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OVERVIEW OF ACHIEVED COUPLING EXPERIMENTS ON ZERO-POWER FACILITIES

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EuCard^2, Status of ADS Research and Technology Development, CERN, 7-9 Feb. 2017

OVERVIEW OF ACHIEVED COUPLING EXPERIMENTS ON ZERO-POWER FACILITIES

- ***Needs and interest for coupling experiments on ZPR***
- ***Brief review of worldwide initiatives***
- ***The very first tests (1994-1998) : FEAT, MUSE 1 & 2***
- ***MUSE-3***
- ***The MUSE-4 /GUINEVERE/FREYA suite***
- ***The YALINA-B experiment***
- ***Activities in KURRI/KUCA***
- ***Others programs***
- ***Conclusions***

Out of scope: experiments involving accelerators and heavy metal blankets (U, Pb, W, ...) (with the exception of FEAT)

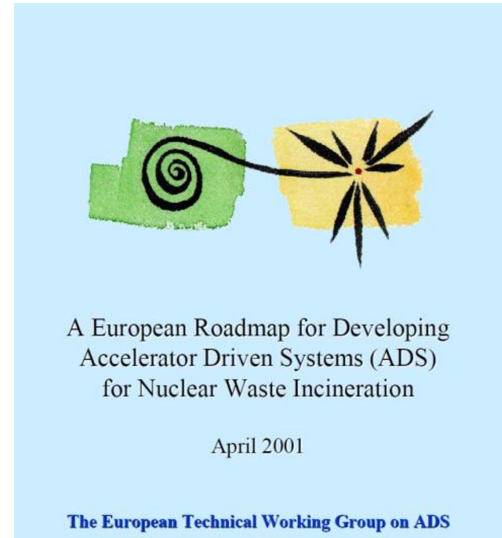
And sorry for the oversights if any !

NEEDS & INTEREST FOR COUPLING EXPERIMENTS ON ZPR

Background

- ***ADSs present many challenges***
  - *- accelerator,*
  - *- spallation module,*
  - *- subcritical core, fuel and fuel cycle,*
  - *- operation, safety, licensing*

- ***Roadmap for developing ADSs in EU***



Phase 1	Phase 2	Phase 3
Validation of the different components in a standalone way (accelerator, target, fuel, core,…)	Validation of the coupling of the components at a significant power with using the existing facilities	Demonstration at a few 10s of MW in a facility to be designed and constructed
- Zero power facilities - Fuel of a well proven type - Well known neutron spectrum	- Beam power ~1 kW - Total core power < 1 MW	- XADS (50-100 MWth)

FP5 → FP6 → FP7 …

NEEDS & INTEREST FOR COUPLING EXPERIMENTS ON ZPR

Interest of zero power facilities

- ***Flexibility***
  - *- many cores arrangements possible*
  - *- moving from one configuration to another needs some days/weeks*

➔ *parametric studies*

➔ *well mastered experimental conditions*

➔ *easy to instrument (the fissile zones too)*

- ***Very low power***
  - ***- absence of thermal effects***
  - ***- no consumption of fuel***
  - *- no major radioprotection issues*
  - *- no build-up of fission products*
  - *- no pressurized fluid circuits*

➔ *wide range of measurements*

➔ *appropriate for validation of both nuclear data and calculation methods*

➔ *also relevant for evaluation of new experimental techniques and analysis methods*

- *Limited maintenance and operating costs*

NEEDS & INTEREST FOR COUPLING EXPERIMENTS ON ZPR

Main physics concerns of ADSs that can be addressed on ZPRs

- ***Proton beam/Spallation target device***
  - properties of radiation fields around the target depending on the beam energy, the materials of the target (Pb, Pb-Bi, W, Ta, U), its geometry, …

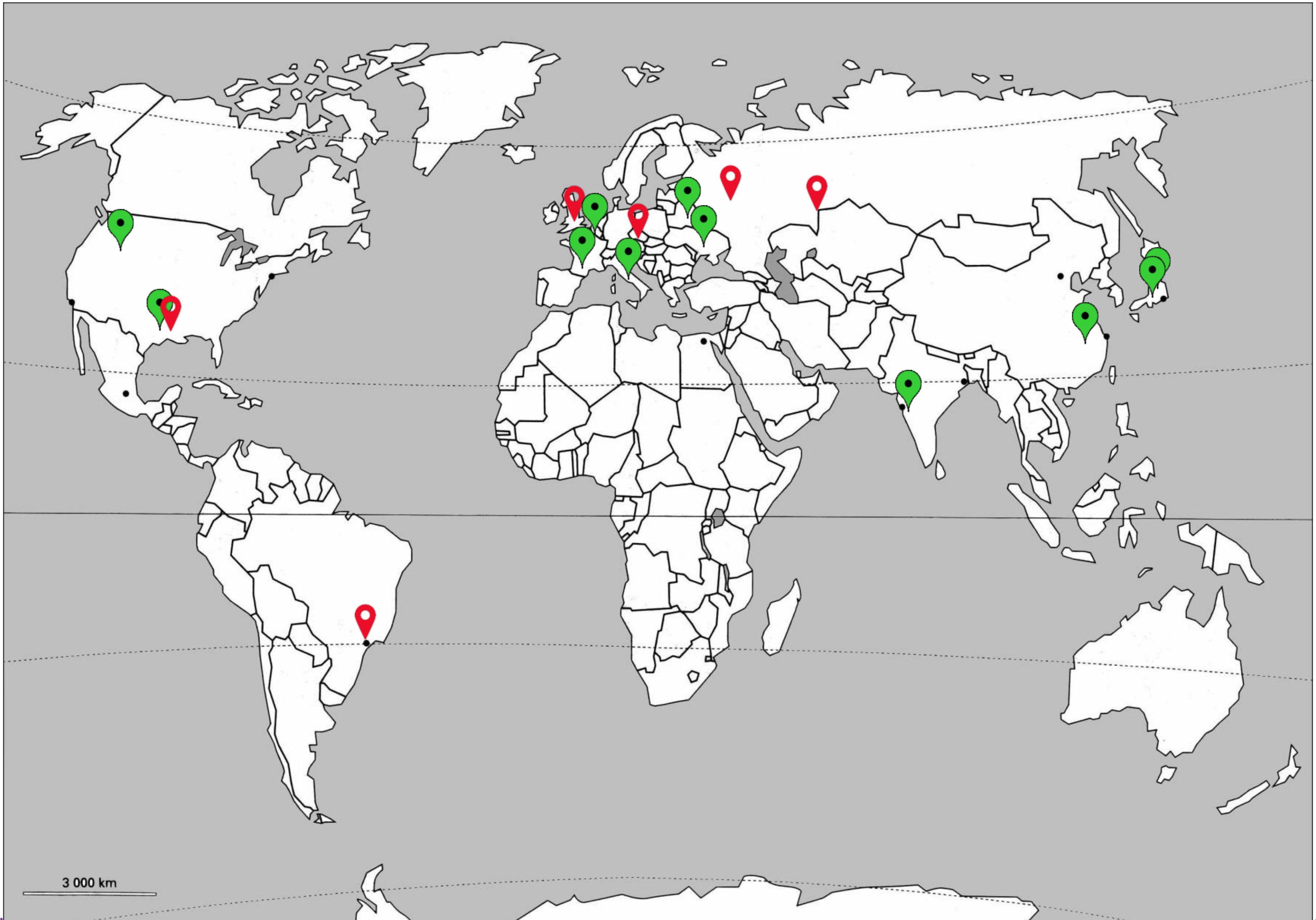
- ***Coupling of external neutron source with the subcritical core***
  - spatial and energy distribution of neutrons into the core,
  - time evolution of neutron population depending on the position
  - source importance as a function of neutron energies, source position, …

