fast neutron source. Taking into account the large amount of thermal neutrons in the horizontal channel, it is possible to use a fission converter i.e. an arrangement containing ^{235}U placed in the axis of the horizontal channel mouth. Thermal neutrons cause the fission reactions producing fast neutrons, which will be used instead of the neutrons from the spallation source. Five fuel rods of EK-10 type fuel placed vertically respect the beam of the thermal neutron flux of the used horizontal channel constitutes the converter. From the preliminary calculations it follows that the fast neutron source is approximately equal to 2 x 10^{10} neutrons/s.

A natural metallic uranium blanket with a moderator island will surround the fast neutron source what will enable us to perform the transmutation investigation of minor actinides (MA) and the long lived fission products (LLFP) in a wide range neutron energy spectrum.

In such a system the mass of the ^{235}U will be deeply sub-critical.

2. Brief description of facilities available.

To perform the transmutation research of minor actinides (MA) and the long lived fission products (LLFP) the multipurpose high flux research reactor MARIA can be used. A vertical cross-section of the reactor pool is shown in Fig. 1



1. control rod drive mechanism
2. mounting plate
3. ionization chamber channel
4. ionization chamber drive mechanism
5. fuel and loop channels support plate
6. plate support console
7. horizontal beam tube shutter drive mechanism
8. beam tube shutter
9. fuel channel
10. ionization chambers shield
11. core and support structure
12. core and reflector support plate
13. reflector blocks
14. beam tube compensator joint

Fig. 1. Vertical section of MARIA reactor.

The reactor MARIA is water and beryllium moderated reactor of a pool type with graphite reflector and pressurised channels containing concentric six-tube assemblies of fuel elements.

The main characteristics and data of MARIA reactor are as follows:

- nominal power 30 MW(th).
- thermal neutron flux density 4.0×10^{14} n/cm^2·s.
- moderator graphite.
- fuel element:
  - material UO_2 – Al. alloy
  - enrichment 36%
  - cladding aluminium
  - shape six concentric tubes
  - active length 1000 mm.

The research reactor MARIA is equipped with 8 horizontal channels. The location of the horizontal channels is presented in Fig. 2. One of the 8 horizontal channels will be used. There are some special requirements for the part of the building where the stand we plan to place it. There is required a safety access to the stand in order to manage it.

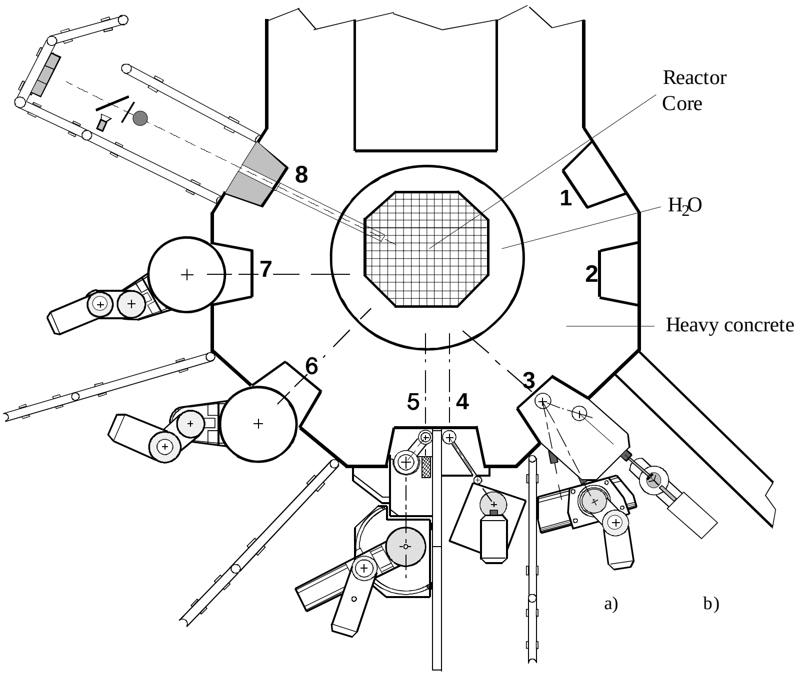


Fig. 2. Location of the horizontal channels of the reactor MARIA.

The measured total neutron flux density at the front of the horizontal channels was equal $\phi^o = 8.4\ 10^{13}$ cm^{-2} ·s^{-1} (at the nominal power of the reactor) and the calculated flux density at the mouth of the channel $\phi^m = 1.1\ 10^{10}$ cm^{-2} ·s^{-1}. Thermal neutrons were the dominating component in the neutron spectrum. Contribution of the epithermal and fast neutrons were equal to 9.7 % and 4.2 % of the total flux density respectively. In general, the output thermal neutron flux at horizontal channels is equal to $3 – 5 \times 10^9$ cm^{-2} ·s^{-1}.

Schematic view of the horizontal channel is shown in Fig. 3.

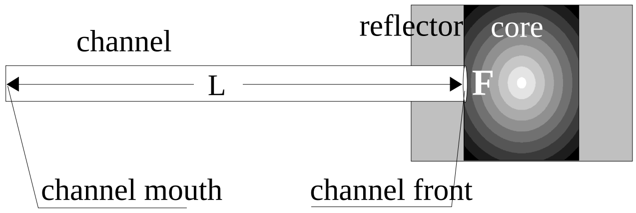


Fig. 3. Schematic view of the horizontal channel.

Taking into account the large amount of thermal neutrons, it is possible to use a fission converter i.e. an arrangement containing ^{235}U placed in the axe of the channel mouth. Thermal neutrons causes the fission reactions and these results is production of fast neutrons which can be used as the neutrons from the spallation source in the metallic natural uranium blanket surrounding the fast neutron source to research the transmutation of minor actinides and long lived fission products.

The converter will be realised by using five fuel rods of the EK-10 type fuel (see Fig. 4) placed so that the rods will be directly seen by the thermal neutron flux of the horizontal channel. The space between the EK-10 type fuel rods will be filled with air what means that the fast neutrons after fissioning are not moderated. This excludes reaching a criticality.

The fuel element EK-10 type is characterised:

- material – dispersion of UO_2 and Mg,
- enrichment - 10%
- cladding – aluminium
- active length – 495 mm.
- Diameter of fuel sample – 7 mm

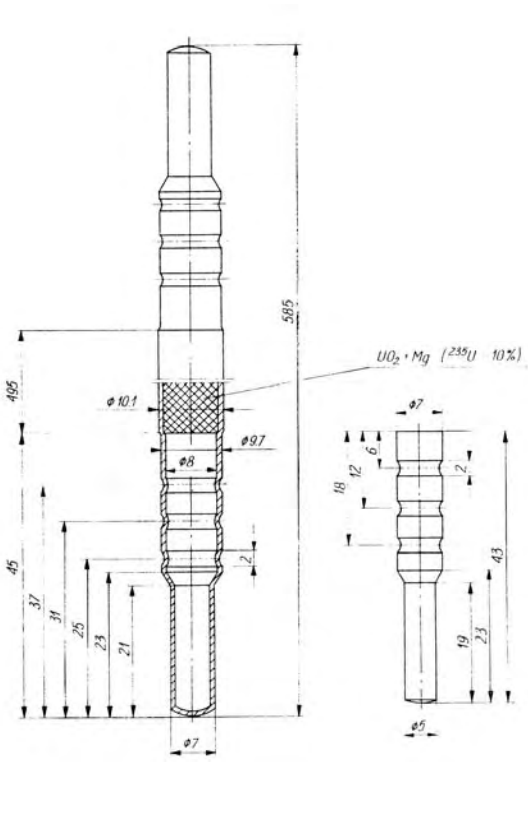


Fig. 4. The fuel element of EK-10 type.

Taking into account the data of the neutron flux from the horizontal channel and the data of the EK-10 type fuel the fast neutron source of the converter is evaluated to be about 2 x 10^{10} neutrons/s.

Both the EK-10 type fuel and the metallic natural uranium are at our disposal. So the design of the fission converter and the research transmutation facility is to be done. The fast neutron source will be surrounded by a natural uranium blanket consisting of uranium rods. The uranium rods of 30 cm length, 2.72 cm diameter and 2.8735 kg weight are hermetically sealed in an aluminium cladding.

The computer system for data collecting and processing of the irradiated targets in the research transmutation facility is to be purchased.

Having the layout of the radioactive waste transmutation stand at the horizontal channel the two-dimensional HEXAGA-II and the three-dimensional HEXAGA-III reactor codes and Monte Carlo method will be used for the computation of the neutron energy distribution in the stand. These codes, elaborated in our Institute, based on the multi-group neutron diffusion computations will be a very useful tool as a very fast one for working out the details of the epi-thermal neutron island planed in the natural metallic uranium blanket. It is assumed that the island will not be a fixed construction, but is thought over as a flexible construction within certain limits during exploitation of the stand. Re-construction of the island in order to fulfil the neutron energy requirement for each fission product transmutation will be supported by the computations using the HEXAGA code in the interactive mode: computation – measurement – computation – experiment.

3. Cooperation - some information on the work already performed referring to the objective of transmutation.

In our Institute (Institute of Atomic Energy, Otwock-Swierk, Poland) there is a group of scientists (with Prof., PhD, and three M.Sc. degrees) performing theoretical and experimental works in the topic of Transmutation and from several years working in cooperation with the scientists from Joint Institute for Nuclear Research (JINR), Dubna, Russia.

We take part in the experiments carried out in the frame of Dubna JINR program ‘Investigation of physical aspects of energy production and radioactive waste transmutation using relativistic beams of Synchrophasotron/Nuclotron ‘ - project - ‘Energy plus Transmutation’.

The base part of the experimental facility is a U/Pb assembly (fig.5) consisting of a lead cylindrical core and natural uranium cylinders [1]. It is divided into 4 identical sections separated by foils with detectors. The same foils are also on front and rear side of the assembly. This give us 5 possible locations of detectors along the axis.

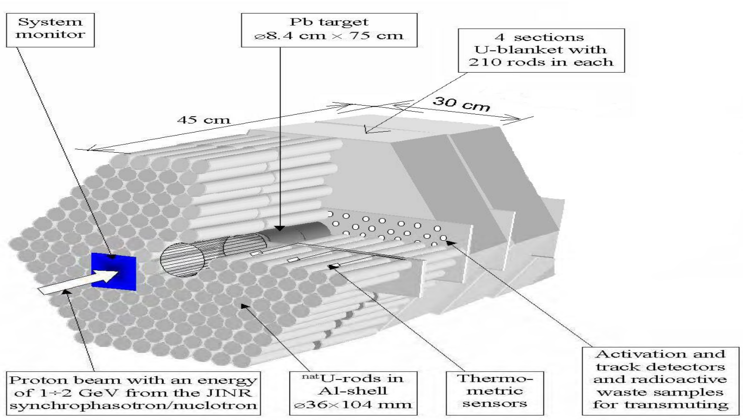


Fig.5 Lead-uranium assembly of “Energy +Transmutation” set [1].

The U/Pb assembly was placed during irradiation in a special wooden chest filled with polystyrene and wrapped in cadmium sheet (fig.6).

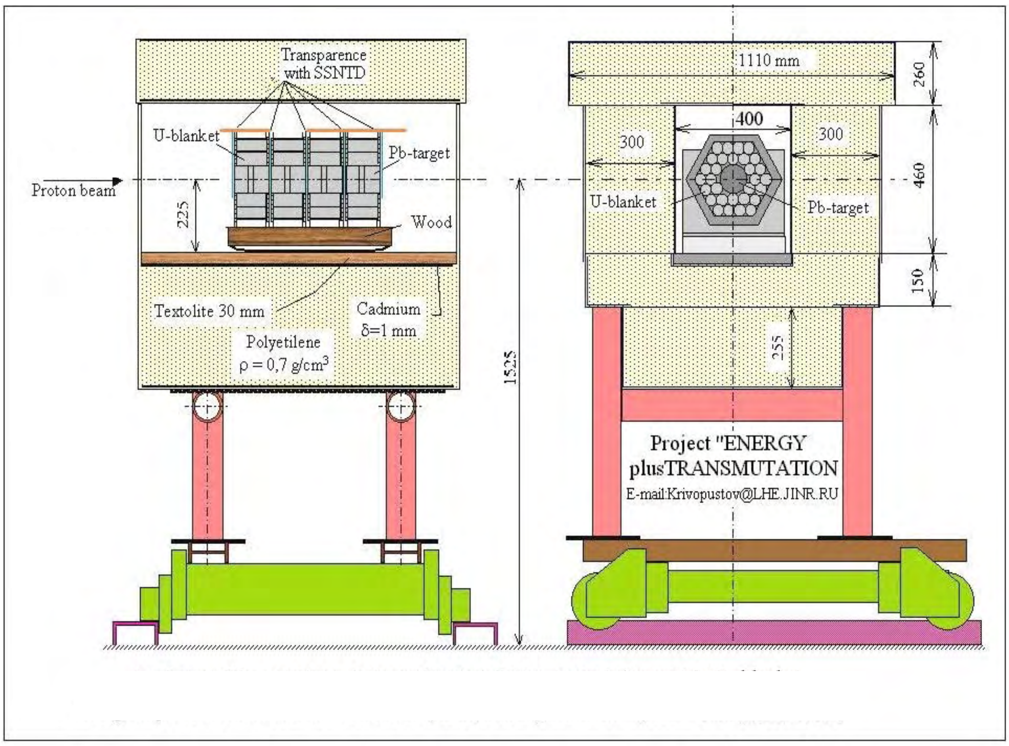


Fig. 6. “Energy +Transmutation” set [1].

To study the spectrum of neutrons generated in the U/Pb assembly the following activation detectors Al, Cu, Au and Bi are usually used. We have used Ytrium-89 detectors which let us to study the high energy of the neutron spectrum from the spallation source. First threshold energy of the reaction (n, 2n) giving ^{88}Y is possible for the threshold energy of neutrons equal 11.5 MeV. The next possible threshold energy 20.8, 32.7, 42.1 and 54.4 MeV are for the reactions (n, 3n) ^{87}Y, (n, 4n) ^{86}Y, (n, 5n) ^{85}Y and (n, 6n) ^{84}Y respectively. Measuring the different isotopes produced by the neutrons generated in the U/Pb assembly irradiated by the proton beam of 0.7 GeV we have obtained ^{77}Kr which is formed probably from the reaction (n, 3p10n) for the threshold neutron energy higher than 75 MeV.

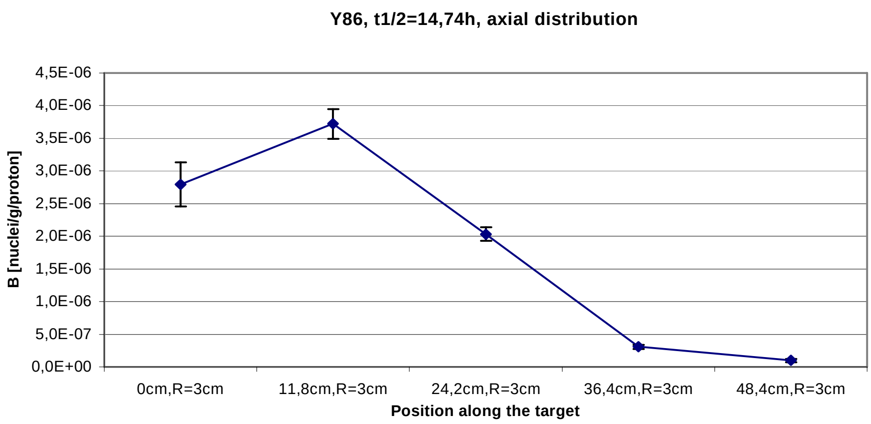


Fig.7 Axial distribution of Y86 generation

Since the neutron energy during the spallation process of evaporation stage where the most significant part of neutrons are emitted, is not higher than 40 MeV, this experiment let us to study the neutron distribution in function of axis and radius of the spallation source referring to the other stages of the spallation process. As an example it is here presented the axial distribution of ^{86}Y and ^{77}Kr generated in the result of proton irradiation the Pb spallation source.

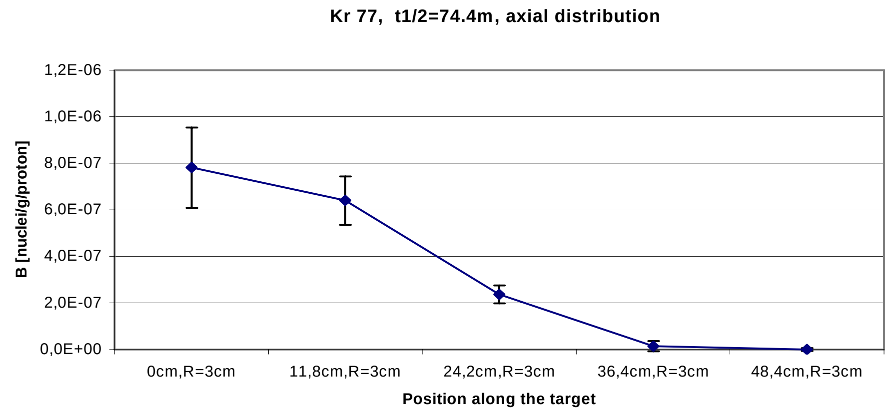


Fig.8 Axial distribution of ^{77}Kr generation.

It is clearly seen that the axial distribution of ^{86}Y generation has maximum for the position of about 12 cm along the target while the axial distribution of ^{77}Kr generation decreases along the target.

Measurement of different isotopes generated should let us to evaluate the relative neutron energy distribution along the axis of the spallation target.

At this moment it is interesting to recall the theory of the spallation process, which occurs when a high-energy nucleon collides with a nucleus. It is considered that the spallation process consists of the following stages [2] (fig. 9].

First stage: intra nuclear cascade.

At energies above a few hundred MeV the de Broglie wavelength of the incoming proton is smaller than the average distance between nucleons in the nucleus and the proton may be considered as interacting with the nucleus individually, setting of a cascade of nucleon-nucleon collisions, i.e. the intra-nuclear cascade. Also pions may be produced , as long as the energy of the incoming nucleon exceeds the pion threshold. During this intra nulear cascade a few secondary particles escape the nucleus. These escaping high-energy nucleons, pions and light ions may give rise to other intra-nuclear cascades (fig. 9a).

Intermediate stage: pre-equilibrium emission.

After the emission of the first few particles, a large amount of energy has been transferred to the remaining nucleus. The energy is distributed over the nucleus via the formation of particle-hole excitation until thermal equilibrium is attained. During this formation process , so called “pre-equilibrium”, neutrons and other light particles may be emitted.

Second stage: evaporation//(high-energy) fission.

When thermal equilibrium has been attained the remaining nucleus is then left behind in a highly excited state from which it decays “evaporating” off more neutrons and light ions. In competiotion the residual nucleus also may undergo high-energy fission with further particles evaporating from the fission products. The high-energy fission also may occur during the above mentioned intermediate state, before equilibrium has been reached.

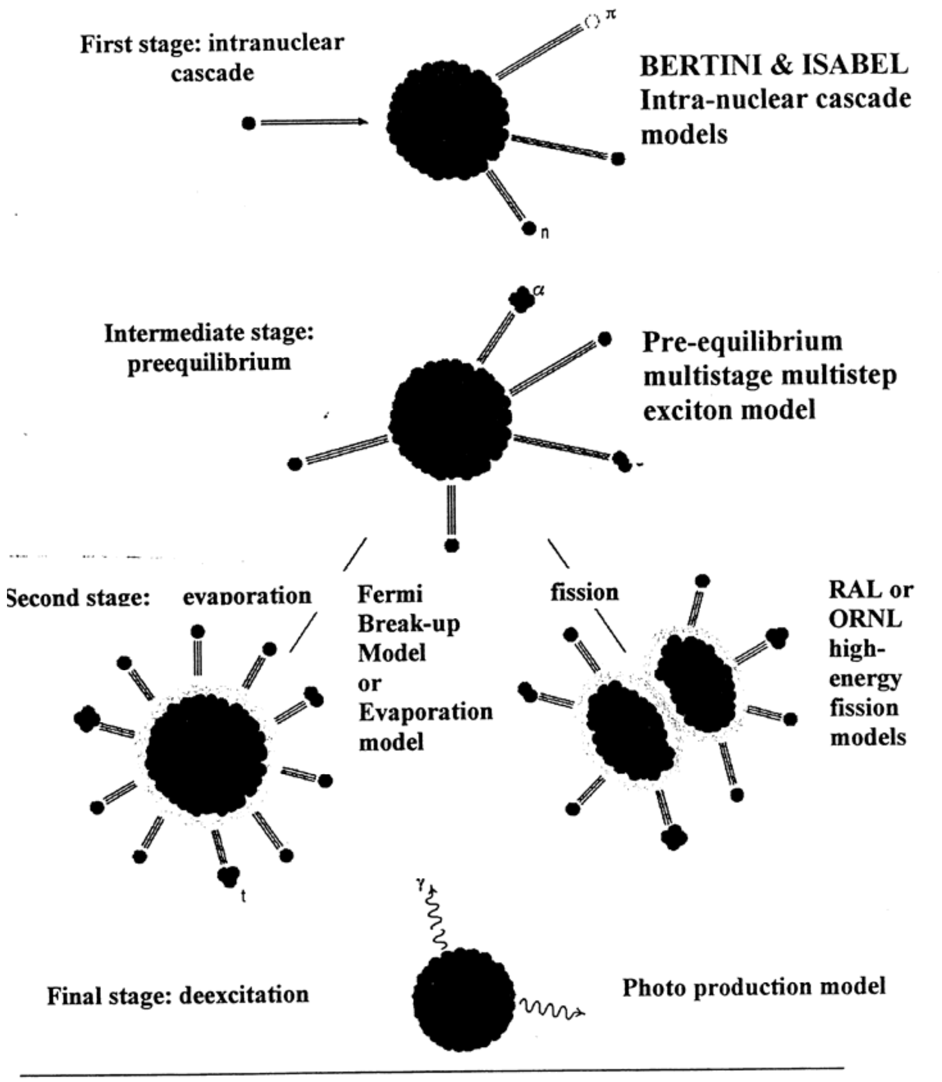


Fig. 9. Nuclear spallation and models used in the LAHET code for "online" treatment of microscopic processes involved in the spallation process [2].

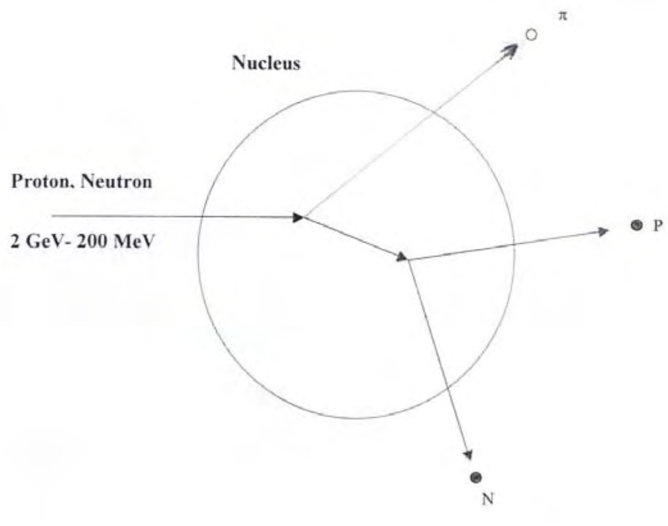


Fig. 9a. Intra-nuclear cascade [2].

Final stage: residual de-excitation.

Finally the excited nuclei or fission fragments decay by emitting photons.

On the base of very reach experimental data of the hadron-hadron collisions with energy higher than 3.5 GeV Z. Strugalski [3] proves , that in the first stage of the spallation process the local damage of nucleus occurs instead of intra-nuclear cascade. Depending on this whether the high energy hadron collides centrally or on the rim of the nucleus, the different amount on nucleons are emitted.

The hadron-hadron collisions can be elastic or inelastic. [4]. Only inelastic collisions are considered and the elastic collisions are neglected. The high energy hadron striking into the nucleus collides successively with following nucleons and it is assumed that along the motion path it creats group of nucleons with mass m_g called a fireball (see fig. 10) The mass of the fireball grows along its displacement inside of the nuclear matter. The process is inelastic as long as the energy per nucleon (in barycentre of fireball system) is greater than $m_\pi c^2 \approx 140$MeV. In other words at small energies of the hadron the inelastic process proceeds only in the first phase of the movement . If the energy of the hadron is large enough then the entire process of the passage of the hadron through the nucleus is inelastic. This causes the fireball creation from all nucleons which are along the path of the motion of the hadron, and then the knocking out the group of particles (fireball) outside nucleus. Fig 10 presents the scheme of such a fireball creation.

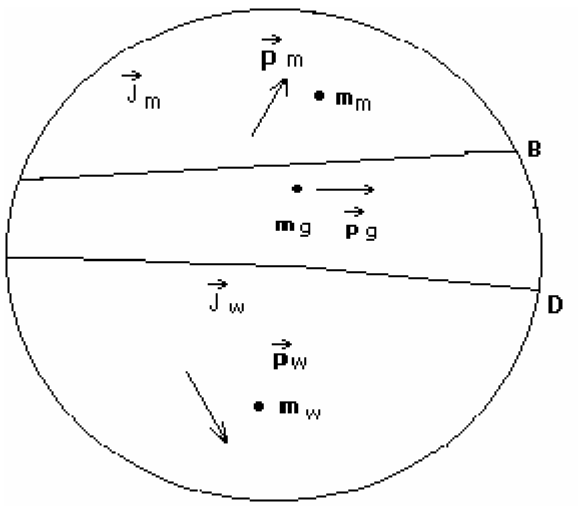


Fig.10. The simplified scheme of interaction of the fireball of a mass m_g with fragments of the nucleus for the high-energy hadron in the laboratory system.

In Figs.11 are presented the experimental data from the 180 litre xenon bubble chamber of the Institute of Theoretical and Experimental of Physics in Moscow (ITEF, Moscow) irradiated by a beam of mesons with momentum 3.5 GeV/c. This figure presents calculated distribution of emitted protons. Graphs in turn for n_π= 0, 1, 2, 3, 4, 5 of pions which will appear as the result of the reaction are presented. It should be noticed that the hadron causing the reaction is a pion, so [the total number of pions] = [the number of created pions]+1.

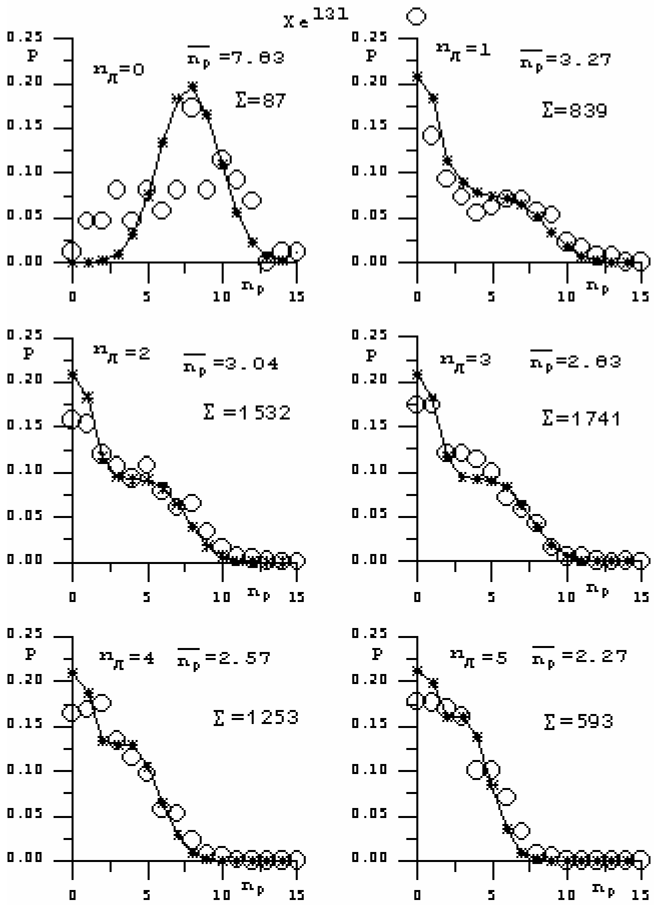


Fig.11. The probability of the emission of protons in reaction π^-+Xe with the energy of pions 3.3GeV. n_p and P on axes mean the number of emitted protons and the probability respectively. o,* are experimental data and calculation results respectively.

The theoretical work done in our Institute [4] can be associated with the experimental data presented in figs 7 and 8 and used for improvement of spallation process modelling.

Transmutation is a current interest in many research institutes all over the World. We look forward first of all to cooperate with the Joint Institute for Nuclear Research (JINR) in Dubna, Russia and with Forschung Zentrum Karlsruhe, Germany.

Extending the present cooperation with the highly qualified scientists involved in CRP "Analytical and experimental Benchmark Analysis of ADS", guarantees the achievement of high level results in the proposed research topic.

Both the experimental data carried in the future on the transmutation stand and the computations are thought over as a support of the project SAD (sub-critical assembly in Dubna).

Within the project SAD we plan to make modelling the parameters of sub-critical assemblies in ADS system, in particular computation of the effective neutron multiplication coefficient k_{eff} in dependence on the modification of the SAD construction.
This objective we intend to do by using the two-dimensional HEXAGA-II and the three-dimensional HEXAGA-III reactor codes [5-7] as well as the Monte Carlo method. Results of these two methods will be compared giving possibility to make analytical benchmark analysis. These codes of HEXAGA-II and HEXAGA-III , elaborated in our Institute, are very useful tools in detailed multi-group neutron diffusion computations of both types,

experimental and power reactors. They are used in ZfK Karlsruhe; ULB, Brussels; INE, Sofia, and our Institute.

4. Work plan for the coming year 2006

- Design of the fission converter and the research transmutation facility.
- Computation of the neutron flux distribution.
- Purchasing the computer system for data collecting and processing of the irradiated targets in the research transmutation facility.
- Purchasing the LLFP targets of ^{99}Tc, ^{129}I and ^{135}Cs.
- Purchasing the MA targets of ^{237}Np., ^{238}Np and ^{239}Pu.

References

[1] M. Krivopustov et al.- *On a First Experiment on the Calorimetry of the Uranium Blanket Using the Model of the U/Pb Electro-Nuclear Assembly "Energy plus Transmutation" on a 1.5 GeV Proton Beam of the Dubna Synchrophasotron.* JINR Preprint P1-2000-168, Dubna, 2000. Kerntechnik, 2003. V.68. p 48-55.

[2] H. Wienke: *Processing of new cross-section libraries with NJOY for ADS applications*; paper presented on the meeting "R&D activity in support of ADS development" held at SCK-CEN – Mol on October 24th, 2000.

[3] Z. Strugalski: *Przenikanie hadronów wysokiej energii przez jądra atomowe*; praca prezentowana na seminarium ZJEA w Dubnej w Laboratorium Wysokich Energii , 31 październik 2001 r.

[4] A. Wojciechowski, E. Strugalska-Gola, Z. Strugalski; Model of inelastic collisions of high-energy hadrons with nucleus.; Joint Institute of Nuclear Research, Dubna, 2004; E1-2004-191.

[5] Z. I. Woźnicki, HEXAGA-II-120,-60,-30 two-dimensional multi-group neutron diffusion programmes for a uniform triangular mesh with arbitrary group scattering, Rep. KfK 2789, Kernforschungscentrum Karlsruhe, Germany, 1979.

[6] Z. I. Woźnicki, HEXAGA-III-120,-30 three-dimensional multi-group neutron diffusion programmes for a uniform triangular mesh with arbitrary group scattering, Rep. KfK 3572, Kernforschungscentrum Karlsruhe, Germany, 1983.

[7] Z.I. Woźnicki, The numerical analysis of eigenvalue problem solutions in the moultigroup neutron diffusion theory, International Review Journal of PROGRESS in NUCLEAR ENERGY, 33(3), 301-391, 1998.

RCM on Analytical and Experimental Benchmark Analysis of Accelerator Driven System (ADS), Belarus, Minsk, 5-9 December 2005.

Project "Installation of a stand at the horizontal channel of the MARIA Research Reactor , Otwock-świerk, Poland, for the research of transmutation of of minor actinides and fission products".

