The GDT-based fusion neutron source as driver of a minor actinides burner

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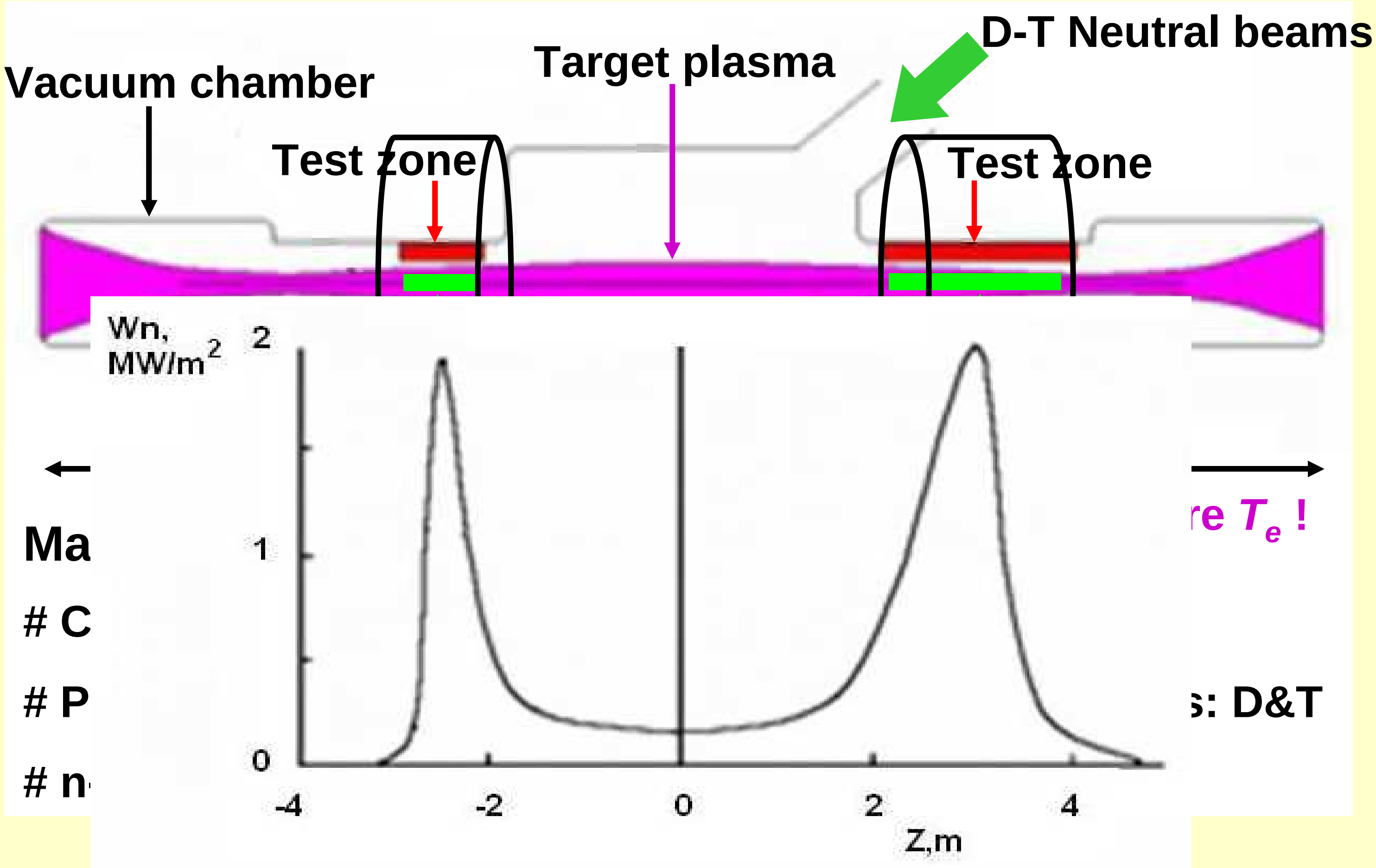
Outline

1. Introduction
2. Fusion versus spallation neutrons in driving a MA-burner
3. Two options of a GDT-driven MA-burner
4. Conclusions

1. Introduction (1/3)

➢ The technical idea of a GDT-driven system:

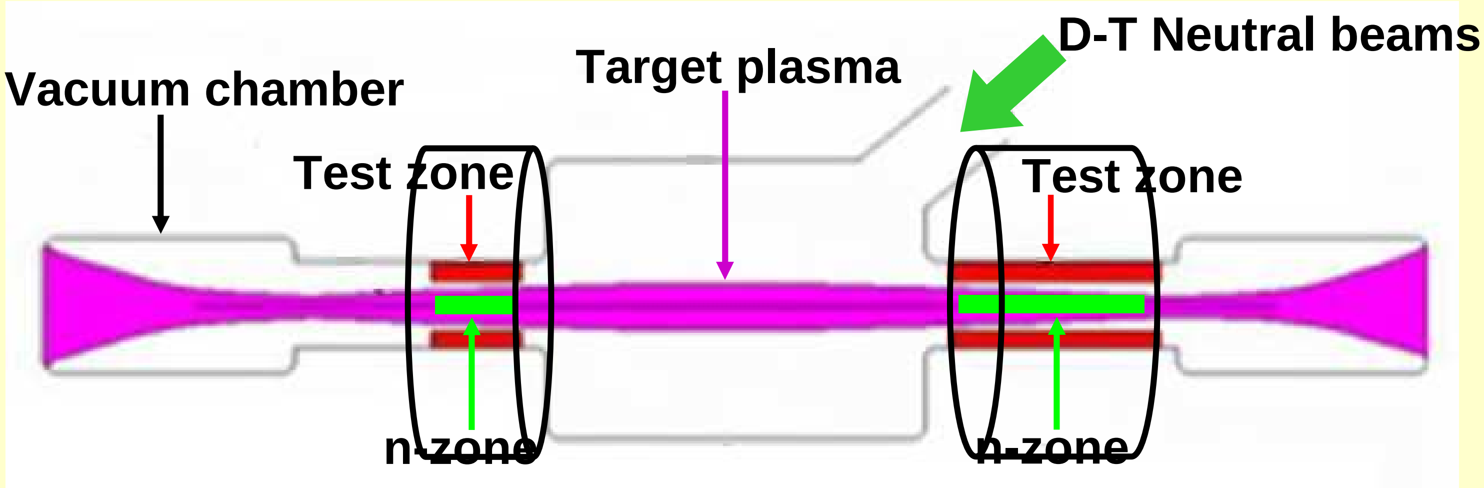
- ***GDT –*** *gas dynamic trap (axially symmetric mirror machine)*



1. Introduction (2/3)

➢ The technical idea of a GDT-driven system:

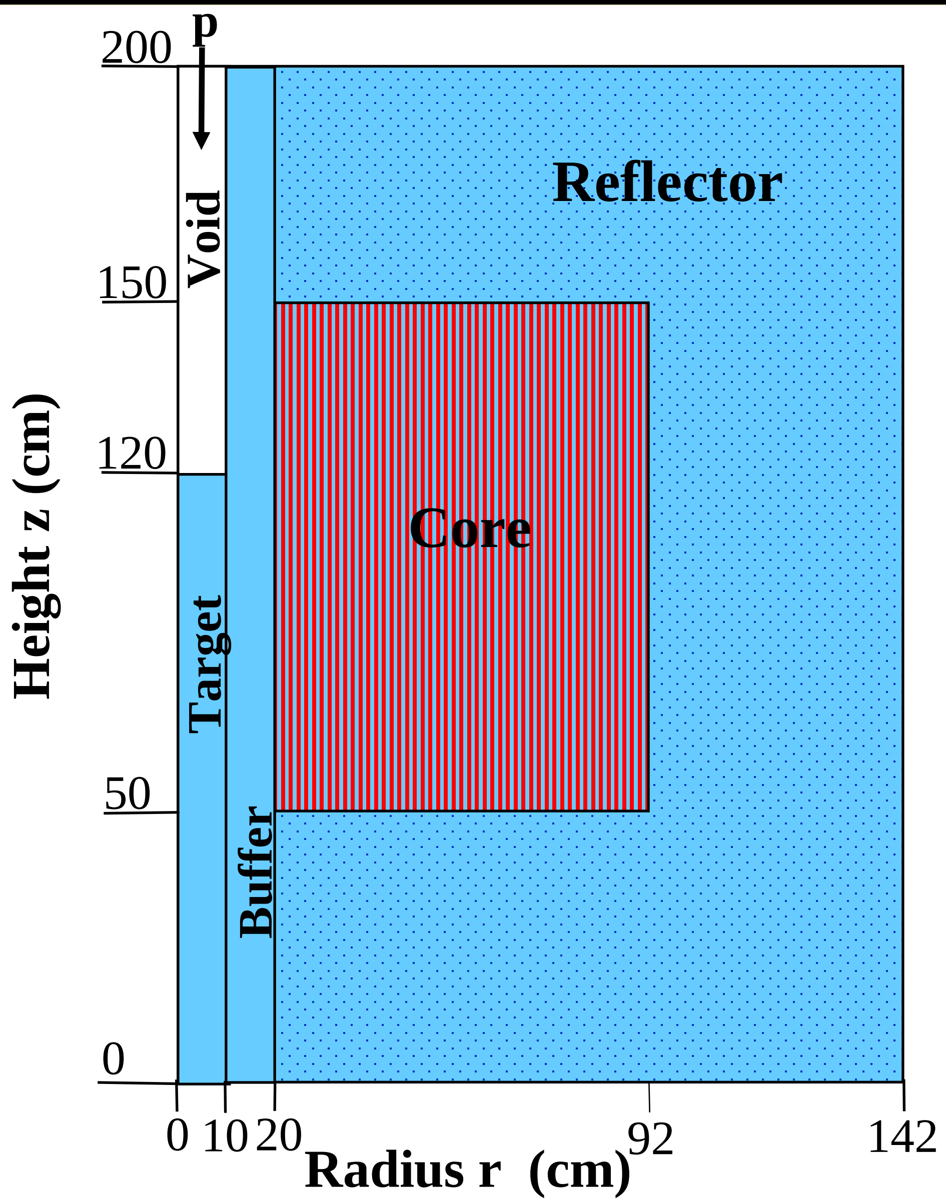
• ***GDT –*** *gas dynamic trap (axially symmetric mirror machine)*