- ***Safe operating of the system***
  - reactivity calibration at core loading and beginning of cycle
  - monitoring of the reactivity during operation

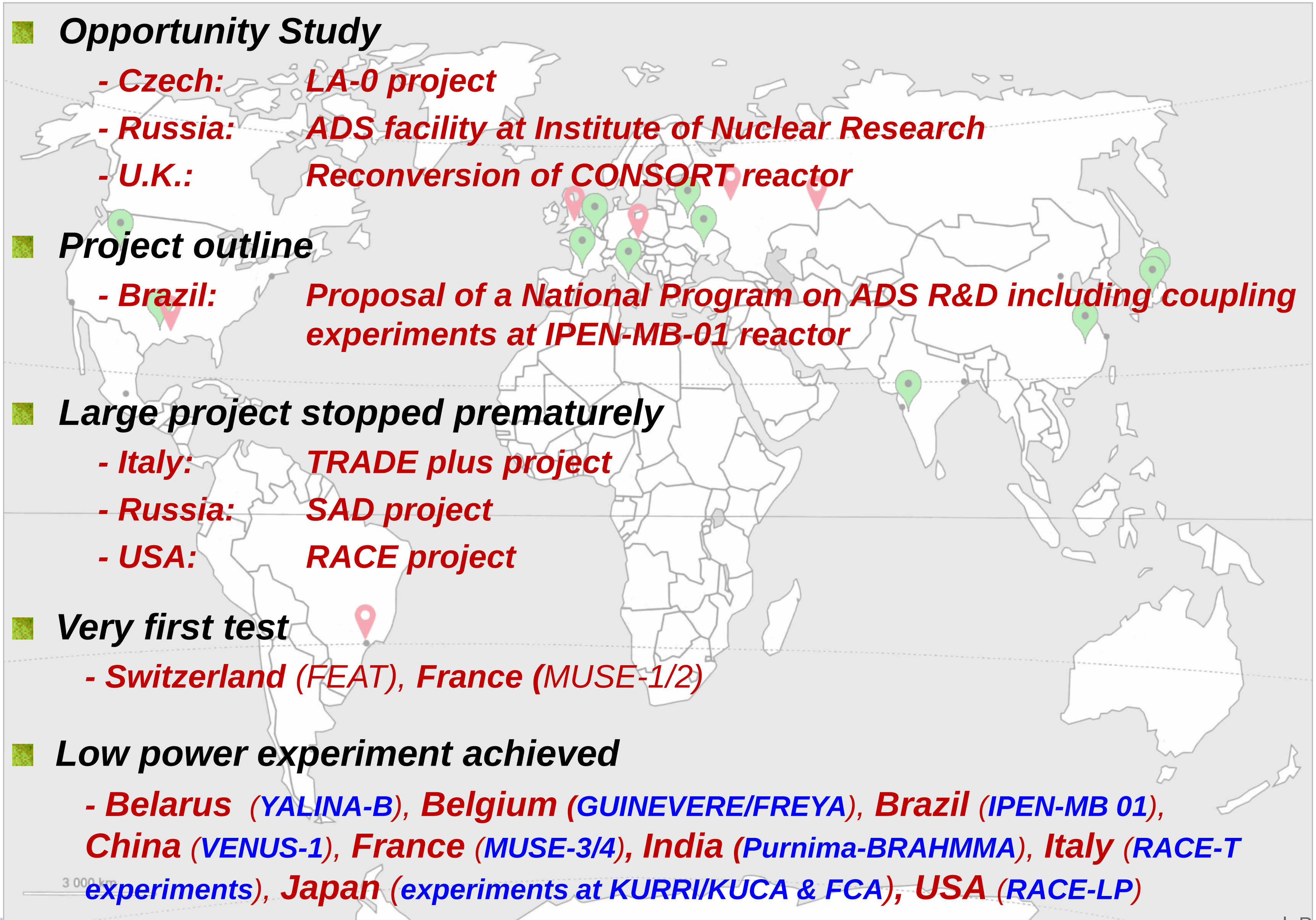
- ***Improvement of nuclear data (neutron cross sections > 20 MeV)***
  - reaction rate distribution

- ***Evaluation/validation of calculation methods***
  - benchmarking on codes and ND libraries

BRIEF REVIEW OF INITIATIVES WORLD-WIDE



BRIEF REVIEW OF INITIATIVES WORLD-WIDE



- ***Opportunity Study***
  - ***- Czech:*** ***LA-0 project***
  - ***- Russia:*** ***ADS facility at Institute of Nuclear Research***
  - ***- U.K.:*** ***Reconversion of CONSORT reactor***
- ***Project outline***
  - ***- Brazil:*** ***Proposal of a National Program on ADS R&D including coupling experiments at IPEN-MB-01 reactor***
- ***Large project stopped prematurely***
  - ***- Italy:*** ***TRADE plus project***
  - ***- Russia:*** ***SAD project***
  - ***- USA:*** ***RACE project***
- ***Very first test***
  - ***- Switzerland** (FEAT), **France (**MUSE-1/2)*
- ***Low power experiment achieved***
  - ***- Belarus** (**YALINA-B**), **Belgium** (**GUINEVERE/FREYA**), **Brazil** (**IPEN-MB 01**), **China** (**VENUS-1**), **France** (**MUSE-3/4**), **India** (**Purnima-BRAHMMA**), **Italy** (**RACE-T experiments**), **Japan** (**experiments at KURRI/KUCA & FCA**), **USA** (**RACE-LP**)*

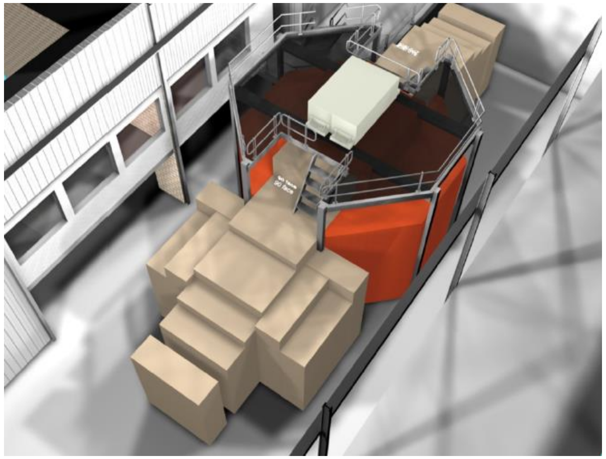
BRIEF REVIEW OF INITIATIVES WORLD-WIDE

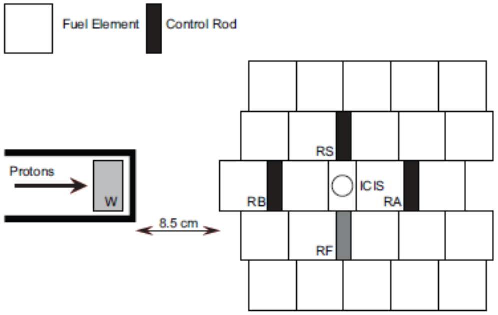
Opportunity study / Project outline

- **Czech Republic:** *Proposal for a molten fluoride salt experimental loop in the LR-0 research reactor and further coupling with protons and a W target (LA-0 project, mid 1990s)*