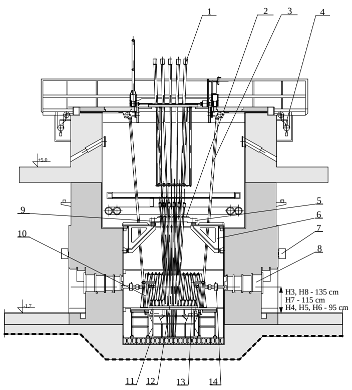
Marcin Szuta
Institute of Atomic Energy, Otwock-Świerk 05-400, Poland, mszuta@cyf.gov.pl

1. Significance of the project and relevance of the project to the CRP "Analytical and experimental Benchmark Analysis of ADS".
2. Brief description of facilities available.
3. Cooperation - some information on the work already performed referring to the objective of transmutation.
4. Work plan for the coming year 2006

1. Significance of the project and relevance of the project to the CRP "Analytical and experimental Benchmark Analysis of ADS".

- A long range objective - management of the fuel economy in the sub-critical assembly of the accelerator driven system (ADS) in terms of long lived fission products (LLFP) and minor actinides (MA) transmutation.
- Analysis of possible ways of reduction of radioactive wastes by transmutation of LLFP and MA implies that the sub-critical assembly of the accelerator driven system should consist of three zones.
- To analyse this topic experimentally, we propose to replace the expensive spallation source requiring accelerator by the neutron source obtained by converting the thermal neutron flux from the horizontal channel of the research reactor MARIA into fast neutron source.
- Five fuel rods of EK-10 type fuel placed vertically respect the beam of the thermal neutron flux of the used horizontal channel constitutes the converter. From the preliminary calculations it follows that the fast neutron source is approximately equal to 2×10^{10} neutrons/s.
- A natural metallic uranium blanket with a moderator island will surround the fast neutron source what will enable us to perform the transmutation investigation of minor actinides (MA) and the long lived fission products (LLFP) in a wide range neutron energy spectrum.
- In such a system the mass of the ^{235}U will be deeply sub-critical.

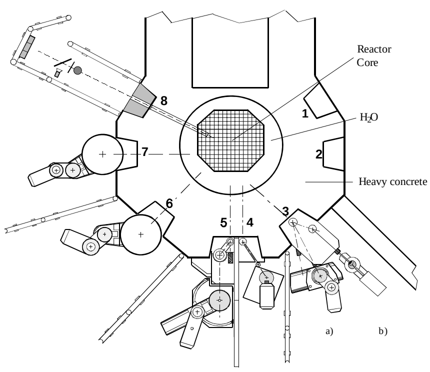
2. Brief description of facilities available.



1. control rod drive mechanism
2. mounting plate
3. ionization chamber channel
4. ionization chamber drive mechanism
5. fuel and loop channels support plate
6. plate support console
7. horizontal beam tube shutter drive mechanism
8. beam tube shutter
9. fuel channel
10. ionization chambers shield
11. core and support structure
12. core and reflector support plate
13. reflector blocks
14. beam tube compensator joint

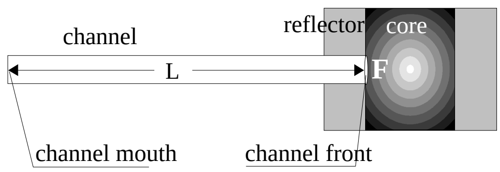
- **Fig. 1. A vertical cross-section of the reactor MARIA.**
- The reactor MARIA is water and beryllium moderated reactor of a pool type with graphite reflector and pressurised channels containing concentric six-tube assemblies of fuel elements.
- The main characteristics and data of MARIA reactor are as follows:
- - nominal power 30 MW(th).
- - thermal neutron flux density 4.0 x 1014 n/cm^{2}·s.
- - moderator graphite
- fuel element:
- material UO_2 – Al. alloy
- enrichment 36%
- cladding aluminium
- shape six concentric tubes
- active length 1000 mm.

2. Brief description of facilities available – cnt.



- **Fig. 2. The location of the horizontal channels.**
- The research reactor MARIA is equipped with 8 horizontal channels. One of the 8 horizontal channels will be used.
- There are some special requirements for the part of the building where the stand we plan to place it. There is required a safety access to the stand in order to manage it.

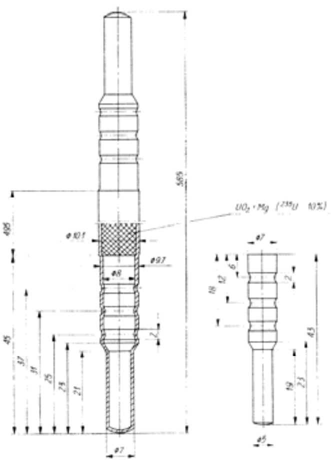
2. Brief description of facilities available – cnt.



- **Fig. 3. Schematic view of the horizontal channel**.
- The measured total neutron flux density at the front of the horizontal channels was equal $\phi o = 8.4 x 10^{13}$ $cm^{-2} \cdot s^{-1}$ (at the nominal power of the reactor) and the calculated flux density at the mouth of the channel $\phi m = 1.1\ 10^{10}$ $cm^{-2} \cdot s^{-1}$. Thermal neutrons were the dominating component in the neutron spectrum. Contribution of the epithermal and fast neutrons were equal to 9.7 % and 4.2 % of the total flux density respectively. In general, the output thermal neutron flux at horizontal channels is equal to 3 – 5 x 10^9 $cm^{-2} \cdot s^{-1}$.

2. Brief description of facilities available – cnt.

- **Fig. 4. The fuel element of EK-10 type.**
- material – dispersion of UO2 and Mg,
- enrichment - 10%
- The fuel element EK-10 type is characterised:
- cladding – aluminium
- active length – 495 mm.
- Diameter of fuel sample – 7 mm
- The converter will be realised by using five fuel rods of the EK-10 type fuel.
- The space between the EK-10 type fuel rods will be filled with air.
- the fast neutron source of the converter is evaluated to be about 2 x10^{10} neutrons/s.



2. Brief description of facilities available – cnt.

- Both the EK-10 type fuel and the metallic natural uranium are at our disposal. So the design of the fission converter and the research transmutation facility is to be done. The fast neutron source will be surrounded by a natural uranium blanket consisting of uranium rods. The uranium rods of 30 cm length, 2.72 cm diameter and 2.8735 kg weight are hermetically sealed in an aluminium cladding.

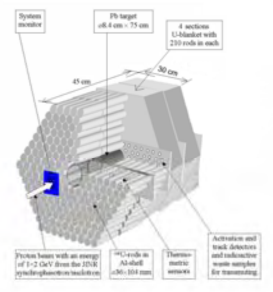
- Having the layout of the radioactive waste transmutation stand at the horizontal channel the two-dimensional HEXAGA-II and the three-dimensional HEXAGA-III reactor codes and the Monte Carlo method will be used for the computation of the neutron energy distribution in the stand.
- It is assumed that the island will not be a fixed construction, but is thought over as a flexible construction within certain limits during exploitation of the stand.
- Computations using the HEXAGA code will be performed in the interactive mode: computation – measurement – computation – experiment.

- The computer system for data collecting and processing of the irradiated targets in the research transmutation facility is to be purchased.

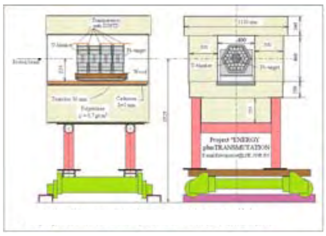
3. Cooperation - some information on the work already performed referring to the objective of transmutation.

- In our Institute (Institute of Atomic Energy, Otwock-Swierk, Poland) there is a group of scientists performing theoretical and experimental works in the topic of Transmutation and from several years working in cooperation with the scientists from Joint Institute for Nuclear Research, Dubna, Russia.
- **Fig.5 Lead-uranium assembly of "Energy +Transmutation" set.**

- The base part of the experimental facility is a U/Pb assembly (fig.5) consisting of a lead cylindrical core and natural uranium cylinders [1]. It is divided into 4 identical sections separated by foils with detectors. The same foils are also on front and rear side of the assembly. This give us 5 possible locations of detectors along the axis.



3. Cooperation - some information on the work already performed referring to the objective of transmutation – cnt.



- **Fig. 6. "Energy +Transmutation" set.**

- The U/Pb assembly was placed during irradiation in a special wooden chest filled with polystyrene and wrapped in cadmium sheet.

3. Cooperation - some information on the work already performed referring to the objective of transmutation – cnt.

- To study the spectrum of neutrons generated in the U/Pb assembly the following activation detectors Al, Cu, Au and Bi are usually used.

- We have used Ytrium-89 detectors which let us to study the high energy of the neutron spectrum from the spallation source.

- First threshold energy of the reaction (n, 2n) giving ^{88}Y is possible for the threshold energy of neutrons equal 11.5 MeV.

- The next possible threshold energy 20.8, 32.7, 42.1 and 54.4 MeV are for the reactions (n, 3n) ^{87}Y, (n, 4n) ^{86}Y, (n, 5n) ^{85}Y and (n, 6n) ^{84}Y respectively.

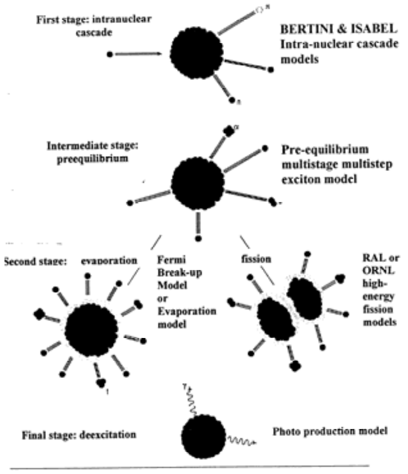
3. Cooperation - some information on the work already performed referring to the objective of transmutation – cnt.

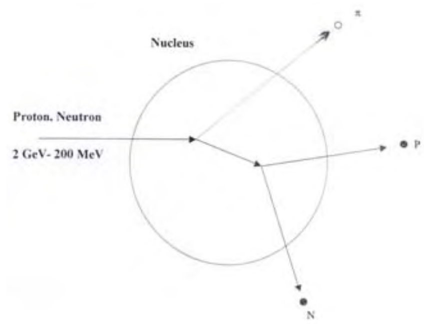
- Measuring the different isotopes produced by the neutrons generated in the U/Pb assembly irradiated by the proton beam of 0.7 GeV we have obtained ^{77}Kr which is formed probably from the reaction (n, 3p10n) for the threshold neutron energy higher than 75 MeV.
- It is clearly seen that the axial distribution of ^{86}Y generation has maximum for the position of about 12 cm along the target while the axial distribution of ^{77}Kr generation decreases along the target.
- Since the neutron energy during the spallation process of evaporation stage where the most significant part of neutrons are emitted, is not higher than 40 MeV, this experiment let us to study the neutron distribution in function of axis and radius of the spallation source referring to the other stages of the spallation process.
- At this moment it is interesting to recall the theory of the spallation process, which occurs when a high-energy nucleon collides with a nucleus. It is considered that the spallation process consists of the following stages:

3. Cooperation - some information on the work already performed referring to the objective of transmutation – cnt.

- <u>First stage: intra nuclear cascade.</u>
- <u>Intermediate stage: pre-equilibrium emission.</u>
- <u>Second stage: evaporation//(high-energy) fission.</u>
- <u>Final stage: residual de-excitation.</u>

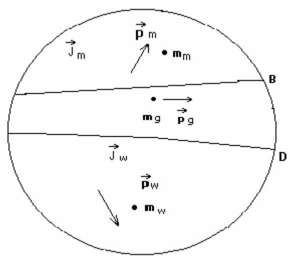
3. Cooperation - some information on the work already performed referring to the objective of transmutation – cnt.





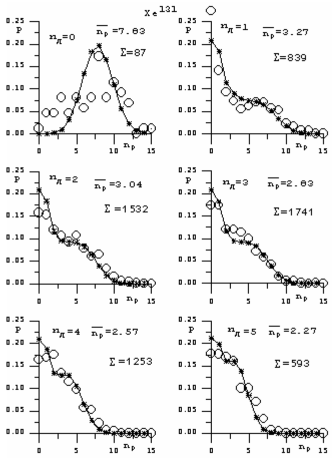
3. Cooperation - some information on the work already performed referring to the objective of transmutation – cnt.

- On the base of very reach experimental data of the hadron-hadron collisions with energy higher than 3.5 GeV Z. Strugalski proves , that in the first stage of the spallation process the local damage of nucleus occurs instead of intra-nuclear cascade. Depending on this whether the high energy hadron collides centrally or on the rim of the nucleus, the different amount on nucleons are emitted.
- . The high energy hadron striking into the nucleus collides successively with following nucleons and it is assumed that along the motion path creats group of nucleons with mass mg called a fireball.
- **Fig.7. Fire ball creation.**



3. Cooperation - some information on the work already performed referring to the objective of transmutation – cnt.

- **In Figs.11** are presented the experimental data from the 180 litre xenon bubble chamber of the Institute of Theoretical and Experimental of Physics in Moscow (ITEF, Moscow) irradiated by a beam of mesons with momentum 3.5 GeV/c.
- This figure presents calculated distribution of emitted protons. Graphs in turn for n_π= 0, 1, 2, 3, 4, 5 of pions which will appear as the result of the reaction are presented. It should be noticed that the hadron causing the reaction is a pion, so [the total number of pions] = [the number of created pions]+1.
- The figure presents probability of the emission of protons in reaction π^-+Xe with the energy of pions 3.3GeV. n_p and P on axes mean the number of emitted protons and the probability respectively. o,* are experimental data and calculation results respectively.



3. Cooperation - some information on the work already performed referring to the objective of transmutation – cnt.

- Both the experimental data carried in the future on the transmutation stand and the computations are thought over as a support of the project SAD (sub-critical assembly in Dubna).
- Within the project SAD we plan to make modelling the parameters of sub-critical assemblies in ADS system, in particular computation of the effective neutron multiplication coefficient keff in dependence on the modification of the SAD construction.
- This objective we intend to do by using the two-dimensional HEXAGA-II and the three-dimensional HEXAGA-III reactor codes [5-7] as well as the Monte Carlo method. Results of these two methods will be compared giving possibility to make analytical benchmark analysis.
- Extending the present cooperation with the highly qualified scientists involved in CRP “Analytical and experimental Benchmark Analysis of ADS”, guarantees the achievement of high level results in the proposed research topic.

4. Work plan for the coming year 2006

- Design of the fission converter and the research transmutation facility.
- Computation of the neutron flux distribution.
- Purchasing the computer system for data collecting and processing of the irradiated targets in the research transmutation facility.
- Purchasing the LLFP targets of ^{99}Tc, ^{129}I and ^{135}Cs.
- Purchasing the MA targets of ^{237}Np., ^{238}Np and ^{239}Pu.

ANALYTICAL AND EXPERIMENTAL BENCHMARK ANALYSES OF ACCELERATOR DRIVEN SYSTEMS (ADS)

RECENT WORKS OF THE AGH TEAM CONNECTED WITH THE ANALYSES OF ADS

AGH - University of Science and Technology,
Faculty of Physics and Applied Computer Science,
Al. Mickiewicza 30, 30-059 Cracow, Poland,

SCIENTIFIC TEAM

J. Janczyszyn, S. Taczanowski, G. Domańska, W. Pohorecki

Present situation

Involvement in EUROTRANS based on co-operation with the SAD project:

- **DM5 NUDATRA (NUclear DAta for TRAnsmutation)**
  - ⇒ analytical benchmark for bare spallation target activation and heating
- **Expected broader participation ⇒ DM2 ECATS**
  (Experiment on the Coupling of an Accelerator, a spallation Target and a Sub-critical blanket)
  - ⇒ experiments in Dubna ⇒ characterisation of the spallation neutron source based on the 660 MeV proton beam

Scope & motivation of the activity in DM2 ECATS

- **Best preparation for the main experimental program of SAD**
  - ⇒ experimental confirmation of the beam parameters
  - ⇒ installation and check of the measuring equipment
- **Completion of measurements on the bare target before the subcritical core is on place**
- **Validation of the shielding design calculations**

Faculty of Physics & Applied Computer Science
AGH University of Science & Technology
Cracow, PL

Proposed tasks

Measurements (the accelerator beam without target and with the use of bare targets) of:

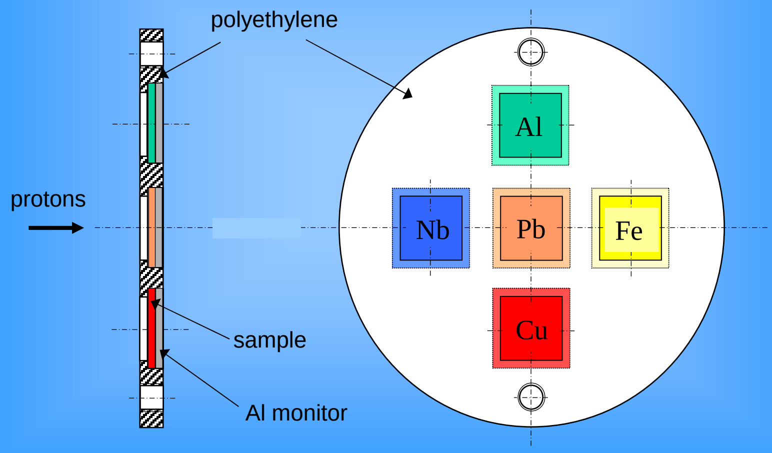
- ⇒ beam heating power
- ⇒ beam time structure
- ⇒ time structure of the neutron field around target
- ⇒ radiation fields around target
- ⇒ SAD target heating and cooling (proton beam only)
- ⇒ effects of the target radiation on fuel materials and the operational and experimental equipment
- ⇒ effects of the core generated neutrons on the target – activation, gas production, heating (measured in critical reactor with an appropriate neutron spectrum)
- ⇒ dosimetric measurements for target originated radiation.

Faculty of Physics & Applied Computer Science
AGH University of Science & Technology
Cracow, PL

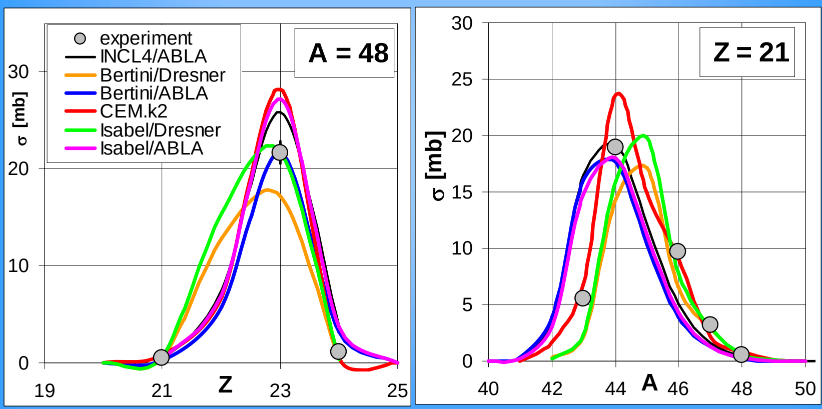
Recent results of the AGH (Cracow) group

1. J. Janczyszyn, W. Pohorecki, G. Domańska, L. Loska, S. Taczanowski, V. Shvetsov, MEASUREMENT AND CALCULATION OF CROSS SECTION FOR (P,X) REACTIONS ON NATURAL FE FOR 650 MEV PROTONS, Annals of Nuclear Energy, in press
2. W. Pohorecki, J. Janczyszyn, S. Taczanowski, I.V. Mirokhin, A.G. Molokanov, G. Domańska, T. Horwacik, EVALUATION OF AN ADS LEAD TARGET ACTIVATION. COMPARISON OF COMPUTATIONS AND MEASUREMENTS, Nuclear Instruments & Methods, in press
3. W. Pohorecki CALCULATION OF INDUCED RADIOACTIVITY IN THE SAD SPALLATION TARGET, ibid.

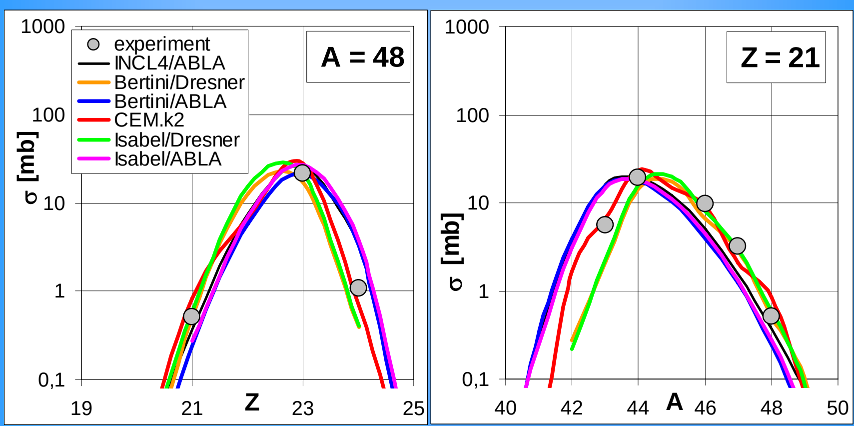
MEASUREMENT AND CALCULATION OF CROSS SECTION FOR (P,X) REACTIONS ON NATURAL FE FOR 650 MEV PROTONS



COMPARISON OF MEASUREMENT AND CALCULATION FOR 650 MEV PROTONS ON NATURAL FE



COMPARISON OF MEASUREMENT AND CALCULATION FOR 650 MEV PROTONS ON NATURAL FE

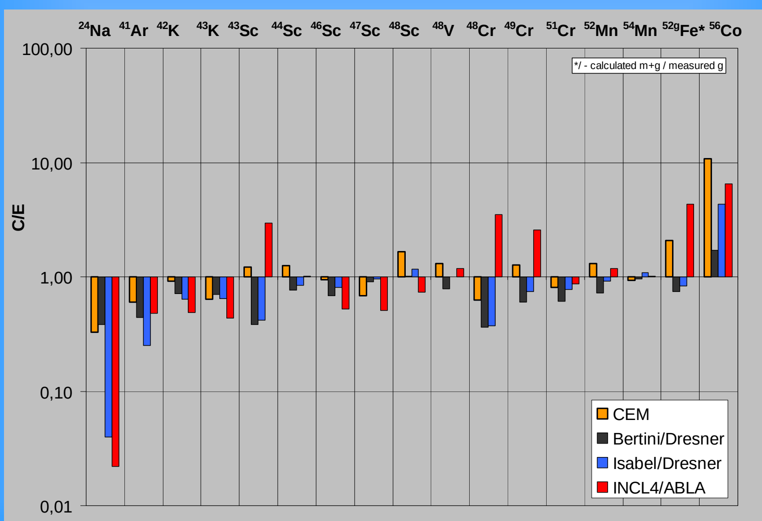


COMPARISON OF MEASUREMENT AND CALCULATION FOR 650 MEV PROTONS ON NATURAL FE

	CEM		Bertini/Dresner		Bertini/ABLA		Isabel/Dresner		Isabel/ABLA		INCL4/ABLA	
	C/E	unc.	C/E	unc.	C/E	unc.	C/E	unc.	C/E	unc.	C/E	unc.
^{24}Na	0,328	0,041	0,382	0,045	0,143	0,025	0,040	0,012	0,007	0,005	0,022	0,007
^{41}Ar	0,602	0,062	0,444	0,051	0,542	0,058	0,252	0,036	0,401	0,048	0,479	0,044
^{42}K	0,917	0,050	0,716	0,040	0,487	0,029	0,638	0,036	0,397	0,024	0,486	0,027
^{43}K	0,640	0,045	0,703	0,048	0,314	0,029	0,646	0,045	0,356	0,031	0,435	0,029
^{43}Sc	1,219	0,057	0,386	0,021	2,883	0,129	0,416	0,022	2,662	0,120	2,968	0,131
^{44}Sc	1,248	0,041	0,760	0,026	0,934	0,031	0,844	0,028	0,950	0,032	1,016	0,033
^{46}Sc	0,945	0,044	0,680	0,032	0,403	0,020	0,808	0,038	0,449	0,022	0,526	0,024
^{47}Sc	0,682	0,038	0,908	0,048	0,396	0,025	0,954	0,050	0,423	0,026	0,505	0,027
^{48}Sc	1,657	0,114	1,015	0,082	0,475	0,051	1,164	0,089	0,545	0,056	0,737	0,054
^{48}V	1,299	0,073	0,790	0,045	0,996	0,056	1,004	0,057	1,252	0,070	1,189	0,066
^{48}Cr	0,626	0,047	0,364	0,033	3,023	0,162	0,371	0,033	3,472	0,183	3,509	0,175
^{49}Cr	1,268	0,063	0,606	0,032	2,163	0,104	0,746	0,038	2,714	0,129	2,582	0,121
^{51}Cr	0,807	0,037	0,608	0,028	0,734	0,033	0,781	0,036	0,940	0,043	0,869	0,039
^{52}Mn	1,298	0,032	0,722	0,019	1,152	0,029	0,913	0,023	1,457	0,036	1,191	0,029
^{54}Mn	0,926	0,055	0,955	0,057	0,817	0,049	1,090	0,065	0,977	0,058	1,015	0,060
^{52g}Fe*	2,079	0,154	0,743	0,072	3,919	0,262	0,838	0,078	4,113	0,274	4,309	0,270
^{56}Co	10,825	1,282	1,709	0,221	3,429	0,422	4,317	0,525	6,076	0,730	6,507	0,770

*/ calculated m+g / measured g

COMPARISON OF MEASUREMENT AND CALCULATION FOR 650 MEV PROTONS ON NATURAL FE



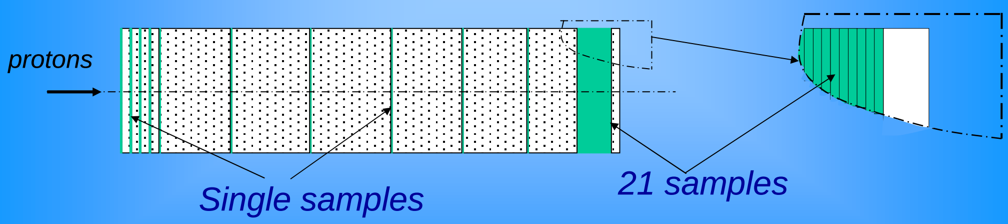
COMPARISON OF MEASUREMENT AND CALCULATION FOR 650 MEV PROTONS ON NATURAL FE

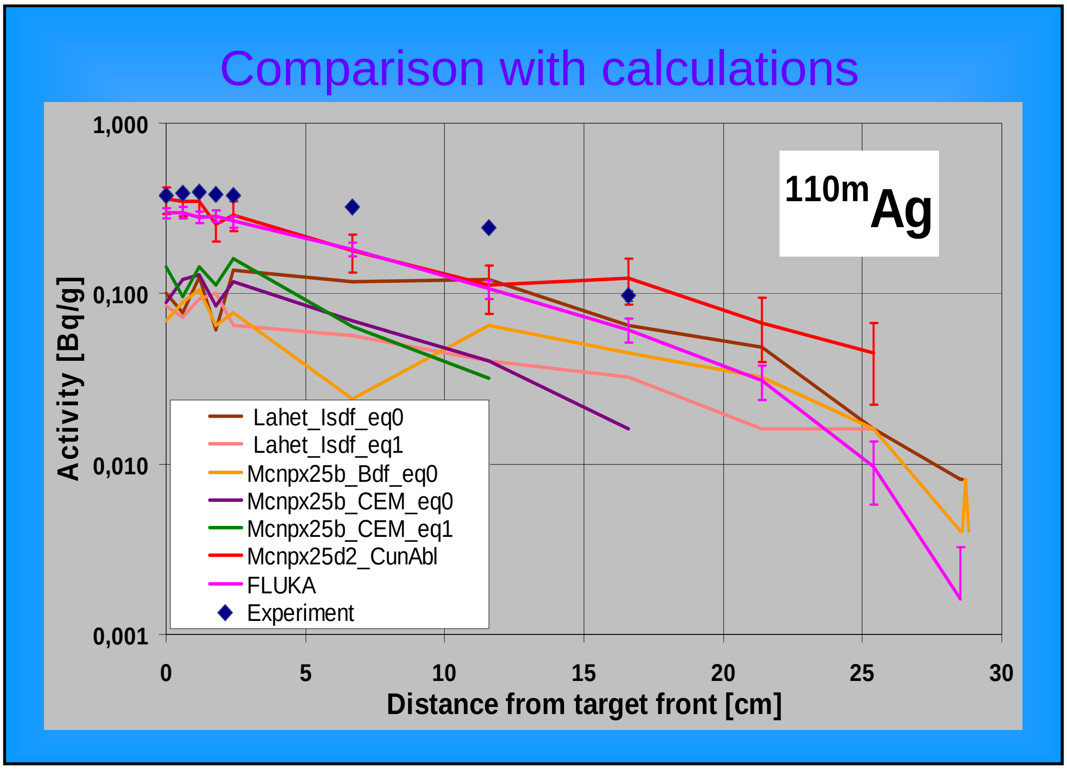
$$FOM1 = \frac{\sum_{1}^{n} \frac{\left(\frac{C}{E}\right)_i}{s_i^2}}{\sum_{1}^{n} \frac{1}{s_i^2}}; \quad FOM2 = \sqrt{\frac{\sum_{1}^{n} \frac{\left[1-\left(\frac{C}{E}\right)_i\right]^2}{s_i^2}}{n}}$$

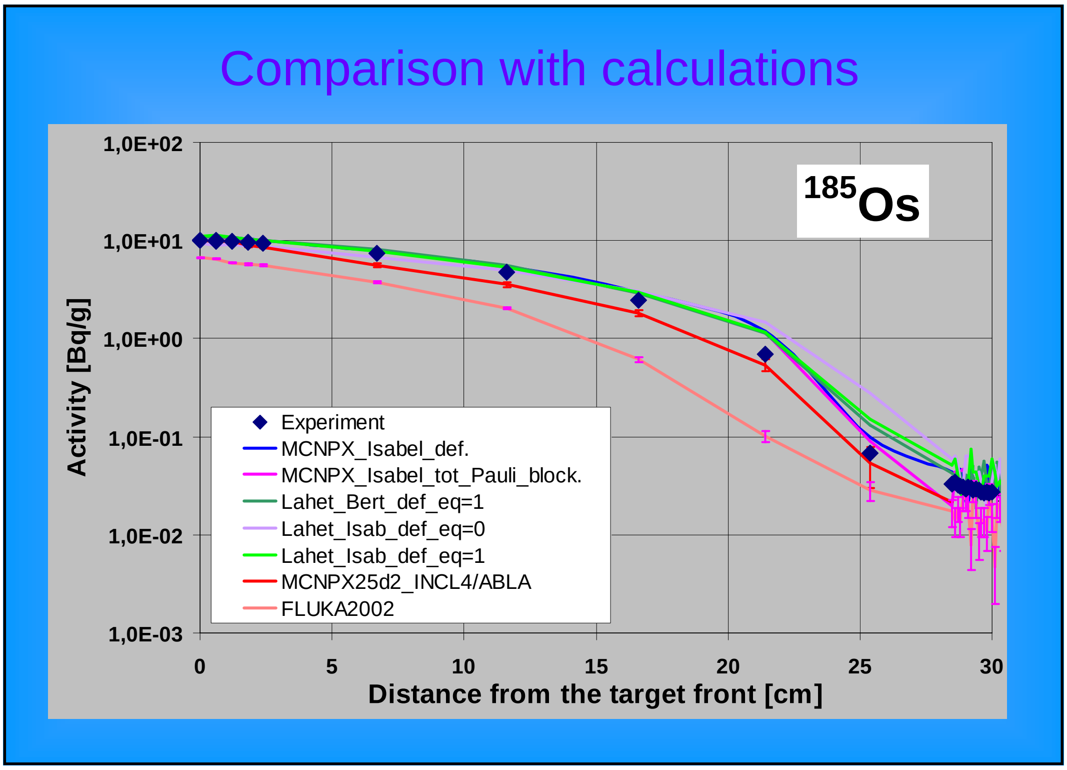
	CEM		Bertini/Dresner		Bertini/ABLA		Isabel/Dresner		Isabel/ABLA		INCL4/ABLA	
		^{24}Na excl.		^{43}Sc excl.		^{24}Na excl.		^{24}Na excl.		^{24}Na excl.		^{24}Na excl.
FOM1=	0,977	1,018	0,650	0,689	0,705	0,751	0,573	0,730	0,343	0,803	0,477	0,843
FOM2=	7,1	6,0	11,9	9,9	16,2	14,4	22,3	10,7	52,9	14,3	36,7	12,5

