ISTC Project #2002 Brief Review

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CONTENT:

- *Formal information*
- *Tasks*
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- *Results applications in other projects*
- *Next project*

ISTC-Contact Expert Group on Nuclear Transmutation related Projects Annual meeting.
January 30 – 31, 2006, **EC, Building CDMA, 21, rue de Champs de Mars, 1050 Brussels**

ISTC#2002: Formal information

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

Duration: *1 January 2002 – 30 October 2004,*

Financing party: *EU*

Budget: *$ 346 527.18*

Collaborators

- *Royal Institute of Technology (**W. Gudowsky**)*
- *Los-Alamos National Laboratory (**S. Mashnik**)*
- *CEA / DRN / DER / CEN Cadarache (**M. Salvatores, I. Slessarev**)*
- *Johannes Gutenberg-Universitat Mainz, (**H.O. Denschlag**)*
- *Tokyo Institute of Technology (**M. Saito**)*

Real colloborators:

- European Commission, **Vade Bhatnagar**
- Royal Institute of Technology, **Waclaw Gudowski,**
- Forschungszemntrum Karlsruhe Institut für Kern und Energiete, **Colnelis H.M. Broeders,**
- Commissariat a l'Energy Atomique, CEN – Cadarache, **M. Salvatores, Igor S. Slessarev,**
- Zentrum fuer Strahlenschutz und Radiooekologie, **R. Michel**
- Commissariat a l'Energy Atomique, CEA Saclay, **S.Leray**
- Los Alamos National Laboratory, **G.J. Van Tuyle, S.G. Mashnik, R.E. Prael,**
- Japan Atomic Energy Research Institute (JAERI), **Hiroshi Takada,**

Prologue: the project is an extension of the researches carried out under:

- ISTC Project#17 (1994-1996, USA)*Feasibility study of the basic technologies for weapon plutonium conversion and for long-lived radioactive waste transmutation*
- 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*

Brief info available via http://tech-db.istc.ru/ISTC/sc.nsf/html/projects.htm?open&id=2002

ISTC#2002 TASKS and RESULTS (1)

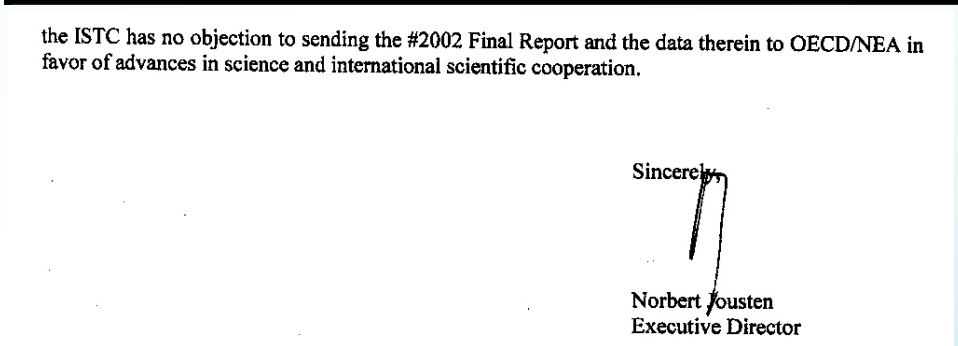
Task	Result
1. Manufacture of samples	**57** pairs of samples (Al+target) were manufactured
2. Calibration of spectrometer; stability tests	CANBERRA GC2518 spectrometer was calibrated every week during the γ-measurements period
3. Adjustment of the 600 MeV proton beam extraction	600 MeV proton beam extraction adjusted. The used beam became capable to provide protons of any energy up to 2.6GeV
4. Irradiation of experimental samples	**57** pairs of samples (Al+target) were irradiated on ITEP accelerator
5. Gamma-spectrometry of the samples	**2207** γ–spectra were measured, including **1548** from targets, **659** – from monitors.

List of irradiations:

Targets	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
^{208}Pb	x	x	x	x	x	x	x	x	x	x	x
^{207}Pb	x	x	x	x	x	x	x	x	x	x	x
^{206}Pb	x	x	x	x	x	x	x	x	x	x	x
^{nat}Pb	x	x	x	x	x	x	x	x	x	x	x
^{209}Bi	x	x	x	x	x	x	x	x	x	x	x

Project #2002 TASKS and RESULTS (2

Task	Result
6. Processing of the gamma-spectra	All the measured gamma spectra were processed in automatic mode and then **411089** found gamma lines were reprocessed in interactive mode, including **408987** from targets, **2102** from monitors
7. Identification of gamma-lines and determination of residual radioactive nuclide yields,	***5972*** nuclide yields were determined + 22 cross sections of $^{27}Al(p,x)^{24}Na$, $^{27}Al(p,x)^{7}Be$ monitor reactions
8. Theoretical simulations and calculations by different codes,	**9** codes were used for simulations: LAHET (Bertini, Isabel) INCL4+ABLA, CASCADE, CASCADE-2004, LAQGSM+GEM2, CEM03, CASCADO, LAHETO
9. Updating the models and codes on the basis of comparison with the new experimental data obtained	**2** codes were modified: LAHETO (on the base of LAHET), CASCADO (on the base of CASCADE)
10. Preparation of reports.	The final technical report was issued and got permission for dissemination. Summary technical report, activity report and technology implementation plan were also submitted to the ISTC. http://www.nea.fr/html/science/egsaatif/ISTC2002-final-report.pdf



the ISTC has no objection to sending the #2002 Final Report and the data therein to OECD/NEA in favor of advances in science and international scientific cooperation.