- **Russia:** *Proposal of an ADS stand of ~5 MWth using INR linear proton accelerator (300-600 MeV, some 100 μA), W or Pb-bi targets, LEU, (early 2010s)*

- **United Kingdom:** *Reconversion of CONSORT reactor (100 kW) in an experimental subcritical facility (early 2010s)*





Schematic drawing of the subcritical driven core

CONSORT reactor

Opportunity study / Project outline

- Brazil: *Sketch of a National ADS R&D Program (early 2000s)*

Idea of coupling IPEN-MB 01 critical assembly with

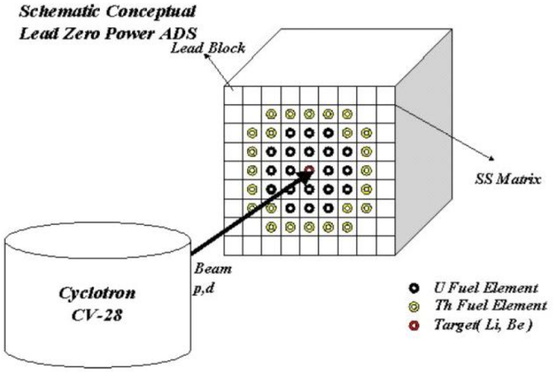
1- a D-D/D-T neutron generator developed by Lawrence Berkeley National Laboratory)

2- a cyclotron (IPEN CV-28) delivering 24 MeV protons impinging a Be target

View of IPEN-MB-01 core

Conceptual design of a lead subcritical core using U/Th fuel

View of IPEN CV-28



BRIEF REVIEW OF INITIATIVES WORLD-WIDE

- ***Large project stopped prematurely***

Italy / TRADE plus

Russia / SAD

USA / RACE-HP

Intermediate power coupling experiments

Necessary for gaining experience with the operating of ADSs

Core powers in the range 20 – 100 kW for all

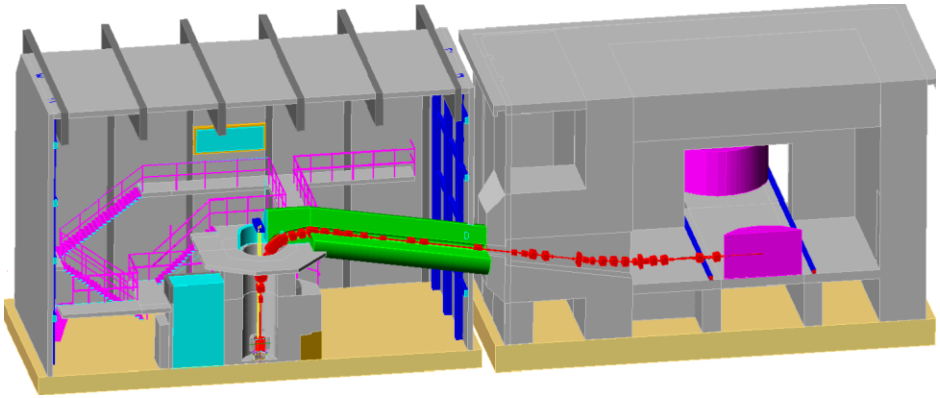
k_{eff} ranging from 0,95 to 0,99

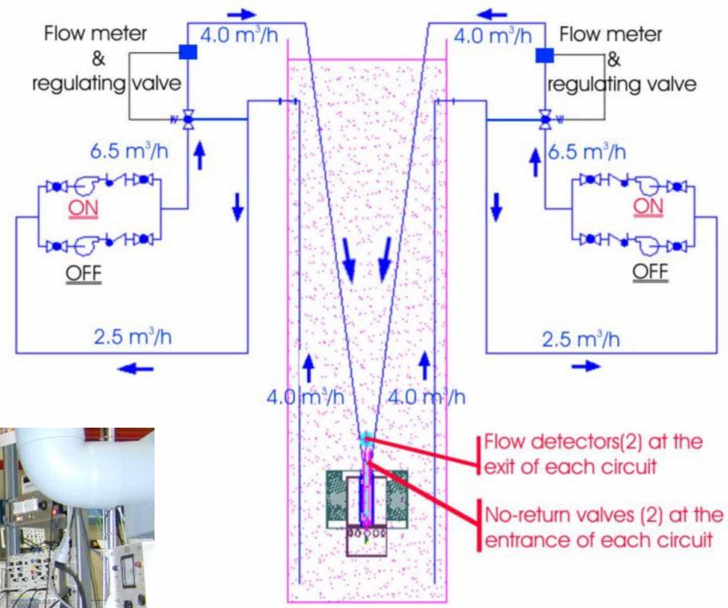
Abandoned by lack of funding

Project stopped prematurely

- *Italy / TRADE plus project (2001 - 2005 / FP6 IP-Eurotrans)*

- *150 MeV protons (cyclotron) (0.1 mA beam current)*
- *Ta target*
- *EXISTING thermal core (ENEA RC-1 TRIGA reactor)*





- Pre-TRADE experiments achieved using Am-Be source and D-D/D-T generator (2004-2006)

BRIEF REVIEW OF INITIATIVES WORLD-WIDE

- ***Project stopped prematurely***

  - Russia / SAD project (2000 – 2006 / ISTC#2267 + support of EU partners)

  - EXISTING 660 MeV protons from JINR-Dubna phasotron (some μA)
  - Pb target (air cooled)
  - fast subcritical core (MOX fuel),

SAD closest system from power ADS

Dubna proton accelerator

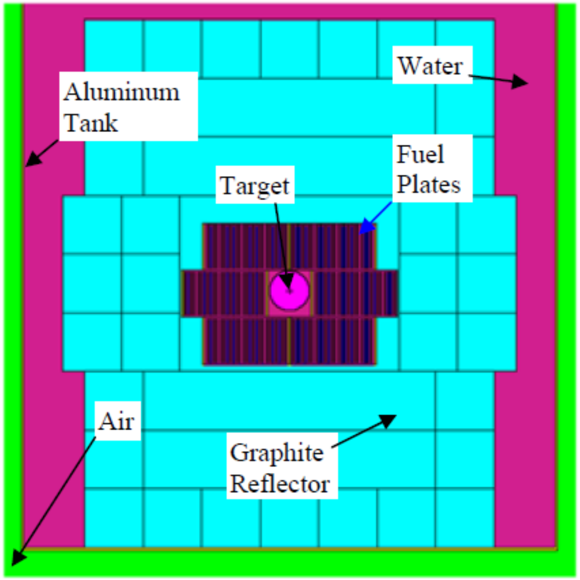
SAD Basic data

k_{eff}	~0,95
Fuel loading	< 420 kg
Fission power	27,6 kW
Cooling	air
Core	
Coolant flow rate, G	~ 0,6 kg/s
velocity, v	10 m/s
Presure, P *(inlet)*	0,12-0,135 MPa
Temperature, T *(inlet, outlet)*	50/96 °C
Target (Pb)	
Coolant flow rate, G	~ 0,0067 kg/s
Velocity, v	50 m/s
Pressure, P *(inlet)*	0,12-0,135 MPa
Temperature, T *(inlet, outlet)*	50/125 °C

Project stopped prematurely

- USA / RACE-HP (High power) (2003 - 2007 / AFCI + Mou IP-Eurotrans)