EVALUATION OF THE LEAD TARGET ACTIVATION. COMPARISON OF COMPUTATIONS AND MEASUREMENTS

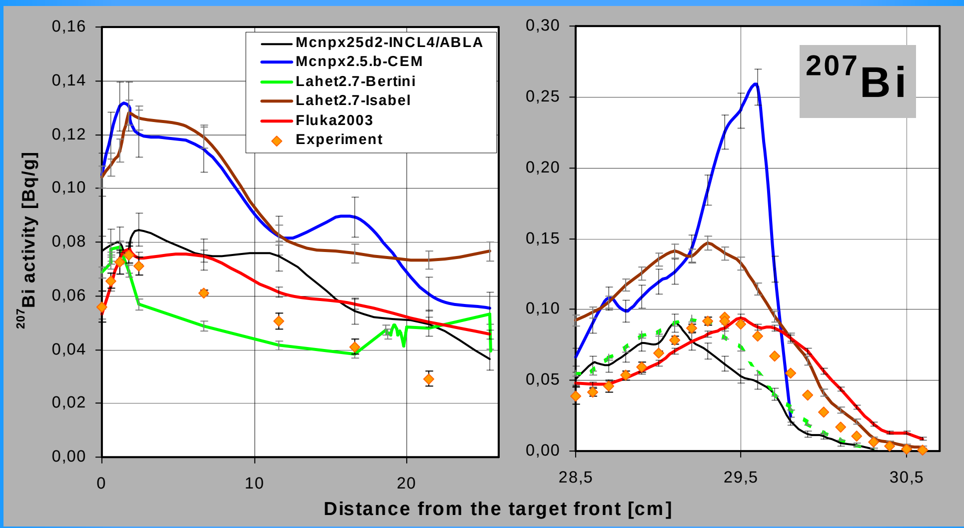
Experiment



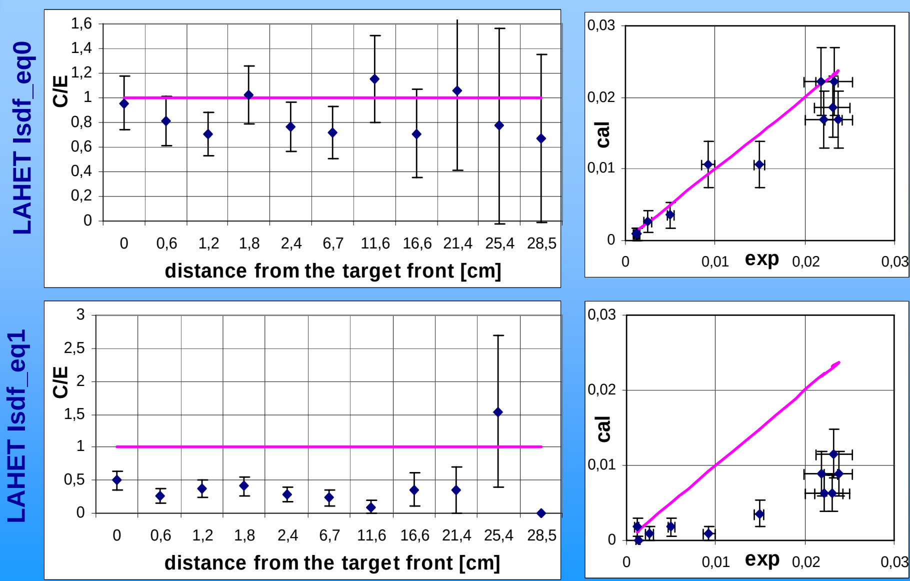

Comparison with calculations
110m Ag
1,000
0,100
0,010
0,001
Activity [Bq/g]
0
5
10
15
20
25
30
Distance from target front [cm]
Lahet_Isdf_eq0
Lahet_Isdf_eq1
Mcnpx25b_Bdf_eq0
Mcnpx25b_CEM_eq0
Mcnpx25b_CEM_eq1
Mcnpx25d2_CunAbl
FLUKA
Experiment


Comparison with calculations
185 Os
1,0E+02
1,0E+01
1,0E+00
1,0E-01
1,0E-02
1,0E-03
Activity [Bq/g]
0
5
10
15
20
25
30
Distance from the target front [cm]
Experiment
MCNPX_Isabel_def.
MCNPX_Isabel_tot_Pauli_block.
Lahet_Bert_def_eq=1
Lahet_Isab_def_eq=0
Lahet_Isab_def_eq=1
MCNPX25d2_INCL4/ABLA
FLUKA2002

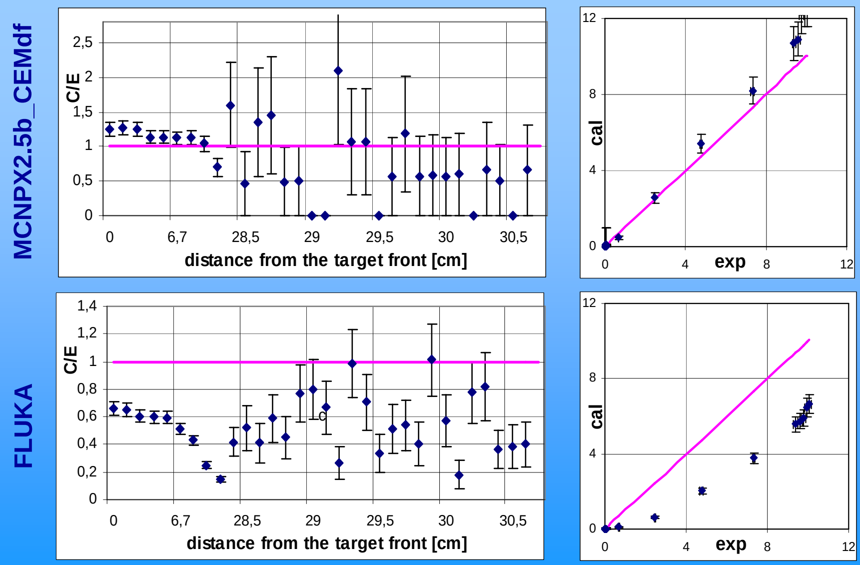
Comparison with calculations



Comparison of measured and calculated activities of ^{60}Co along Pb target [Bq/g]



Comparison of measured and calculated activities of ^{185}Os along Pb target [Bq/g]



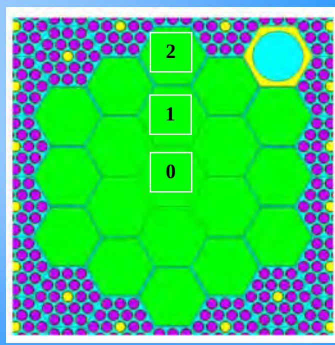
C/E for the whole Pb target

		Exp.	Uncert.	BerAbl	Berdef	CunAbl	CunDre	CEM	Isadef	IsaDre	FLUKA
fission products	^{60}Co	148	6	0.50	0.48	0.50	0.60	0.46	0.46	0.50	0.38
	^{65}Zn	274	8	0.87	1.71	1.64	0.67	2.04	0.82	1.64	0.78
	^{83}Rb	3540	170	0.49	0.43	0.37	0.63	0.50	0.53	0.37	0.68
	^{85}Sr	1640	85	0.67	0.59	0.50	0.80	0.77	0.76	0.51	0.09
	^{88}Y	6050	160	0.45	0.45	0.42	0.54	0.56	0.53	0.42	0.73
	^{95}Zr	5070	58	0.89	0.57	0.57	1.67	0.57	1.26	0.57	1.20
	^{102m}Rh	905	39	0.60	0.38	0.37	0.80	0.36	0.76	0.37	0.77
	^{110m}Ag	3460	92	0.44	0.39	0.24	0.75	0.19	0.59	0.24	0.59
	^{121m}Te	1580	44	0.63	0.78	0.71	0.85	0.57	0.78	0.71	0.54
spallation prod.	^{173}Lu	6640	120	1.42	1.86	1.33	0.55	1.03	0.94	1.33	0.07
	^{175}Hf	13350	450	1.14	1.32	1.03	0.51	0.89	0.80	1.03	0.10
	^{183}Re	32950	830	1.55	1.63	1.53	1.03	1.42	1.37	1.53	0.56
	^{185}Os	63770	890	1.27	1.15	1.14	0.89	1.20	1.18	1.14	0.51
	^{194}Au	435	41	1.08	0.97	1.05	1.06	1.28	1.15	1.05	1.34
	^{203}Hg	4480	33	1.30	1.28	1.01	1.60	0.48	1.01	1.01	0.68
p,xn	^{207}Bi	825	18	1.06	1.41	2.21	1.18	1.67	1.86	2.21	1.17

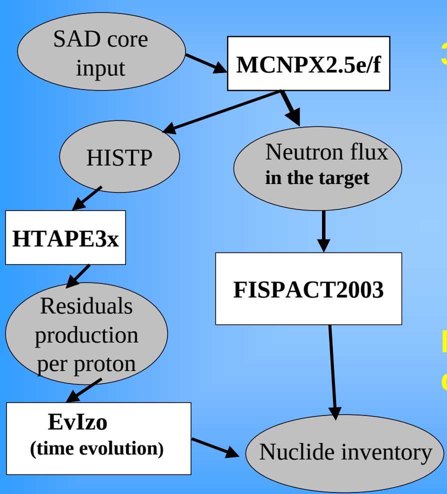
	(black)	< 10%		10% <	(grey)	< 20%

CALCULATION OF INDUCED RADIOACTIVITY IN THE SAD SPALLATION TARGET

The SAD spallation target consists of one central and 18 hexagonal (36mm pitch) Pb prisms in 2 concentric layers



Scheme of the calculation process

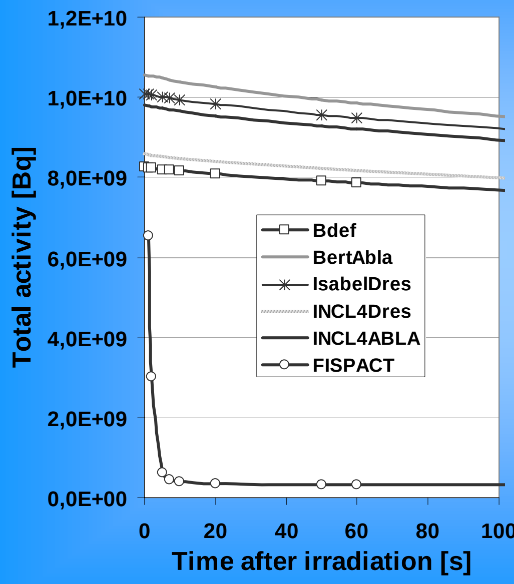


3 irradiation scenarios:

- **-a) experiment - Pb bare target (t_i = 9h, i_p = 1.3nA)**
- **-b) SAD target (t_i = 10h, i_p = 1.5μA)**
- **-c) SAD target, i_p = 1.5μA 5 d with 10h/d**

Neutrons from the subcritical core are also considered

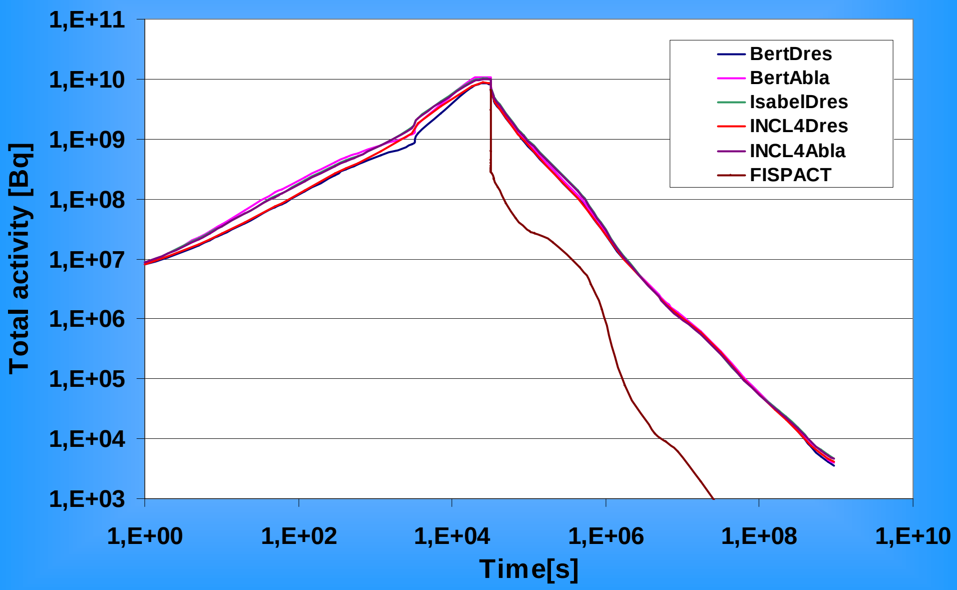
Time evolution of the total target activity (i_p=1.3 nA)

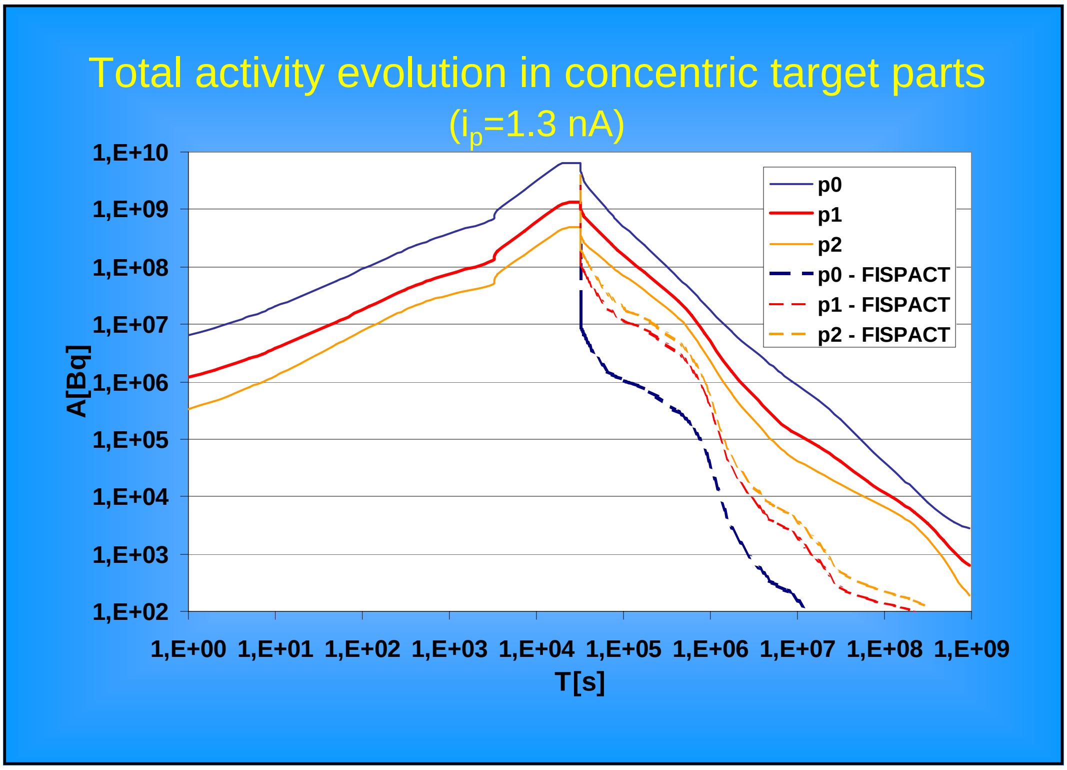


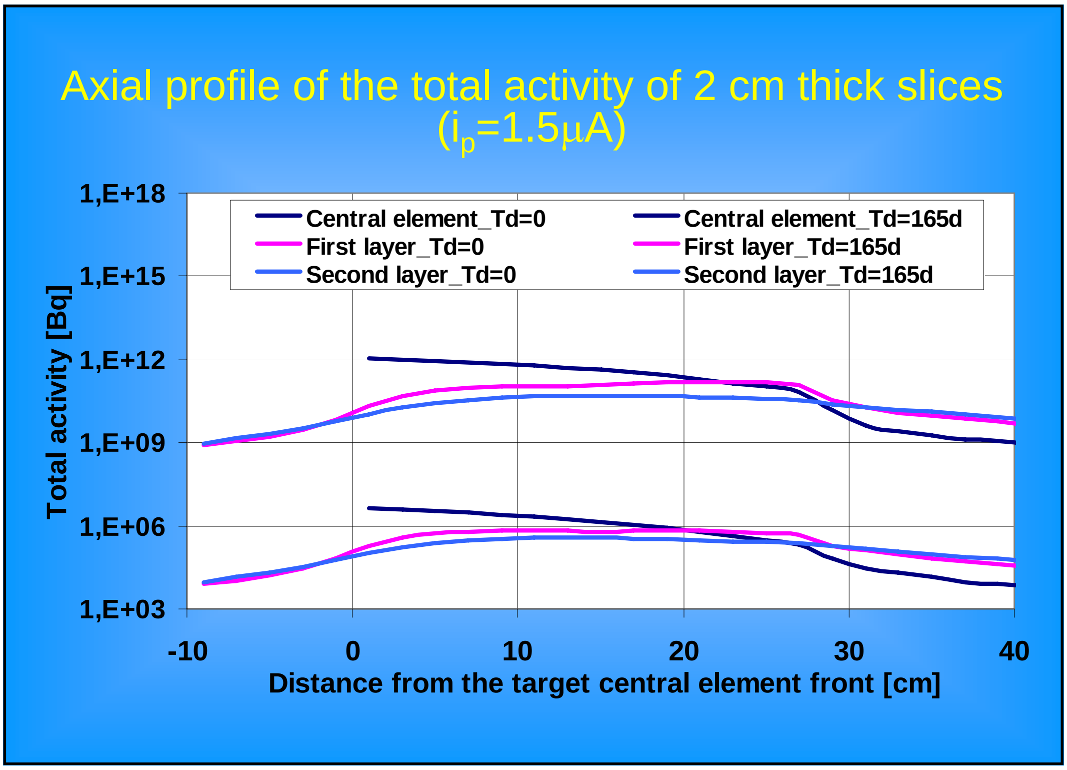
First 100 seconds after irradiation.

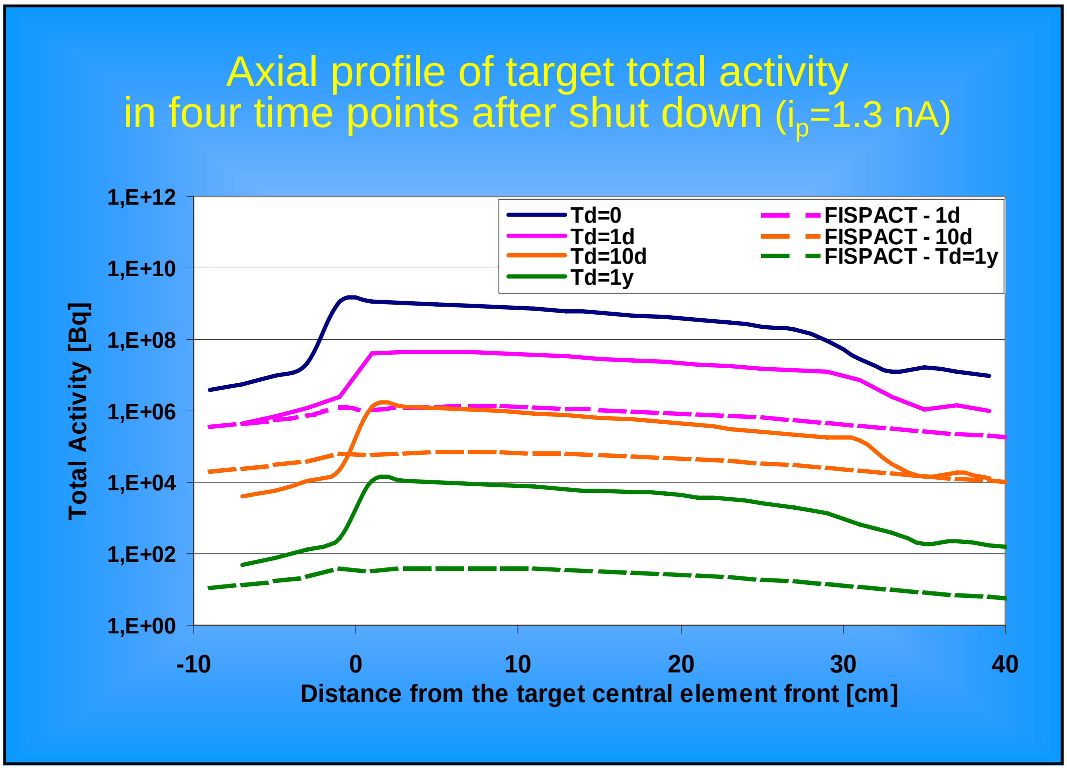
After the first 10 seconds the activity induced by low energy particles (calculated with FISPACT) constitutes less than 5% of the high energy one (HTAPE).

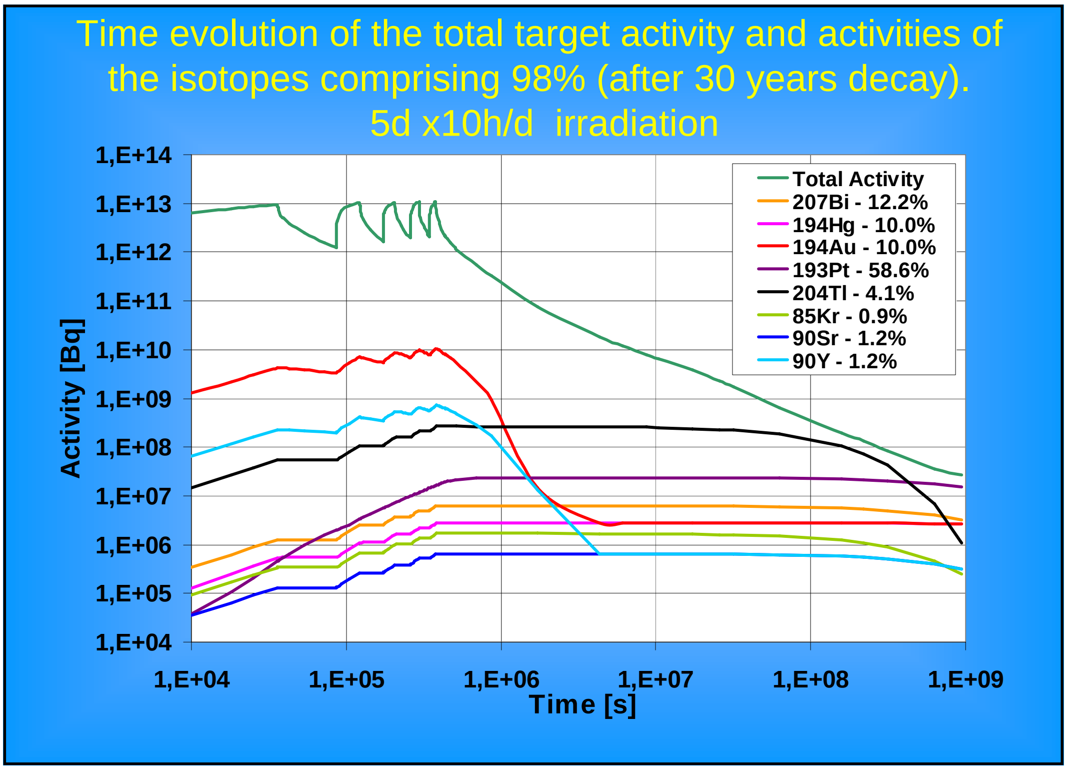
Time evolution of the total target activity (i_p=1.3 nA)




Total activity evolution in concentric target parts
(ip=1.3 nA)
A[Bq]
1,E+10
1,E+09
1,E+08
1,E+07
1,E+06
1,E+05
1,E+04
1,E+03
1,E+02
1,E+00 1,E+01 1,E+02 1,E+03 1,E+04 1,E+05 1,E+06 1,E+07 1,E+08 1,E+09
T[s]
p0
p1
p2
p0 - FISPACT
p1 - FISPACT
p2 - FISPACT


Axial profile of the total activity of 2 cm thick slices
(ip=1.5μA)
Total activity [Bq]
1,E+18
1,E+15
1,E+12
1,E+09
1,E+06
1,E+03
-10 0 10 20 30 40
Distance from the target central element front [cm]
Central element_Td=0
First layer_Td=0
Second layer_Td=0
Central element_Td=165d
First layer_Td=165d
Second layer_Td=165d


Axial profile of target total activity
in four time points after shut down (i_p=1.3 nA)
Total Activity [Bq]
1,E+12
1,E+10
1,E+08
1,E+06
1,E+04
1,E+02
1,E+00
-10
0
10
20
30
40
Distance from the target central element front [cm]
Td=0
Td=1d
Td=10d
Td=1y
FISPACT - 1d
FISPACT - 10d
FISPACT - Td=1y


Time evolution of the total target activity and activities of the isotopes comprising 98% (after 30 years decay).
5d x10h/d irradiation
Activity [Bq]
1,E+14
1,E+13
1,E+12
1,E+11
1,E+10
1,E+09
1,E+08
1,E+07
1,E+06
1,E+05
1,E+04
1,E+04
1,E+05
1,E+06
1,E+07
1,E+08
1,E+09
Time [s]
Total Activity
207Bi - 12.2%
194Hg - 10.0%
194Au - 10.0%
193Pt - 58.6%
204Tl - 4.1%
85Kr - 0.9%
90Sr - 1.2%
90Y - 1.2%

Conclusions

1. The measured and simulated (LAHET, MCNPX, FLUKA) proton cross sections for ^{nat}Fe and activity distributions along the Pb target agree only for some radionuclides.
2. For all axial distributions in Pb target some general regularities were found:
   - underestimated in calculations values for fission fragments (i.e. ^{60}Co, ^{65}Zn, ^{83}Rb, ^{110m}Ag),
   - better ones for heavier nuclides (A > 170).
   - at worst, the comparison shows the discrepancy within one order of magnitude
   - almost always the C/E ratio remains between 3 and 1/3

Conclusions (cont.)

3. For the activity of the whole target the differences even below 10% are observed, in particular for the nuclides for which the atomic mass differs by ~ 10 - 30 from the original lead nuclei, however, one cannot point out a single code and/or model yielding good results for all examined nuclides. The model of Cugnon-Schmidt gives the best agreement with our experimental values - about 70 % of results remain within 30 % difference.
4. An analytical benchmark (based on the measurements on Dubna Phasotron) is proposed to improve the reliability of calculations.

Conclusions (cont.)

5. In order to improve the accuracy of activity measurement in the future “bare-target” experiments, the access to the more intesive beam is necessary. One could than concentrate on the assessment of the long-lived nuclides:

   ^{207}Bi - 33.4y, $^{208-210}$ Po – 0.4-102y and ^{194}Hg - 367y.

   For Po isotopes, ^{193}Pt(β,50y) and ^{148}Gd(α,90y) α and β counting techniques can be applied.
6. Having in mind the influence of the high energy protons on fuel materials, the proton capture reactions in Pb ($\Rightarrow$ $^{203-206}$Bi) and Bi ($\Rightarrow$ $^{204-207}$Po) can be used for the assessment of protons leaving the lateral surface of SAD targets.

Conclusions (cont.)

7. The spatial and time distributions of the calculated radioactivity for SAD target (with the use of MCNPX2.5e and FISPACT) show that:
   - the activity is concentrated in the central element; shares in subsequent layers are 75, 20, 5 %,
   - the main isotopes forming ~ 98 % of the long-lived activity are ^{90}Y/Sr, ^{193}Pt, ^{194}Hg/Au, ^{204}Tl and ^{207}Bi,
   - total radioactivity of the target after 5 days of irradiation (10 h a day, 1.5 μA) and 40 h decay amounts to ~ 10^{12} Bq.

   The work will be continued towards assessment of radiation hazard in real conditions accompanying replacement of SAD target.

Proton-Induced Polonium Production in Massive Lead-Bismuth Target

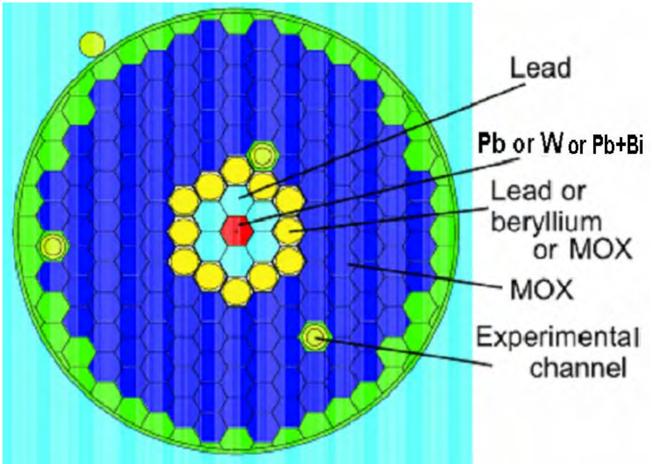
Aleksander Polanski [a*],

**Andrzej Soltan Institute for Nuclear Studies, Warsaw, Poland.*
a) Joint Institute for Nuclear Research, 141980 Dubna , Russia

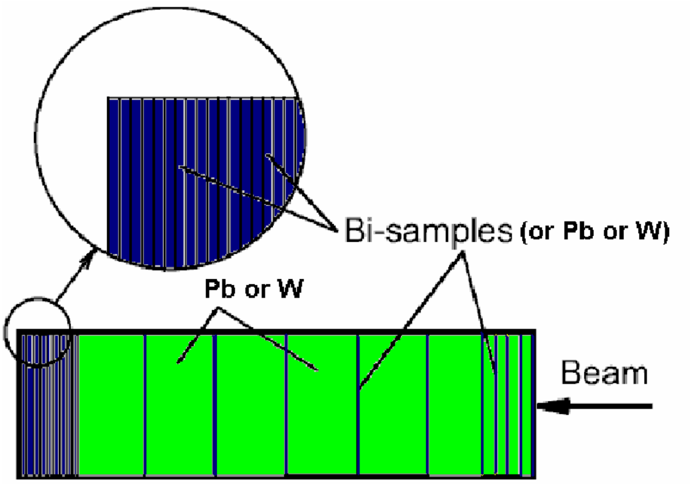
Contents

- Intoduction.
- Experimental Program With Different Targets.
- Distribution of bismuth isotopes in lead target.
- Distribution of poloniun isotopes in bismuth-lead target.
- Conclusions.

Target of SAD (Subcritical Assembly in Dubna).



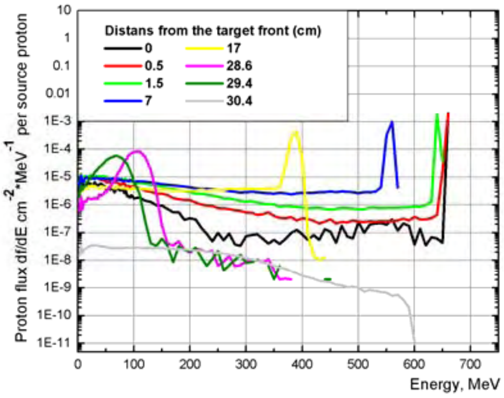
Geometry of Central Part of Target



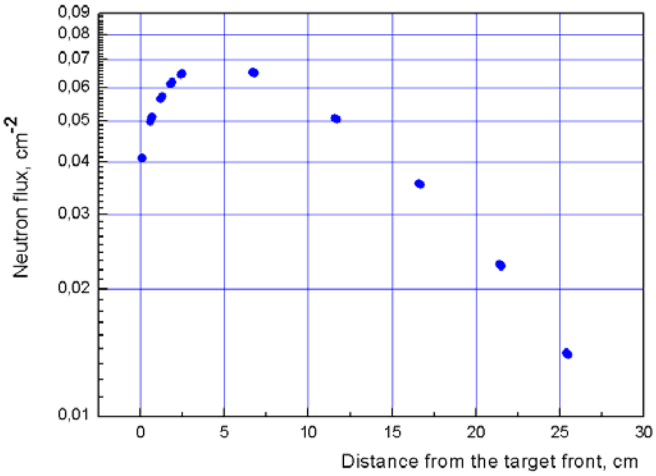
Experimental Program For Different Targets of SAD.

