Workshop on Applications of High Intensity Proton Accelerators

WG4: Subcritical Core Summary

Presented

by

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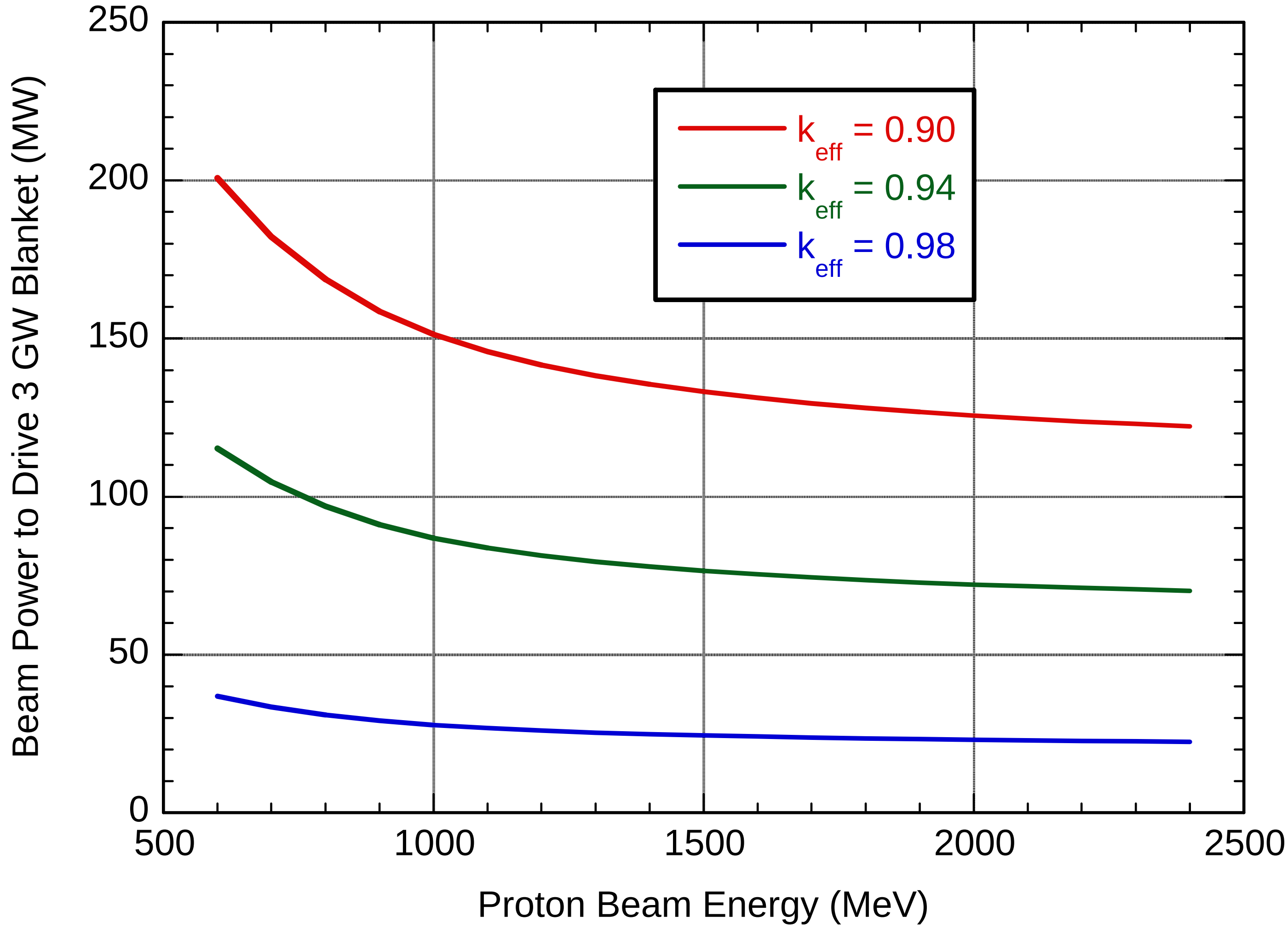
WG4: Subcritical Core Summary