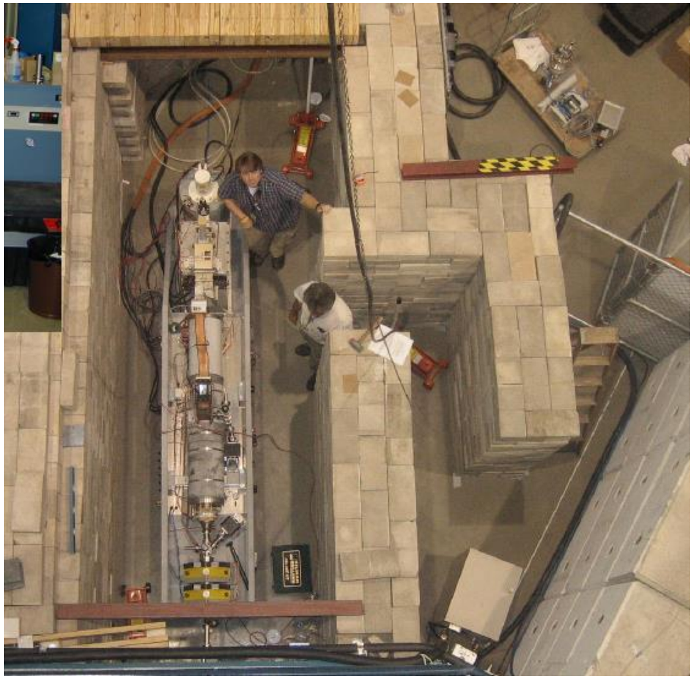
- EXISTING 20 MeV electrons (portable LINAC)
(80-100 mA beam current => 2 kW max.)
- Prototype W-Cu target (water cooled)
- EXISTING thermal cores (UT NETL & TAMU TRIGA) reactors



IAC full core configuration

- zero power experiments achieved at ISU-IAC (RACE-LP).
Main outcome: PNS techniques are applicable with an e^- LINAC

- very preliminary experiments at UT-NETL at low core power
(< 100 W) (many operationnal problems to solve)



LINAC in place at UT NETL TRIGA

BRIEF REVIEW OF INITIATIVES WORLD-WIDE

Low power experiments completed

Country	Project	Period	Facility	Operator	Type of facility	Core	Neutron source
Belarus	Yalina-Thermal	2000 - 2005	YALINA	JIPNR	Subcritical assembly (keff < 0,98)	Thermal	252Cf, Am-Be, D-D/D-T generator (NG-12-1)
	Yalina-Booster	2005 - 2008				Fast/Thermal	
Belgium	GUINEVERE, FREYA	2006 - 2016	VENUS-F	SCK	Zero power critical assembly	Fast	Am-Be, D-D/D-T generator (GENEPI 3C)
☆ Brazil	-	2014	IPEN-MB-01	IPEN	Zero power critical assembly	Thermal	Am-Be
China	NBRPC	2005 -	VENUS-1	CIAE	Subcritical assembly (keff < 0,98)	Fast/Thermal	^{252}Cf, Am-Be, D-D/D-T generator (CIAE PNG)
France	MUSE-1	1995	MASURCA	CEA	Zero power critical assembly	Fast	^{252}Cf
	MUSE-2	1996					^{252}Cf
	MUSE-3	1998					D-T generator (Sodern Genie 26)
	MUSE-4	1999 - 2004					D-D/D-T generator (GENEPI 1)
India	-	2013 -	PURMINA BRAHMMA	BARC	Subcritical assembly (keff ~ 0,85 - 0,9)	Thermal	D-D/D-T generator (BARC PNG)
Italy	TRADE phase I (RACE-T)	2004 - 2006	ENEA RC-1	ENEA	TRIGA (1 MW MarkII)	Thermal	^{252}Cf
							Commercial D-T generator
☆ Japan	FCA XX1-1	2001	FCA	JAEA	Zero power critical assembly	Fast	^{252}Cf + W test zone
Japan	KART, Lab project	2002 -	KUCA	KURRI	Zero power critical assembly	Thermal	D-D/D-Tgenerator
							100 MeV protons / W target
USA	RACE	2004 - 2007	ISU subcritical assembly	ISU-IAC, UNLV, UT, TAMU	Subcritical assembly (keff ~0,90)	Thermal	20-25 MeV electrons (LINAC) + W-Cu target
			UT NETL		TRIGA (1 MW Mark II)	Thermal	

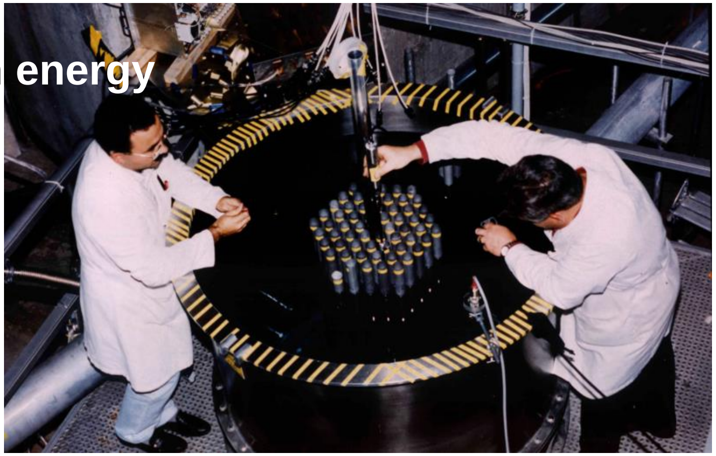
ACHIEVED COUPLING EXPERIMENTS

- ***The very first tests : FEAT, MUSE-1 & 2***
- ***MUSE-3***
- ***The MUSE-4/GUINEVERE/FREYA suite***
- ***The YALINA-B experiment***
- ***Activities IN KURRI/KUCA***
- ***Others programs***

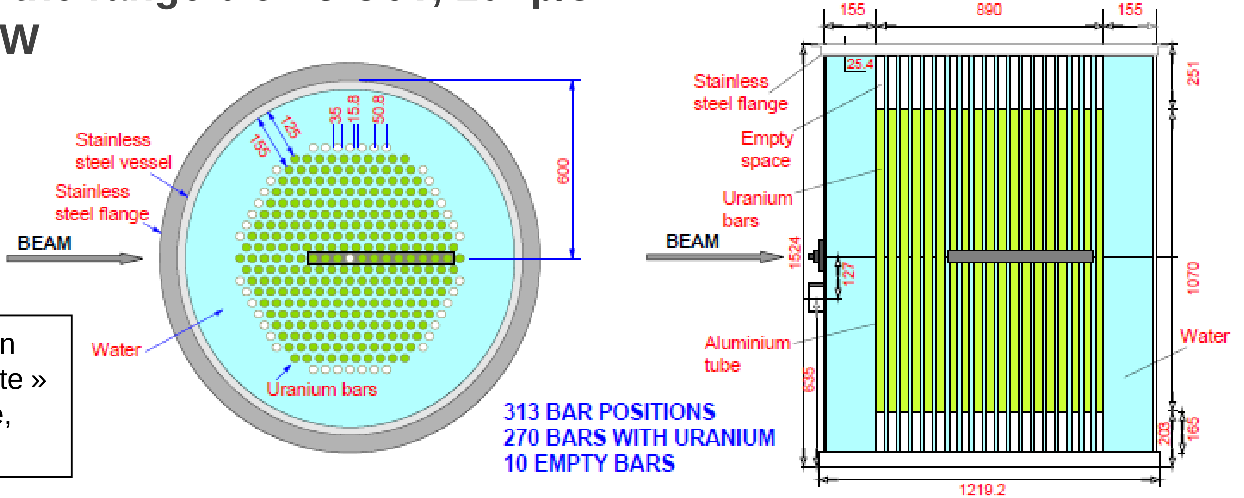
THE BEGINNINGS : FEAT, MUSE-1/2

FEAT : First Energy Amplifier Test (1994 / CERN)