- Investigation of the the isotope production and heat generation for different target materials (lead or lead-bismuth or tungsten).
- Study of protons and neutron spectrum inside and outside different targets.

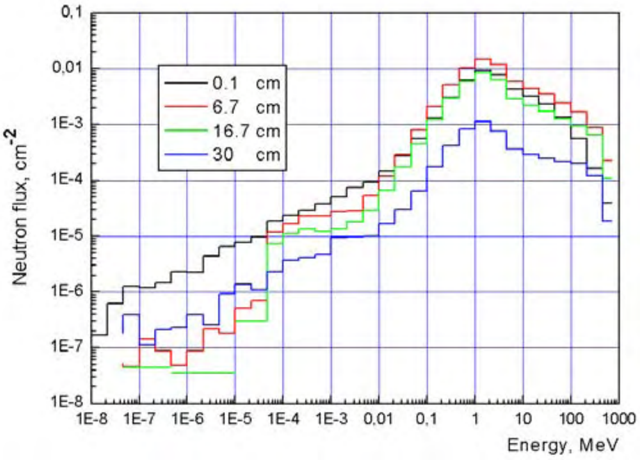
Proton Energy Spectrum in Central Lead Target



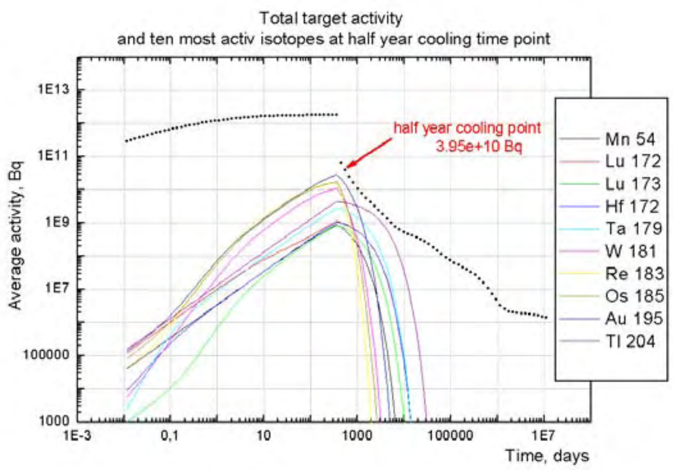
Neutron flux along the target



Neutron Energy Spectrum in Central Lead Target

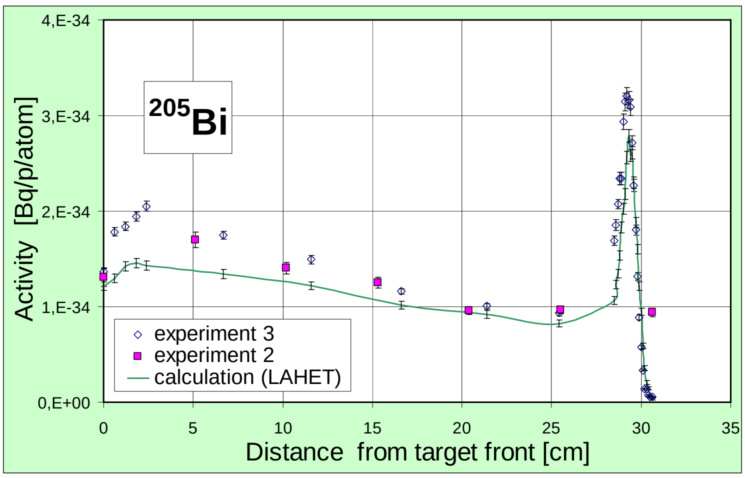


Activation of Lead Target

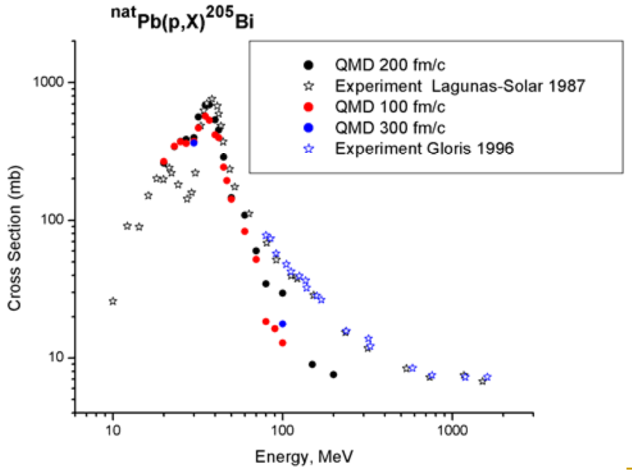


Activation 1000 h, 1 year, cooling ½ year

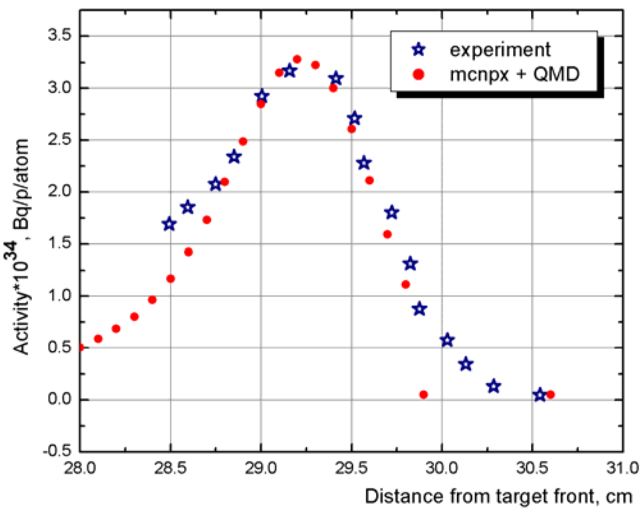
Distribution of bismuth isotopes in central part of lead target



Calculation of bismuth production cross sections



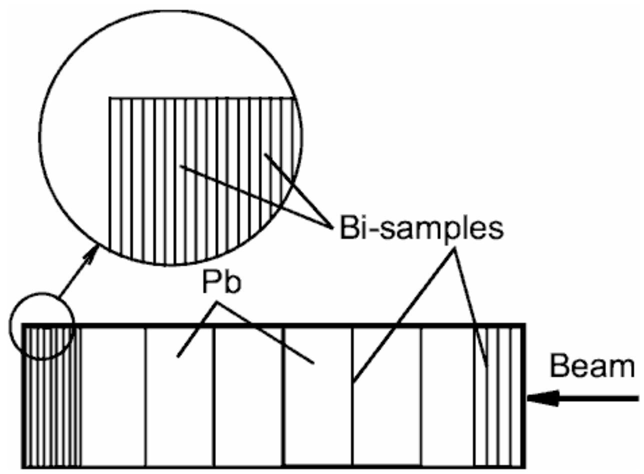
^{205}Bi profile(peak part)



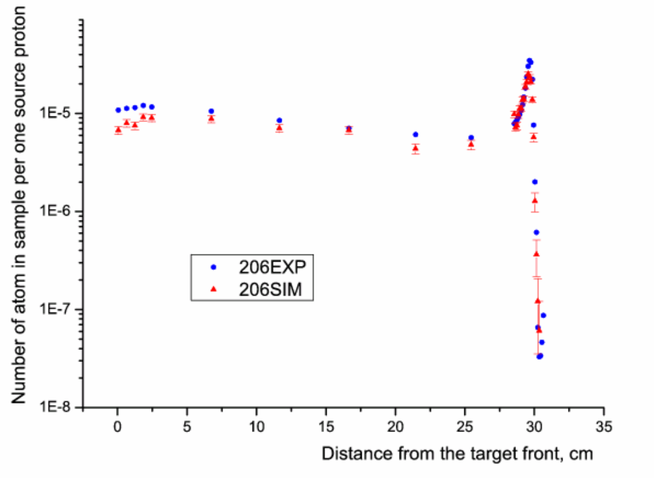
Distribution of Poloniun Isotopes in Bismuth-lead Target

- We calculated the production of the following isotopes: Po-206, Po-207, Po-208, Po-209 and Po-210. Different methods were applied in calculations of the induced activity. We calculated isotopes production by two ways:
- First by calculations spatial-energy proton distribution in target and by using experimental cross sections.
- The second way by using cascade-evaporation model for simulation of the isotopes production.

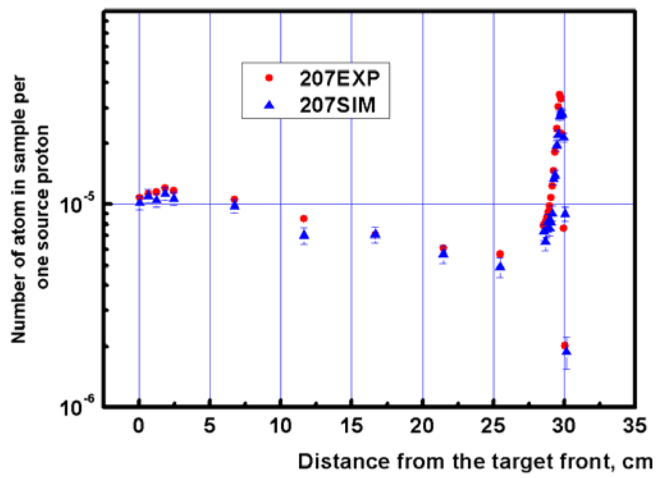
Geometry of Calculations



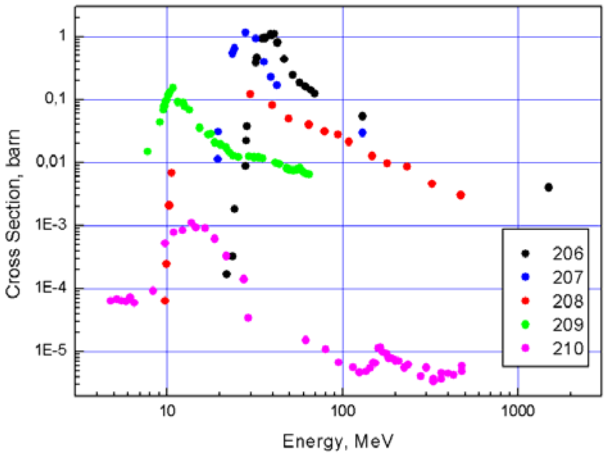
Distribution of the Po-206 Radionuclide Production Along the Target Irradiated With 660 MeV Protons.



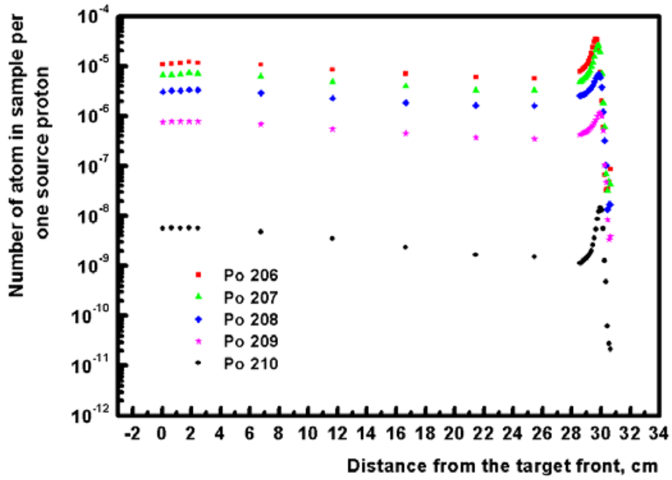
Distribution of the Po-207 Radionuclide Production Along the Target Irradiated With 660 MeV Protons.



Experimental Excitation Functions for the Production of Po-206 and Po-207 in Bi-209 Taken From EXFOR.



Distribution of the Polonium radionuclide Production Along the Target Irradiated With 660 MeV Protons.



Conclusions

- The maximum of production polonium and bismuth isotopes by protons in lead-bismuth target is for energy of protons less than 100 MeV.
- This production we observe on the end of range of protons in massive target.
- High energy protons produce secondary neutrons and therefore at beginning of target we observe production of isotopes by protons induced by neutrons.

Status of preparation of SAD

V.Shvetsov

JINR – EUROTRANS Commitment

Statement of

Joint Institute for Nuclear Research (JINR)

on the scientific working programme of the Sub-critical Assembly Dubna (SAD) project, in close co-operation with the Domain DM2 ECATS activities of the European sponsored integrated project EUROTRANS.

During the 4th SAD / YALINA Steering Committee Meeting dated September 15-16, 2005 in Dubna Russian Federation, JINR representatives discussed with representatives of the EUROTRANS project (EUROpean Research Programme for the TRANSmutation of High Level Nuclear Waste in an Accelerator Driven System) the working programme of SAD facility in relation to the Domain DM2 ECATS (Experimental activities on the Coupling of an Accelerator, a spallation Target and a Sub-critical blanket) of the EUROTRANS project.

Domain DM2 ECATS aims to provide validated experimental input from relevant experiments at sufficient core power to get feedback effects related to the coupling of an accelerator, a spallation target and a sub-critical blanket in order to assist the design of XT-ADS (eXperimental facility demonstrating the technical feasibility of Transmutation in an Accelerator Driven System) and EFIT (European Facility for Industrial Transmutation). These experiments shall also provide design input on the dynamics / kinetic behaviour, on experimental techniques for such a coupled system with feedback effects. Biological shielding, safety and licensing are important issues of this project.

The JINR representatives agree to make a commitment to extend the present SAD project in order to support the needs of the EUROTRANS project, especially the validation of: sub-criticality management, assessment and control of experimental methods, start-up / operational / shut-down procedures, shielding, and generic dynamic behaviour of an ADS in a wide range of sub-critical levels. The planned Russian experiment SAD will be performed to meet the agreed EUROTRANS requirements of ~30 kW reactor core power, and especially of Work Package WP2.3 of Domain DM2 ECATS.

The Working Programme of SAD, its Time Schedule and Budget over the full duration of DM2 ECATS (ending March 2009) was discussed and committed by the JINR representatives. The JINR representatives are committed to get the associated accelerator fully operational again in due time prior to start-up operation of the SAD facility in 2006.

The JINR representatives agree to exchange scientific-technical staff (especially Masters, PhD, and Post Doctoral students) with the EUROTRANS partners so as to use this unique opportunity of co-operation of human resource and training tools.

The JINR representatives presented the SAD project (working programme, time schedule) during the 2nd ECATS Meeting in Brussels dated to 20.04.2005. The estimated realisation time is 4 years. First protons on a spallation target are planned to be at the end of 2009. The design operation time of SAD is 10.000 hours at nominal

estimated realisation time is 4 years. First protons on a spallation target are planned to be at the end of 2009. The design operation time of SAD is 10.000 hours at nominal power. The JINR representatives understand that the future operation of SAD to be a common endeavour of European and Russian partners.

The JINR representatives assume that the project can be realised providing that JINR and DM2 ECATS of EUROTRANS fund SAD project at the level 1/3 each under the condition that another 1/3 of the necessary funding will be provided by ISTC. At present time JINR is ready to take responsibility on 1.2 M Euro funding, having in mind that the rest of the funds necessary to cover 1/3 of the project cost will be covered by a collaboration that will be created in Russia.

Detailed commitment from JINR will be given after the meeting of JINR Program Advisory Committee on nuclear physics which is planned for November 9-10 2005.

The assumed cost split for the project is given in the following table.

Cost split for the SAD project funding numbers are in M Euro

Year	ECATS	ISTC	JINR	
			Budget	Collaboration
2006	1.7 + 0.6 (in kind contribution)	0.8	0.1	*
2007		1.3	0.1	*
2008		0.4	0.5	*
2009			0.5	*

* Numbers to be clarified after creation of the collaboration

A.N.Sissakian
JINR Director designate

M.G.Itkis
Director of the FLNR JINR

A.G.Olshevsky
Director of the DLNP JINR

V.N.Shvetsov
Deputy director of the FLNP JINR

Dubna
September 16 2005

Program Advisory Committee on nuclear physics of JINR (Nov. 7-8)

- SAD project was presented by W.Gudowski
- After some discussions project was approved by PAC for implementation, but it was stressed that such large scale projects should be supported on the level on national Agencies/Ministries

ISTC #2267 Extension

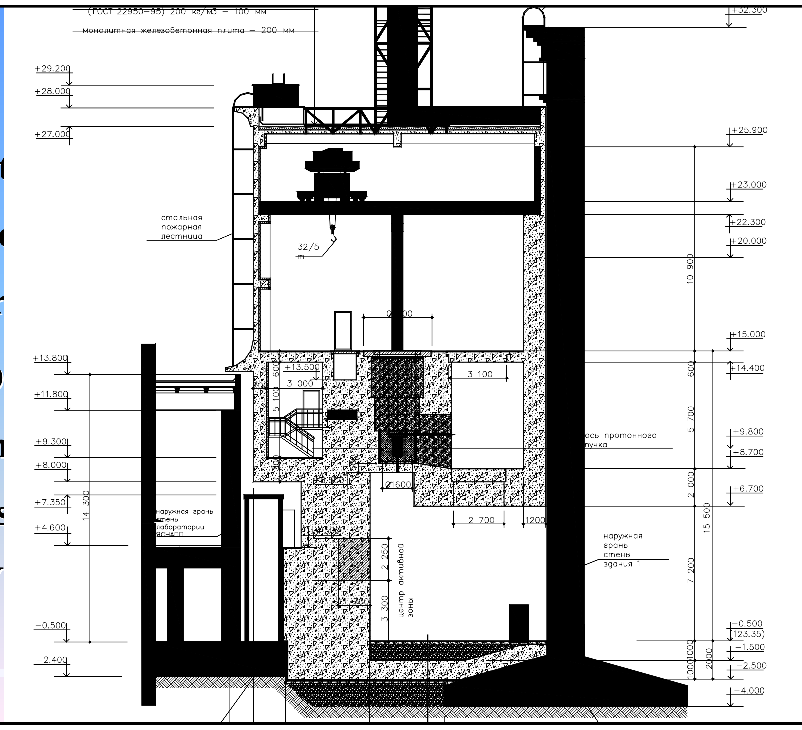
- 1 year extension
- Main tasks:
  - Preparation of the experiment at BFS;
  - SAD core and biological shielding working documentation;
  - SAD building working documentation;
  - SAD beamline working documentation;
  - Fuel pellets manufacturing;

Phasotron recovery

- All equipment was tested – no serious damages for the main components;
- Cabling is repairing;
- Support grid in Lab.4 is under expertise;

Plans are to startup Phasotron in June 2006

- St
  n g
  (r
- D or
  in
  as le:
  Y



Input for CRP from SAD (cont.)

- Analysis of the experimental data obtained at IBR-30 subcritical assembly driven by electron accelerator (responsible: Yu.Pepelyshev); Time constants for multiplications 2 – 200;
- Analysis of the malfunctions in operation of the fast pulsed reactors/boosters at FLNP JINR (responsible: Yu.Pepelyshev);

SAD financing – general situation

- Available resources cover less than ½ of the project cost;
- Efficiency of the ISTC funding is definitely less than 2.5;
- JINR is working to attract support from Rosatom and interested institutions;

In this situation it's very difficult to plan and implement the project

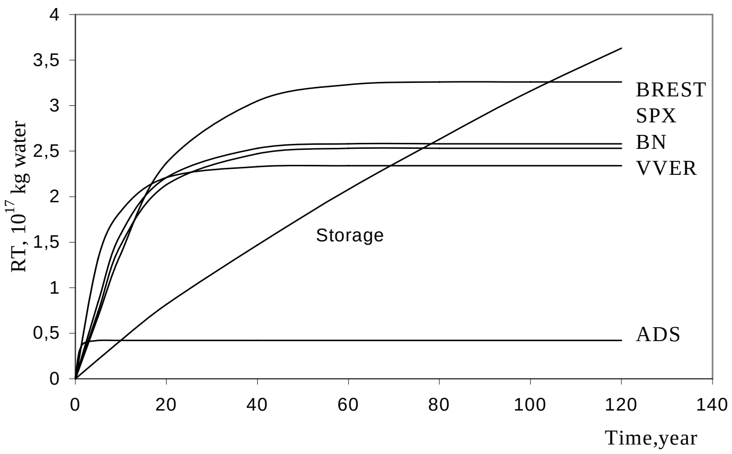
Comparative study of ADS-burners with fast, intermediate and thermal spectra

Leonid I. Ponomarev
Russian Research Centre ''Kurchatov Institute'' and
Research Coordinative Centre MUCATEX, Russian Federation

Institutions:
IPPE(Obninsk),ITEP(Moscow),VNIIEF(Sarov),VNIIKHT(Moscow),RIAR(Dimitrovgrad)

- Three types of ADS-burners:

- Fast neutron spectrum (heavy metal coolant);
- Thermal spectrum (heavy water, graphite);
- Intermediate spectrum (molten salt).



Radiotoxicity R accumulated in storage and transmutation facilities with ADS-800, VVER-1000, BN-800, SUPER-PHENIX-1200, and BREST-1000 type reactors at feed by actinides extracted from VVER-1000 type reactor

Initial conditions:

- Accelerator – 10 MW (1 GeV, 10 mA);
- Fuel – MA and Pu from spent fuel of VVER or PWR (50 MW.d/kg) after 30 years storage;
- keff = 0.95 and 0.97.

- Additional: cascade schema.

Criteria for comparison:

- W (MW) – unit power;
- Q (kg/year) – MA transmutation efficiency;
- F (kg/kg) – additional fissile nuclei;
- T (year) – transmutation time;
- MA fuel handling efficiency;
- Stability of operation.

Heavy water reactor - burner

Conception of RW - burning in thermal reactor is developing intensively at ITEP (Moscow)

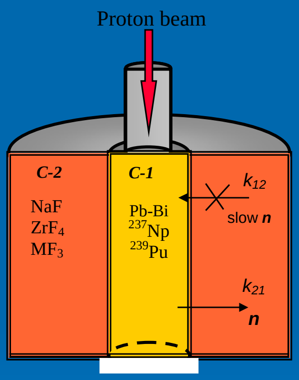
Molten salt reactor-burner

Conception of the molten salt burner is developing at Kurchatov Institute (Moscow)

Solubility of MA !

- It is not known properly today;
- Salts: LiF – BeF2; NaF – ZrF4;
- RIAR (Dimitrovgrad),
- VNIIKHT (Moscow).

Cascade subcritical molten salt reactor (CSMSR)



$k_{12} << k_{21} \quad (k_{12} \approx 10^{-3})$

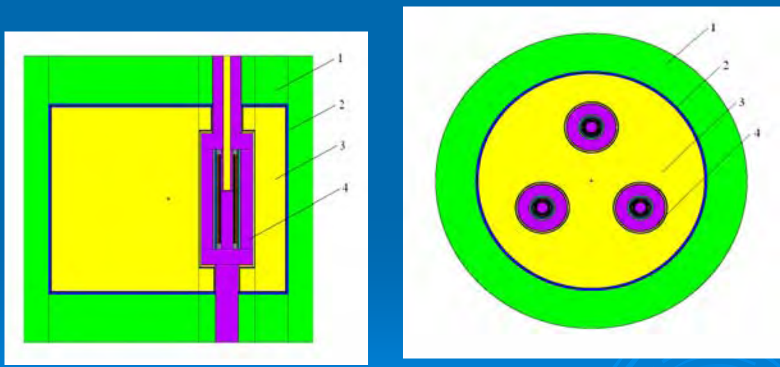
$$\Delta k = \frac{\Delta k_1 + \Delta k_2}{2} - \sqrt{\left(\frac{\Delta k_1 - \Delta k_2}{2}\right)^2 + \delta^2},$$

$$\delta = (k_{12} k_{21})^{1/2}$$

Cascade Amplification Factor is equal

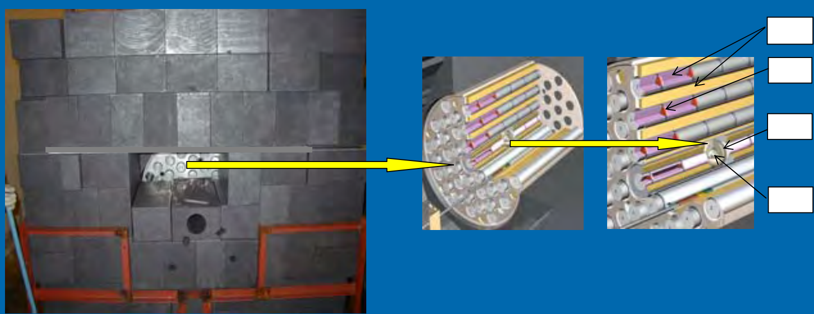
$$A \approx 1 + \frac{k_{21} - \delta}{\Delta k + 2\delta}$$

CSMSR composition



a) vertical section b) horizontal section

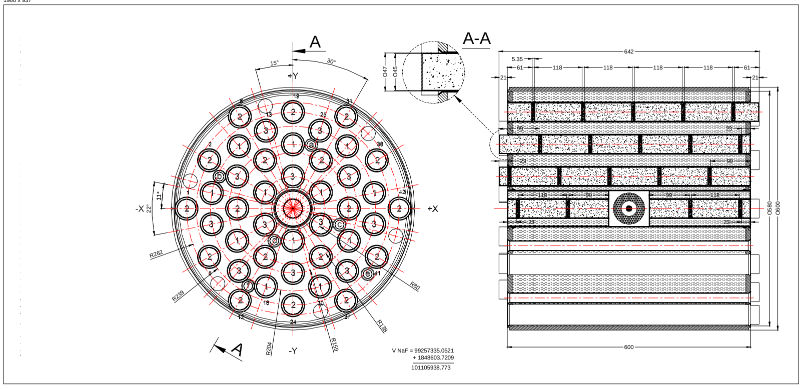
CSMSR structure. 1 - reflector; 2 - hull; 3 - core2; 4 - core1

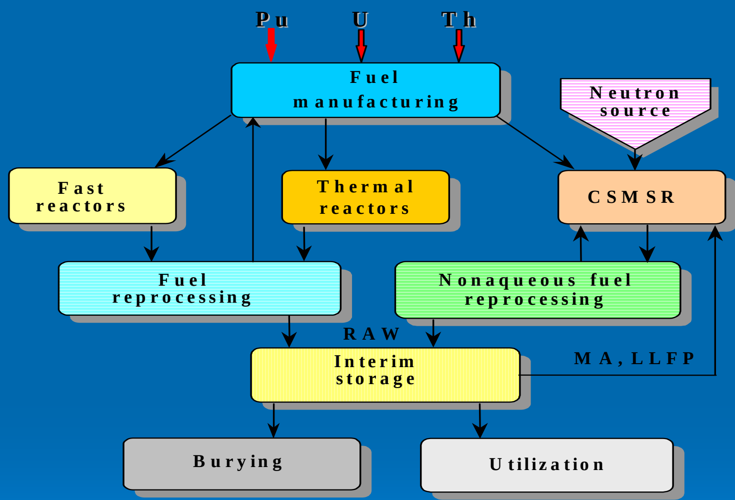


Experimental setup for study of the neutron flux cascade amplification

Layout of the experimental model

Mass of U – 18.74 kg (214 × 87.6 g)
Mass of ZrF_4 – 87 kg
Mass of ^{237}Np – 4.984 kg
Mass of NaF – 195 kg





Three-component nuclear power system with a closed nuclear fuel cycle

Program of Minor Actinide Nuclear Data Measurements and Evaluation.

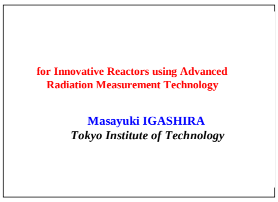
Leonid I. Ponomarev

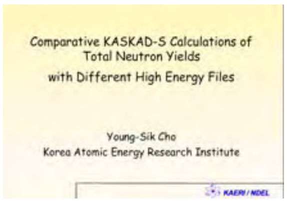
Russian Research Center "Kurchatov Institute"
and
Research Coordinative Center "MUCATEX",
Moscow, Russia

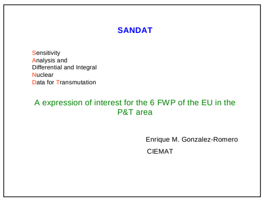
- Why it is important?
- What we are planning to study?
- Who will do that?
- How it will be done?
- What is a final result of the program?

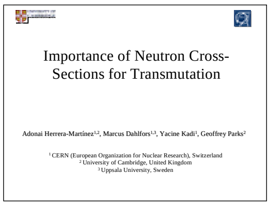
Objectives of studying MA.

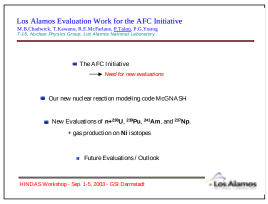
- Nuclear date for minor actinides (isotopes of Am, Cm, Cf, etc.) are very poor and contradictive.
- In reactor – burners the concentration of MA is high and they essentially influence the neutron spectrum.
- For optimization of different types of burning scenarios we need in bench – mark experiments with MA.

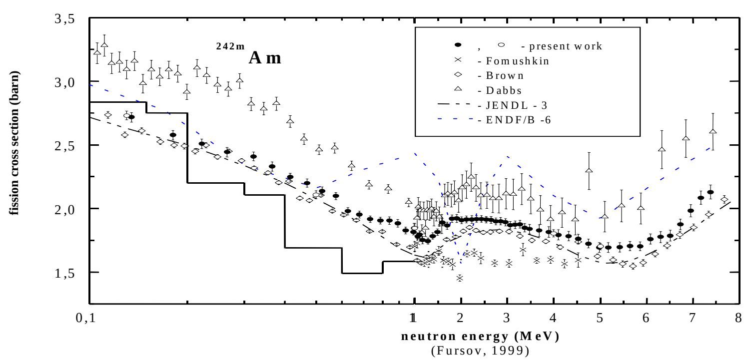

for Innovative Reactors using Advanced
Radiation Measurement Technology
Masayuki IGASHIRA
Tokyo Institute of Technology

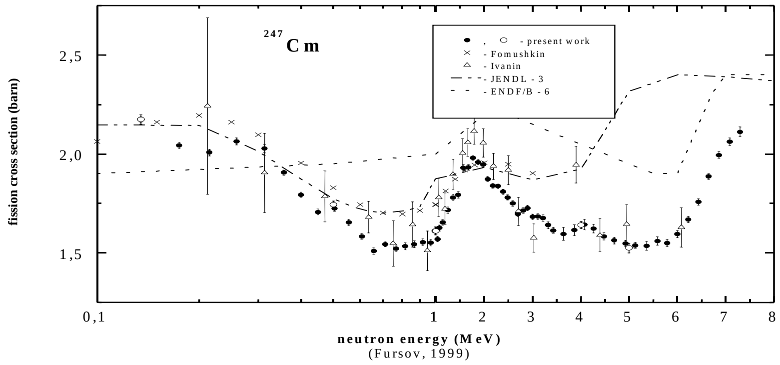

Comparative KASKAD-S Calculations of
Total Neutron Yields
with Different High Energy Files
Young-Sik Cho
Korea Atomic Energy Research Institute
KAERI / NDEL


SANDAT
Sensitivity
Analysis and
Differential and Integral
Nuclear
Data for Transmutation
A expression of interest for the 6 FWP of the EU in the
P&T area
Enrique M. Gonzalez-Romero
CIEMAT


Importance of Neutron Cross-
Sections for Transmutation
Adonai Herrera-Martínez1,2, Marcus Dahlfors1,3, Yacine Kadi1, Geoffrey Parks2
1 CERN (European Organization for Nuclear Research), Switzerland
2 University of Cambridge, United Kingdom
3 Uppsala University, Sweden


Los Alamos Evaluation Work for the AFC Initiative
M.B.Chadwick, T.Kawano, R.E.McFarlane, P.Talou, P.G.Young
T-16, Nuclear Physics Group, Los Alamos National Laboratory
The AFC Initiative
Need for new evaluations
Our new nuclear reaction modeling code McGNASH
New Evaluations of n+238U, 239Pu, 241Am, and 237Np.
+ gas production on Ni isotopes
Future Evaluations / Outlook
HINDAS Workshop - Sep. 1-5, 2003 - GSI Darmstadt
Los Alamos


242m Am
fission cross section (barn)
3,5
3,0
2,5
2,0
1,5
0,1
1
2
3
4
5
6
7
8
neutron energy (MeV)
(Fursov, 1999)
, - present work
- Fomushkin
- Brown
- Dabbs
- JENDL - 3
- ENDF/B -6



What we are planning to study?