Particularities:

- ***Continous source.***
- ***2 neutron source volumes with variable intensities.***
- ***n-zones can be longitudinally extended.***
- ***n-emission intensity can be axially profiled.***
- ***Neutron energy = 14 MeV ➔ : No high-energetic particles!***

2. Fusion vs. spallation neutrons (1/7)



 # OECD-NEA Calculational Excercise (1999) for an accelerator-driven <u>MA burner</u> with nominal power = 377 MW. (Developed from A*LMR/PRISM*).

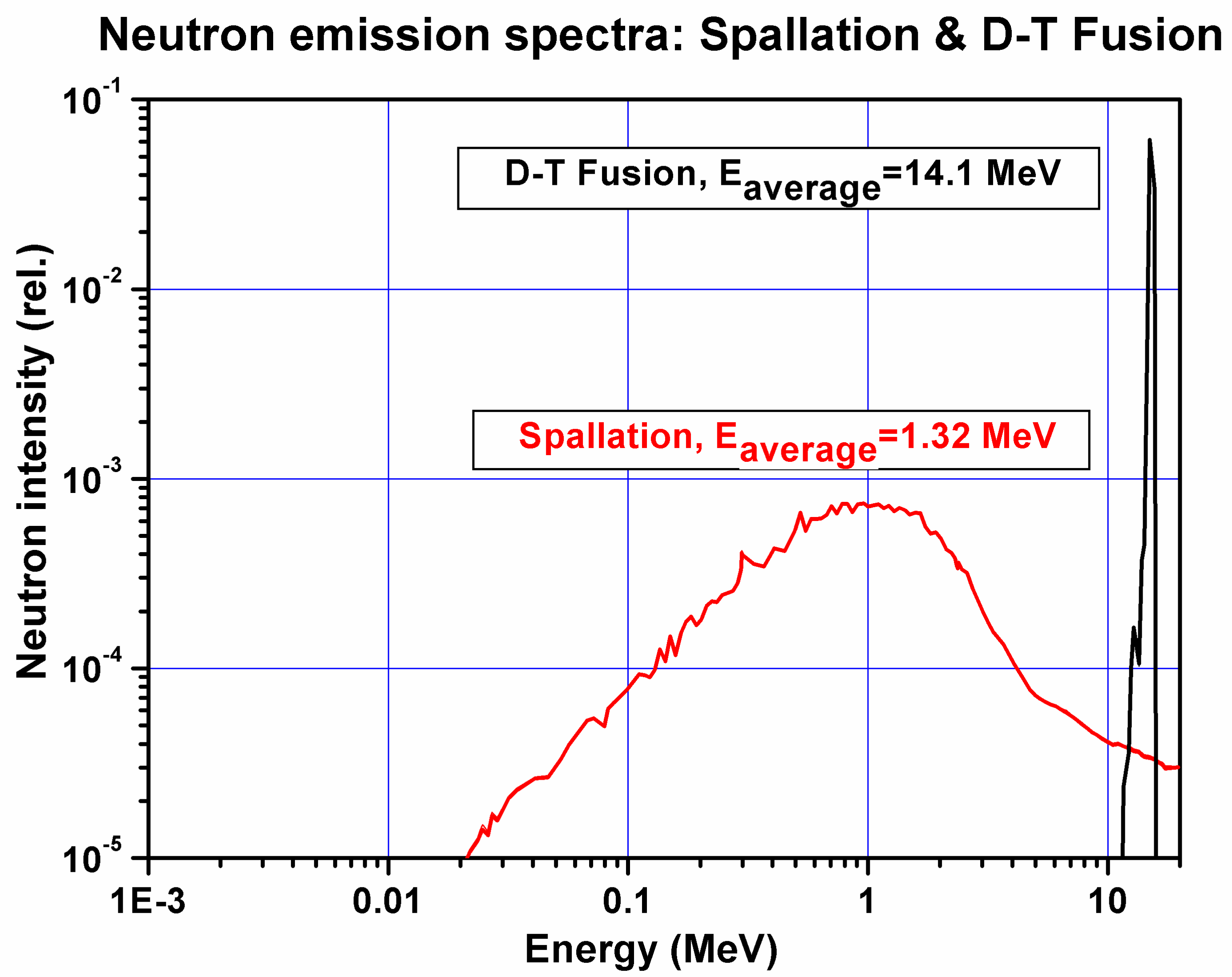
- Modified by *G. Aliberti et al., NSE **146**, 13-50 (2004)*