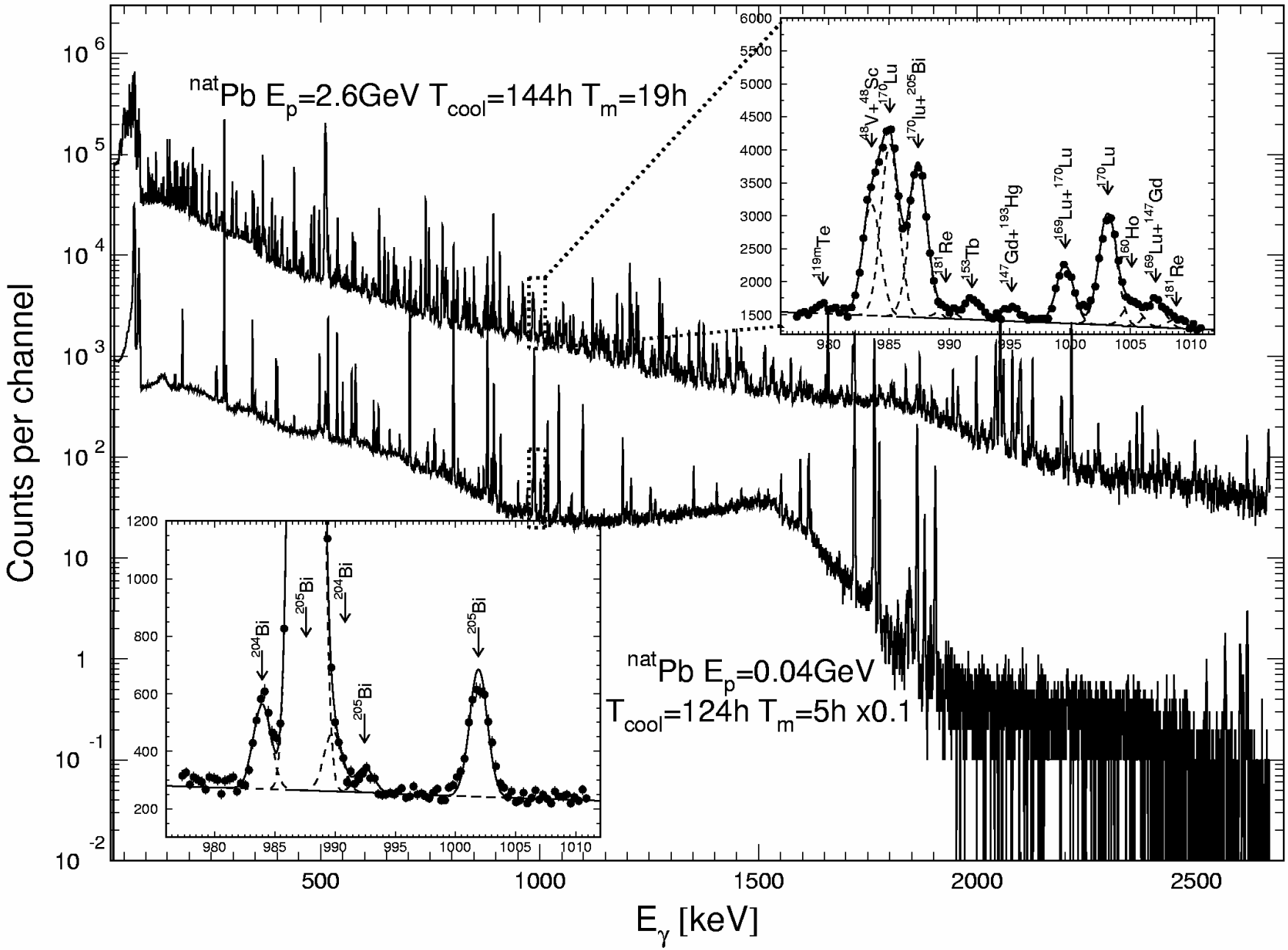
Sincerely,

Norbert Jousten
Executive Director

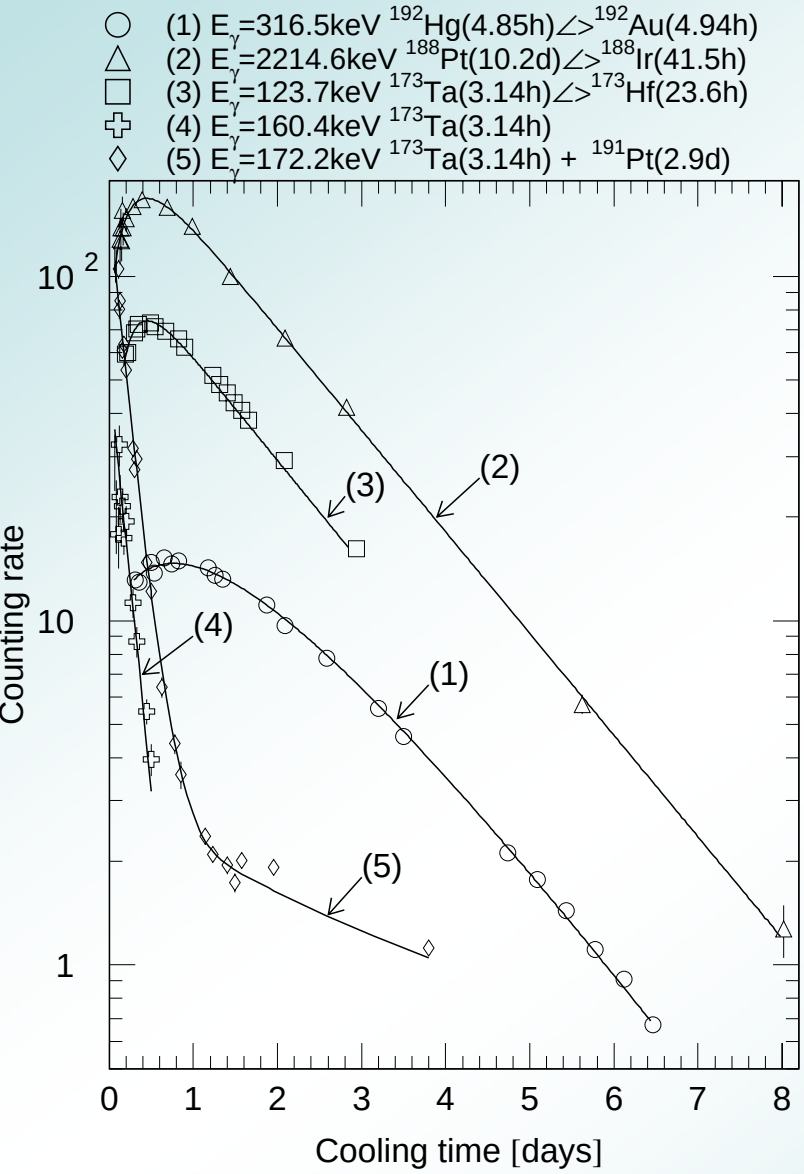
The numerical data also were sent to OECD/NEA to be inserted to the EXFOR database