- Objectives:
  - Study the Energy gain as a function of proton energy
  - Validate Monte Carlo simulation



- Set-up:
  - 3.5 tons of U_{nat} immerged in water
  - $k\infty = 0.97$, $k_{source} \sim 0.91$
  - Proton beam from CERN PS accelerator
  - Proton energy in the range 0.5 - 3 GeV, 10^8 p/s
  - Beam power ~ 1W
  - Target : Pb, W



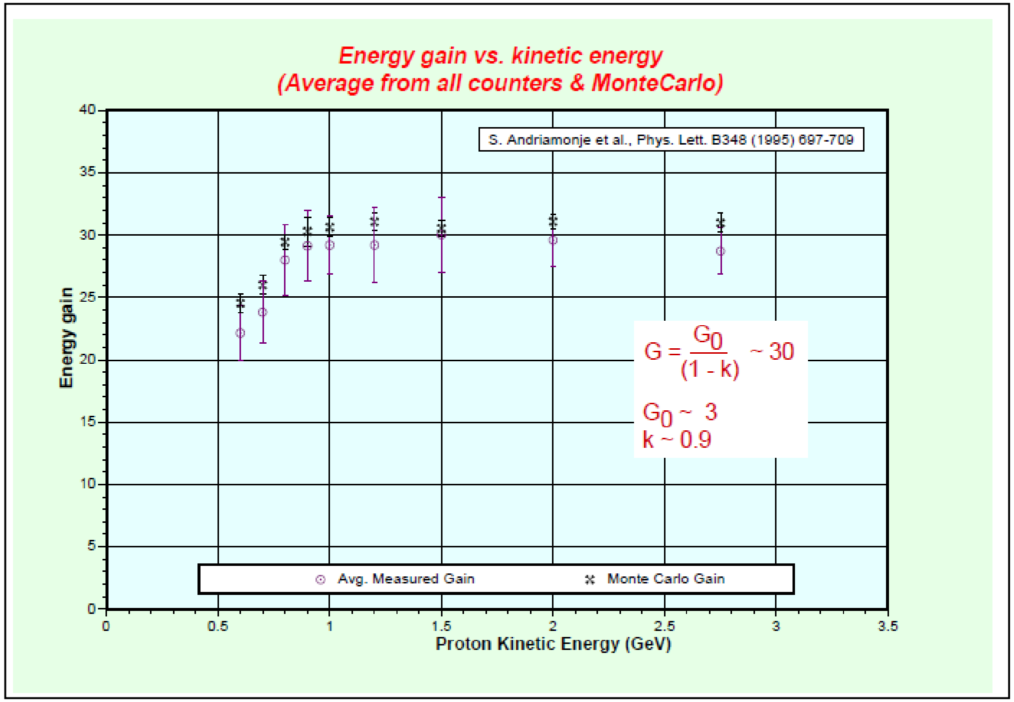
313 BAR POSITIONS
270 BARS WITH URANIUM
10 EMPTY BARS

« Demonstration of an Accelerator-Driven System for the Destruction of Nuclear Waste » Y. Kadi, J.-P. Revol – Workshop, Trieste, September 2001 »

FEAT : First Energy Amplifier Test (1994 / CERN)

- Objectives :
  - Study of the ratio ''Energy produced in the device / Beam energy'' (Energy gain as a function of proton energy)
  - Monte Carlo code validation

- Main results
  - Optimum proton energy at ~900 MeV
  - Phenomena well predicted by MC simulation



S. Andriamonje & al., "Experimental determination of the energy generated in nuclear cascades by a high energy beam", Physics Letter B, Volume 348, Issues 3-4, 6 April 1995, Pages 697-709

THE BEGINNINGS : FEAT, MUSE-1/2/3

MUSE-1 & 2 : first parametric studies (1995-1996 / CEA+CNRS)

- **Short tests** (2 weeks & 2 months) taking advantages of fast cores loaded in the MASURCA facility at CEA /Cadarache for programs underway at that period (Mox fuel, Pu content ~24.5%)
- **Neutron source = ^{252}Cf** (7.6 10^7 & 6.1 10^7 n/s) at different axial positions (mid core plane, +15 cm , +25 cm)
- Two different diffusing materials (sodium, steel) placed around the source
- Measurements of : reactivities (standard method used for critical reactors), ^{235}U fission rate distributions, source importance

- **Main results**
  - **feasibility of measurements at deep subcritical levels confirmed**
  - **demonstration the source effect/importance (more "peaked" distributions as expected)**
  - **good agreement between calculations and experiments (deterministic and MC simulations)**

THE MUSE-3 EXPERIMENT AT MASURCA FACILITY

MUSE-3 experiments (1998 / CEA+CNRS+EDF+FRAMATOME)

- Enlargment of collaboration between french institutes (GEDEON research network)

- **Several subcritical cores** (k_{eff} = 0.995, 0.99, 0.985, 0.95)

- Neutron source = SODERN genie 26 D-T pulse generator at core center (3, 10^8 n/s)

- Two different diffusing materials (sodium, lead) placed around the source

- Measurements of : reactivity (standard method, PNS/fit method), ^{235}U fission rate distributions, source importance

- **<u>First Pulsed Neutron Source measurements</u>** and first difficulties with the analysis of data

Main outcome of the program

- need for a dedicated neutron generator with improved performances (in terms of quality of the pulse and source intensity)

➔ GENEPI (GEnerator of NEutrons Pulsed & Intense)

- Designed and built by CNRS

MUSE-4 project (2000-2004 / Euratom FP5)

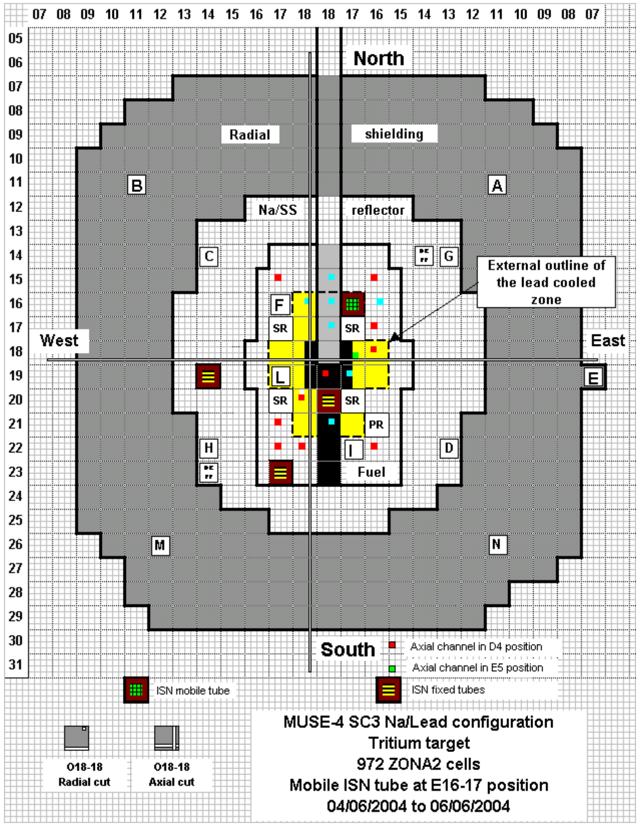
- international collaborations (FP 5 /12 partners; bilateral collaborations with DOE, PSI and JAERI)

*- **fast Mox core especially designed** for the program **(lead zone simulating a spallation target)***

- horizontal beam line

- licencing of the experience more time consuming due to the presence of GENEPI and the physics of a coupled systems (first of a kind for our safety authorities)

- Five phases : critical, SC0 (0,994), SC2 (0,97), SC3 (0,97), SC3 Na/Pb (0,965)



*- **extensive characterization** of the cores*

- not only ^{235}U fission rate distributions; also : ^{232}Th, ^{238}U, ^{237}Np, $^{239, 240, 242}Pu$, ^{241}Am …, a number of dosimeters , ..