Beam Power Requirements as a function of the proton energy

(for example 4 MW beam of 600 MeV protons generates 100 MW_{th} with 0.98 keff)



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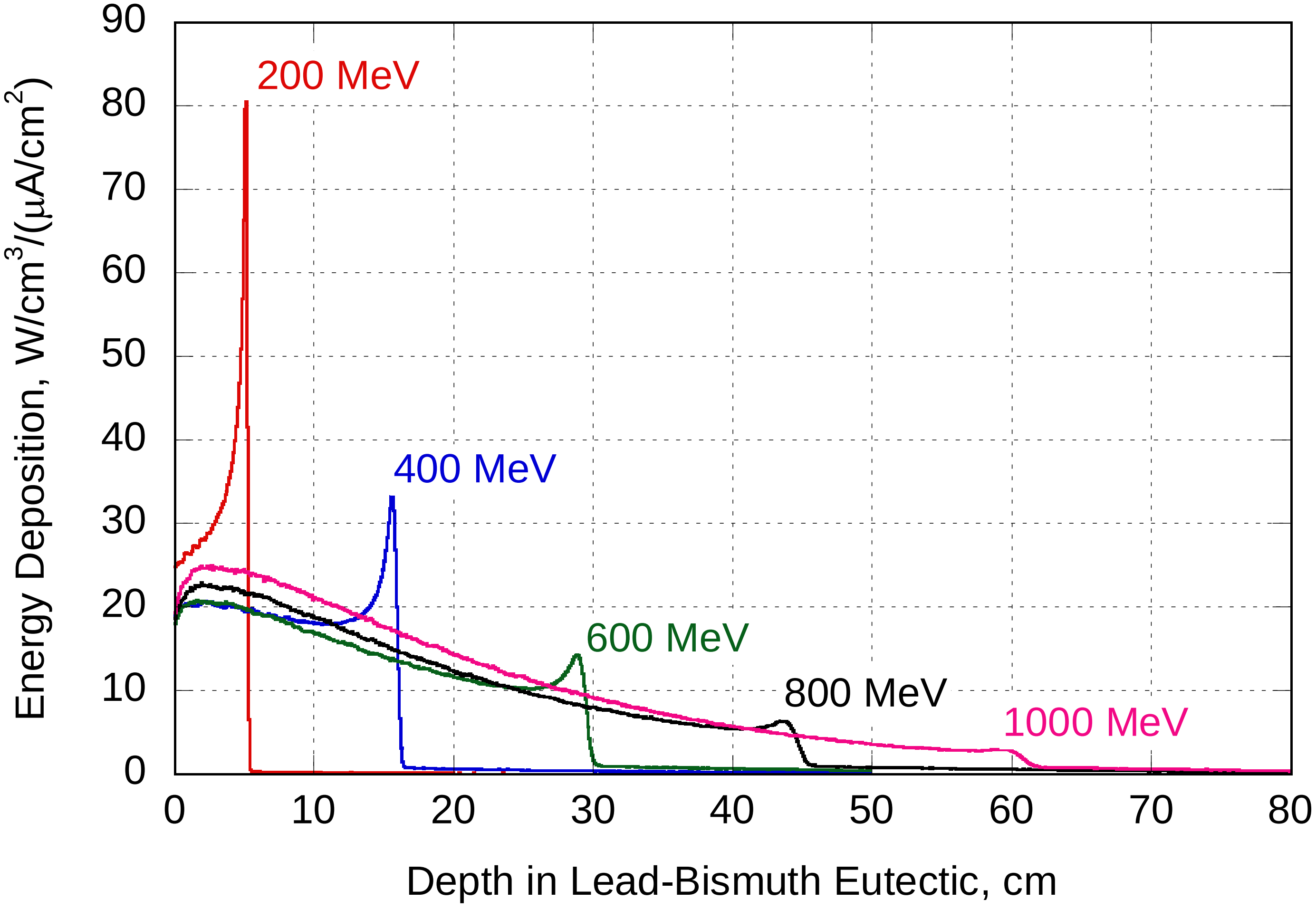
Spatial Energy Deposition in the Lead-bismuth Eutectic for Different Proton Energies with a Uniform Proton Beam Distribution