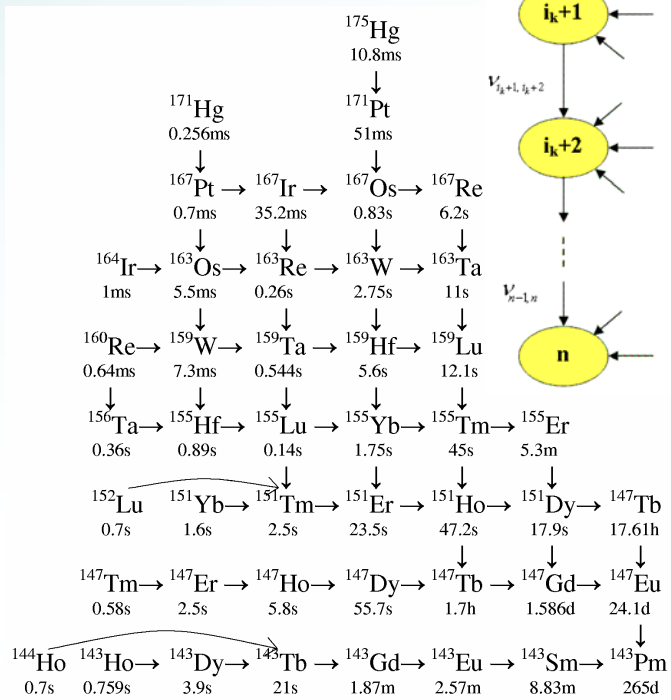
Apart of the Report and Conferences (ICRS10, ND2004, AccApp05) Proceedings, the results are expected to be published in Phys. Rev.

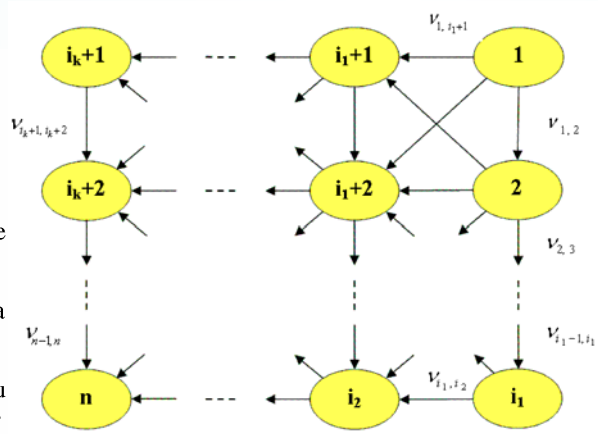
Gamma – spectra measurements



Determination of cross sections







^{143}Pm decay chain

$$R_1^{cum/ind} = \frac{1}{N_{Tag}\eta_2\varepsilon_2}\cdot\frac{B_1^*}{F_1}\cdot\frac{1}{\nu_{12}}\left(1-\frac{\lambda_1}{\lambda_2}\right),$$

$$R_2^{ind} = \frac{1}{N_{Tag}\eta_2\varepsilon_2}\left[\frac{B_2^*}{F_2}+\frac{B_1^*}{F_1}\frac{\lambda_1}{\lambda_2}\right],$$

$$R_2^{cum} = R_2^{ind}+\nu_{12}R_1^{cum/ind} = \frac{1}{N_{Tag}\eta_2\varepsilon_2}\left[\frac{B_1^*}{F_1}+\frac{B_2^*}{F_2}\right]$$

$$\sigma = R/\Phi_p$$

ISTC Project #2002 results (3)

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

TOTAL number of measured yields: 5972

- Detailed information on reaction rates per each gamma-line presented!
- Decay chains description presented