 # Features

32% , 68%!!!

- **<u>Dedicated fuel</u>: *Pu & <u>MA</u> as nitrides in ZrN***
- **Coolant: *Pb-Bi eutectic***
- **Reflector: *Steel, Pb-Bi***
- **Target: *Pb-Bi***
- **Buffer: *Pb-Bi***

1. Introduction (3/3)

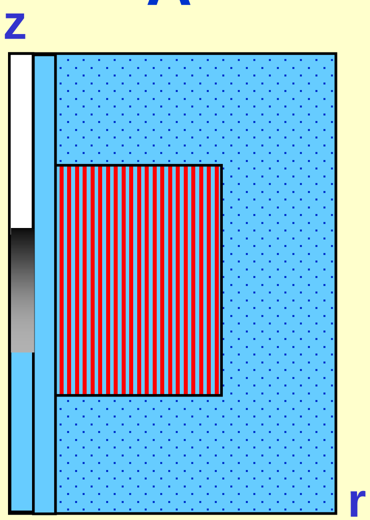


2. Fusion vs. spallation neutrons (2/7)

➢ Geometric systems:

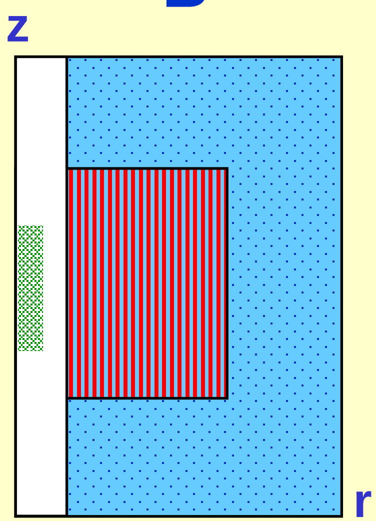
GDT-driven systems

A



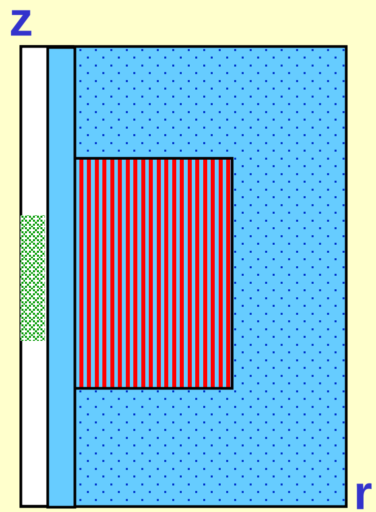
„ADS“

B



„GDT-DS“

C



„GDT-DS+B“

“External” neutron sources:

Spallation source

DT fusion source – cylinder: Radius: 10 cm, Height: 50 cm

„MIXED“ → Spallation spectrum in „GDT-DS“

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2. Fusion vs. spallation neutrons (3/7)

- **Two types of transport calculations:**
  - **Reactor criticality calculation (without external source)** → k_{eff}, $\Phi_n(r,E)$
  - **With external sources** → M_S, $\Phi_n(r,E)$, …
- **Tools:**
  - **Neutron transport code: *MCNP-4C2***
  - **Nuclear data from: *JENDL-3.3 (NDC of JAEA)***