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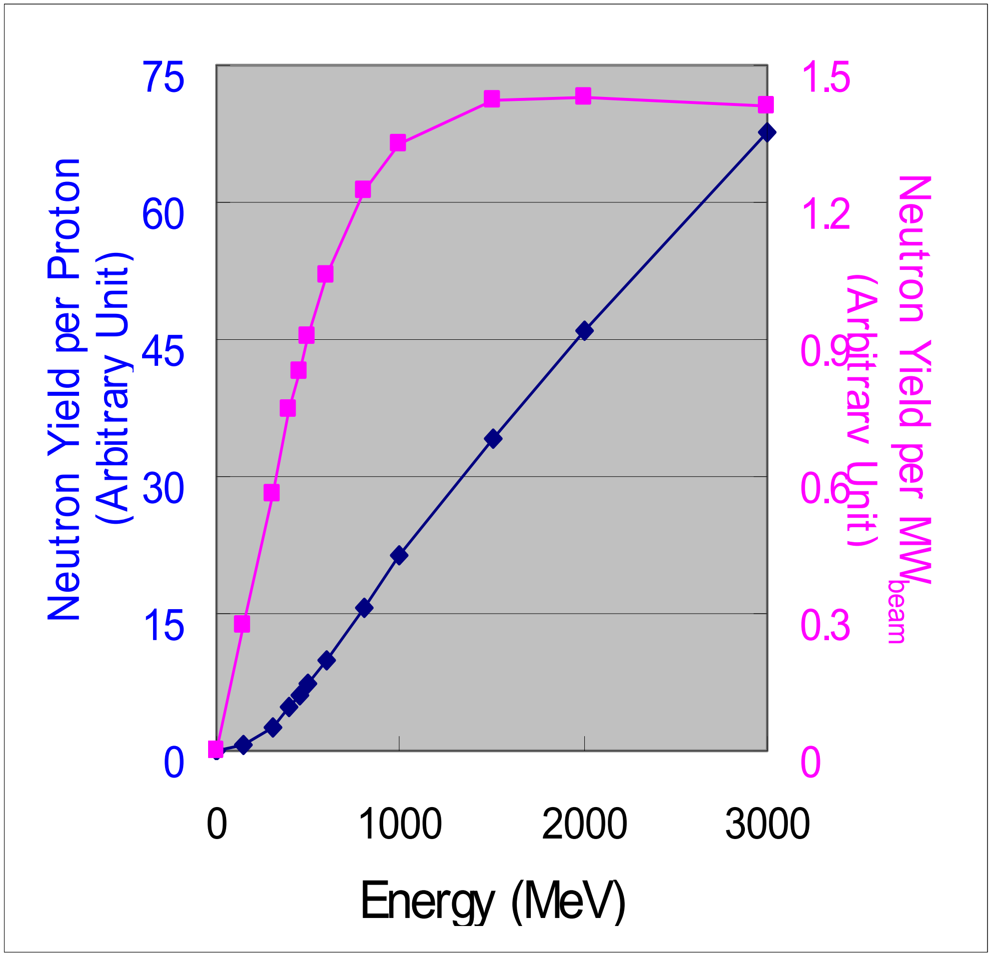
Neutron Yield as a Function of the Proton Energy