- measurement of kinetics parameters

THE MUSE-4/GUINEVERE/FREYA SUITE

- ***MUSE-4 project (2000-2004 / Euratom FP5)***

  - much time and effort devoted to the reactivity control issue (without a priori for their applicability)

Nature of neutron source	Analysis method		Experimental parameter
Core intrinsic source	Reference method (rod drop + Multiplication source method)		$\rho_{\$}$
	Rossi-α method		α_p
	Feynman-α method		
	APSD and CPSD methods		
^{252}Cf source	Rossi-α method		α_p
	Source jerk method		$\rho_{\$}$
Pulsed neutron source	Area method		$\rho_{\$}$
	Slope fit methods (several kinetics models : one/two/three zones; one/two energy groups)		α_p
	k_p method		k_p
	Rossi-α method		α_p
	Feynman-α method	Deterministic way	
		Stochastic way	
	APSD and CPSD methods		
	Frequency variation method		$\rho_{\$}$

More than 10 methods (Pulsed neutron source)

THE MUSE-4/GUINEVERE/FREYA SUITE

- ***MUSE-4 project (2000-2004 / Euratom FP5)***
  - ***- several theoretical developments in support of analysis :***
    - *- derivation of Feynman-a functions considering a pulsed source*
    - *- development of a new kinetics model based on the neutron inter-generation lifetime distribution (the k_{promt} method),*

S. Chabod & al., "Reactivity Measurement at GUINEVERE Facility Using the Integral kp Method, PHYSOR 2014, Kyoto, Japan, Sept. 28th–Oct. 3rd

Main outcome

- a proposal of strategy for the control and monitoring of the reactivity based on :

- PNS measurements for the control of reactivity at BOC (and a selection of most appropriate methods : area method, k_{prompt} method, fit methods),

- continuous monitoring of the beam current/flux ratio (monitoring of source to be implemented in next programs)

- intermediate cross checking, during operation, taking advantage of regular and short beam interruption)

➔ New specifications for next external neutron source
➔ Base for futur experimental program to be performed in FP 6 IP-EUROTRANS

THE MUSE-4/GUINEVERE/FREYA SUITE

- ***GUINEVERE (2005-2010 / Euratom FP6 – IP Eurotrans)***

  - facing with abandoning of TRADE plus project, SCK-CEN proposed to host the continuation of MUSE-4 in the VENUS facility

  - only preparatory work could be achieved during FP 6 time window:

  - ***transformation of the VENUS facility*** *(initially devoted to light water reactor studies)* ***into a fast critical assembly VENUS-F***

P. Baeten, "The GUINEVERE project at the VENUS-F facility", Proceedings of the International Conference on the Physics of Reactors - PHYSOR 2008, Interlaken, Switzerland

THE MUSE-4/GUINEVERE/FREYA SUITE

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  - ***development of a new generator*** *able to operate in* ***continuous wave, pulsed and beam trip modes***

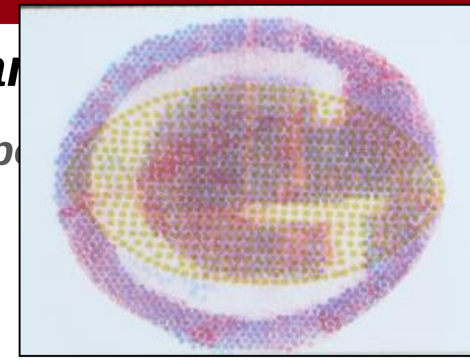
Table 1: Beam specifications.

Pulsed mode	**Continuous mode**
Peak current: 40 mA	Mean current: 160 µA to 1 mA
Repetition rate: 10 Hz to 5 kHz	Beam interruption rate: 0.1 to 100 Hz
Pulse width: ~0.7 µs (FWHM)	Beam interruption duration: ~20 µs to 10 ms
Reproducibility: 1% pulse to pulse	Transition time on/off: ~1 µs

M. Baylac, "The GENEPIC-3C accelerator for the GUINEVERE project", International topical meeting on nuclear research applications and utilization of accelerators; Vienna (Austria); 4-8 May 2009

THE MUSE-4/GUINEVERE/FREYA SUITE

GUINEVERE (2005-2010 / Euratom FP 6 – IP Eurotra



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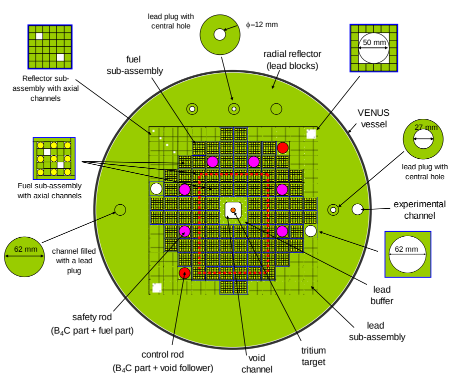
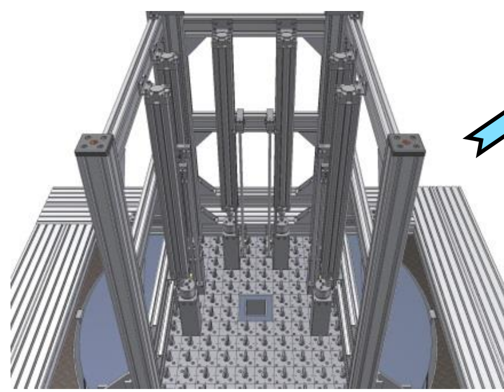
- ***transformation of the VENUS facility*** *(initially devoted to light water reactor studies)* ***into a fast critical assembly VENUS-F***

- development of a new generator able to operate in continuous wave, pulse and beam trip modes

- design & building of a brand new core, preparation of safety file, licencing





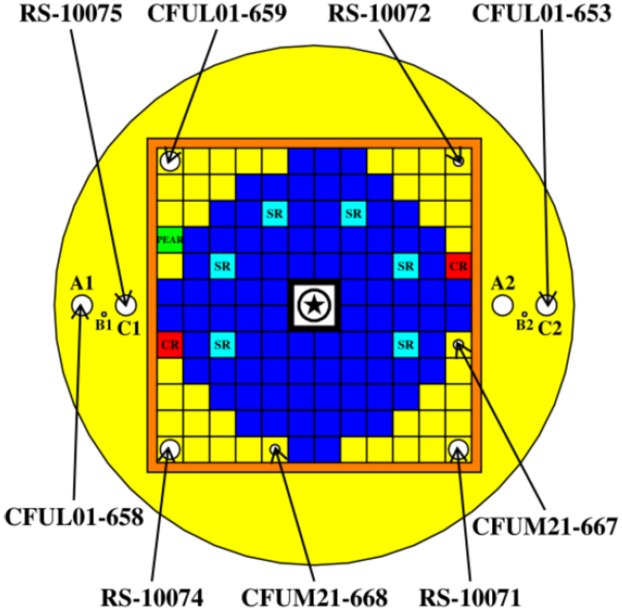
- first criticality on february 2011

- experimental program to be conducted in next program (FREYA / FP 7)