Four types of measurements are planned:

- Measurements of cross-section of fission SIG-F(E), capture SIG-C(E), absorption SIG-A(E), resonance parameters (RP) and resonance integrals of fission (RIF) and capture (RIC), and ALFA-value in the neutron energy range E = 0.5 ÷ 200 eV.
  (FACEL Linac, RRC "Kurchatov Institute").
- Measurements of differential nuclear characteristics of minor actinides (cross-sections $\sigma(E)$, multiplicity ν_f, etc.) in the energy range E = 0.1 ÷ 30 MeV.
  (LU – 50 Linac, VNIIEF, Sarov; EG-1 and EGP-15, IPPE, Obninsk).
- Integral in-pile experiments with burning minor actinides.
  (High flux reactors SM-3 and BOR-60, RIAR, Dimitrovgrad).
- Benchmark experiments with critical and subcritical assemblies.
  (BFS, IPPE, Obninsk).

I. High precision measurement of MA nuclear date in resonance neutron energy range

G. Muradyan et al.
(RRC ''Kurchatov Institute'', Moscow)

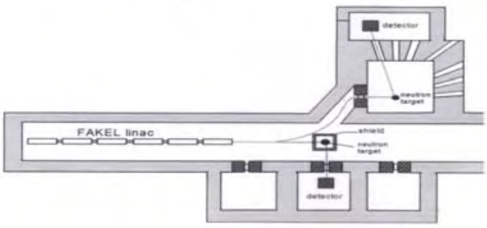
$\sigma_f(E)$ – fission
$\sigma_c(E)$ – capture
$\sigma_a(E)$ – absorption
$\alpha(E) = \sigma_c/\sigma_f$
RI – resonance integrals
RP – resonance parameters

^{237}Np
^{238}Pu, ^{241}Pu
^{241}Am, ^{242m}Am, ^{243}Am
^{243}Cm, ^{244}Cm, ^{245}Cm, ^{246}Cm, ^{247}Cm
^{251}Cf

with accuracy ~ 3% at energy rage E = 1 ÷ 100 eV.

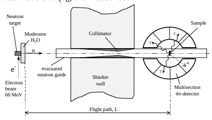
Measurements of neutron cross sections are performed on FAKEL linac – 60MeV (Kurchatov Institute). Maximum average beam power is 20 KW

Neutron spectrometry carried out by the time of flight method. There are 9 flight path – from 5 m to 300 m.

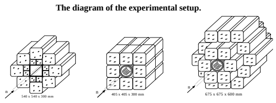


Multiplicity Spectrometry Method

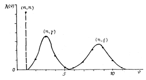
Capture, fission and scattering events are detected by a multisection 4π-detector. In each neutron-nucleus interaction act, incident neutron energy, number of γ-quanta (ν_γ) and energy of each γ-quanta ($E_{\gamma i}$) in emitted γ-cascade as well as the number of emitted neutrons (ν_n) are measured.



The diagram of the experimental setup.



4π-detectors assembly



Scattering $\mathbf{\nu = \nu_n = 1}$
Capture $\nu = \nu_\gamma \sim 3$
Fission $\mathbf{\nu = \nu_\gamma + \nu_n} \sim 7 + 2 = 9$

Measurements of the fission characteristics of transuranium isotopes

Yu.A. Khokhlov, I.A. Ivanin, et al.,

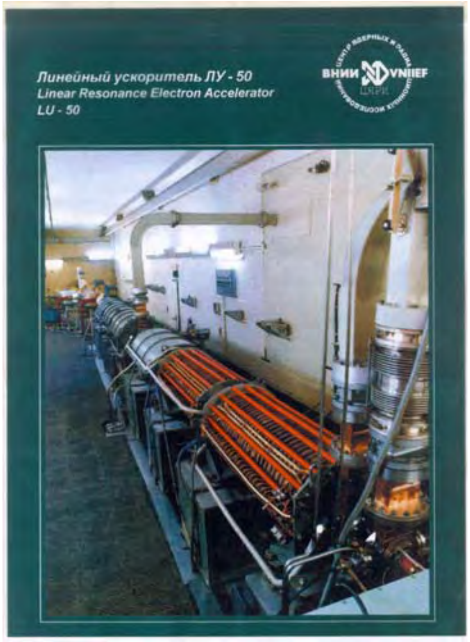
(*Russian Federal Nuclear Center, VNIIEF, Sarov)*

Fission cross sections and neutron multiplicities in the energy range E = 20 keV – 12 MeV for isotopes:

^{237}Np,

^{241}Am, ^{242m}Am, ^{243}Am,

^{244}Cm(?), ^{245}Cm, ^{246}Cm, ^{247}Cm.



III. Measurement of cross sections of fast and resonance neutrons induced fission of MA

B.I.Fursov et al.

(IPPE, Obninsk and INR, Troitsk.)

^{241}Am, ^{242m}Am, ^{243}Am, ^{243}Cm, ^{244}Cm, ^{245}Cm, ^{246}Cm, ^{247}Cm, ^{248}Cm.

- measurement of fission cross-sections of **Am** and **Cm** isotopes in the neutron energy range E=5÷30 MeV using neutrons produced in reactions *t(p,n), d(p,n)* and *t(d,n)* at tandem generator (IPPE, Obninsk);
- measurements in the neutron energy range E=1eV÷50 keV using lead slow down spectrometer (100 tons lead cube at INR, Troitsk).

Tandem generanor EGP-15
(IPPE, Obninsk)

IV. Integral Experiments in High-Flux Reactor SM-3 and Fast Reactor BOR-60

Yu.G.Toporov, A.V. Bychkov, et al.
(RIAR, Dimitrovgrad, Russia)

- **Irradiation.**
- **Monitoring: four-group neutron flux density, neutron gas temperature, energy release.**
- **Postreactor analysis of irradiated ampules.**
- **Comparison of experimental results and calculations.**

^{238}U,
^{237}Np,
^{240}Pu, ^{242}Pu, ^{244}Pu,
^{241}Am, ^{242m}Am, ^{243}Am,
^{242}Cm, ^{244}Cm, ^{245}Cm, ^{246}Cm, ^{248}Cm,
^{249}Bk,
^{250}Cf, ^{251}Cf, ^{252}Cf.

Experimental fast reactor BOR-60

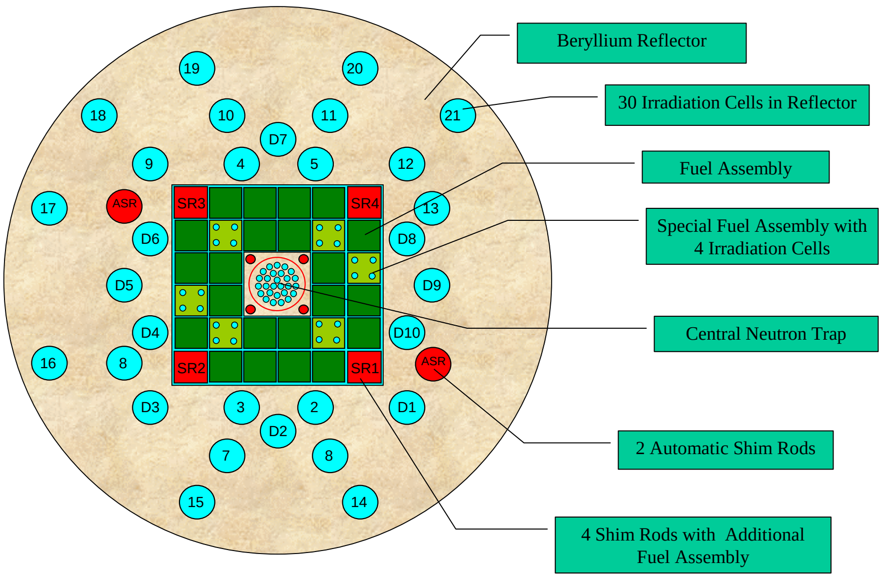
(RIAR, Dimitrovgrad)

Reactor BOR-60 is an unique many-purpose facility that has been operating to solve sodium cooled fast reactor problems. It is used also for providing investigations that are urgent in different spheres of science and engineering.

BOR - 60 main characteristics

Reactor capacity	
thermal	60 MW
electrical	10 MW
Maximum neutron flux density	3,7 10^{15} $sm^{-2}s^{-1}$
Maximum specific power	1100 kW/l
Non-uniformity factor of heat rating	1,15
Average neutron flux density	0,45 MeV
Fuel	UO_2 - PuO_2
^{235}U enrichment	45 - 90 %
Fuel burn up rate	up to 6% per year
Neutron fluence per year	$5 \cdot 10^{22} sm^{-2}$
Damage dose rate	up to 25 dpa /year
Fuel pin zone layout, from upper part of pin:	
upper reflector	100 mm
core	450 mm
lower reflector	150 mm
lower gas volume	300 mm
Coolant	sodium
Coolant temperature:	
at inlet in reactor	up to330°C
at outlet of reactor	up to 530 °C
Microcompaign duration	up to 120 days
Reactor generates energy	approximately 265 days per year

Reactor SM Cartogram *(RIAR, Dimitrivgrad)*



V. Benchmark Experiments with Minor Actinides at BFS-complex

I.P. Matvyenko, et al.

(IPPE, Obninsk)

- Fission rate distribution;
- Capture rate distribution;
- Reactivity coefficients;
- Spectral indexes as a function of (r, z) - geometry;
- Neutron importance as a function of (r, z) - geometry;
- Void reactivity effect;
- Doppler effect **(^{237}Np, ^{241}Am);**
- Analysis of experimental results;
- Estimation of data uncertainties;
- Development and verification of ADS - oriented nuclear data base.

BFS-1
(IPPE, Obninsk)

BFS-2
(IPPE, Obninsk)

List of MA isotopes planned to be measured.

	Isotope	Measuring characteristics	Energy range	Team leader
1	^{237}Np	$\sigma_c(E)$, RIC	0.5÷2000 eV	*Muradyan*
		$\sigma_f(E)$	0.04÷12 MeV	*Ivanin*
		$\langle\sigma_f\rangle$,$\langle\sigma_c\rangle$	0.1÷100 keV	*Toporov*
		$\langle\sigma_f\rangle$ *) $\langle\sigma_c\rangle$ Doppler effect $\langle\sigma_{in}\rangle$ *CRC*	Fis.thres.÷5 MeV 0.05÷100 keV 0.05÷100 keV 0.8÷5 MeV	*Matveyenko*
2	^{238}U	Doppler effect	0.05÷100 keV	*Matveyenko*
		$\langle\sigma_f\rangle$,$\langle\sigma_c\rangle$	0.1÷100 keV	*Toporov*
3	^{238}Pu	$\sigma_c(E)$ RIA	0.5÷30 eV 0.5÷300 eV	*Muradyan*
		$\langle\sigma_f\rangle$ $\langle\sigma_c\rangle$	0.1÷5000 keV 0.05÷100 keV	*Matveyenko*
		$\sigma_f(E)$	0.04÷12 MeV	*Ivanin*
4	^{239}Pu	$\langle\sigma_f\rangle$ $\langle\sigma_c\rangle$ *CRC*	0.1÷5000 keV**) 1÷5000 keV***) 0.1÷100 keV	*Matveyenko*
5	^{240}Pu	$\langle\sigma_f\rangle$ $\langle\sigma_c\rangle$ *CRC*	Fis.thres. – 5 MeV 0.05÷100 keV	*Matveyenko*
		$\langle\sigma_f\rangle$, $\langle\sigma_c\rangle$	0.1-100 keV	*Toporov*
6	^{241}Pu	$\alpha(E)$ RIF, RIC $\sigma_f(E)$	0.5÷200 eV 0.5÷300 eV 0.5÷2000 eV	*Muradyan*
7	^{242}Pu	$\langle\sigma_f\rangle$, $\langle\sigma_c\rangle$	0.1-100 keV	*Toporov*
8	^{244}Pu			
9	^{241}Am	RP RIF, RIA $\sigma_f(E)$	0.5÷5 eV 0.5÷300 eV 0.5÷2000 eV	*Muradyan*
		$\sigma_f(E)$	5÷30 MeV 1 eV÷50 keV (Pb-cube)	*Fursov*
		$\langle\sigma_f\rangle$, $\langle\sigma_c\rangle$	0.1-100 keV	*Toporov*
		$\langle\sigma_f\rangle$ Doppler effect $\langle\sigma_c\rangle$ *CRC*	Fis.thres. – 5 MeV 0.05÷100 keV 0.05÷100 keV	*Matveyenko*
		$\sigma_f(E)$	0.04÷12 MeV	*Ivanin*
10	^{242m}Am	RP RIF, RIA $\sigma_f(E)$	0.5÷5 eV 0.5÷300 eV 0.5÷2000 eV	*Muradyan*
		$\sigma_f(E)$	5÷30 MeV 1 eV÷50 keV	*Fursov*
		$\sigma_f(E)$	0.04÷12 MeV	*Ivanin*
		$\langle\sigma_f\rangle$, $\langle\sigma_c\rangle$	0.1-100 keV	*Toporov*

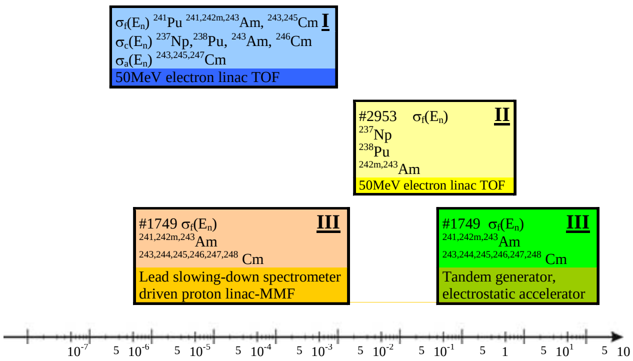
11	^{243}Am	$\sigma_\gamma(E)$ RIF, RIA $\sigma_f(E)$	0.5÷10 eV 0.5÷300 eV 0.5÷2000 eV	*Muradyan*
		$\sigma_f(E)$	5÷30 MeV 1 eV÷50 keV (Pb-cube)	*Fursov*
		$\sigma_f(E)$	0.04-12 MeV	*Ivanin*
		$\langle\sigma_f\rangle$, $\langle\sigma_c\rangle$	0.1-100 keV	*Toporov*
		$\langle\sigma_f\rangle$	Fis.thres. – 5 MeV	*Matveyenko*
12	^{242}Cm	$\langle\sigma_f\rangle$, $\langle\sigma_c\rangle$	0.1-100 keV	*Toporov*
13	^{243}Cm	$\sigma_f(E)$	5÷30 MeV 1 eV÷50 keV (Pb-cube)	*Fursov*
		$\sigma_\gamma(E)$, RP, RIF, RIA	0.5÷10	*Muradyan*
14	^{244}Cm	$\langle\sigma_f\rangle$, $\langle\sigma_c\rangle$	0.1-100 keV	*Toporov*
		$\sigma_f(E)$	5÷30 MeV 1 eV÷50 keV (Pb-cube)	*Fursov*
		$\sigma_f(E)$, $\sigma_\gamma(E)$, $\alpha(E)$ RIF, RIC	0.5÷200 eV	*Muradyan*
		$\langle\sigma_f\rangle$ $\langle\sigma_c\rangle$	Fis.thres.÷5 MeV 0.05÷100 keV	Matveyenko
15	^{245}Cm	$\langle\sigma_f\rangle$, $\langle\sigma_c\rangle$	0.1÷100 keV	*Toporov*
		$\sigma_f(E)$	5÷30 MeV 1 eV÷50 keV (Pb-cube)	*Fursov*
		$\langle\sigma_f\rangle$ $\langle\sigma_c\rangle$	0.1÷500 keV**) 0.1÷5 MeV***) 0.05÷100 keV	*Matveyenko*
		RP, $\sigma_a(E)$, $\alpha(E)$ RIF, RIA $\sigma_f(E)$	0.5÷20 eV 0.5÷300 eV 0.5÷2000 eV	*Muradyan*
16	^{246}Cm	$\langle\sigma_f\rangle$, $\langle\sigma_c\rangle$	0.1-100 keV	*Toporov*
		$\sigma_f(E)$	5÷30 MeV 1 eV÷50 keV (Pb-cube)	*Fursov*
		RP, $\sigma_c(E)$, RIC	0.5÷50 eV	*Muradyan*
17	^{247}Cm	$\sigma_f(E)$	5÷30 MeV 1 eV÷50 keV (Pb-cube)	*Fursov*
		$\sigma_a(E)$ RIF, RIA $\sigma_f(E)$	0.5÷100 eV 0.5÷300 eV 0.5÷2000 eV	*Muradyan*
18	^{248}Cm	$\langle\sigma_f\rangle$, $\langle\sigma_c\rangle$	0.1-100 keV	*Toporov*
		$\sigma_f(E)$	5÷30 MeV 1 eV÷50 keV (Pb-cube)	*Fursov*
19	^{249}Bk	$\langle\sigma_f\rangle$, $\langle\sigma_c\rangle$	0.1-100 keV	*Toporov*
20	^{250}Cf			
21	^{251}Cf	$\langle\sigma_f\rangle$, $\langle\sigma_c\rangle$	0.1-100 keV	*Toporov*
		RP, RIF, RIA	0.5÷5.	*Muradyan*
22	^{252}Cf	$\langle\sigma_f\rangle$, $\langle\sigma_c\rangle$	0.1-100 keV	*Toporov*

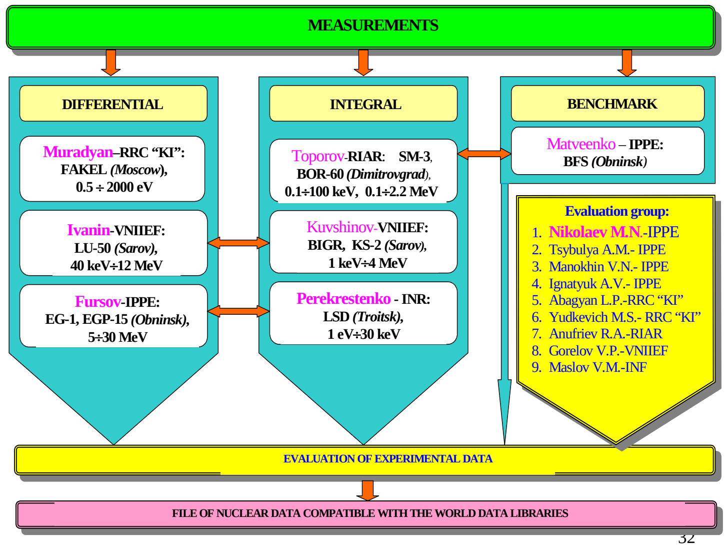
*) $\langle\sigma\rangle$ - spectrum averaged cross-section. **) MSR neutron spectrum averaged.
*) LBC neutron spectrum averaged.+) CRC - central reactivity coefficient.

Characteristics of the isotope production by VNIIEF mass separator

Isotope	Isotope composition (atom %)										
	238	239	240	241	242	243	244	245	246	247	248
^{238}Pu	99.6	0.4	0.015								
^{239}Pu		99.997	$2 \cdot 10^{-3}$	$2 \cdot 10^{-4}$	$1 \cdot 10^{-4}$						
^{240}Pu		$4 \cdot 10^{-3}$	99.9	$6 \cdot 10^{-2}$	$1 \cdot 10^{-3}$						
^{241}Pu		$1 \cdot 10^{-4}$	$3 \cdot 10^{-4}$	99.998	$1.6 \cdot 10^{-3}$		$1 \cdot 10^{-4}$				
^{242}Pu		$5 \cdot 10^{-4}$	$5 \cdot 10^{-4}$	0.04	99.96		$5 \cdot 10^{-4}$				
^{241}Am				99.99							
^{242}Am				13.0	85.6	1.6					
^{243}Am				$1.6 \cdot 10^{-3}$	$4 \cdot 10^{-4}$	99.998					
^{243}Cm						99.99	$8 \cdot 10^{-3}$	$5 \cdot 10^{-5}$	$1 \cdot 10^{-4}$	$1 \cdot 10^{-4}$	$1 \cdot 10^{-4}$
^{244}Cm						$1.5 \cdot 10^{-2}$	99.3	$6 \cdot 10^{-2}$	$4 \cdot 10^{-3}$	$1 \cdot 10^{-3}$	$1 \cdot 10^{-4}$
^{245}Cm							$6 \cdot 10^{-3}$	99.998	$2.5 \cdot 10^{-3}$		
^{246}Cm							$1 \cdot 10^{-2}$	$8 \cdot 10^{-3}$	99.98	$1 \cdot 10^{-2}$	$1 \cdot 10^{-2}$
^{247}Cm							2.7	0.8	5	90.2	0.5
^{248}Cm						0.1	2.2		0.7		97.0

Energy range of the differential neutron data measurements





CONCLUSION

We are planning
three types of the MA nuclear data measurements:

- Differential measurements in the energy range
  0.5÷100 eV (accelerator FAKEL, *Kurchatov Institute*)
  0.1÷10 MeV (accelerator LU-50, *VNIIEF, Sarov*);
  5÷30 MeV (Van de Graaf EG-1, Tandem EG-15, *IPPE, Obninsk*)

- Integral in-pile experiments with irradiation of MA ampoules in high-flux reactor SM-3 and fast reactor BOR-60 (*RIAR, Dimitrovgrad*);

- Benchmark experiments with MA at BFS-installation (*IPPE, Obninsk*)

  &

- Evaluation of obtained data and preparation of the oriented nuclear data base.

We are searching
for collaborators who are interested in the mentioned research in the framework of the various international projects. ISTC-project is one of the possibilities but there are many others (IPP, INTAS, SANDAT, CRDF).

Cumulative information on the Program

Project	I	II	III	IV	V
Duration, months	36	24	36	36	27
Grants, k$	261	192	404	480	514
Man×months	562	380	1015	1020	950
Total number of participants	51	79	114	137	90
Average grant/ month/man, $	142	102	98	174	211
Equipment, k$	56	81	132	200	42
Materials, k$	12	44	40	50	92
Others, k$	27	17	33	30	32
Travels, k$	18	23	26	46	36
Overhead, k$	18	25	38	56	48
Total cost, k$	392	382	680	862	764

Total cost of the program **k$ 3 080.**

Experimental Benchmark Analyses of ADS

Yu.E. Titarenko, V. F. Batyaev

Institute for Theoretical and Experimental Physics (ITEP)

IAEA meeting, 5-9 december 2005

Contents

- THIN TARGET experiments (CRS, activation, Neutron spectra)
  - Techniques (U-10 accelerator, γ-spectra, CRS definition, …)
  - Scope of activities (ISTC projects 839-0, 839, 1145, 2002)
  - Results comparison with other labs (ZSR, GSI, JAERI,…)
  - Co-operation with theoretical groups
- THICK TARGET experiments (reaction rates, dose rates…)
  - W-Na target (1145 project)
  - Pb target (2405)
- CRITICAL experiments
  - MAKET facility
  - NaF-ZrF4 salt micromodel actinide fission rate measurements
- Current plans
  - 2405 project
  - 3266 project

Thin target experiments (839, 1145, 2002 projects

- ***Residual nuclides CRS in proton-induced reactions measurements:***
  - **ISTC #839 (1997-1998; 1999-2000, Japan, EU, Norway): Experimental and Theoretical Study of the Residual Product Nuclide Yields in Thin Targets Irradiated with 100-2600 MeV Protons**
  - **ISTC # 2002 (2002-2004, EU): Experimental and theoretical studies of the yields of residual product nuclei produced in thin Pb and Bi targets irradiated by 40-2600 MeV protons**

- ***Neutron spectra measurements***
  - **ISTC#1145 (1999-2001, Japan): Nuclear - physics investigations aimed at the solution of weapon plutonium conversion and long-lived radioactive wastes transmutation problems**

ISTC Project #839 **(1997-1998; 1999-2000, Japan, EU, Norway)**

Experimental and Theoretical Study of the Residual Product Nuclide Yields in Thin Targets Irradiated with 100-2600 MeV Protons

Proton Energy [GeV]	Targets																			
	^{56}Fe	^{58}Ni	^{59}Co	^{63}Cu	^{65}Cu	^{93}Nb	^{99}Tc	^{182}W	^{183}W	^{184}W	^{186}W	^{nat}W	^{nat}Hg	^{206}Pb	^{207}Pb	^{208}Pb	^{nat}Pb	^{209}Bi	^{232}Th	^{nat}U
0.1			25	11	6		18						44	22	22	20		26	87	108
0.2			29	29	29		39	32	35	36	36		65						128	123
0.8							72	70	76	77	62								130	195
1.0							64									114				
1.2			41	47	54		67						103						214	226
1.5				35	36									92	93	94	93	99		
1.6			41	42	47		78	109	111	114	119		141						212	231
2.6	36	38	41	42	48	85	85					129								
ADS element	SM, Sh, TM	SM	SM	SM	SM	SM	FP	TM	TM	TM	TM	TM	TM	TM	TM	TM	TM	TM	Th-cycle	Fuel

SM – Structure Material; **Sh** – Shielding Material; **FP** – Fission Product;
TM - Target material; **Th** - Th fuel cycle, breeding; **Fuel** - Fuel compositions

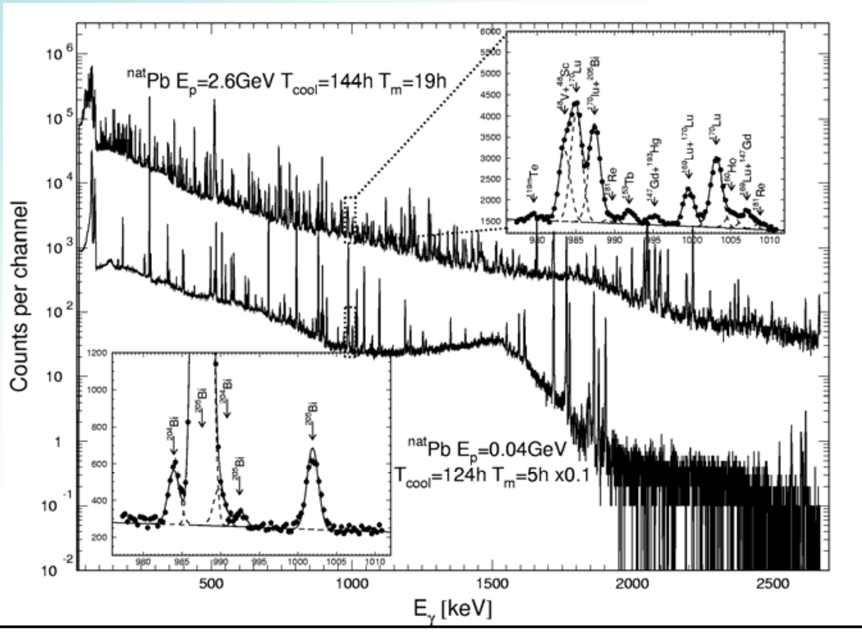
More than 5000 products determined. Final Technical Report is available via http://www-nds.iaea.org/reports/indc-ccp-434.pdf; EXFOR Data files#: O0781, O0782, O0978-O0987, O1018-O1021

Irradiation of thin targets

U10 Synchrotron at ITEP:

- Proton energy: 40-10000 MeV;
- Beam section: a circle of ~ 10 mm diameter;
- Intensity: ~$1 \cdot 10^{11}$ protons per pulse;
- Extraction runs: 1-4 50-ns bunches spaced 150 ns apart.


Gamma – spectra measurements



ISTC Project #2002

Experimental and theoretical studies of the yields of residual product nuclei produced in thin Pb and Bi targets irradiated by 40-2600 MeV protons

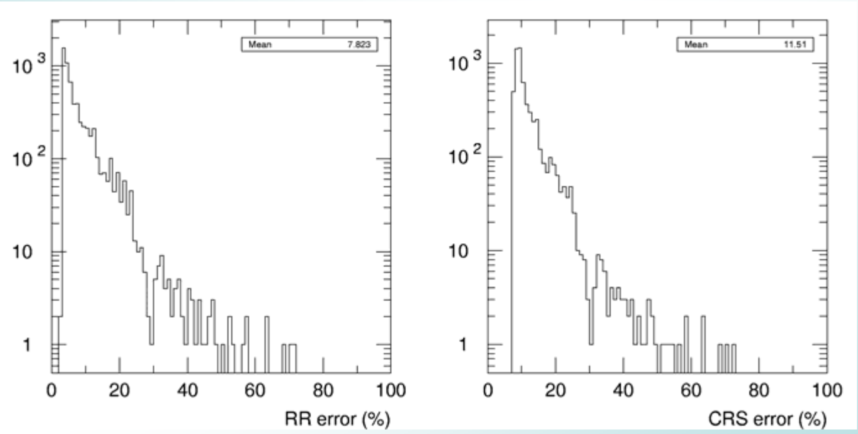
Target	Proton Energy (GeV)										
	0.04	0.07	0.1	0.15	0.25	0.4	0.6	0.8	1.2	1.6	2.6
^{nat}Pb	18	28	43	63	95	116	141	154	171	181	178
^{208}Pb	8	28	36	63	94	113	141	154	170	182	172
^{207}Pb	9	29	42	65	94	112	140	152	170	180	171
^{206}Pb	13	28	46	65	94	112	139	156	170	180	171
^{209}Bi	13	35	50	71	106	128	147	162	183	192	198

- Isotopic composition of targets

TOTAL: 5972

Targets	Isotopic composition, %				
	^{204}Pb	^{206}Pb	^{207}Pb	^{206}Pb	^{209}Bi
^{208}Pb	<0.01	0.87	1.93	97.2	-
^{207}Pb	<0.01	1.39	93.2	5.41	-
^{206}Pb	0.19	92.3	5.1	2.41	-
^{nat}Pb	1.4	24.1	22.1	52.4	-
^{209}Bi	-	-	-	-	>99.9

Uncertainty RR and CRS



Comparison with other data and codes

Two labs (GSI & ZSR) have measured comparable number of yields in LEAD:

GSI, Darmstadt	ZSR, Hannover
^{208}Pb 1GeV*A: **T. Enqvist**, et al., *Nucl. Phys. A686, 481 (2001).* **^{208}Pb 0.5GeV*A:** *Priv. comm..*	**M. Gloris**, et al. *Nucl. Instr. Meth., A464, 593 (2001);* EXFOR Data File O0500 ^{nat}Pb

Other works provide a minority of such data: ^{48}V, ^{48}Sc, ^{46}Sc at 1, 2 and 3 GeV from [6]; ^{83}Rb, ^{84}Rb, ^{86}Rb, ^{106m}Ag, ^{110m}Ag, ^{110}In and ^{129}Cs at 0.6 GeV from [7], ^{7}Be and ^{24}Na from [8], ^{7}Be at 0.4 GeV from [9]; ^{111}In at 0.45 GeV from [10].

[6] Y. Y. Chu, G. Friedlander, L. Husain. Phys. Rev. C, v. 15, p. 352, 1977; EXFOR file O0399.
[7] E.Hagebo, T.Lund. J, JIN, v. 37, p. 1569, 1975; EXFOR file O0327 .
[8] J.Hudis, S.Tanaka Phys. Rev., v. 171, p.1297, 1968; EXFOR file C0341 .
[9] R.G.Korteling, A.A.Caretto J, JIN, v. 29, p. 2863, 1967; EXFOR file O0412.
[10] J. A. Panontin, N. T. Porile., . J, JIN, v. 30, p. 2891, 1968; EXFOR file O0332.