2. Fusion vs. spallation neutrons (4/7)

➢ Calculated integral parameters (per source neutron):

Effective multiplicity: $M_{eff}=k_{eff}/(1-k_{eff})$

$\varphi^*=M_s/M_{eff}$

Geom. system	´Reactor´		Driven Systems				
	k_{eff}	M_{eff}		M_S	h_{fis} / MeV	φ^*	$r_{n,2n}$
A	0.95856	23.1	ADS	21.5	1316	0.93	0.09
B	0.95008	19.0	GDT-DS Mixed	34.7 17.5	2119 1070	1.83 0.92	1.20 0.065
C	0.95817	22.9	GDT-DS+B	44.4	2710	1.94	1.73

$0.95 \leq k_{eff} \leq 0.96$

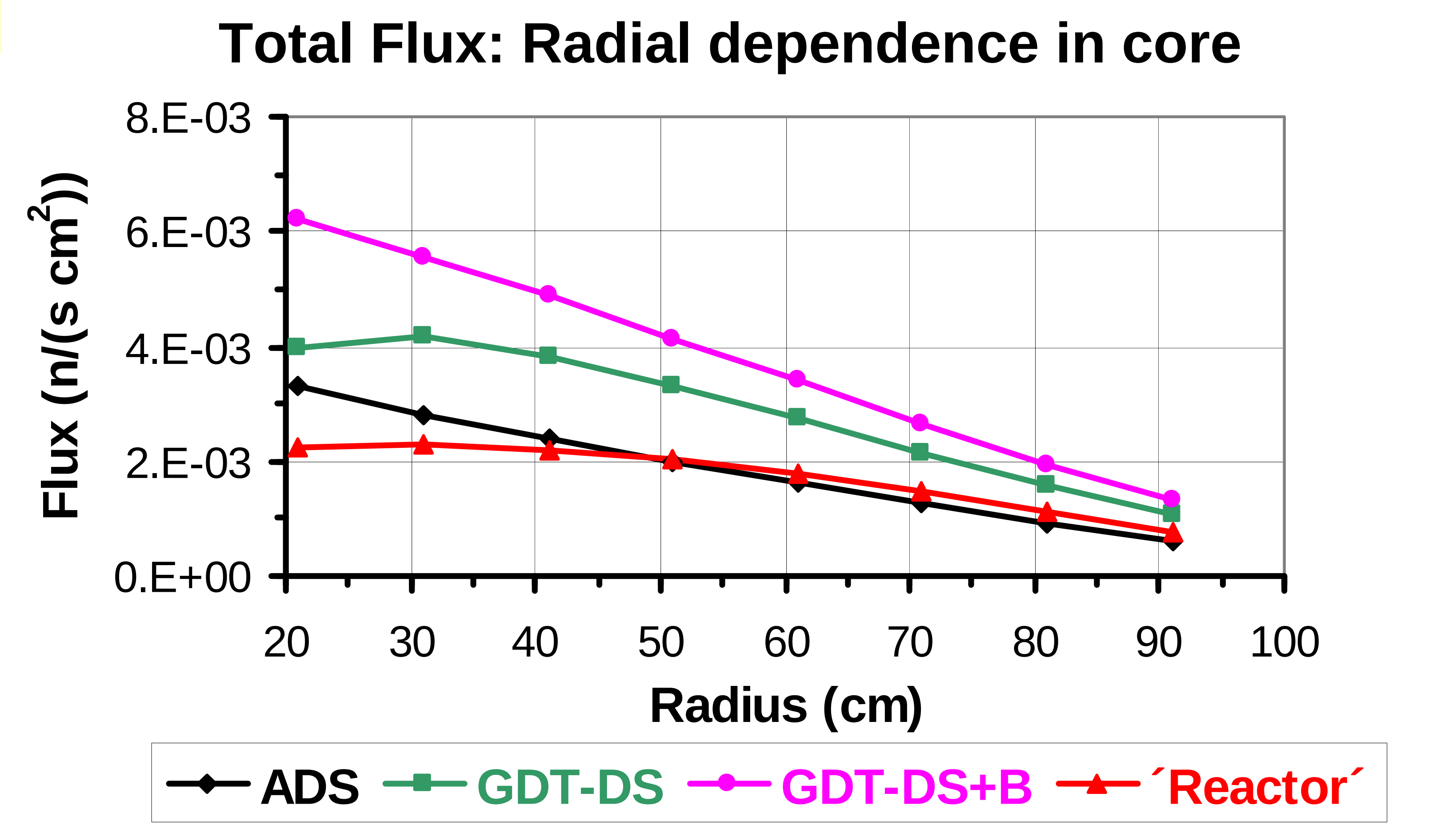
 # Positive feature of 14 MeV neutrons:

High probability of n,2n reactions at Pb and Bi !