WG4: Subcritical Core Summary
Accelerator Requirements to Drive Subcritical Core

- **JAEA allowable beam trips–evaluated based thermal cycling of subcritical structures was (Oigawa-Japan)**
  - **Target window:** **10^5 per 2 years of <1 sec**
  - **reactor vessel:** **10^4 per 40 years of 1 sec to 5 min**
  - **Turbine:** **> 400s stop the Power production**
  - **system availability:** **1 per week of > 5 min**

- **EU beam specifications (Junquera-EU)**

	Current step	Next step
- beam trips (>1 s to few min.)	< 20 per year	< 3 per year
- Beam stability	Power ± 1%, Intensity ± 2%, Size ± 10%	

WG4: Subcritical Core Summary
Accelerator Requirements to Drive Subcritical Core

- **Current Views (Sheffield-US)**
  - Safety-class beam shutdown
  - Limit maximum beam current and its change rate
  - Low beam trips incidence based on current analysis including margin
    - 0.3 < t < 100 s   < 1000 trips/yr
    - t > 100 s   < 30 trips/yr
  - Active current control: automatic, independent-feedback from plant power monitors, dynamic current-control mechanism.
  - Must have ability to smoothly ramp up (or down) beam current over seconds to minutes
  - Availability during run cycle: >80%

Current ADS Experimental programs

	Accelerator Parameter	External Source	Neutron Spectrum	Core	Status
MUSE (France)	GENEPI (D^+) 250keV, < 5kHz, < 50mA	T Target 14MeV Neutron	Fast	Critical Assy < 1 kW	Finished
RACE (USA)	Electron Linac 20-40MeV, ~300Hz, 1mA	W-Cu Alloy (γ,n) 90 W (25MeV-80mA)	Thermal	TRIGA Reactor < 100 kW	Finished
KART/LAB (KURRI)	FFAG (Proton) 150MeV, 100Hz, 1nA	W Outside Core	Thermal	Critical Assy	Running
GUINEVERE (EUROTRANS)	GENEPI (D^+) 250keV, < 5kHz, < 50mA	T Target 14MeV Neutron	Fast	Critical Assy	Under Constructi on
TEF-P (JAEA)	LINAC (Proton) 600MeV, 25Hz, 2μA	Pb, W (Solid form) Spallation, 10 W	Fast	Critical Assy < 1 kW	Planning
XT-ADS (EUROTRANS)	LINAC (Proton) 1GeV, Few mA	Liquid Pb-Bi Few MW	Fast	~100 MW	Design Study
ADS Exp. Reactor (JAEA)	LINAC (Proton) 1GeV, 2mA	Liquid Pb-Bi 2MW	Fast	80 MW	Design Study

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EU Current Programs

- EU main activities: the 6th (2002 – 2006) and the 7th (2007 – 2011) Framework Programmes (FPs)
- EUROTRANS project of the 6th frame work program was funded with a total of EUR 45 million
- Objectives
  - **Develop Preliminary designs for MYRRHA/XT-ADS (experimental ADS, 50 – 100 MWth)**
  - **Develop conceptual design - European Transmutation Demonstrator (ETD, several hundred MWth, modular)**
- Major projects
  - **MEGAPIE**
  - **MYRRHA / XT-ADS project**
  - **GUINEVERE experimental facility**
  - **FASTEF and CDT (Central Design Team)**

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Belarus Program

YALINA Facility Research activities

(YALINA-BOOSTER and YALINA-Thermal Configurations)

– Develop and test reactivity monitoring techniques used in power ADS
– Investigate spatial kinetics of sub-critical systems driven by external neutron sources
– Measure transmutation reaction rates
– Maintain and operate sub-critical systems driven by external neutron sources

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India Programs

- **Objectives of ADS R&D programs**
  - **P&T as part of advanced fuel cycles**
  - **Fissile material breeding (thorium fuel cycle)**
- **Nuclear data Program**
- **Code development for high energy particle transport**
- **High power proton accelerator technology**
- **14-MeV D-T neutron source coupling with subcritical reactor (water cooled, natural uranium fuelled)**

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India Programs (continued)