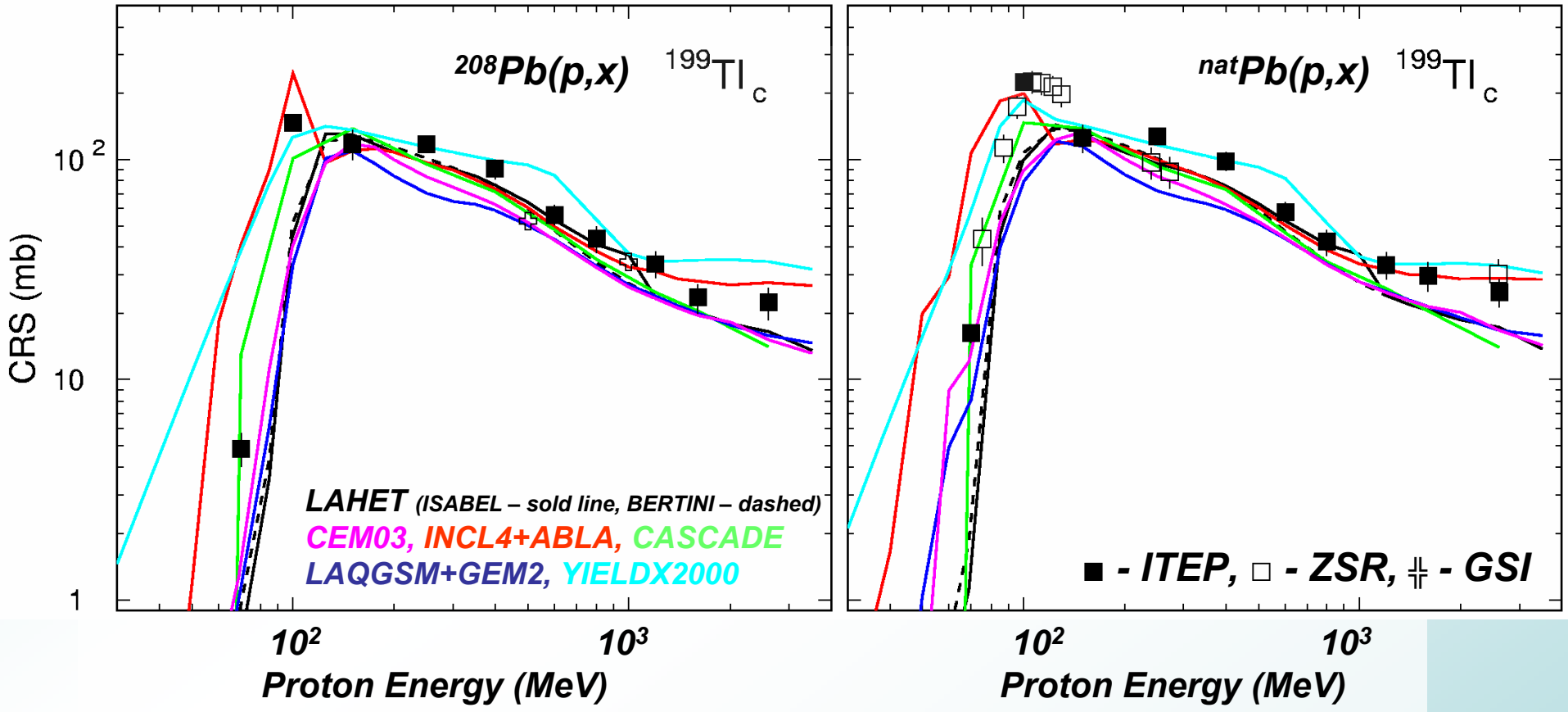
- Isotopic composition of targets

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

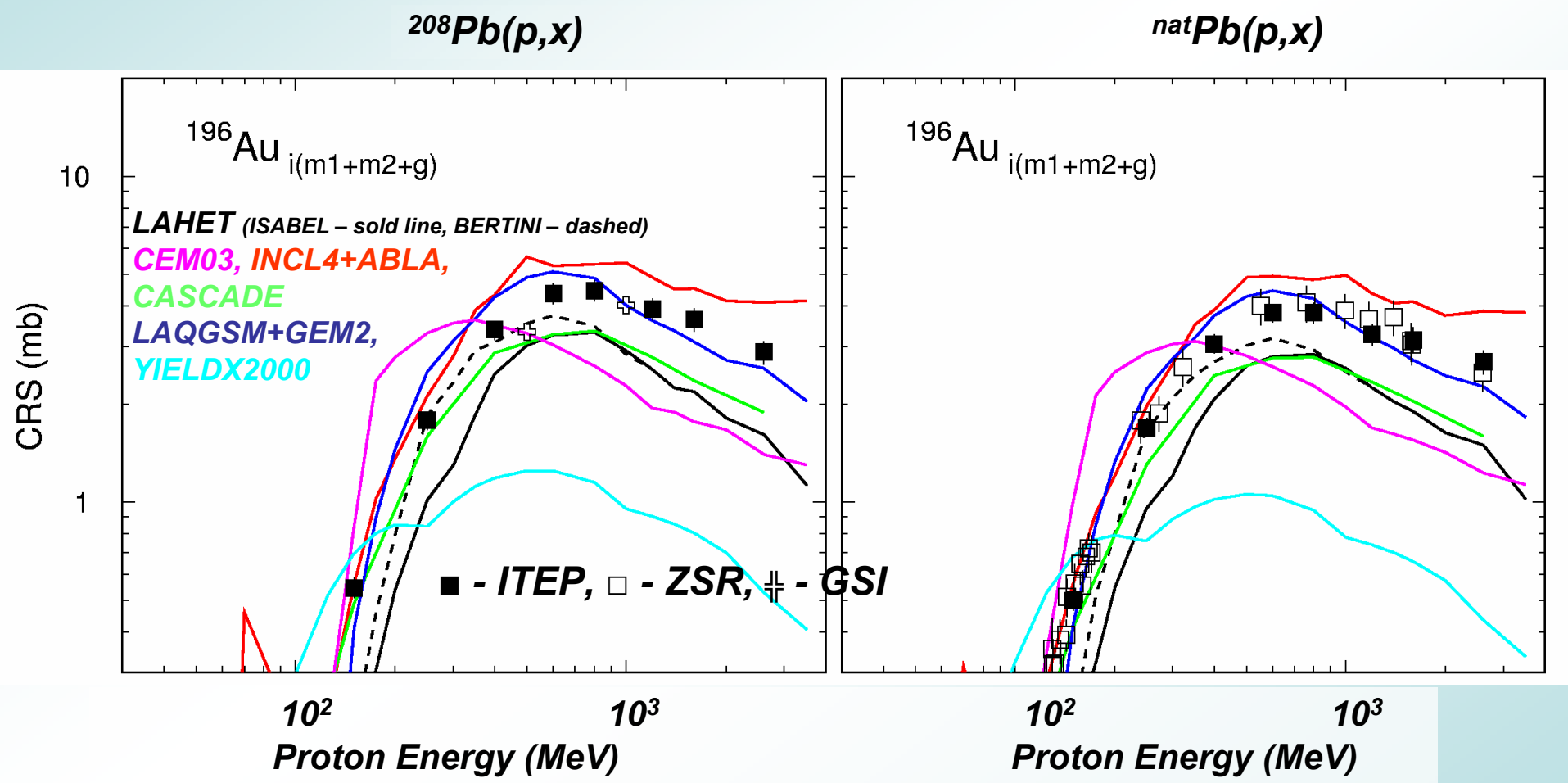
Final Technical report:

http://www.nea.fr/html/science/egsaatif/ISTC2002-final-report.pdf

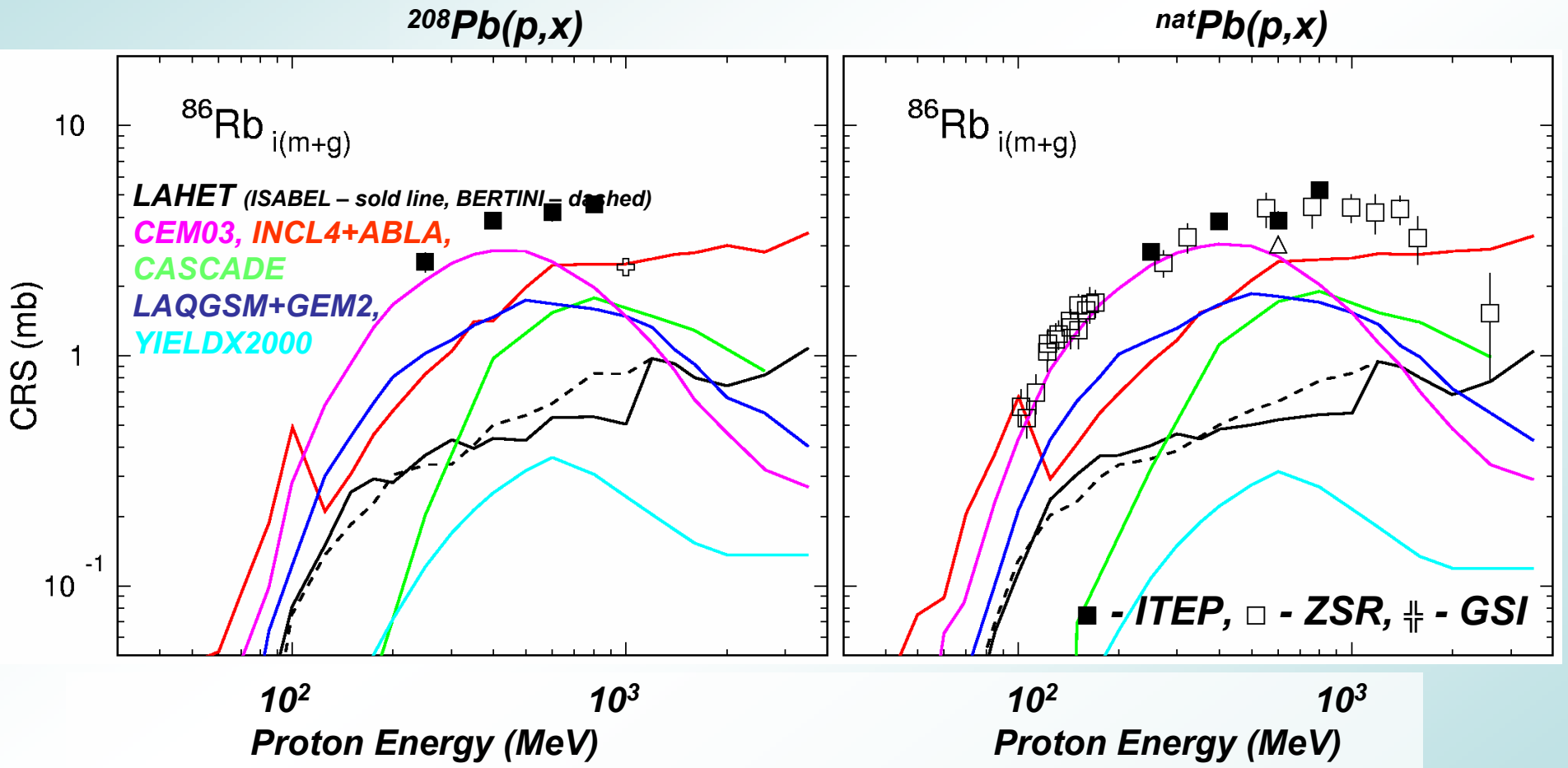
^{208}Pb-, ^{nat}Pb(p,x) excitation functions (1)