THE MUSE-4/GUINEVERE/FREYA SUITE

FREYA (2011-2016 / Euratom FP7)

*- better representativity of ADS : **a full fast lead system** (core+reflector) , an **axial beam line**, an **external source** allowing to operate in **CW mode and with short beam interruptions**, most of detectors out-core*



- experimental program in the line of MUSE-4 and also taking into account the outcomes and lessons from YALINA-B

*- **extensive measurement** program **in the three modes** (pulsed, CW, BT) of neutron generator*

THE MUSE-4/GUINEVERE/FREYA SUITE

FREYA (2011-2016 / Euratom FP7)

- again much effort devoted to the reactivity calibration and monitoring issue

- most of detectors out of core

*- results compared to a **robust reference** established in critical configuration (as it was also in MUSE-4)*

J.L. Lecouey & al., "Estimate of the reactivity of the VENUS-F subcritical configuration using a Monte Carlo MSM method", Annals of Nuclear Energy 83 (2015) 65-75

- reactivity calibration:

- ❑ *confirmation of **accuracy and robustness of area method***

- ❑ *confirmation of **potential of k_{prompt} method for <u>short time measurements</u>***

- reactivity monitoring:

- ❑ ***detailed and successfull analysis of beam trip experiments***

T. Chevret, ''Mesure de la réactivité de réacteurs sous-critiques pilotés par accélérateur par l'analyse d'expériences d'interruptions de faisceau programmées'', 2016, Thesis

THE YALINA-BOOSTER EXPERIMENTS

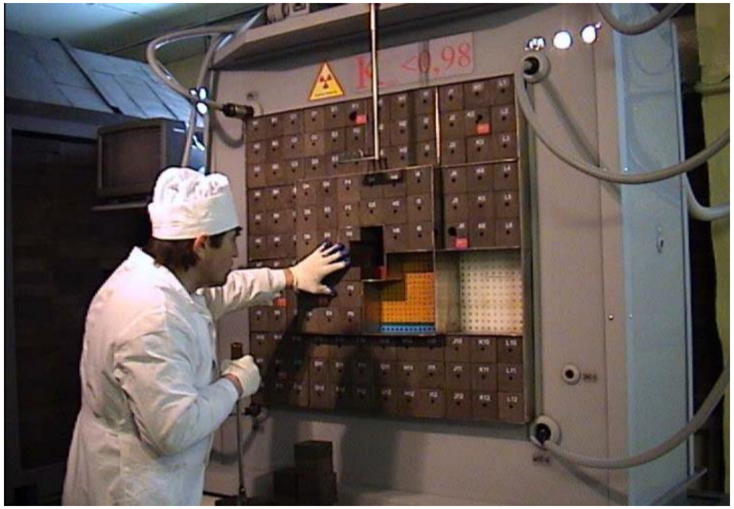
- ***YALINA (''spruce'' in Belarus langage)***

  - ***subcritical facility (k_{eff} < 0,98),***

  - ***purpose : investigate the static and dynamics behaviour of ADS and properties of MA transmutation reactions***

  - ***^{252}Cf, Am-Be, D-D/D-T generator (up to 1,5 10^{12} n/s with rotating TTi target device)***

  - ***first operation in the early 2000s***



- ***Initially, thermal core using LEU (10%)***

- ***New configuration Yalina-Booster (2005-2006)***

  - more representative of ADS neutron spectrum (central fast zone)
  - **first experiments with beam trips** (nevertheless polluted by electromagnetic interference)
  - appreciation of reactivity measurement results accuracy remains difficult due to the lack of reference
  - participation of IP EUROTRANS partners to the experiments and further analysis

V. Becares, Evaluation of reactivity monitoring techniques at the Yalina – Booster subcritical facility, 2014, Thesis

ACTIVITIES AT KUCA (KYOTO UNIVERSITY CRITICAL ASSEMBLY)

- **Critical facility (100 W max.)**
  - Enriched uranium core moderated and reflected by high density polythen (A core)

- **2002: launch of the KART project (five years) with the aim of**
  - Constructing of a FFAG (Fixed Field Alternating Gradient)
  - Coupling it at KUCA A core
  - *First experiments with 14 Mev neutrons from D-T generator*

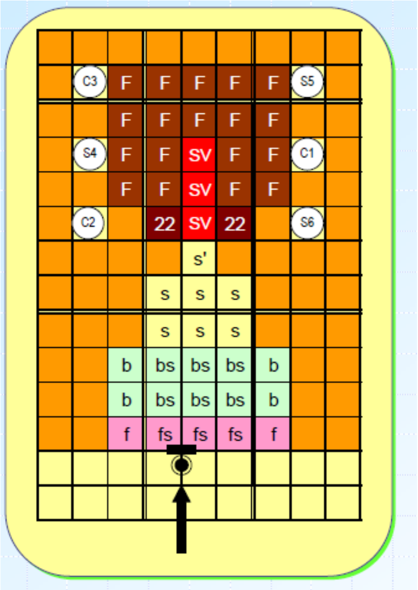
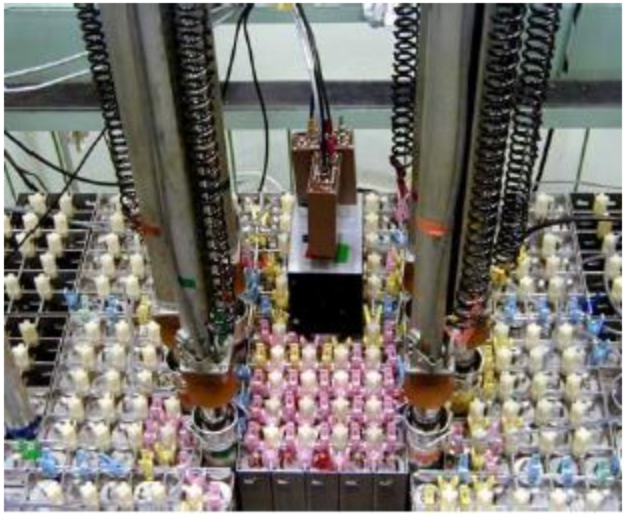


Fig. KUCA A-core with neutron guide




Cockcroft-Walton type Accelerator

ACTIVITIES AT KUCA (KYOTO UNIVERSITY CRITICAL ASSEMBLY)

- **2008**
- **Marc** … **W targ**
- **Marc** … **rget locat**

- **Since : further studies with different spallation targets + D-T generator, various Th cells and fuel, several sucritical levels + critical states, different target positions, …, many publications**

OTHER PROGRAMS

- ***BRAHMMA experimental facility (India/BARC, 2013)***
  - **subcritical facility,** Made in India D-T generator
  - **natural uranium core moderated by high density polythen + Be0 reflector**
  - **series of PNS and source jerk experiments with keff in the range [0.89 ; 0.95]**
  - **analysis with point kinetics without any added correction; few results published**