- Spallation target systems
  - Pb-Bi eutectic loop with simulated proton beam window heating (plasma torch and electron beam)
  - Corrosion testing
  - Validation and qualification of Computational Fluid Dynamics codes
- Sub-critical core design
  - Thorium fuel utilization in sub-critical systems
  - Experimental reactor with the flexibility of being transformed into a subcritical system driven by a spallation source

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Japan Programs

- Transmutation of long-lived radioactive nuclides
- Develop 800 MW_{th} ADS with lead-bismuth eutectic target and coolant
- Examine corrosion issues for different structural materials with low oxygen concentration in the temperature range of 450°C and at 550°C
- Perform transmutation experimental studies and design test facility
  - Handling of minor actinides fuel
  - Remote handling system design

WG4: Subcritical Core Summary
IAEA Activities

- Member states with ADS activities: Belarus, Belgium, Brazil, China, France, Germany, India, Italy, Japan, Kazakhstan, Republic of Korea, Russia, Sweden, Switzerland, and USA
- Information exchange on scientific and technical topics
- Collaborative R&D (Coordinated Research Projects, CRPs)
  - Studies of Innovative technology options for effective utilization of spent nuclear fuels
  - Analytical and experimental benchmark analyses of accelerator driven systems

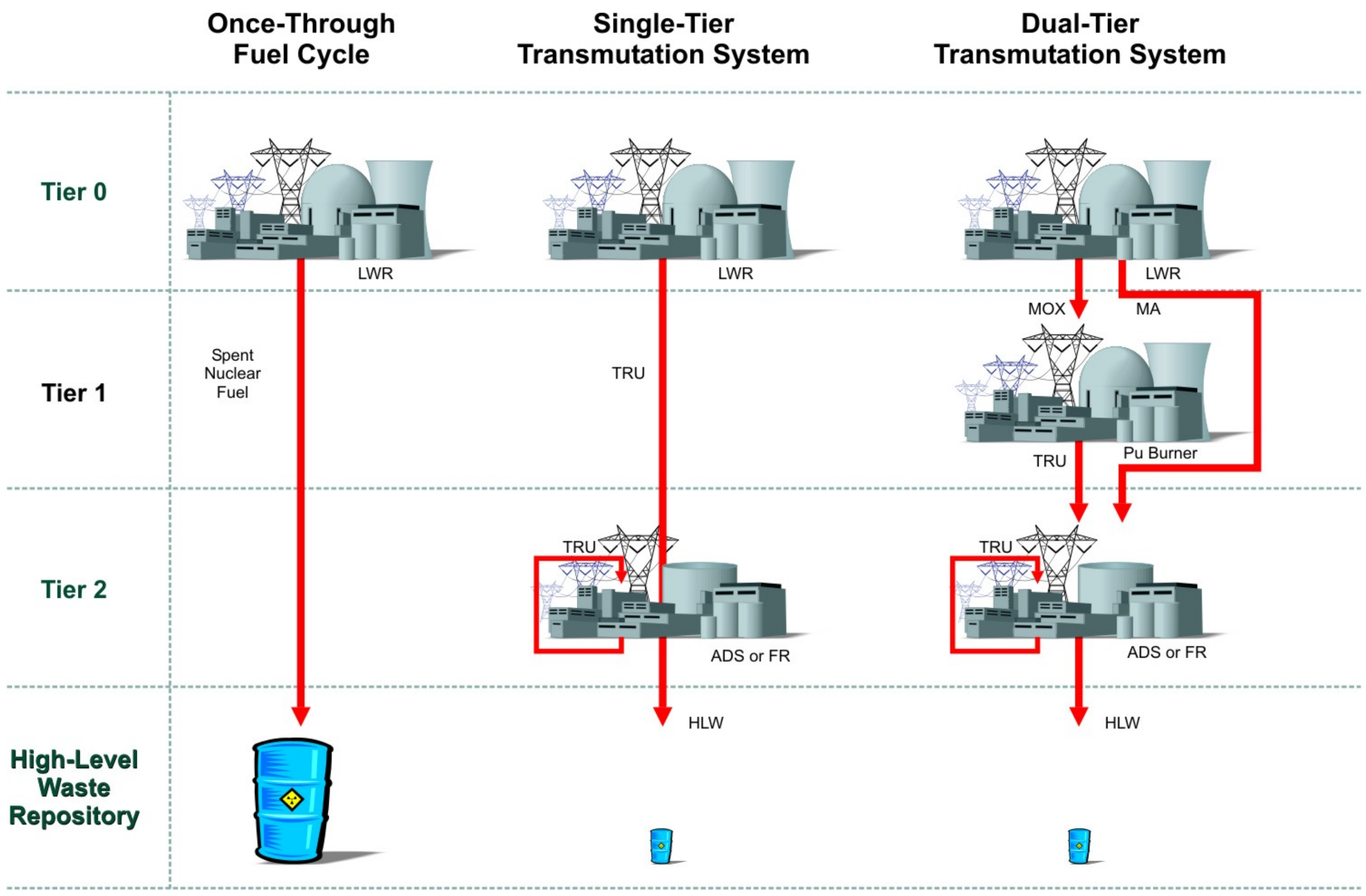
WG4: Subcritical Core Summary

Subcritical Assembly Functions

- Utilize the transuranics of the spent nuclear fuels for energy production and reduce the required geological repository capacity (Main function)
- Provide a fast neutron field for fuels and materials irradiation testing
- Generate a neutron source facility for medical isotope production, basic and applied neutron research, and train young specialists
- Breed fissile materials and generate energy

WG4: Subcritical Core Summary (Continued)

Spent Fuel Disposal Options



WG4: Subcritical Core Summary (Continued)

Spallation Targets

- Both solid and liquid high atomic number target materials were successfully operated.
- The MEGAPIE experiment: a liquid lead-bismuth eutectic target with 600 MeV protons and 0.8 MW power was successfully tested for ADS applications.