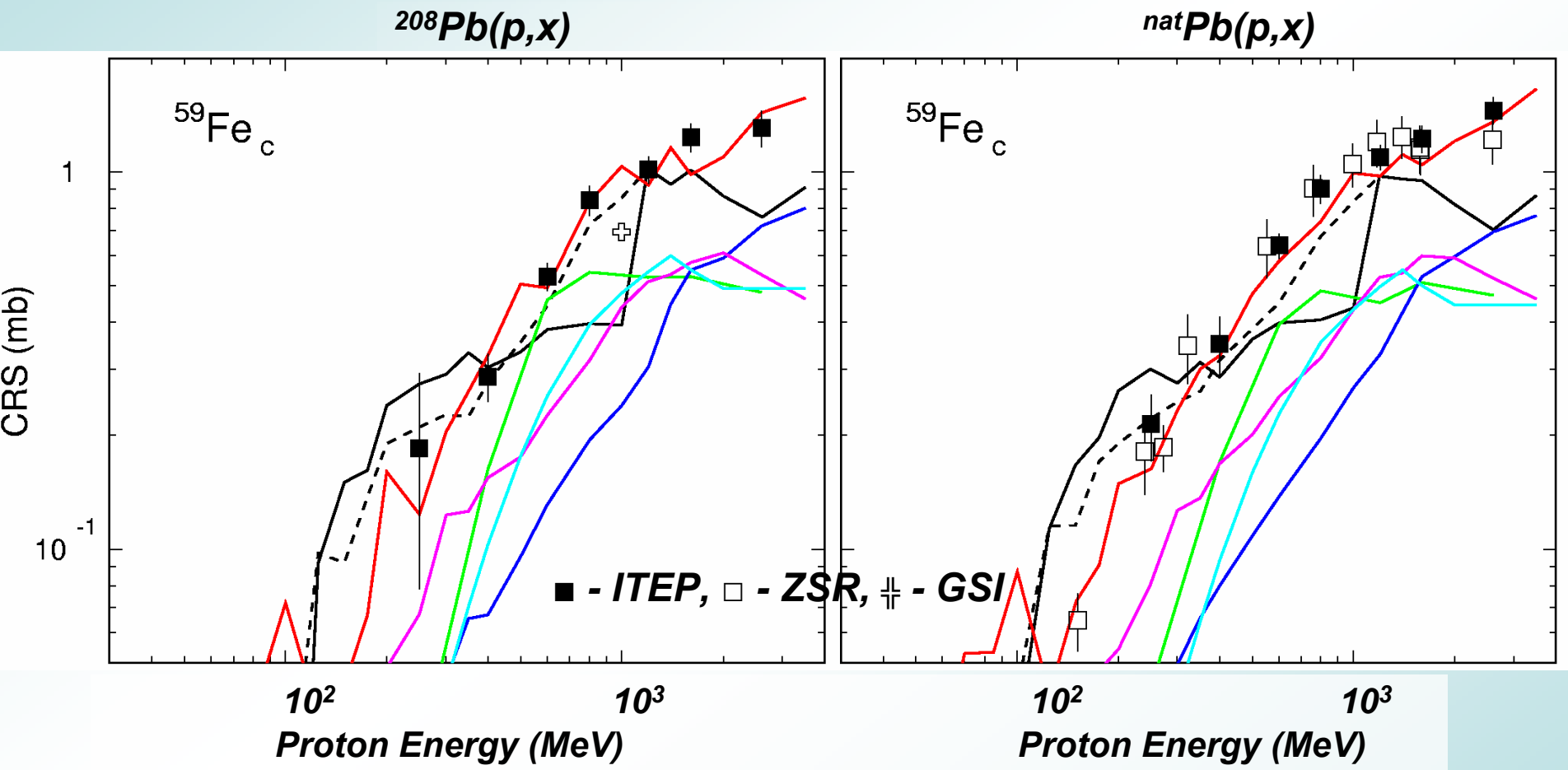
^{208}Pb-, ^{nat}Pb(p,x) excitation functions (2)



^{208}Pb-, ^{nat}Pb(p,x) excitation functions (5)