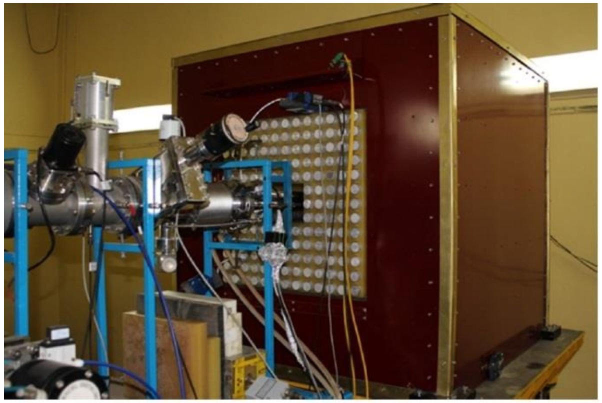
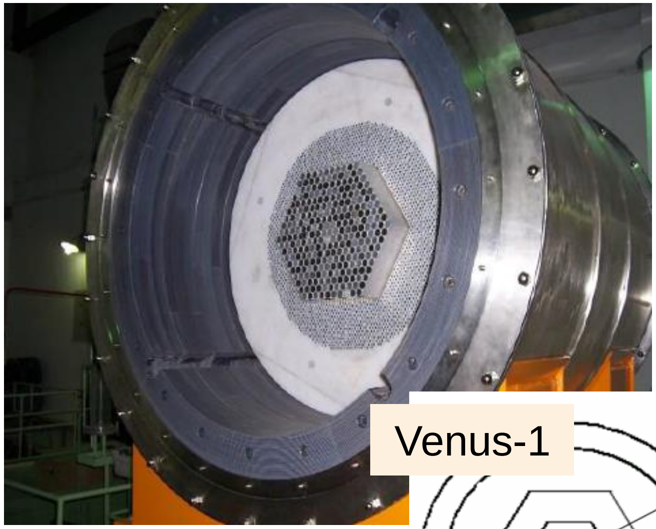
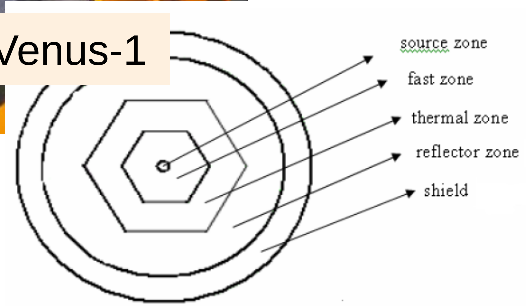


Fig. 3. BRAHMMA subcritical core coupled with neutron generator.



Venus-1

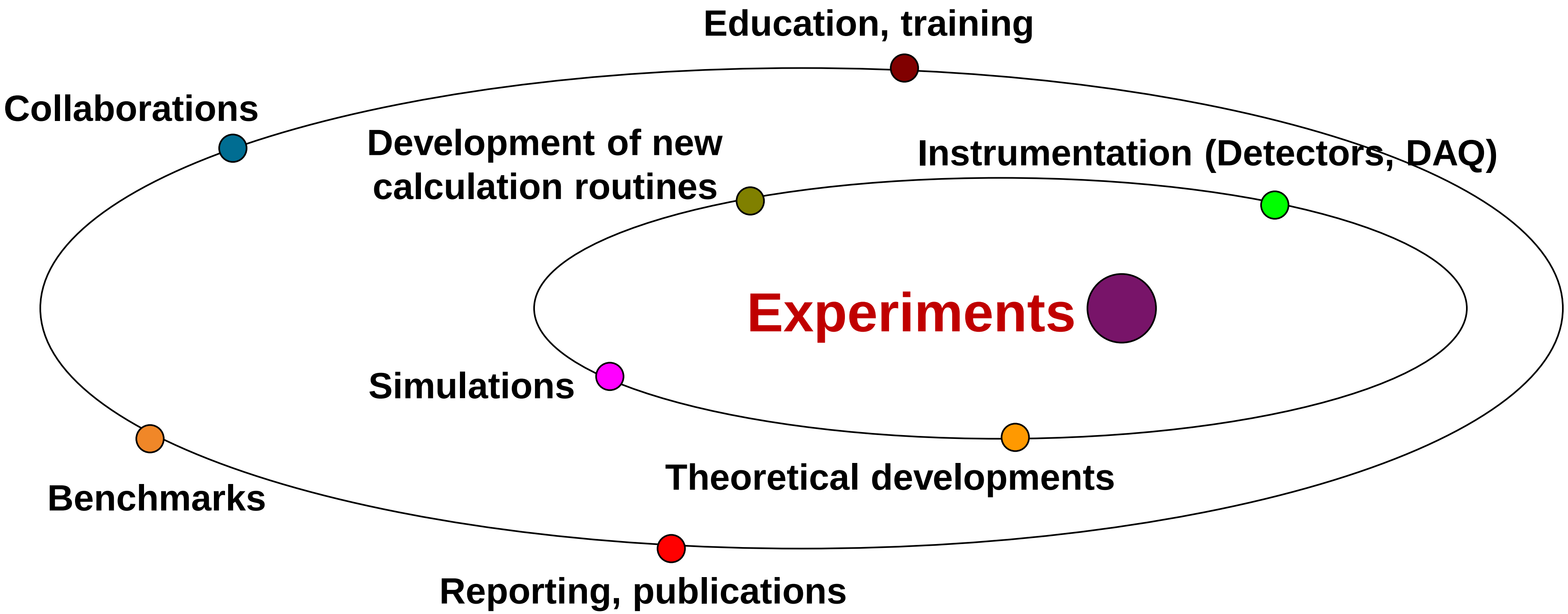


- ***VENUS-1 experimental facility (China, 2005)***
  - **Subcritical facility (keff < 0.98)**
  - **Coupled fast/thermal zones, CH_2 reflector**
  - **CIAE Pulsed Neutron generator**
  - **first coupling in 2005, five keff**
  - **PNS experiment analysis work in 2007**
  - **PNS simulation work in 2011**

Programs that used only radioactive neutron sources

- ***FCA XXI-1***
  - FCA (Fast Critical Assembly), similar to MASURCA, operated by JAEA
  - FCA XXI-1 core devoted to investigations on measurement of deep subcritical levels
  - ^{252}Cf + W test zone at core center
  - FCA design serves as a reference for TEF-P

- ***Experiments at IPEN-MB-01***
  - Critical facility for light water cooled reactor studies
  - Tests with an Am-Be neutron source for investigating a new experimental approach for the determination of subcritical levels using the '**generalized reactivity kinetic model**' (A. Gandini & al., Journal of Nuclear Science and Technology 39 6 pp 673-686)



- **Extensive Monte Carlo simulations (much less in the early 90's)**
- New approaches and kinetics models developed for the determination of subcritical levels (standard PK model is no more valid !)
- Much work on noise methods (ex : derivations of Feynman-α formulae considering PNS)

CONCLUSIONS

- **For more than 20 years, coupling experiments on ZPR have been motivating many teams worldwide,**
- **Different realizations (of unequal size) were carried out although some aspects (fuel and neutron spectrum in particular) were not always representative of a power ADS.**
- **Some experiments combining the three main components of ADS (high energy protons, a heavy metal target, a subcritical core) could be achieved**
- **The control and monitoring of reactivity is a shared key issue that concentrated most effort in EU initiatives and valuable progress have been made in this field (R&D conducted on this item is also relevant for critical reactors),**
- **Further advances will need higher power experiments (core power of several tens/hundreds of kW). They remain a major objective.**

CONCLUSIONS

Next steps

- **MYRTHE project in Belgium**
  - follow-up of FREYA in VENUS-F facility, next step forward MYRRHA
  - funded by HORIZON 2020 EU Research and Innovation Program
- **Commissioning of NSC KIPT ADS in Ukraine**
- **CLEAR-0 facility and associate experimental programs in China**

(more information in the upcoming presentation)

Beyond !

The future is the result of chance, of will and necessity
(Jacques Lesourne / French economsist engineer)

Thanks for your attention

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