- High power target designs were developed and analyzed.
- Liquid lithium targets were examined and tested for isotope production.
- Spallation targets were designed to drive cold neutron sources.

WG4: Subcritical Core Summary (Continued)

Unique Safety Issues

- **The proton beam must penetrate the containment building**
- **Design decisions are necessary to determine the interface configurations between the beam tunnel and the containment building boundary, and between the beam and the primary coolant system**
  - **Does the beam tunnel become part of the containment building?**
  - **Does the target become integral with the reactor coolant system?**
  - **Are the interfaces able to be inspected, tested, repaired?**
- **The subcritical control and shutdown functions focus on beam management and cooling systems operation**
  - **The normal reactor instrumentation for critical reactor reactivity control and protection will be used for beam management**
  - **Beam Interfaces are needed for start-up and shutdown, as well as emergency shut down**
  - **Hard limit maximum beam current and its change rate are required**

WG4: Subcritical Core Summary (Continued)

Unique Safety Issues

- **The accelerator/reactor control interface is a two-way system**
  - **A fault on the accelerator side (beam interruption) must be communicated to the reactor to allow normal shutdown**
  - **A fault on the reactor side must be communicated back to the accelerator to command beam shutdown (or diversion) to permit graceful termination of power production**
    - **Terminate power deposition in the target and reactor**
    - **Programmed reduction of reactor coolant flow**
    - **Avoid thermal shocks in the reactor system**
- **10CFR50 Appendix A requires an inherent (passive) mechanism separate from the active systems to protect against external events that can suddenly increase reactor power (e.g. seismic motions, inlet temperature decrease, etc.)**
  - **In a critical system, prompt negative reactivity feedback is provided by the fuel Doppler effect**
  - **In a subcritical system, depending on the level of sub-criticality, the reactivity and power are uncoupled, and the fuel Doppler effect may not be effective**