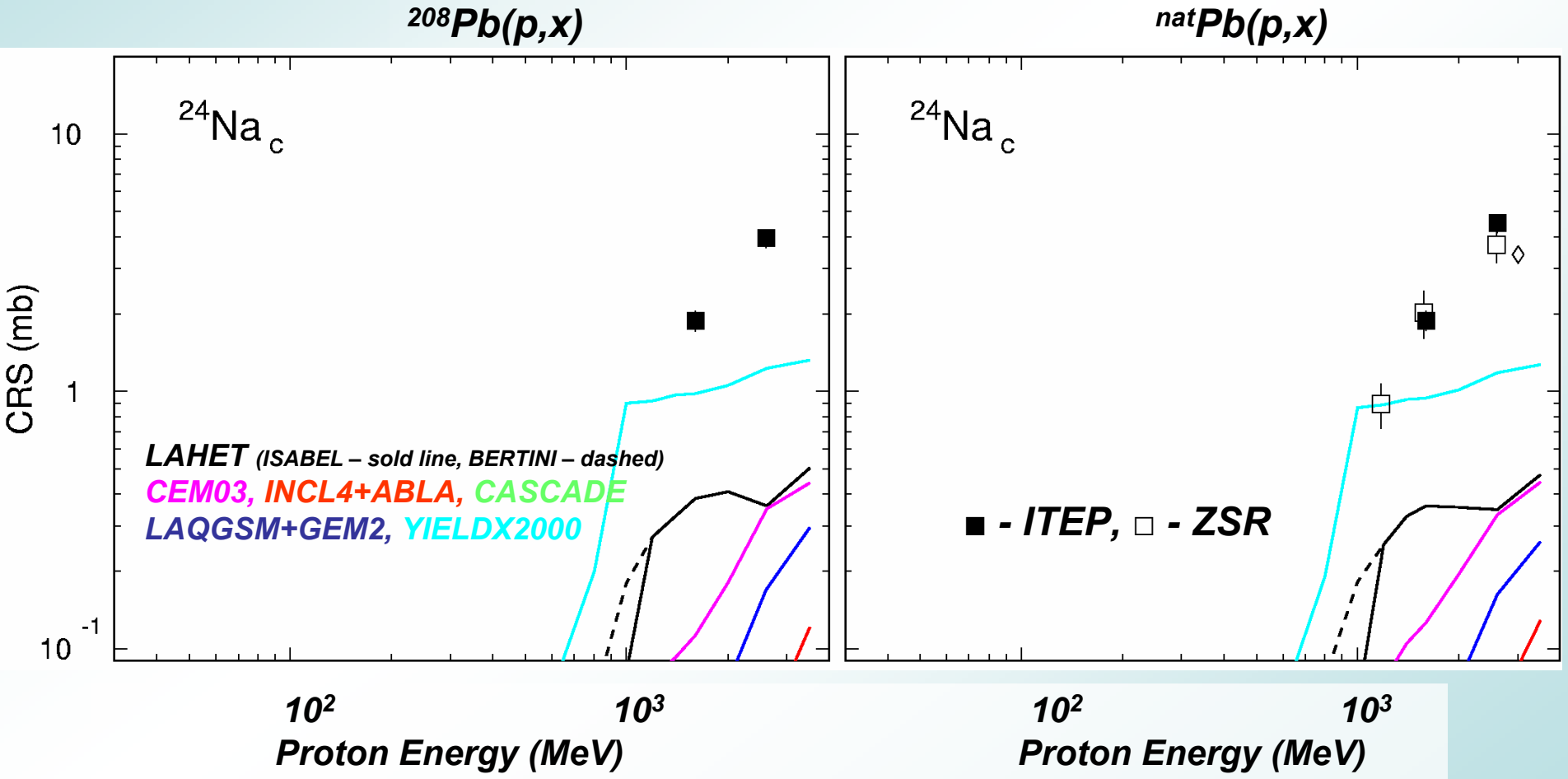


^{208}Pb-, ^{nat}Pb(p,x) excitation functions (2)

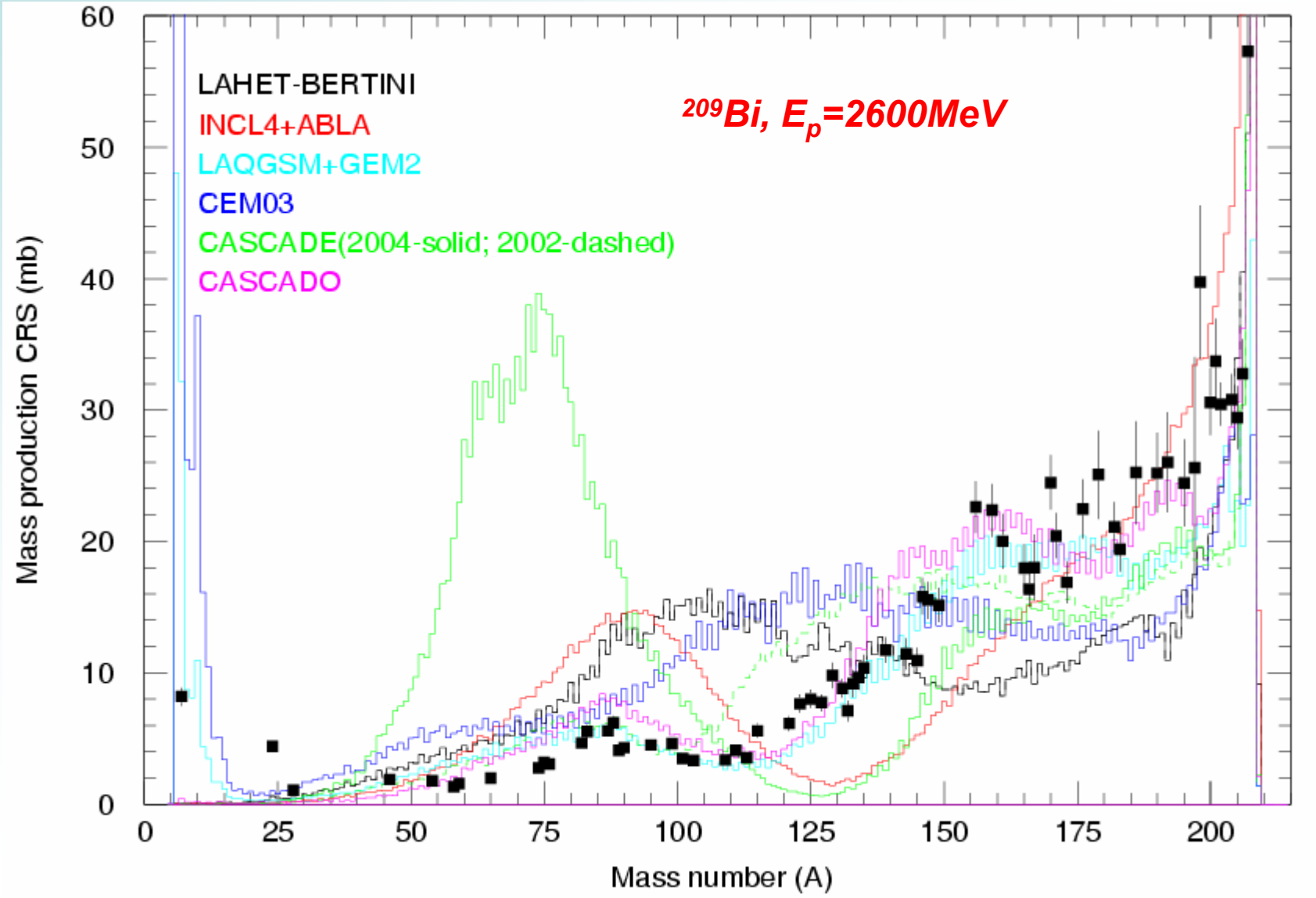


LAHET (ISABEL – sold line, BERTINI – dashed)
CEM03, INCL4+ABLA, CASCADE
LAQGSM+GEM2, YIELDX2000