But: No effect at Na !

2. Fusion vs. spallation neutrons (5/7)

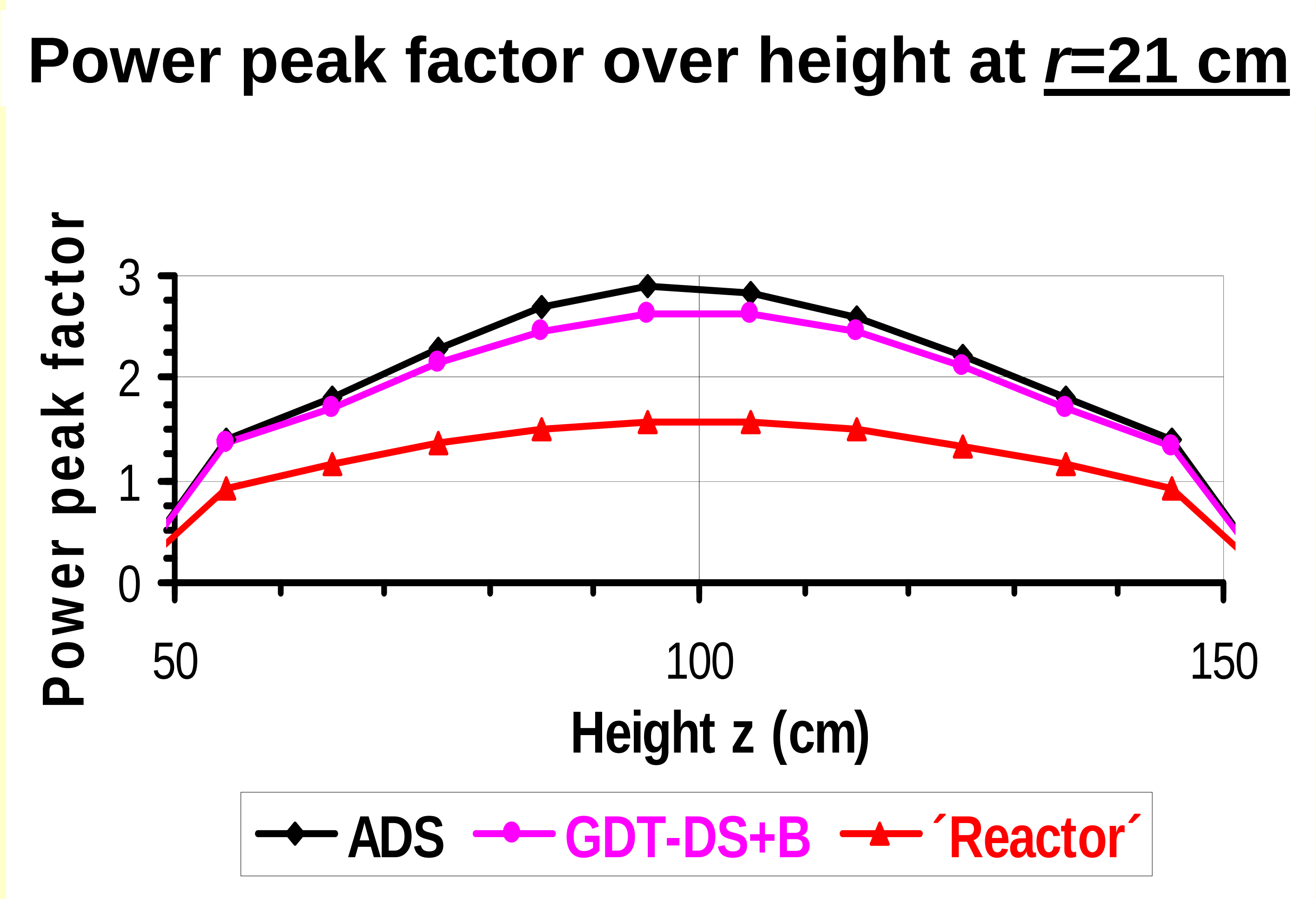
➢ Flux distributions (per source neutron):



(System A)