The codes used for simulation:

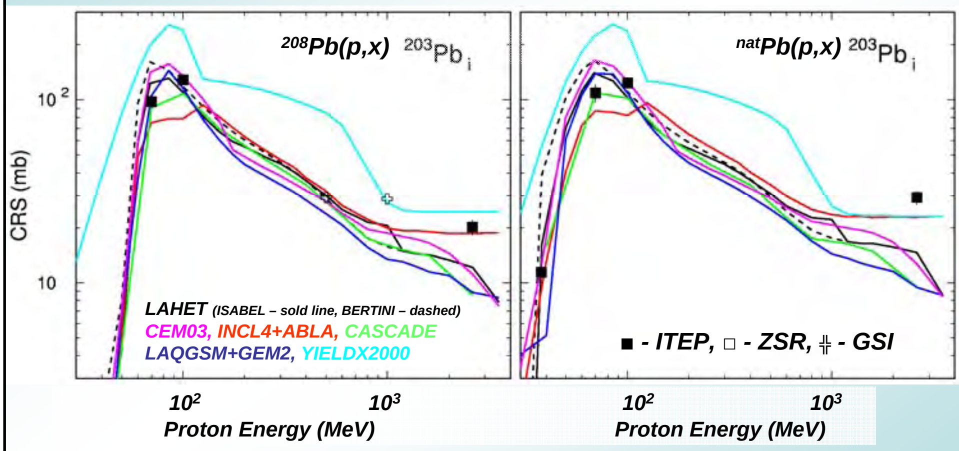
Details are in: Titarenko et al., ICRS10, Madeira, May 2004

LAHET (ISABEL and BERTINI models) (LANL)
CEM03 (LANL)
INCL4+ABLA (CEA, Liege, GSI)
CASCADE (JINR)
LAQGSM+GEM2 (LANL)
YIELDX2000 (NASA)

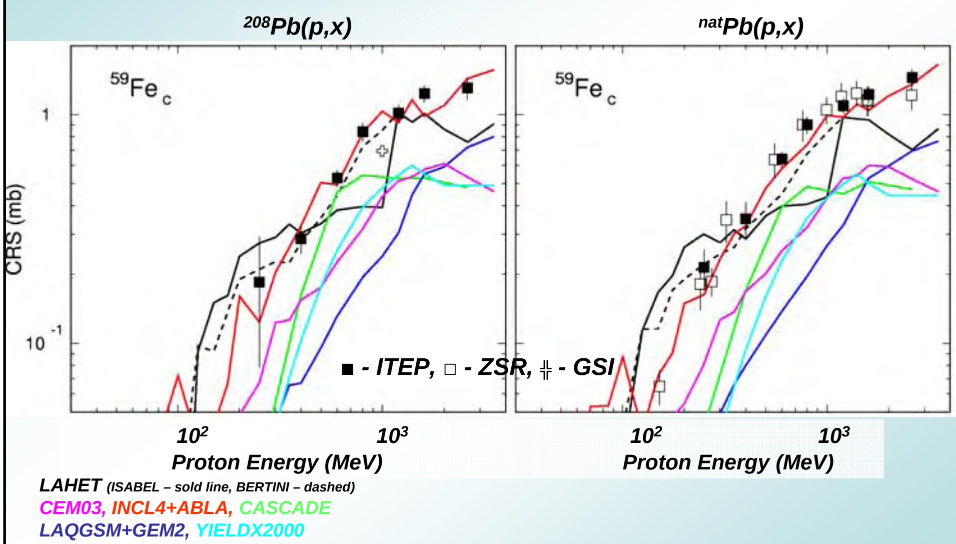
Table 44: Mean squared deviation factors <F> separately for different energy groups and ranges of products (A>30) and for all comparisons as well.

Code	Product mass (A)			Proton energy (E_p, GeV)			**Total**
	A>170	140<A<170	30<A<140	E_p <0.1	0.1<E_p <1.0	E_p >1.0	
ISABEL	1.81	1.81	2.87	4.88	2.13	–	**2.16**
BERTINI	1.75	1.93	2.75	4.26	2.06	1.97	**2.10**
INCL4+ABLA	1.90	3.74	2.22	4.63	2.18	2.13	**2.25**
CASCADE	1.77	2.01	6.93	4.93	3.93	2.44	**3.25**
CASCADE-2004	1.93	1.47	5.54	6.54	3.23	2.42	**2.94**
LAQGSM+GEM2	1.98	2.32	2.71	3.03	2.35	2.09	**2.26**
CEM03	1.98	2.07	2.25	2.08	1.77	2.39	**2.07**
CASCADO	1.99	2.22	2.83	2.69	2.33	2.22	**2.29**
LAHETO	1.99	1.96	1.98	4.85	1.76	–	**1.98**

^{208}Pb-, ^{nat}Pb(p,x) excitation functions (1)



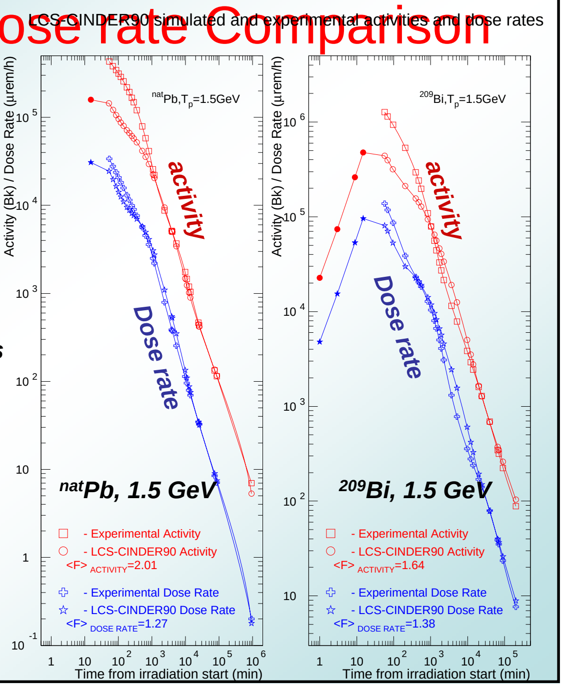
^{208}Pb-, ^{nat}Pb(p,x) excitation functions (12



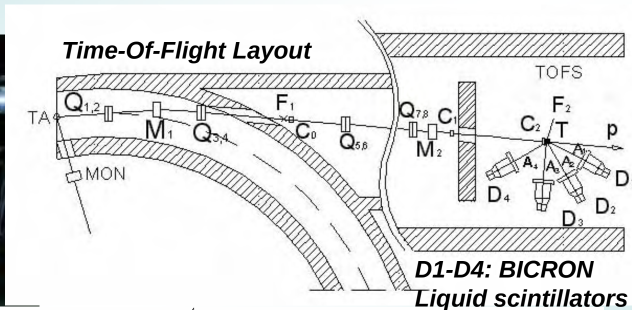
Activity and Dose rate Comparison

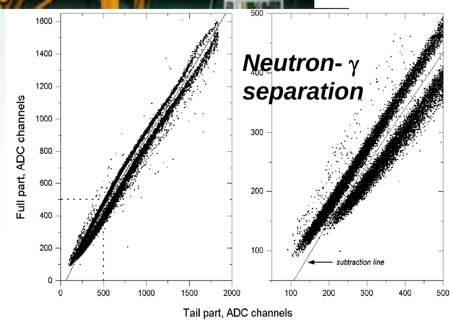
The LAHET + CINDER'90 Code System was used to calculate Activity and Dose rates of thin targets of 839 project.

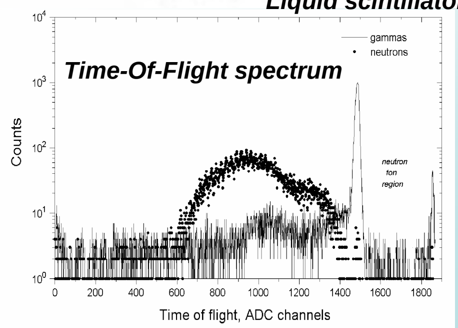
Simulation-to-Experimental Comparison show underestimation at first hours after irradiation.



Neutron spectra: TOF measurements

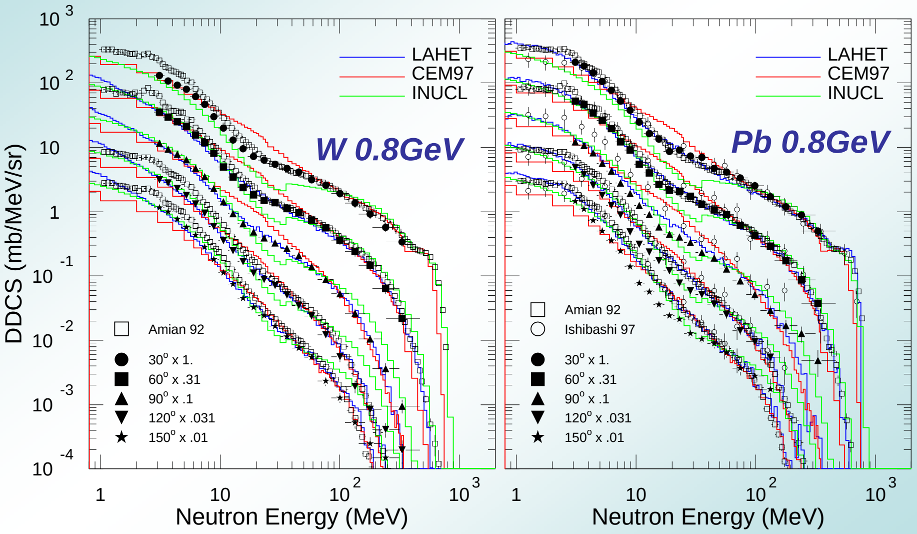




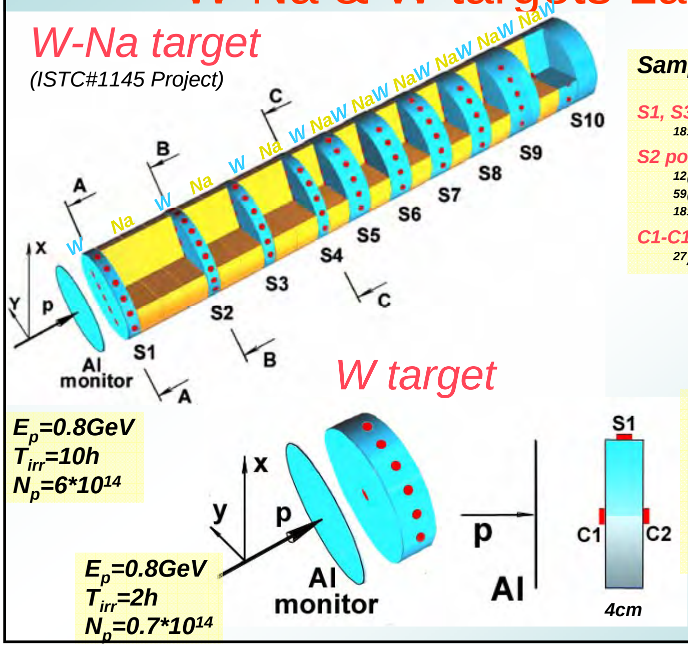


Neutron Spectra: Results

Neutron spectra from W and Pb induced by 0.8 GeV protons



W-Na & W targets Layout



E_p=0.8GeV
T_{irr}=10h
N_p=6*10[14]

Samples arrangements:

S1, S3-10 points:
^{181}Ta, ^{115}In, ^{209}Bi, ^{27}Al, ^{197}Au

S2 point:
^{12}C, ^{19}F, ^{27}Al, ^{63}Cu, ^{65}Cu, ^{59}Co, ^{64}Zn, ^{93}Nb, ^{115}In, ^{169}Tm, ^{181}Ta, ^{197}Au, ^{209}Bi.

C1-C10 points (axis):
^{27}Al, ^{59}Co.

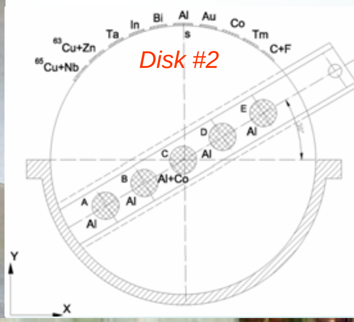
E_p=0.8GeV
T_{irr}=2h
N_p=0.7*10[14]

Samples arrangements:

S1 point:
^{12}C, ^{19}F, ^{27}Al, ^{63}Cu, ^{65}Cu, ^{59}Co, ^{64}Zn, ^{93}Nb, ^{115}In, ^{197}Au, ^{209}Bi.

C1, C2 points (axis):
^{27}Al, ^{59}Co , ^{115}In.

W disks and foils arrangement



Special rulers are used to mount/dismount the foils inside the disks

Results & Simulation

Target nuclide	The products for the Reaction Rates measured	Number of values: W-Na	Number of values: W
^{209}Bi	^{207}Po, ^{206}Po, ^{206}Bi(i,c), ^{205}Bi, ^{204}Bi, ^{203}Bi, ^{203}Pb(i,c), ^{201}Pb, ^{200}Pb, ^{202}Tl, ^{200}Tl(i,c), ^{191}Pt, ^{96}Tc, ^{96}Nb, ^{82}Br	165	14
^{197}Au	^{198}Au, ^{196}Au, ^{194}Au, ^{191}Pt	33	6
^{181}Ta	^{182}Ta, ^{178m}Ta, ^{176}Ta, ^{175}Ta, ^{173}Ta, ^{180m}Hf, ^{175}Hf, ^{173}Hf, ^{170}Hf, ^{172}Lu, ^{171}Lu, ^{169}Lu, ^{167}Tm, ^{165}Tm, ^{161}Er	112	-
^{169}Tm	^{166}Yb, ^{168}Tm, ^{167}Tm, ^{166}Tm(i,c), ^{165}Tm, ^{163}Tm, ^{161}Er, ^{160}Er, ^{160m}Ho(i,c), ^{157}Dy, ^{155}Dy, ^{153}Dy, ^{152}Dy, ^{153}Tb, ^{152}Tb, ^{151}Tb, ^{150}Tb	19	-
^{115}In	^{113}Sn, ^{116}In, ^{115m}In(i,c) ^{114m}In, ^{113m}In(i,c), ^{111}In, ^{110}In, ^{109}In, ^{115}Cd, ^{111}Ag, ^{110m}Ag, ^{106m}Ag, ^{105}Ag, ^{101}Pd, ^{100}Pd, ^{101}Rh, ^{100}Rh(i,c), ^{99}Rh, ^{97}Ru, ^{96}Tc, ^{95}Tc, ^{90}Mo, ^{99}Nb(i,c), ^{89}Zr, ^{87}Y	207	119
^{93}Nb	^{90}Nb, ^{89}Zr, ^{86}Zr, ^{90}Y, ^{87m}Y, ^{87}Y, ^{86}Y(i,c)	8	21
^{65}Cu	^{64}Cu, ^{61}Cu, ^{65}Ni, ^{58}Co, ^{57}Co, ^{56}Co, ^{55}Co, ^{56}Mn, ^{52}Mn, ^{44m}Sc, ^{44}Sc(i,m+g)	12	9
^{64}Zn	^{65}Zn, ^{63}Zn, ^{62}Zn, ^{64}Cu, ^{61}Cu, ^{60}Cu, ^{57}Ni, ^{58}Co, ^{57}Co, ^{56}Co, ^{55}Co, ^{56}Mn, ^{52}Mn, ^{48}Cr, ^{44m}Sc, ^{44}Sc(i,m+g)	17	18
^{63}Cu	^{61}Cu, ^{58}Co, ^{55}Co, ^{52}Mn	4	13
^{59}Co	^{57}Ni, ^{58}Co(i,m+g), ^{58m}Co, ^{57}Co, ^{56}Co, ^{55}Co, ^{59}Fe, ^{52}Fe, ^{56}Mn, ^{52}Mn, ^{51}Cr, ^{48}Cr, ^{48}V, ^{48}Sc, ^{47}Sc(I,c), ^{46}Sc, ^{44m}Sc, ^{44}Sc(i,m+g), ^{43}Sc, ^{47}Ca, ^{43}K, ^{24} Na, ^{7}Be	222	73
^{27}Al	^{27}Mg, ^{24}Na, ^{22}Na, ^{7}Be	186	21
^{19}F	^{18}F	1	1
^{12}C	^{11}C	1	1
	Total	979	296

Reaction Rates Simulation :

$$R_x = R_{n,x} + R_{p,x} = \sum_{i=n,p} \int \sigma_{i,x}(E) \cdot \varphi_i(E) dE$$

ENERGY	NEUTRONS	PROTONS	
< 100 MeV	MENDL2, IEAF2001*	MENDL2p**	+ EXFOR
> 100 MeV	LAHET***	LAHET***	

* - up to 150 MeV; ** - up to 200 MeV, *** - LAHET does not provide metastable products.

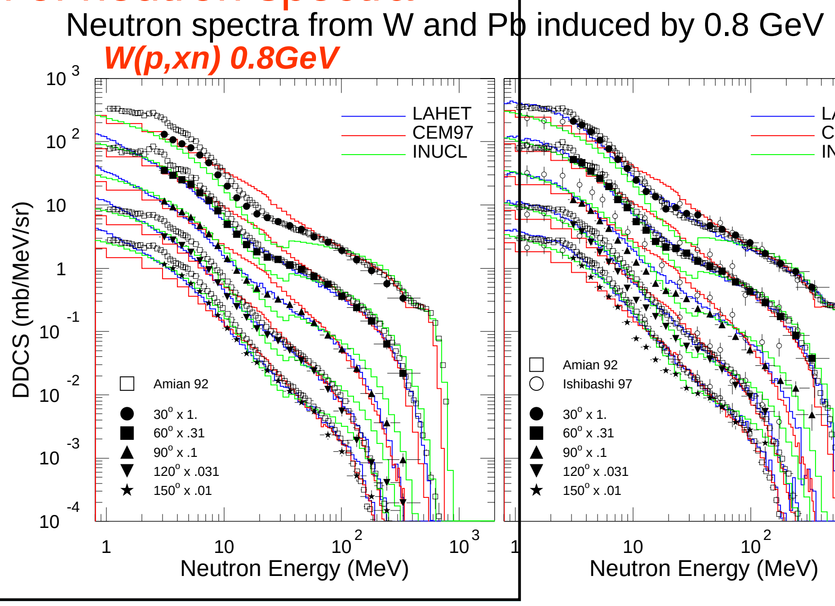
LAHET Code System: Lahet, hmcnp4, … Neutron production was verified via $d^2\sigma/dE/d\Omega$ experiments on 0.8GeV irradiated W and Na thin targets

LAHET simulation of neutron spectra

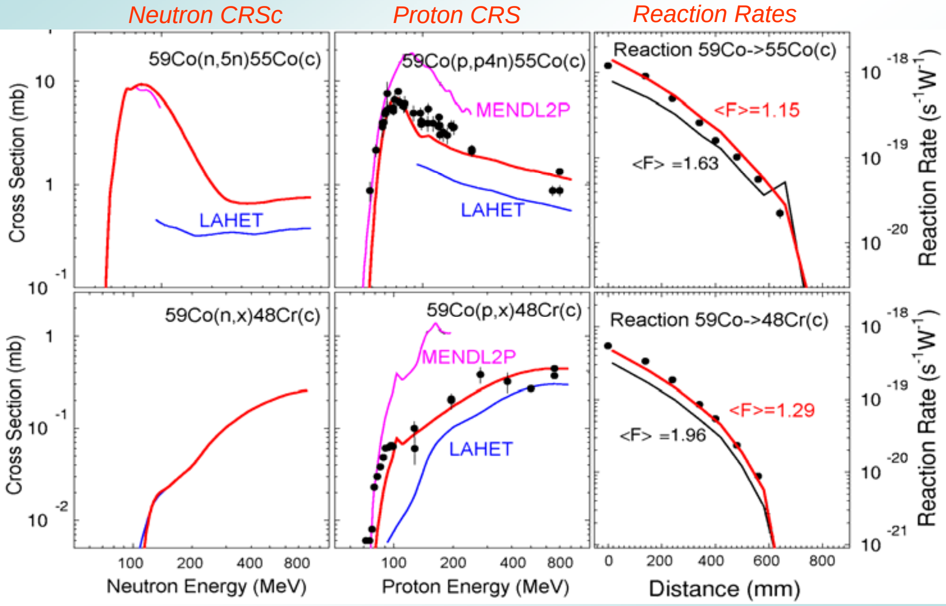
The Lahet Code System have been tested via numerous comparison with d²σ/dE/dΩ neutron production data, among them are the ITEP experiments on thin W and Na induced with 0.8GeV protons

(ISTC#1145 project)

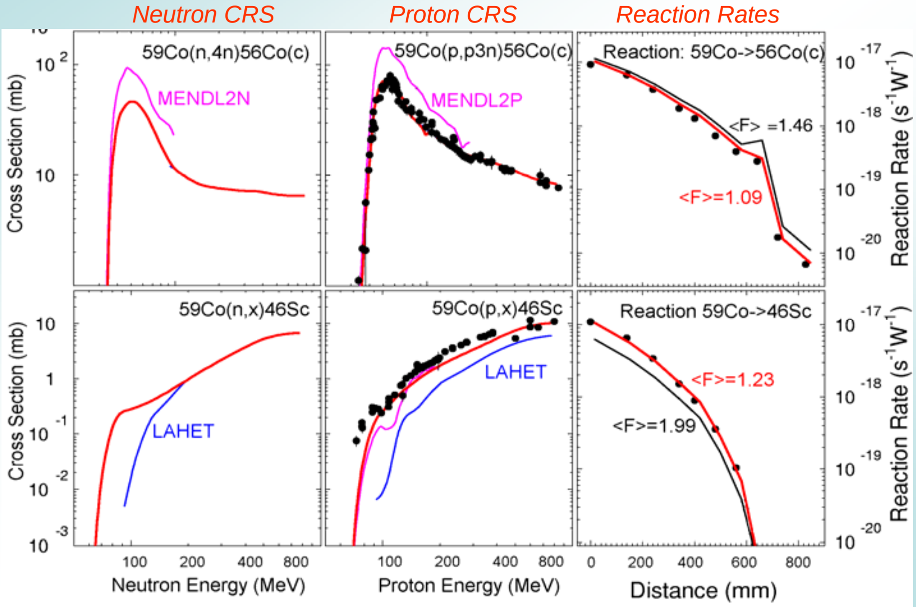
So, the LCS simulated spectra are assumed to be of <u>high reliability</u>



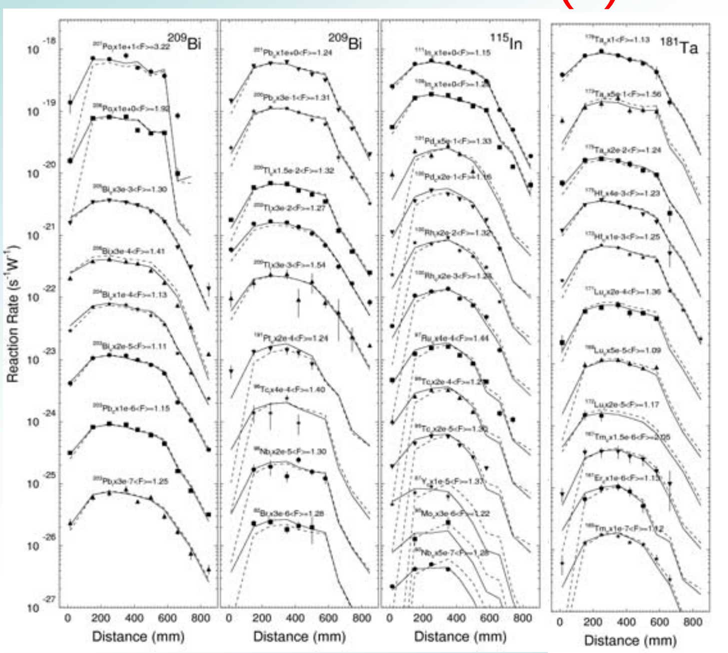
W-Na target: CRS(E) and RR (1)



W-Na target: CRS(E) and RR (2)



W-Na results (1)



3266 Project: Irradiations List

Targets	Proton energy (MeV)										
	40	70	100	150	250	400	600	800	1200	1600	2600
^{56}Fe	x	x	x	x	x	x	x	x	x	x	-
^{52}Cr	x	x	x	x	x	x	x	x	x	x	x
^{nat}Cr	x	x	x	x	x	x	x	x	x	x	x
^{58}Ni	x	x	x	x	x	x	x	x	x	x	-
^{nat}Ni	x	x	x	x	x	x	x	x	x	x	x
^{93}Nb	x	x	x	x	x	x	x	x	x	x	-
^{Nat}Zr	x	x	x	x	x	x	x	x	x	x	x
^{181}Ta	x	x	x	x	x	x	x	x	x	x	x
^{nat}W	x	x	x	x	x	x	x	x	x	x	-

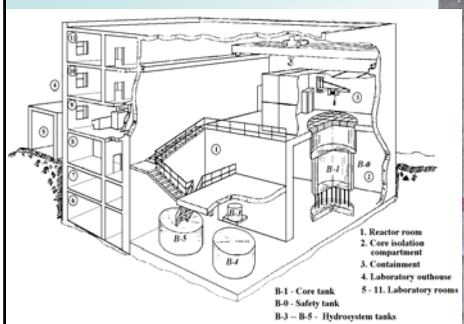
- – irradiations were been done in the ISTC Project #839

New Project: Isotopic composition of targets

Target	State	Quantity	Isotopic composition, %
^{56}Fe	metal	10	^{54}Fe-0.3 %, ^{56}Fe-99.5±0.1 %, ^{57}Fe-0.2 %, ^{58}Fe-<0.05 %.
^{52}Cr	metal	11	
^{nat}Cr	metal	11	^{50}Cr-4.345 %, ^{52}Cr-83.789 %, ^{53}Cr-9.501%, ^{54}Cr-2.365 %.
^{58}Ni	metal	10	^{58}Ni-99.8±0.1 %, ^{60}Ni-0.19 %, ^{61}Ni-<0.01 %, ^{62}Ni-0.01 %, ^{64}Ni-<0.01 %
^{nat}Ni	metal	11	^{58}Ni-68.077 %, ^{60}Ni-26.223 %, ^{61}Ni-1.140 %, ^{62}Ni-3.634 %, ^{64}Ni-0.926 %
^{93}Nb	metal	10	^{93}Nb-100 %
^{nat}Zr	metal	11	^{90}Zr-51.45 %, ^{91}Zr-11.22 %, ^{92}Zr-17.15 %, ^{94}Zr-17.38, ^{96}Zr-2.80%
^{181}Ta	metal	11	^{180m}Ta-0.012 %, ^{181}Ta-99,988 %
^{nat}W	metal	10	^{180}W-0.12 %, ^{182}W-26.50 %, ^{183}W-14.31 %, ^{184}W-30,64%, ^{186}W – 28.43 %.

Critical measurements

MAKET heavy water zero-power reactor

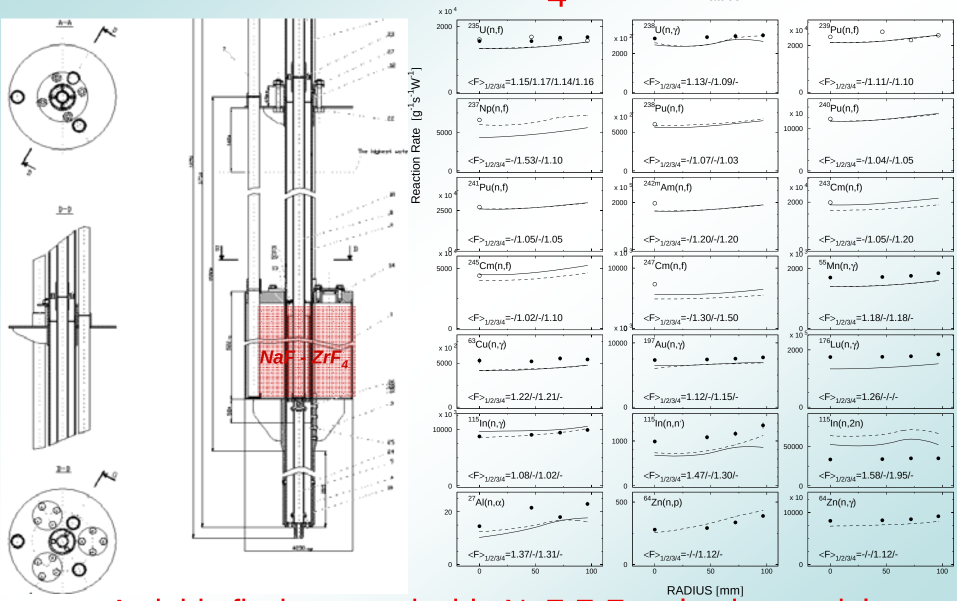


- The fission cross sections were measured for ten isotopes (^{235}U, ^{237}Np, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{242m}Am, ^{243}Cm, ^{245}Cm, ^{247}Cm) in the $NaF\text{-}ZrF_4$ salt blanket micromodel in thermal spectrum of heavy water critical MAKET facility.

(co-operation with VNIIEF)

All the results obtained have been simulated by MCNP code with the use of the ENDF/B-VI, JENDL-3.2, nuclear data libraries.

ISTC #1145: $NaF\text{-}ZrF_4$ salt micromodel



Actinide fission rates inside $NaF\text{-}ZrF_4$ salt micromodel

ENDF/B-VI, JENDL-3.2 verification

Reaction	21-1 lattice				21-2 lattice			
	ENDF/B-VI rev 7		JENDL-3.2		ENDF/B-VI rev 7		JENDL-3.2	
	Absolute Norm.	Relative Norm.	Absolute Norm.	Relative Norm.	Absolute Norm.	Relative Norm.	Absolute Norm.	Relative Norm.
$^{235}U(n,f)$	+		+		+		+	
$^{238}U(n,\gamma)$	+	+	+	+	+	+	-	-
$^{239}Pu(n,f)$	+	+	+	+	+	+	+	+
$^{237}Np(n,f)$	-	-	+	+	-	-	+	+
$^{238}Pu(n,f)$	+	+	+	+	+	+	+	+
$^{240}Pu(n,f)$	+	+	+	+	+	+	+	+
$^{241}Pu(n,f)$	+	+	+	+	+	+	+	+
$^{242m}Am(n,f)$	+	+	+	+	+	+	+	+
$^{243}Cm(n,f)$	+	-	-	+	+	+	-	-
$^{245}Cm(n,f)$	+	-	-	+	+	-	-	+
$^{247}Cm(n,f)$	-	-	+	+	-	-	+	+

TRANSMUTATION OF RADIOACTIVE NUCLEAR WASTE – PRESENT STATUS AND REQUIREMENT FOR THE PROBLEM-ORIENTED NUCLEAR DATA BASE
ISTC Project #2578

Y. Korovin
Project Manager

- **INTRODUCTION**
- **ASSESSMENT OF THE PRESENT-DAY DEMAND FOR NUCLEAR DATA ON TRANSMUTATION NUCLEAR WASTE**
- **CURRENT STATUS AND PERSPECTIVES OF NUCLEAR DATA EVALUATION AND DEVELOPMENT OF NUCLEAR MODELS FOR HEAVY NUCLEI**
- **EFFECT OF NUCLEAR DATA UNCERTAINTIES ON RADIATION DAMAGE OF STRUCTURAL MATERIALS**
- **PROJECT ANALYSIS**
- **RECOMMENDATIONS**

RECOMMENDATIONS FOR DIFFERENTIAL EXPERIMENTS- 1 of 2

- From the analysis of completed ISTC projects and present-day requirements to accuracy of nuclear data related to MA transmutation in ADS, it might be concluded that the first priority list of reactions to be studied includes:
  - Neutron inelastic scattering on ^{243}Am;
- Neutron induced fission of ^{244}Cm above ~200 keV;
- Neutron capture on ^{238}Pu, ^{237,238}Np;
- (n,2n) reaction on ^{235}U, ^{238}U, ^{239}Pu;
- (n,xn) reactions on Pb and Bi isotopes in the wide energy range (up to proton beam energies if lead, bismuth or lead-bismuth is assumed to be a spallation target material and coolant).
- The ultimate goal of obtaining reliable evaluated data files covering all the needs of ADS-related pending and forthcoming projects would require performing the following experiments (however understanding that the majority of them are hardly to be realized in the foreseeable future):
  1. Measurement of the total neutron yield, total neutron spectra and fission neutron spectra for isotopes of Th, Pa, U, Np, Pu, Am, as well as for spallation target materials Ta, W, Pb, Bi, irradiated by neutrons and protons of energies from 20 MeV up to 1 GeV.