^{208}Pb-, ^{nat}Pb(p,x) excitation functions (6)



Mass production



The simulation codes prediction power

Mean squared deviation factor <F>

$$< F >= 10^{\sqrt{A}},$$

$$A =< (\lg(\sigma_{cal,i} / \sigma_{\exp,i}))^2 >$$

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**

Results application in other projects

Project	Results	Application
2002	***Residual nuclide yields in lead and bismuth***	**Projects with lead (lead-bismuth) targets:** **SAD (ISTC#2267), MYRRHA (Belgium), etc.** **Prediction of target activation (including long-lived!) at the design stage. Measurements.**
839	*Residual nuclide yields in various targets, including tungsten, mercury, etc.*	Projects with alternative (Hg, W) targets: SNS, etc
1145, **2405**	*High-energy neutron spectra,* *Threshold reaction rates*	Neutron spectra unfolding , W-Na, Pb target Two benchmarks for IAEA CRP

Cooperation with foreign collaborators

• **S.Mashnik (LANL)** conducted simulation the Project-measured residual product yields by CEM03 and LAQGSM+GEM2 codes

• **A. Boudard (CEA-Sacley)** provided (26/09/2003) the INCL4+ABLA code to calculate the product nuclide yields and made some comments (6/04/2004) on the code operation results.

The tentative results of the Project were sent to:

C.H.M. Broeders (FZK)	5 February 2003; ^{nat}Pb 600MeV to use for the MEGAPIE and PDS-XADS Projects
E. Gonzales (CIEMAT)	6 March 2004
K.H. Schmidt (GSI)	10 December 2004 (draft report)
W. Gudowski (KTH)	17 December 2004 (draft report)

Discussion of the next ISTC proposal (ISTC Project #3266):

S.Leray (CEA-Sacley)	October 2004, December 2004, August 2005
R.Michel (ZSR)	January 2005
C.H.M. Broeders (FZK)	December 2004
S. Mashnik: (LANL)	December 2004
H. A. Abderrahim (SCK)	October 2004, December 2004
T. Fukahori (JAERI)	October 2004, December 2004, February 2005

The discussed Project #3266 was approved for funding in October 2005. The Workplan is to be discussed 31 January 2006.

From: "Tokio Fukahori" <fukahori@ndc.tokai.jaeri.go.jp>
To: "'Yury Titarenko'" <Yury.Titarenko@itep.ru>
Subject: RE: ISTC Project #3266
Date: Tue, 22 Nov 2005 13:32:14 +0900

Dear Yury

Thank you for your information. I have just submitted the form to JAEA for the collaborator.

The ISTC project #839 and #2002 have been very useful as following reason;

1) To polish up model code
2) To validate JENDL/HE
3) To be used evaluation for JENDL/HE

best regards,
Tokio

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http://wwwndc.tokai-sc.jaea.go.jp/

The post-graduate students training:
T. Kobayashi (October 2004); C.-M. Persson, M. Tesinsky (February 2006)

ISTC Project #3266

The Project #3266 was approved for funding in October 2005

Financing party - EU
Budget – k$430

The Workplan is to be discussed by CEG 31 January 2006

List of irradiation runs for beta-active nuclide production measurements.

Targets	Proton energies (MeV)										
	40	70	100	150	250	400	600	800	1200	1600	2600
^{56}Fe +	x	x	x	x	x	x	x	x	x	x	o
^{nat}Cr	x	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	o
^{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	o

o – the irradiations were made under the ISTC Project#839.

+ Additionally, ^{56}Fe will be irradiated by 300, 500, 750, 1000 and 1500 MeV prot to be compared with recent GSI measurements!

List of irradiation runs for alpha-active nuclide (^{148}Gd) production measurements.

Targets	Proton energies (MeV)			
	600	800	1600	2600
^{181}Ta	x	x	x	x
^{nat}W	x	x	x	x

Isotopic composition of the targets

Isotope	Number of samples	Isotopic composition, %
^{56}Fe	15	^{54}Fe-0.3, ^{56}Fe-99.5±0.1, ^{57}Fe-0.2, ^{58}Fe-<0.05.
^{nat}Cr	11	^{50}Cr-4.345 , ^{52}Cr-83.789 , ^{53}Cr-9.501, ^{54}Cr-2.365 .
^{nat}Ni	11	^{58}Ni-68.077, ^{60}Ni-26.223, ^{61}Ni-1.140, ^{62}Ni-3.634, ^{64}Ni-0.926
^{93}Nb	10	^{93}Nb > 99.9
^{181}Ta	15	^{180}Ta-0.012, ^{181}Ta-99,988.
^{nat}W	14	^{180}W-0.12, ^{182}W-26.50, ^{183}W-14.31, ^{184}W-30.64, ^{186}W – 28.43.

68 short (~0.7h) irradiations
8 long (~20h) irradiations
~130h accelerator time

For comparison:
ISTC#2002 took **37h** acc.time
(disregarding time for accelerator preparation and beam adjustment)