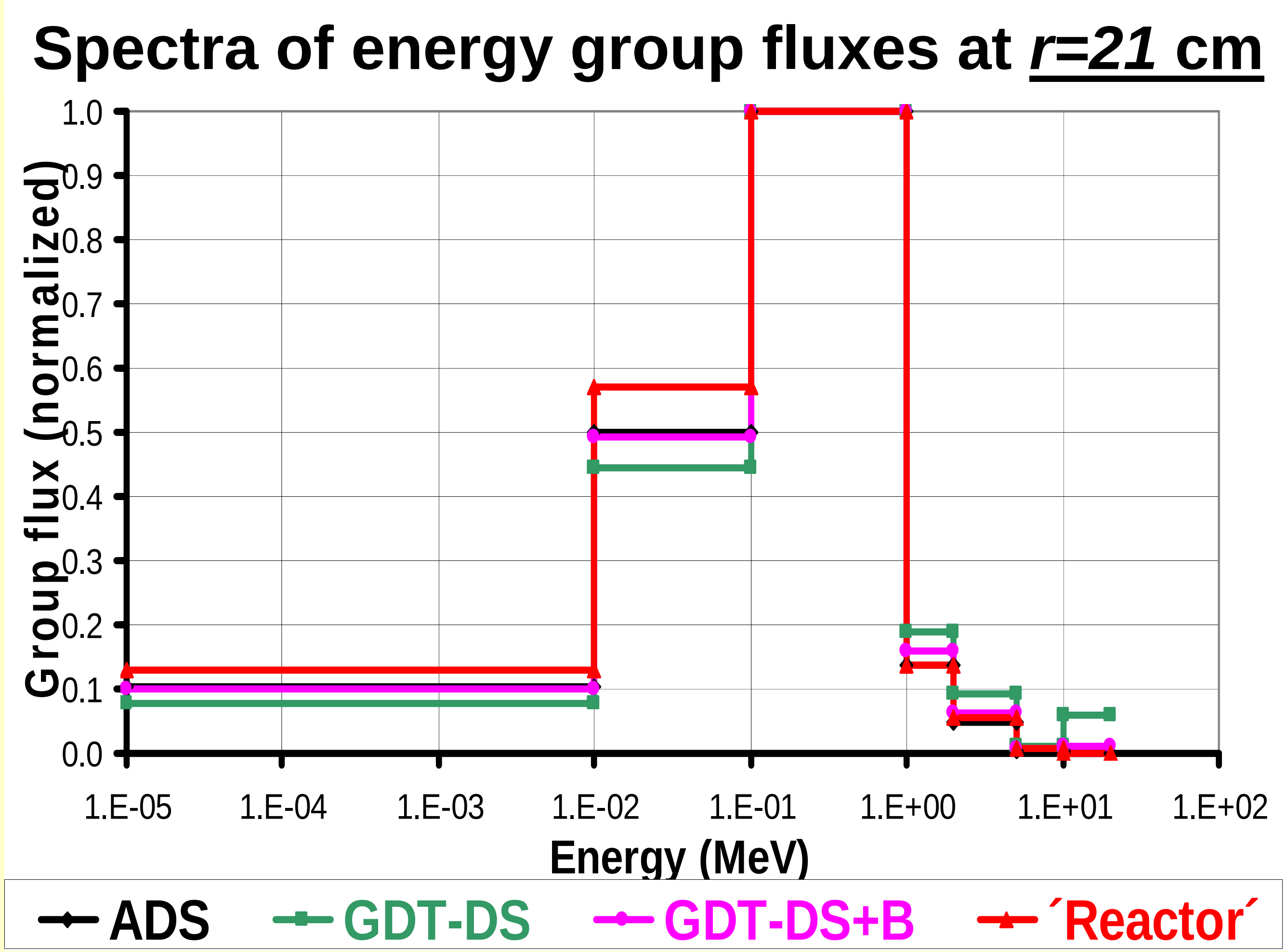
2. Fusion vs. spallation neutrons (6/7)

- **Flux distributions (per source neutron):**



2. Fusion vs. spallation neutrons (7/7)

➢ **Flux distributions (per source neutron):**



3. GDT-driven MA-burners (1/7)

➢ GDT neutron source – "basic version":

	GDT source ("basic variant")	Spallation
1) Total intensity		
	• "Useful" n-power: $P_n = 0.44$ MW	• p-beam: – 1 GeV – $Y_n = 20$ n/p (at Pb)
	• $S_{GDT/2} \cong 1.0 \times 10^{17}$ n/s	➔ $I_p = 0.8$ mA !
2) Energetic efficiency		
	• $P_{NBI} = 50$ MW_{el}	• $\eta_{acc.} = 50$ %
price [W/(n/s)]:	• $p_{GDT} = 2.6 \times 10^{-10}$	• $p_{ADS} = 1.6 \times 10^{-11}$