2. Measurement of the total gamma yield and emission spectra for isotopes of Th, Pa, U, Np, Pu, Am in the energy region 20 MeV – 1 GeV.
3. Measurement of fission product yields for transuranics at the energies 20 - 200 MeV.
4. Obtaining the excitation functions for reactions (n,xn), (n,pxn), (n,2pxn) etc for isotopes of Th, Pa, U, Np, Pu, Am at the primary neutron energies 20 – 200 MeV as well as for analogous reactions initiated by protons.

RECOMMENDATIONS FOR DIFFERENTIAL EXPERIMENTS- 2 of 2

5. Measurements of the resistivity damage rates necessary for evaluation of damage energy cross-sections for iron, chromium, nickel and other components of steels at the energies 20 MeV – 1 GeV.
6. Measurements and analysis of the total yields, time and energy dependencies of characteristics of delayed neutrons from fission of Np-237, Am-241, Am-242m by fast neutrons.
7. Carrying out the sensitive measurements of neutron capture and fission cross-sections for minor actinides at resonance and fast neutron energies to define the accuracy of nuclear data.
8. Measurements of excitation functions to obtain secondary reaction alpha- and beta-active product yields from spallation target unit structural materials irradiated by protons and neutrons with energies up to ~ 1 GeV.

RECOMMENDATIONS FOR INTEGRAL EXPERIMENTS

- Two types of integral experiments are used at present to improve nuclear data, namely:
- measurements of neutronics characteristics on critical assemblies with zero power;
- irradiation of samples (often monoisotopic) in reactors with subsequent investigation of the isotopic composition change.
- It is obvious that to perform integral experiments as applied to physics of innovative nuclear reactors and ADS is reasonable if the following conditions necessarily satisfied:
- The principal choice of the transmuter type is made, i.e. materials and zone dimensions are specified.
- Material composition and geometry dimensions of characteristic physical zones of an experimental prototype and designed installation should be comparable (this should be substantiated by calculations at the stage of experiment preparation), i.e. space and energy distribution of neutron fields should be close.
- The verification of nuclear data should be performed on the basis of experimental results (outlined in the experimental workplan) and their evaluated version has to be included in the open nuclear data library; or the experimental results with estimated uncertainty and the detailed description of the experimental installation (geometries, material compositions, temperatures) are described (or will be described at the final stage of experiments), which will be used by the developer of the transmutor to verify the calculation methods.

RECOMMENDATIONS ON THE EVALUATED DATA PREPARATION

- It is expedient to perform the following works on the preparation of new nuclear data files, which are absent at present, or contain the insufficient information on nuclear data, necessary for calculation of transmutation installation:
- Forming the files of recommended neutron and proton data for the total actinide chain from Th to Cm at the energies up to 150-200 MeV with inclusion the information on the secondary gamma-quanta production and complete information on data uncertainties and corresponding correlation matrixes. It is necessary to perform the following tasks:
  - The estimation of neutron and proton integral and differential cross-sections on the basis of analysis of available experimental data and developed in the framework of ISTC projects new theoretical methods of cross-section description at the intermediate (up to 200 MeV) energies;
  - On the basis of energy release balance analysis in the fissionable nuclei and with the use of theoretical models to prepare the consistent sets of the evaluated nuclear data of secondary gamma production for the total number of actinides, relied on available experiments on energy release for the basic fuel elements.
  - Creation of consistent correlation uncertainty matrixes of recommended cross-section data for the basic fuel elements;
- Forming the files of recommended data on fission products yields for actinides from Th to Cm at the neutron and proton energies up to 150 – 200 MeV.
- Specification of radioactive nuclei characteristics in the fission products region on the basis of experimental works performed in Russia during last 15 years, and preparation of corrected files containing the data on radioactive decay modes for essential nuclides.

IAEA CRP
Analytical and Experimental Benchmark Analyses of Accelerator Driven Systems (ADS)

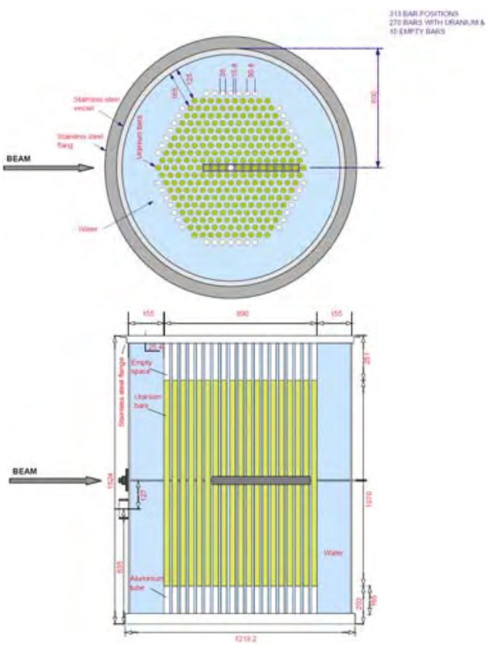
FEAT & TARC

Enrique M. González Romero
CIEMAT
Spain

- What were FEAT and TARC
- Information available

Minsk, 5-9 December 2005

FEAT



In 1994, an already existing sub-critical system made of natural uranium and light water was exposed to a low intensity (10^9 ppp at 14.4 s repetition rate) proton beam from the CERN-PS at several kinetic energies: from 600 MeV to 2.75 GeV.

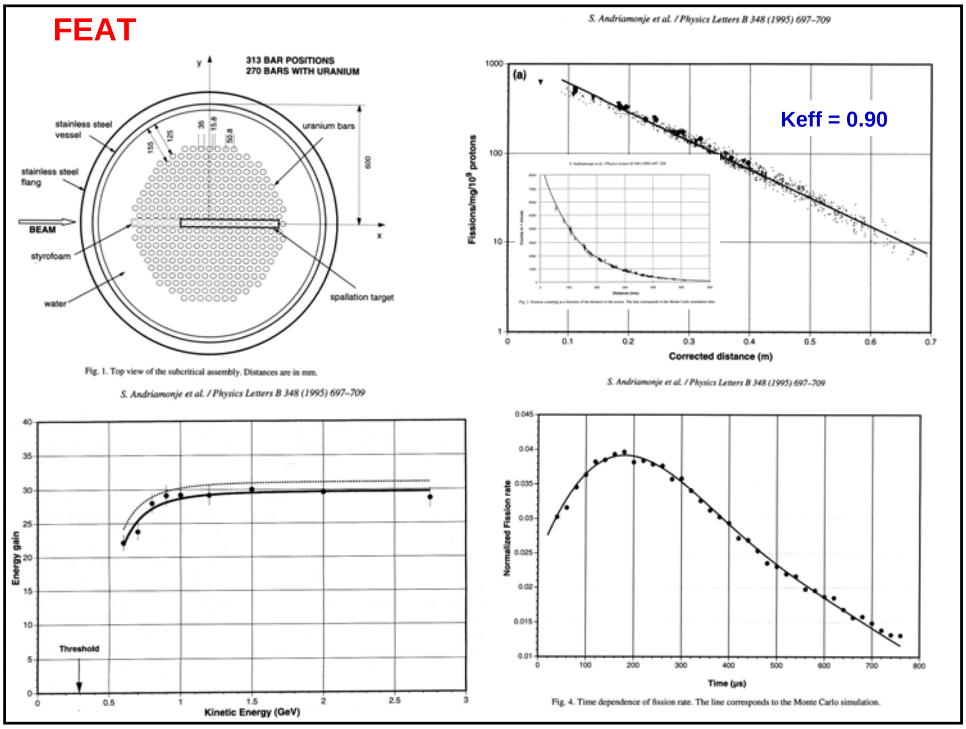
Estimated K_{eff} = 0.895.

Measurements of:

The energy gain vs the proton energy,

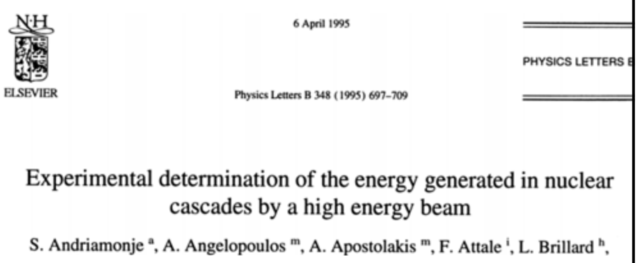
The spatial distribution,

The time evolution



FEAT

Available information:



6 April 1995

PHYSICS LETTERS B

ELSEVIER

Physics Letters B 348 (1995) 697–709

Experimental determination of the energy generated in nuclear cascades by a high energy beam

S. Andriamonje [a], A. Angelopoulos [m], A. Apostolakis [m], F. Attale [i], L. Brillard [h],

Documents:

S. Andriamonje at al., Physics Letters B 348 (1995) 697-709

Report on Feat from the FEAT group provided by Yacine Kadi (Y.K.)

Available data:

Detailed geometry description and approximate material definition

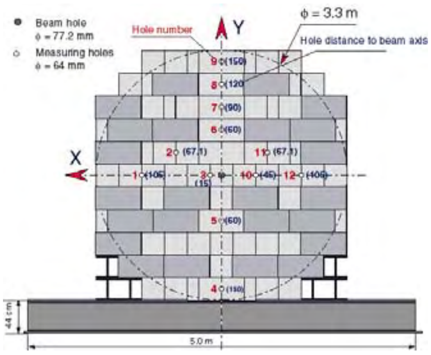
$\Rightarrow$ *Also available as MCNP input (Y.K.)*

Only the energy gain can be recovered in numerical form easily

Space distribution and time evolution available in graphical form

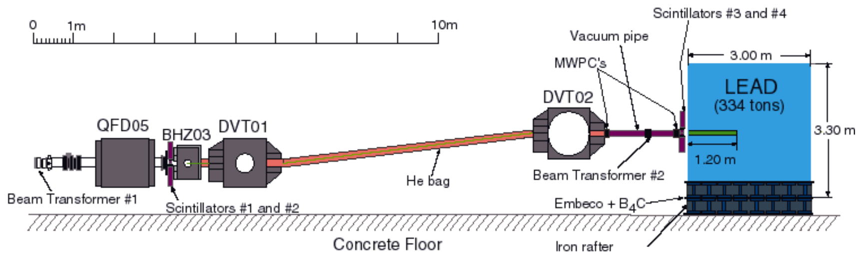
TARC

From April of 1996 till May of 1997 the TARC experiment took data at CERN, using proton beams, of 2.75 GeV and 1.73 GeV kinetic energy, introduced near the center of a large instrumented Lead volume of 3.5 × 3.5 × 3.0 m^3 and 334 Tons.



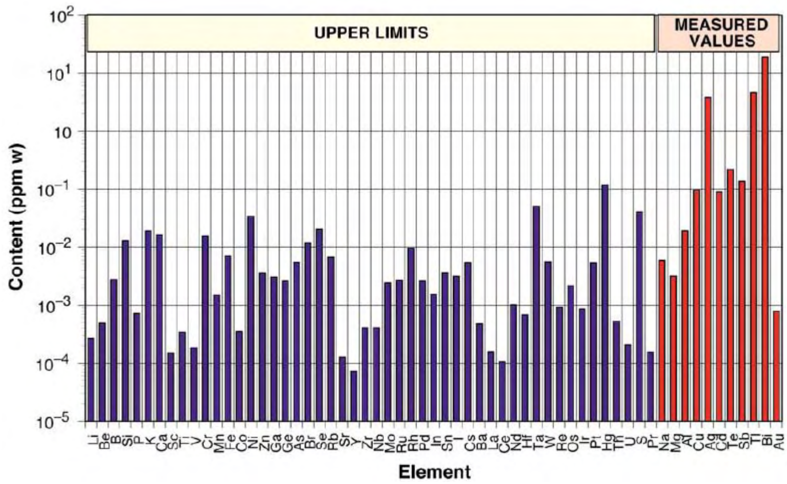
The combination of several detectors allowed the measurement of the complete energy range of the neutron flux spectra, from fractions of eV to few MeV, for an extensive set of positions in the TARC lead block.

The transmutation of ^{99}Tc and ^{129}I was also measured

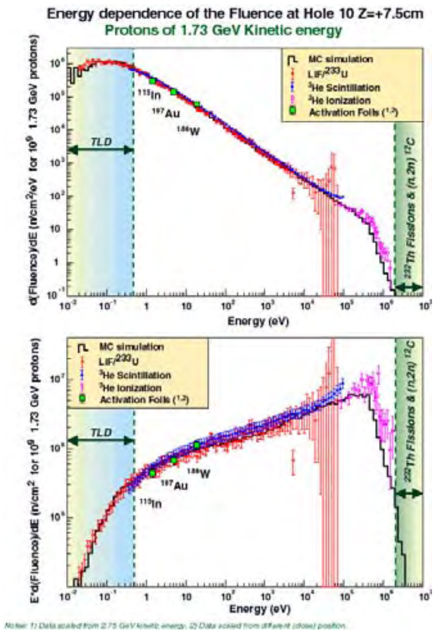


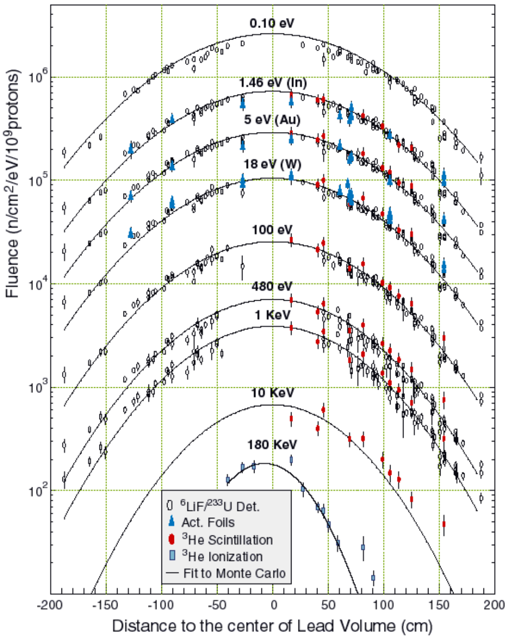
TARC

Very simple and verified material composition

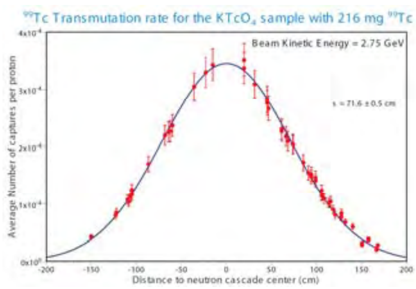


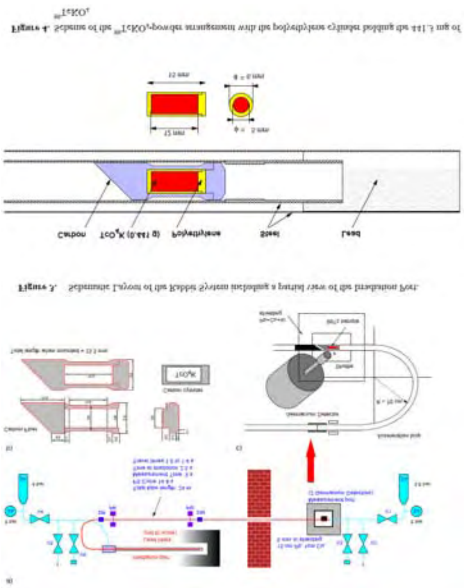
TARC-Fluxes





TARC- Transmutation





TARC

Available information:

Nuclear Instruments and Methods in Physics Research A 478 (2002) 577–730

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

www.elsevier.com/locate/nima

ELSEVIER

Results from the TARC experiment: spallation neutron phenomenology in lead and neutron-driven nuclear transmutation by adiabatic resonance crossing

A. Abánades[a,1], J. Aleixandre[b], S. Andriamonje[c,d], A. Angelopoulos[e],

Documents:

- A. Abánades at al., Nucl. Instrum. and Meth. in Phys. Res. A 478 (2002) 577-730
- Report on TARC CERN/ET/Internal Note "TARC general purpose MonteCarlo" F. Carminati, et al. 17/04/96 provided by Yacine Kadi (Y.K.)
- CIEMAT Report DFN/TR-01/II-98 (1998) "Simulation of the TARC Neutron Flux measurements (0.1 eV to 10 KeV)", S. Díez et al.
- CIIEMAT Report DFN/TR-05/II-98 (1998) "Simulation of the ^{99}TC Capture rate measurements performed in the TARC experiment", S. Díez et al.

Available data:

Detailed geometry description and material composition

⇒ *Also available as MCNP input (Y.K.)*

All data can be recovered in numerical form with some effort

TARC

dfn INFORME DFN/TR-01/II-98

REF. EXTERNA

SIMULATION OF THE TARC NEUTRON FLUX MEASUREMENTS (0.1 eV to 10 KeV)

Ciemat

CENTRO DE INVESTIGACIONES ENERGETICAS MEDIOAMBIENTALES Y TECNOLOGICAS

DEPARTAMENTO DE FISIÓN NUCLEAR
Avda. Complutense, 22
28040 MADRID

Ciemat	INFORME DFN/TR-01/II-98	HOJA 1 DE 11
	REF. EXTERNA	REVISIÓN 0

TITULO: **SIMULATION OF THE TARC NEUTRON FLUX MEASUREMENTS (0.1 eV to 10 KeV).**

AUTORES: **S. Díez[2], M. Embid[1], R. Fernández[1], E. González[1]**

[1] *Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT), Madrid, Spain.*

[2] *Universidad Alfonso X el Sabio (UAX), Madrid, Spain.*

ABSTRACT:

From April of 1996 till May of 1997 the TARC experiment took data at CERN, at the T7 beam line of the PS East Area. The beam line was designed in such a way that the proton beam, of 2.75 GeV kinetic energy, was introduced near the centre of a large instrumented Lead volume of 3.5 × 3.5 × 3.0 m³ and 334 Tons producing, by the spallation process, a neutron cascade.

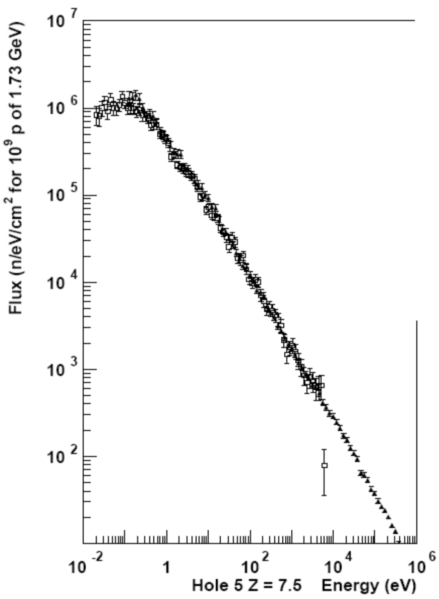
The combination of several detectors allowed the measurement of the complete energy range of the neutron flux spectra, from fractions of eV to few MeV, for an extensive set of positions in the TARC lead block.

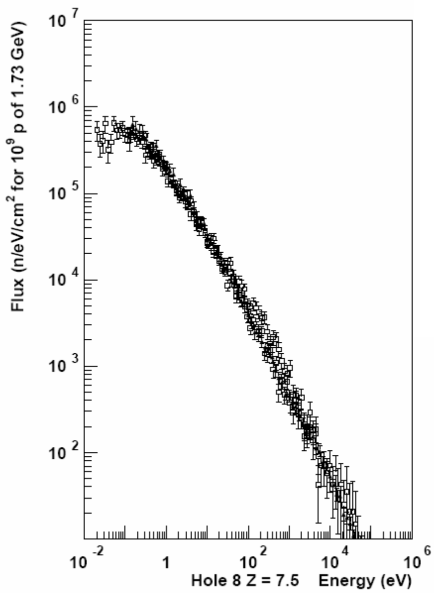
In this note the Monte Carlo predictions for the neutron flux in the TARC experiment, using different high energy transport codes and different cross sections nuclear databases, are compared between themselves and directly to the available experimental data.

	NOMBRE	FIRMA	FECHA
Preparado por:	R. Fernández		
Revisado por:	E. González		
Conf. por A. C.:	E. Milla		
Aprobado por:	J.L. Díaz		

FECHA DE EMISIÓN: 0 6 0 4 9 8

TARC





TARC

Lead impurities: Ag, Cd & Bi

Comparison LAHET vs FLUKA: No big difference

Comparison JENCL3.2 vs ENDF (V,VI):

	LAHET-MCNP (JENDL/3.2)	LAHET-MCNP (ENDF)
Number of experimental data used	4684	4684
Total χ^2	7326.5	15950
χ^2 **Per degree of freedom**	1.56	3.41
Average difference (Data-MC) in number of standard deviation	-11.6%	-21.0%
Average difference (Data-MC) in fraction to MC	-0.84	-1.47

The 1.73 GeV vs 2.75 GeV

TARC

INFORME DFN/TR-05/II-98

REF. EXTERNA

SIMULATION OF THE ^{99}Tc CAPTURE RATE MEASUREMENTS PERFORMED IN THE TARC EXPERIMENT

CENTRO DE INVESTIGACIONES ENERGÉTICAS, MEDIOAMBIENTALES Y TECNOLÓGICAS

DEPARTAMENTO DE FISIÓN NUCLEAR
Avda. Complutense, 22
28040 MADRID

INFORME DFN/TR-01/II-98	HOJA 1 DE 21
REF. EXTERNA	REVISIÓN 0

TITULO: **SIMULATION OF THE ^{99}Tc CAPTURE RATE MEASUREMENTS PERFORMED IN THE TARC EXPERIMENT.**

AUTORES: S. Diez[2], R. Fernández[1], E. González[1].

[1] *Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT), Madrid, Spain.*
[2] *Universidad Alfonso X el Sabio (UAX), Madrid, Spain.*

ABSTRACT:

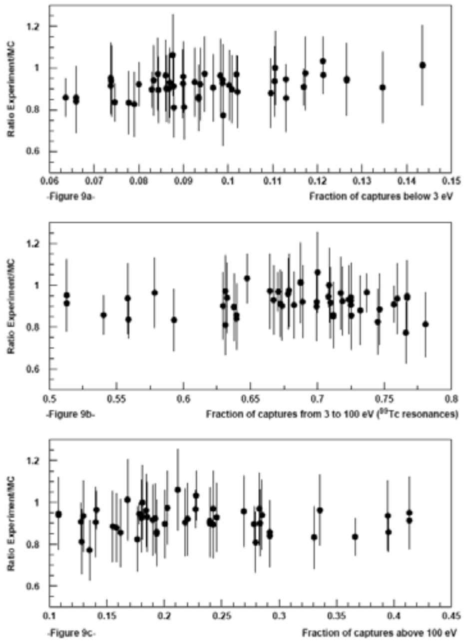
The TARC experiment that took place at CERN from April of 1996 till May of 1997 has provided a demonstration of the basic principles of the ARC transmutation technique in Lead, producing a set of ^{99}Tc neutron capture rate measurements in a wide range of neutron energies. The comparison of this set of measurements with predictions made by neutronic codes that deal with spallation neutron sources and use the last available nuclear databases is a very useful way of validating these tools for future studies on transmutation. The work presented in this note is focused on the comparison of the Monte Carlo code system LAHET/MCNP predictions for the ^{99}Tc integral capture rate measurements and the TARC experimental data.

	NOMBRE	FIRMA	FECHA
Preparado por:	R. Fernández		
Revisado por:	E. González		
Conf. por A. C.:	E. Mills		
Aprobado por:	J.L. Diaz		

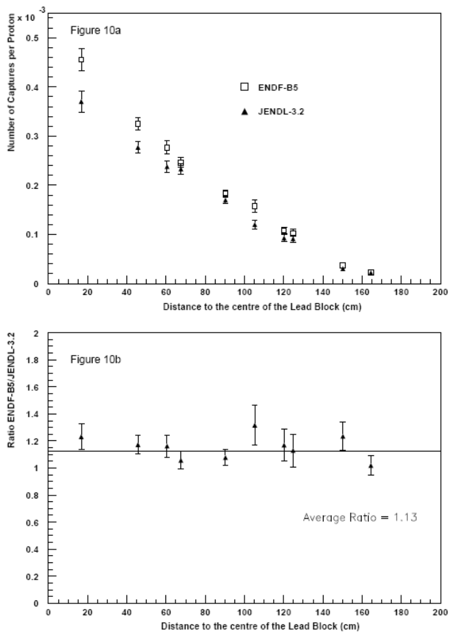
FECHA DE EMISIÓN: 2 0 1 1 9 8

TARC

Experiment/JENDL MCNP



ENDF-B/JENDL MCNP



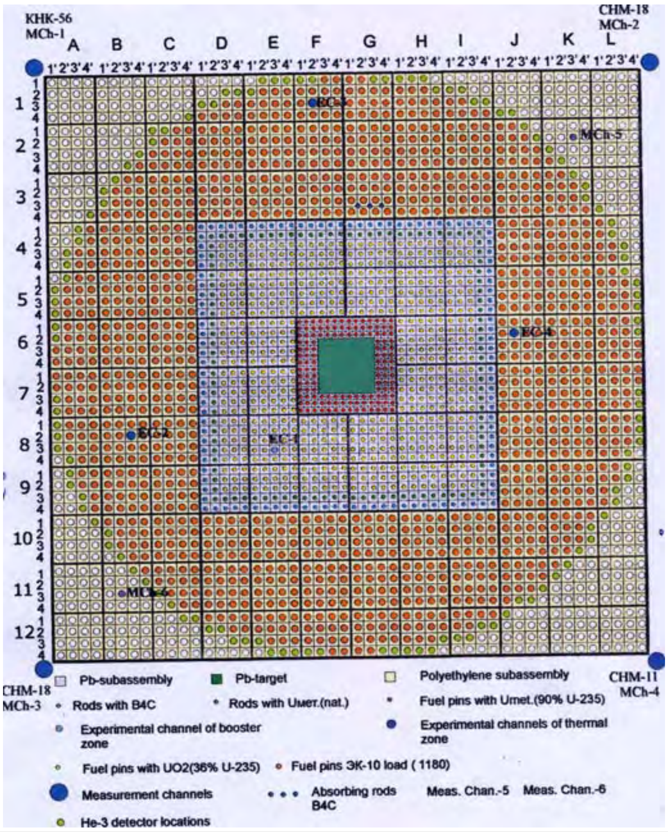
First results of the October 2005 experimental campaign YALINA experiments

(24/10/2005 – 2/11/2005)

E. M. González Romero
CIEMAT

SAD/YALINA-B Steering Committee Fifth Meeting. Minsk. December 5-6, 2005

Experimental Setup



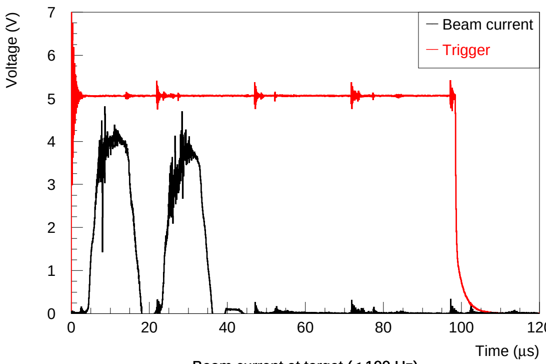
MINISTERIO DE EDUCACION Y CIENCIA

Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

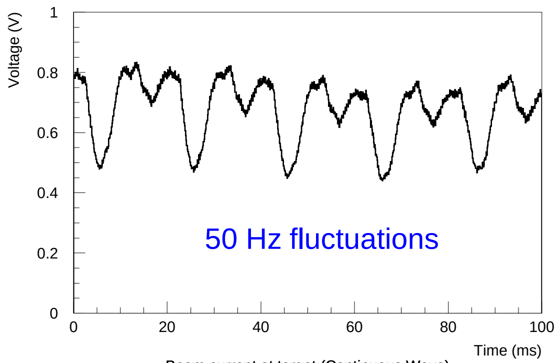
Present situation of the accelerator (I)

- Maximum intensity with the small target: 1 mA
- Maximum intensity with the large target: 8 mA
- Maximum frequency: at least 7.6 kHz
- Minimum operational pulse width is 2 μs.
- Maximum pulse width: 130 μs
- There is no way to monitor the neutron production, but Sosny is working on it (Polyethylene Sphere + ^{3}He - only for D-T neutron production)
- In pulse mode, the present way to stop the beam is using a Ti foil, but it takes at least a few milliseconds and may generate an after-pulse. Flexible pulsing should be made available.
- In continuous wave, stopping the beam can be done in less than a microsecond. Source interruption
- The power for the dipole magnet is, at present, obtained from the standard electricity supply, affecting the efficiency of the optics. The consequence is that the intensity of the beam oscillates about a 30% with a frequency of 50 Hz. An additional oscillation with 23 kHz is observed.
- Below 100 Hz, practically every pulse has a twin pulse after 20-30 μs.

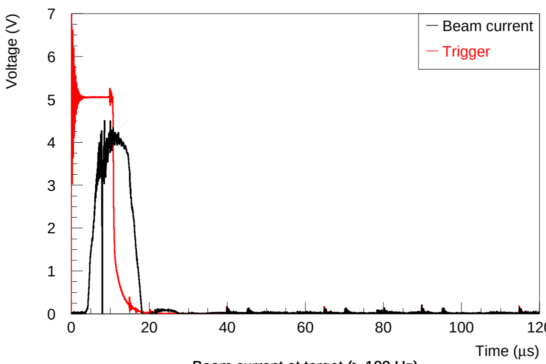
Present situation of the accelerator (II)



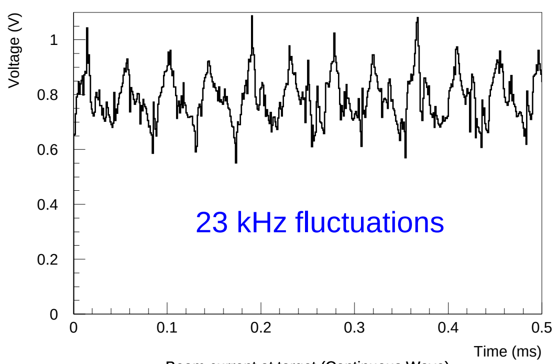
Beam current at target (< 100 Hz)



Beam current at target (Continuous Wave)



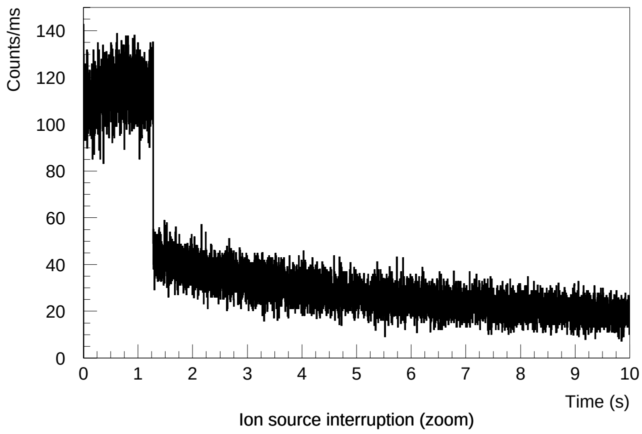
Beam current at target (> 100 Hz)



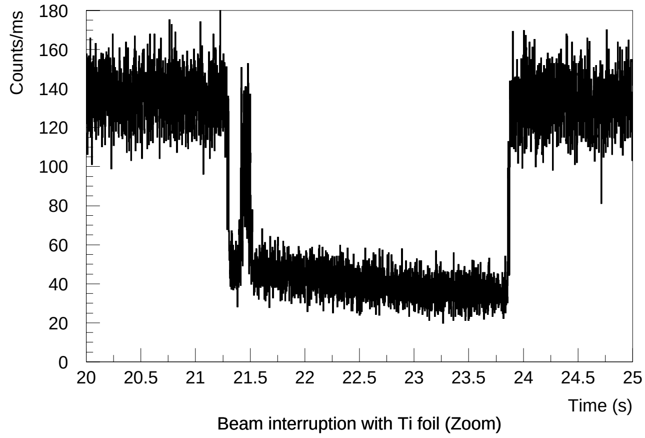
Beam current at target (Continuous Wave)

Beam Interruption experiments

(continuous beam vs. quasi-continuous beam)

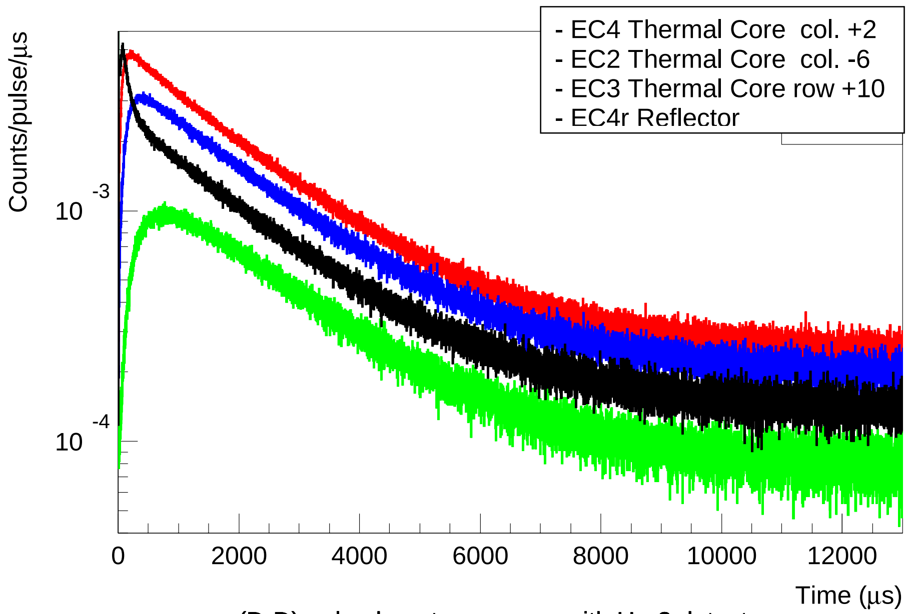


Ion source interruption (zoom)



Beam interruption with Ti foil (Zoom)

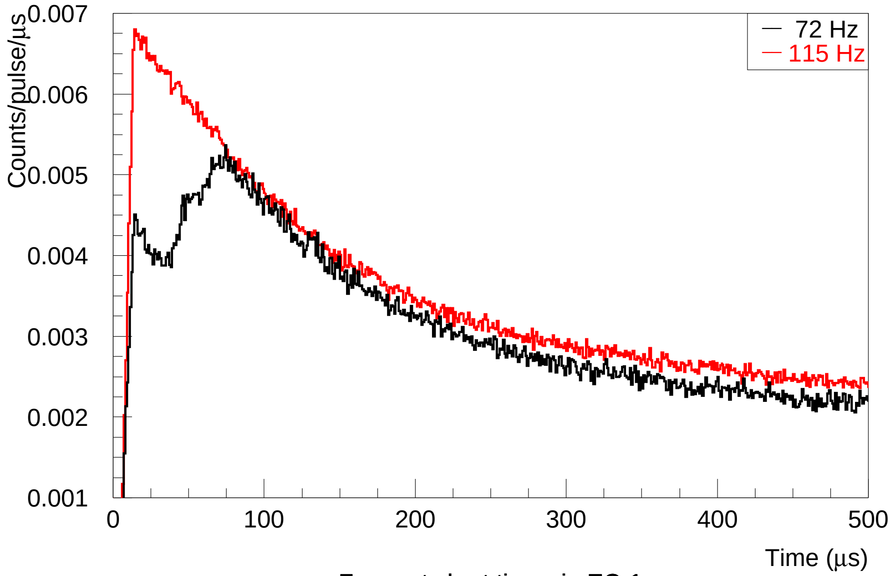
Pulsed Neutron Source experiments



(D-D) pulsed neutron source with He-3 detectors

- Pulse width was 10 µs.

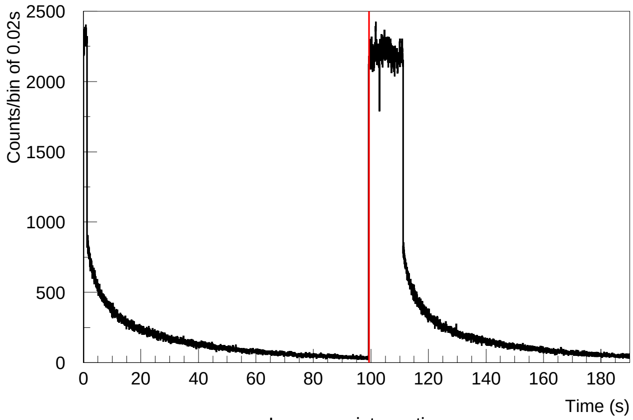
Pulsed Neutron Source experiments



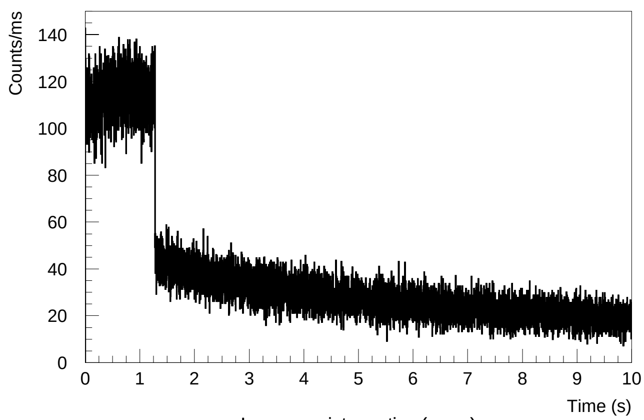
Zoom at short times in EC-1

- Pulse width was 10 µs.

Beam Interruption experiments (Continuous beam)

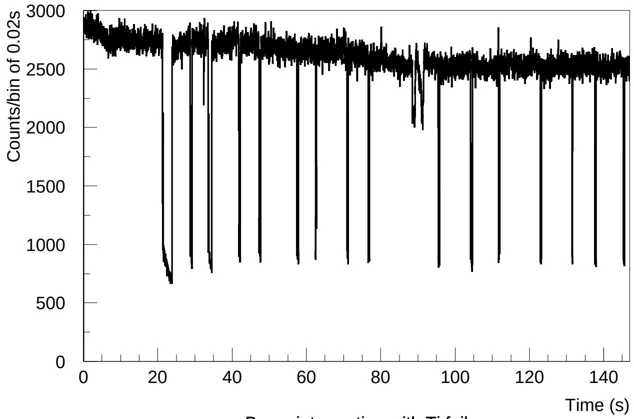


Ion source interruption

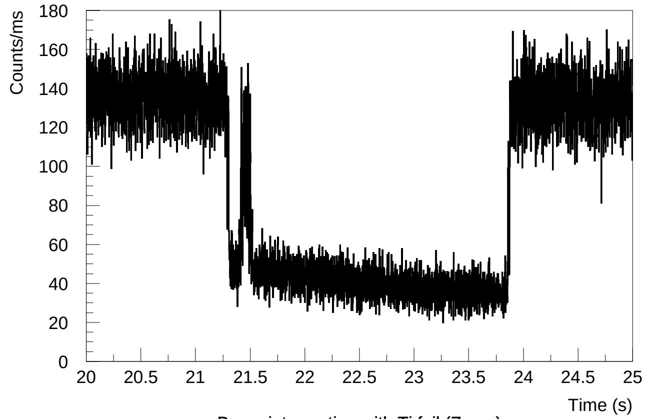


Ion source interruption (zoom)

Beam Interruption experiments (quasi-continuous beam)



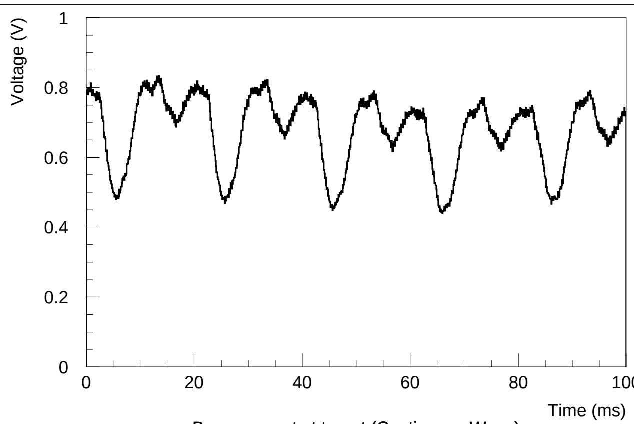
Beam interruption with Ti foil



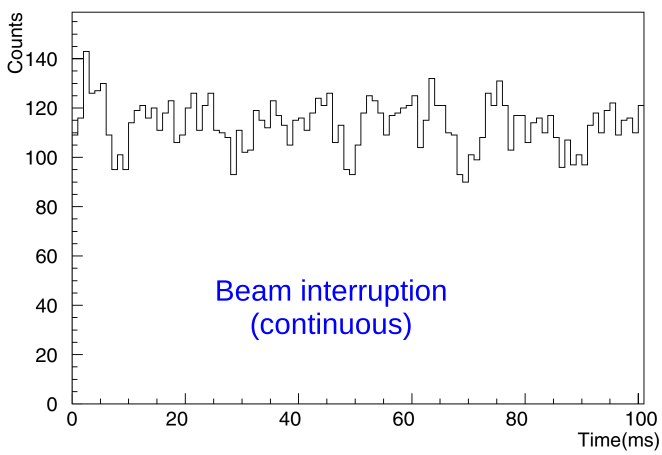
Beam interruption with Ti foil (Zoom)

Reactivity results in dollars

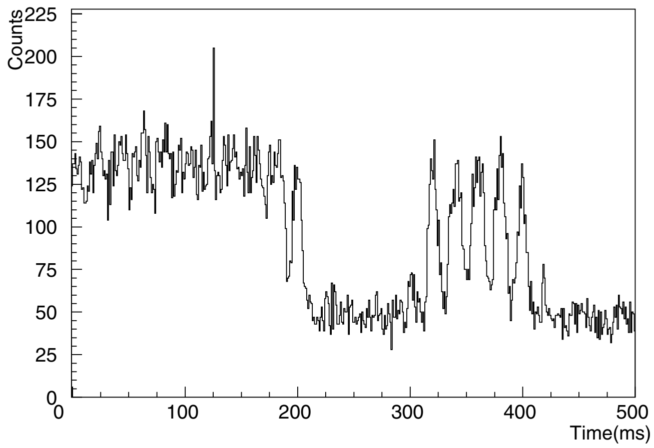
	EC-1	EC-2	EC-3	EC-4	EC-6
Area method	2.87 ± 0.01	2.81 ± 0.01	2.68 ± 0.01	2.62 ± 0.01	
Beam interruption (continuous)					Data
Beam interruption (pulsed)	Data				

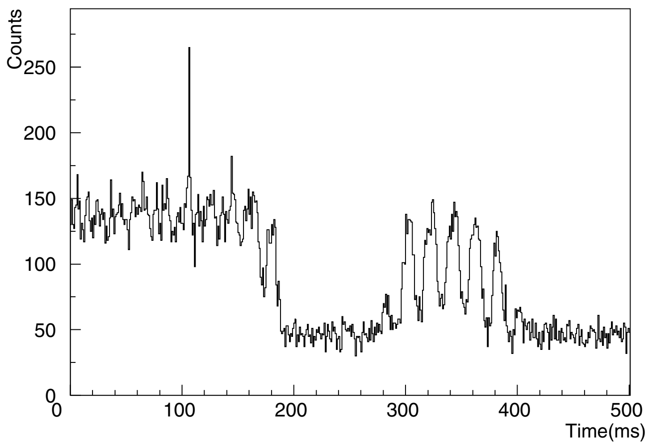


Beam current at target (Continuous Wave)



Beam interruptions in pseudo-continuous – pulsed mode

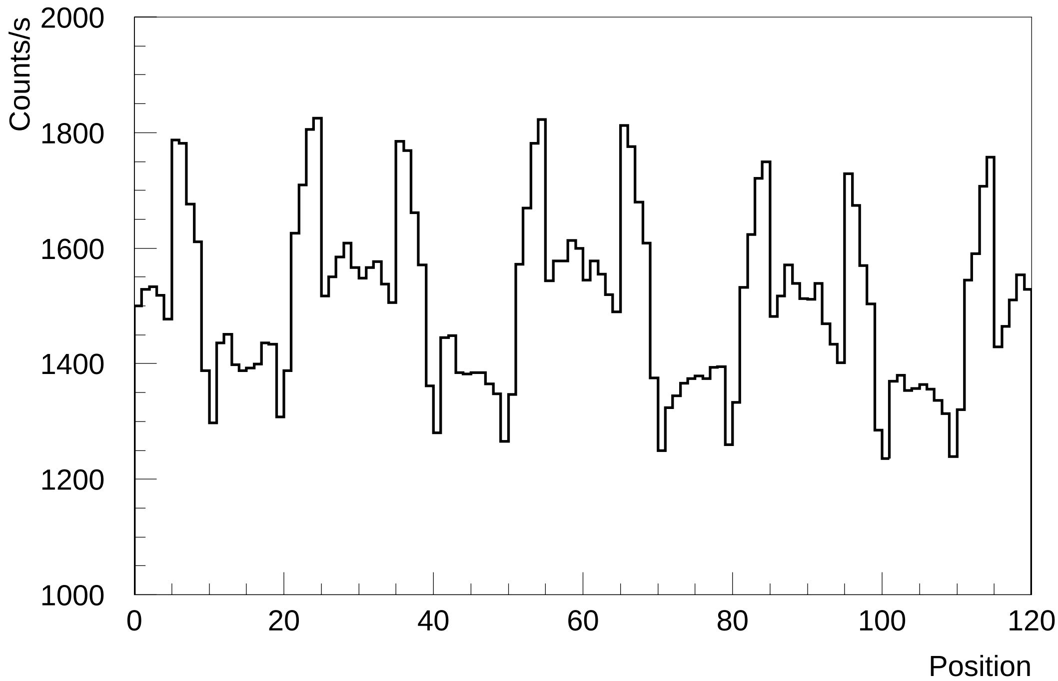




MINISTERIO DE EDUCACION Y CIENCIA

Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

^{3}He counting rate in the core periphery

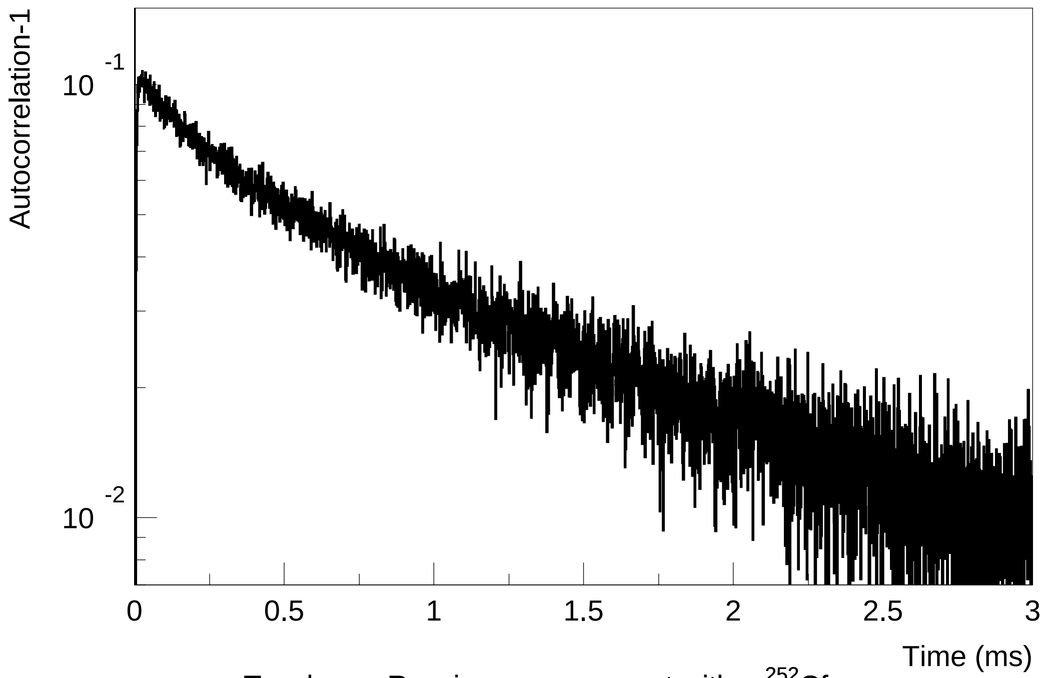


He-3 reaction rate in the fuel periphery

MINISTERIO DE EDUCACION Y CIENCIA

Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

Noise experiments with ^{252}Cf source



Two hours Rossi-α measurement with a ^{252}Cf source

Conclusions of the experiments and extrapolation to future experiments

Difficulties observed with the present situation of the facility

- There is only one electronic chain available
- Diameter of the experimental channels do not allow the insertion of fission chambers with enough sensitivity to perform pulsed neutron source measurements in the fuel region
- The intensity of the beam can be monitored but not the neutron production in the target
- Fluctuations of the beam intensity introduce additional complexity to the analysis of the experimental results
- The trigger system of the accelerator does not allow short beam interruptions. In addition, there is no available signal to synchronise the data acquisition systems with the beam interruption

Measurements with pulsed source and pulsed mode detection

- To reduce statistical uncertainties below 1% (1 µs binning), a minimum of 5 10^7 counts are required per detector and measurement
- With the present characteristics of the accelerator, the extrapolation of using a D-T source, 3 µs pulse width, 66 Hz repetition rate, 1 mA beam current and k_{eff} ~ 0.98:
  - Counting rate with a 1mg ^{235}U fission chamber in the booster: ~7 c/s
  - 0.5 g ^{235}U fission chambers and ^{3}He detectors do not fit in the booster experimental channel
  - Thus, with this counting rate the expected measurement time is: 3000 h!
- A time reduction of a factor 2000 can be obtained with the following improvements of the accelerator and detectors:
  - Beam intensity in pulsed mode: 8 mA
  - Suppression of the double pulse
  - Increase of the deposit mass of the fission chambers to 500 mg

Measurements with continuous source and pulsed mode detection

- Two type of measurements are foreseen in continuous mode:
  - Measurements related to the current-to-power technique. A variation of few percents in neutron population detected in 1 s seems to be the minimum requirement that has to be achieved. Thus 10^4 c/s should be the minimum counting rate with the source in continuous mode.
  - Measurements related to the reactivity calibration during operation. 20 ms interruptions imply that counting rates should be greater than 2000 c/ms to apply source-jerk techniques (greater if we want to use decay fitting techniques), which introduces severe dead time effects.
- With the present characteristics of the accelerator, the extrapolation of using a D-T source, 1 mA beam current and k_{eff} ~ 0.98:
  - Counting rate with a 1mg ^{235}U fission chamber in the booster: ~1900 c/s
  - 0.5 g ^{235}U fission chambers and ^{3}He detectors do not fit in the booster experimental channel
  - Thus, with this counting rate the sensitivity to neutron population changes is about 4%
  - Uncertainties in the beam current and neutron production can decrease sensitivity to variations of 10-15%
- An increase in the accuracy of the current-to-power measurements can be obtained with the following improvements of the accelerator and detectors:
  - Monitoring system of the neutron production with accuracy better than 5%, or
  - Stabilisation of the beam to <5% variations
  - Increase of the deposit mass of the fission chambers to 0.5 g

Measurements with continuous source and current mode detection

- To increase the accuracy of the measurements in continuous mode without dead time effects and to be able to apply decay constant fitting techniques, detectors can be used in current mode
- As shown before, with the present available detectors fitting in the booster experimental channel, it is not possible to use this mode
- To reach the same accuracy than in PNS experiments 10^{10} c/s are needed. This counting rate cannot be achieved with ^{235}U detectors. However, it could be possible to reach 10^{9}-10^{10} c/s with ^{3}He chambers.
- It has to be also investigated the possibility to use ^{235}U chambers in current mode detection at counting rate of 10^{6}-10^{7} c/s

Measurements with pulsed source and current mode detection

- This possibility could be investigated in order to validate the results obtained in continuous mode
- ^{3}He chamber could even allow the investigation of the reactivity pulse by pulse

Characterisation of the core

- These measurements are divided in:
  - Axial and radial traverses of ^{3}He detectors and ^{235}U and ^{238}U fission chambers.
  - Several spectral indices. ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{242}Pu, ^{237}Np, ^{232}Th, ^{241}Am and ^{243}Am are candidates (are the facilities and detectors available?)
  - Activation foils measurements. (These have to be agreed by interested partners)
- These measurements should be performed with D-T source and when possible with ^{252}Cf source

Necessary improvements of the YALINA facility

- Electronic support to share at least five detectors (pulse and current detection mode chains)
- Enlargement of the experimental channels to allow the 0.5 g ^{235}U fission chambers fit in the booster and in the thermal regions
- New ^{232}Th, ^{238}U fission chambers with 1 g deposit and with the diameter of the new experimental channels (Dubna has offered its capabilities to build them). Also ^{3}He chambers to work in current mode
- Beam intensity in pulsed mode up to 10 mA
- Stabilisation of the beam intensity
- Complex triggering of the accelerator
- Monitoring system of the current and neutron production at the target
- Absolute calibration of the neutron production
- Available signals of the accelerator monitoring system and neutron production

Experiments that can be performed in the framework of ISTC

- Validation of different reactivity monitoring techniques:
  - Detector reaction rates vs. Source intensity (Different positions and detector types)
  - Beam interruption experiments (Short time and Long time source jerk, Slope analysis)
  - Pulsed source (Area method, Slopes analysis)
  - Noise techniques (Isotopic source, D-T source)
  - Validation of pulse and current detection
- Evaluation of different core configurations
  - Different spectra
  - Same global Keff for different booster reactivity
  - Reactivity evaluation vs Booster (global) source multiplication
  - Source monitoring techniques

IAEA CRP: 1st RCM, Minsk

Benchmark calculation

proposals from the

Yalina Booster team

Sosny - KTH

First IAEA RCM on Analytical and Experimental Benchmark Analyses of ADS

Calle Persson

Department of Nuclear and Reactor Physics

Royal Institute of Technology (KTH), Stockholm

Yalina Booster: $\boldsymbol{\beta_{eff}}$

Effective delayed neutron fraction, $\boldsymbol{\beta_{eff}}$

– ”Exact” method:

$$\beta_{eff} = \frac{N_d}{N_{Tot}}$$

Fissions induced by delayed neutrons (N_d)

Total number of induced fissions (N_{Tot})

– Prompt approximation:

$$\beta_{eff} = (1-\beta)\left(\frac{k_{eff}}{k_p} - 1\right) \approx 1 - \frac{k_p}{k_{eff}}$$

– Deterministic calculation

Yalina Booster: Λ

Mean generation time, Λ

– No direct way to estimate the adjoint weighted Λ correctly in MCNP

New calculation scheme developed at SCK·CEN?

– Calculation of Λ for the booster zone separately

– Deterministic approach?

Carl-Magnus Persson
KTH, Stockholm

Yalina Booster: k_{eff}

Effective multiplication factor, k_{eff}

– MCNP KCODE

– Calculation of k_{eff} for the booster zone separately

– Deterministic calculation

Carl-Magnus Persson
KTH, Stockholm

Yalina Booster: α

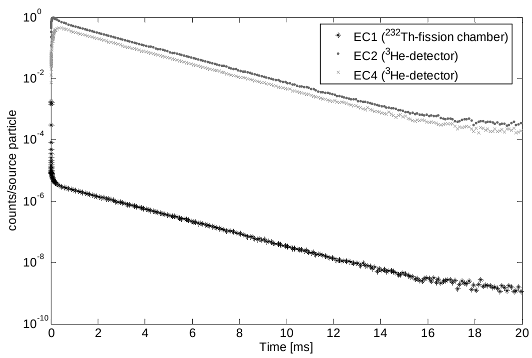
Prompt neutron decay rate, α

– MCNP ACODE, can only be used close to criticality

– Simulation of the neutron flux after a pulse insertion

Carl-Magnus Persson
KTH, Stockholm

Yalina Booster: α



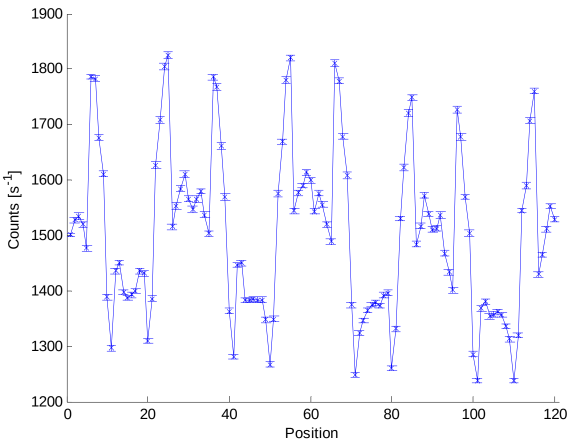
α = -470 s^{-1}

– Reference design configuration

(MCNP - ENDF/B-6.8)

Carl-Magnus Persson
KTH, Stockholm

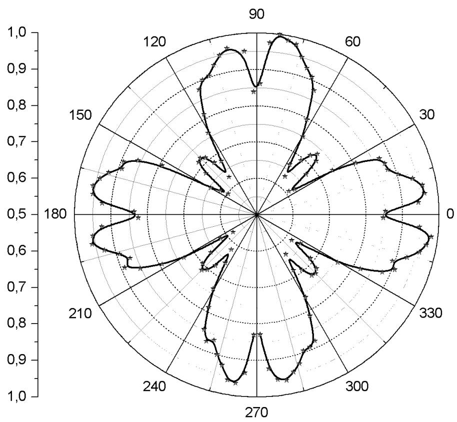
Yalina Booster: Neutron flux



– The neutron flux around the core can easily be compared with a calculated flux.

Carl-Magnus Persson
KTH, Stockholm

Yalina Booster: Neutron flux



Carl-Magnus Persson
KTH, Stockholm

Yalina Booster: Summary

Suggested benchmark calculations for different configurations of Yalina Booster:

– **Effective delayed neutron fraction, β_{eff}**

– **Neutron mean generation time, Λ (booster and total).**

– **Effective multplication factor, k_{eff}**

– **Evolution of the neutron flux in time after a neutron pulse insertion and extraction of the prompt neutron decay rate, α.**

– **Neutron flux at the periphery of the core.**

Calculations should be done with deterministic codes as well as Monte Carlo methods for the different libraries aviable.

Carl-Magnus Persson
KTH, Stockholm

Neutron Time Parameters

Reactor Theory

–Neutron lifetime

$$l = \frac{1}{v\Sigma_a (1 + L^2 B^2)}$$

The mean time for one neutron to be removed from the reactor due to absorption or leakage

–Mean generation time

$$\Lambda = \frac{1}{\nu v \Sigma_f}$$

The mean time to produce *one* more neutron

–Mean fission time

$$\tau = \frac{1}{v\Sigma_f}$$

The mean time for one neutron to cause fission

$$k_{eff} = \frac{l}{\Lambda}$$

$$\Lambda = \frac{\tau}{\nu}$$

Carl-Magnus Persson
KTH, Stockholm

Neutron Time Parameters

MCNP

–**Lifespans** Mean time from *birth* to *event*

$$t_x = \frac{1}{N_x}\sum_{k=1}^{N_x} t_k$$

–Removal lifespan
–Fission lifespan
–Capture lifespan
–Escape lifespan

–**Lifetimes** Mean time from *event* to *event*

$$\tau_x = \frac{\tau_r}{P_x}$$

$$\tau_r = \sum_x P_x t_x = P_f t_f + P_c t_c + P_e t_e$$

–Removal lifetime
–Fission lifetime
–Capture lifetime
–Escape lifetime

Carl-Magnus Persson
KTH, Stockholm

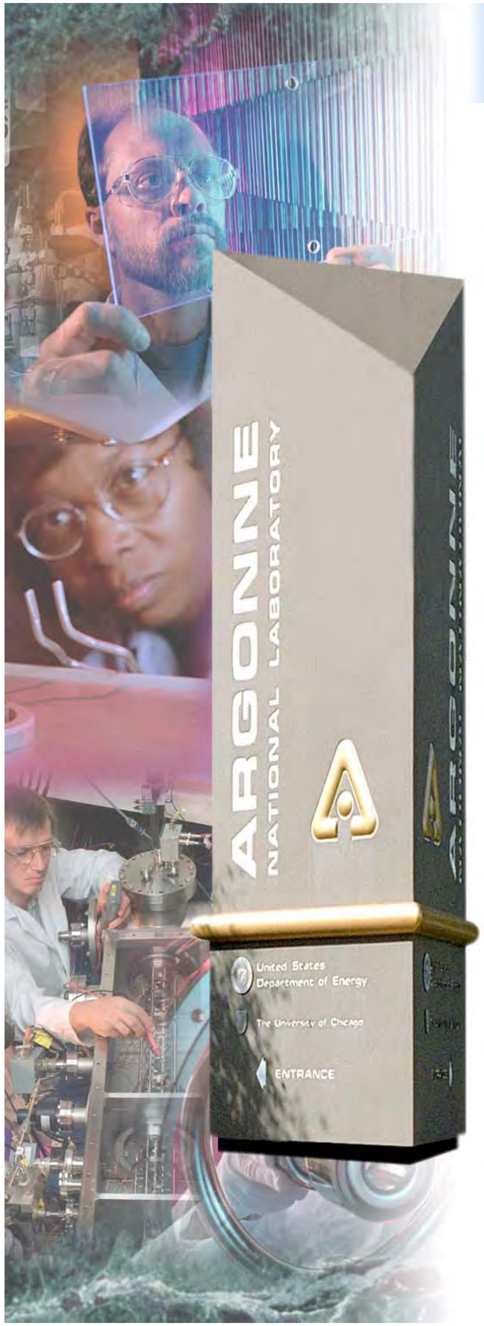
Neutron Time Parameters

Reactor theory			MCNP	
l	(neutron lifetime)	→	τ_r	(removal lifetime)
τ	(mean fission time)	→	τ_f	(fission lifetime)
Λ	(mean generation time)	→		No corresponding quantity

$$\Lambda = \frac{\tau}{\nu} \qquad k_{eff} = \frac{l}{\Lambda}$$

Adjoint-weighted **Non-adjoint-weighted**

Carl-Magnus Persson
KTH, Stockholm



ARGONNE NATIONAL LABORATORY

Characterization of Accelerator Driven Neutron Sources for Nuclear Systems

Yousry Gohar
Argonne National Laboratory, Department of Energy, USA

Technical Meeting on Analytical and Experimental Benchmark Analyses of Accelerator Driven Systems (ADS)

Joint Institute of Power Engineering and Nuclear Research SOSNY
December 5-9, 2005, Minsk, Belarus

THE UNIVERSITY OF CHICAGO

NNSA
National Nuclear Security Administration

Argonne National Laboratory is managed by The University of Chicago for the U.S. Department of Energy

Work sponsored by National Nuclear Security Administration The U.S. Department of Energy

Characterization of Accelerator Driven Neutron Sources for Nuclear Systems

Objective:

Characterize *accelerator driven neutron sources* used for nuclear systems. Utilize different computer codes for performing this characterization and compare with experimental results as much as possible.

Main Variables and Design Selections:

- **Charged particle type and energy**
- **Target material**
- **Buffer thickness**
- **Target length**

Characterization of Accelerator Driven Neutron Sources for Nuclear Systems

Main Combination:

Particle Type	Particle Energy, MeV	Target Material
Proton	200 and 1000	Lead-Bismuth Eutectic and Tungsten
Deuteron	200 and 1000	Lead-Bismuth Eutectic and Tungsten
Electron	50, 100, 150, and 200	Tungsten and Natural Uranium

Performance Parameters:

- **Neutron yield**
- **Energy deposition**
- **Top, radial, and bottom neutron fractions**
- **Neutron spatial distribution**
- **Neutron spectrum**
- **Buffer size impact on the above parameters**

Specific System Analyses

- Thermal and Booster YALINA
  - Monte Carlo Analyses
  - Deterministic Analyses
  - ENDF Data
  - JEFF Data

- KIPT Neutron Source Facility