3. GDT-driven MA-burners (2/7)

➢ "Basic version" as driver:

Parameter	GDT-DS+B* k_{eff} = 0.95817	ADS k_{eff} = 0.95856
S (10^{17} *n/s*)	1.0	
P_{fis} (MW)	42	
Q (=P_{fis}/P_{inp})	0.67	5.25
Nominal Power 377 MW:		
1) *S´* (10^{17} *n/s*)	8.7	I_p=14.4 *mA*
2) k'_{eff}	0.9952 X	

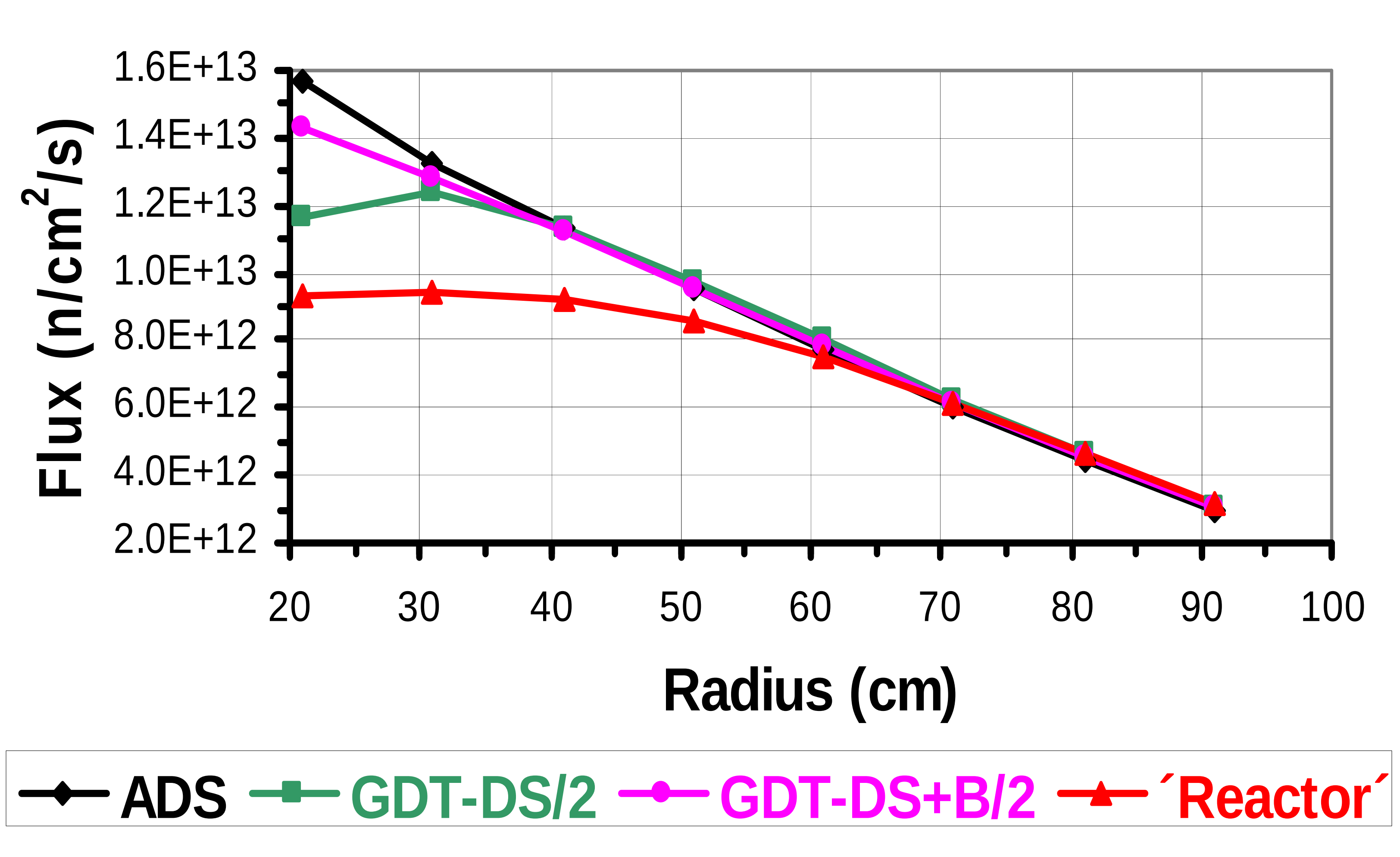
x ~ 8 !

x ~9 !

* One MA-burner on each side !

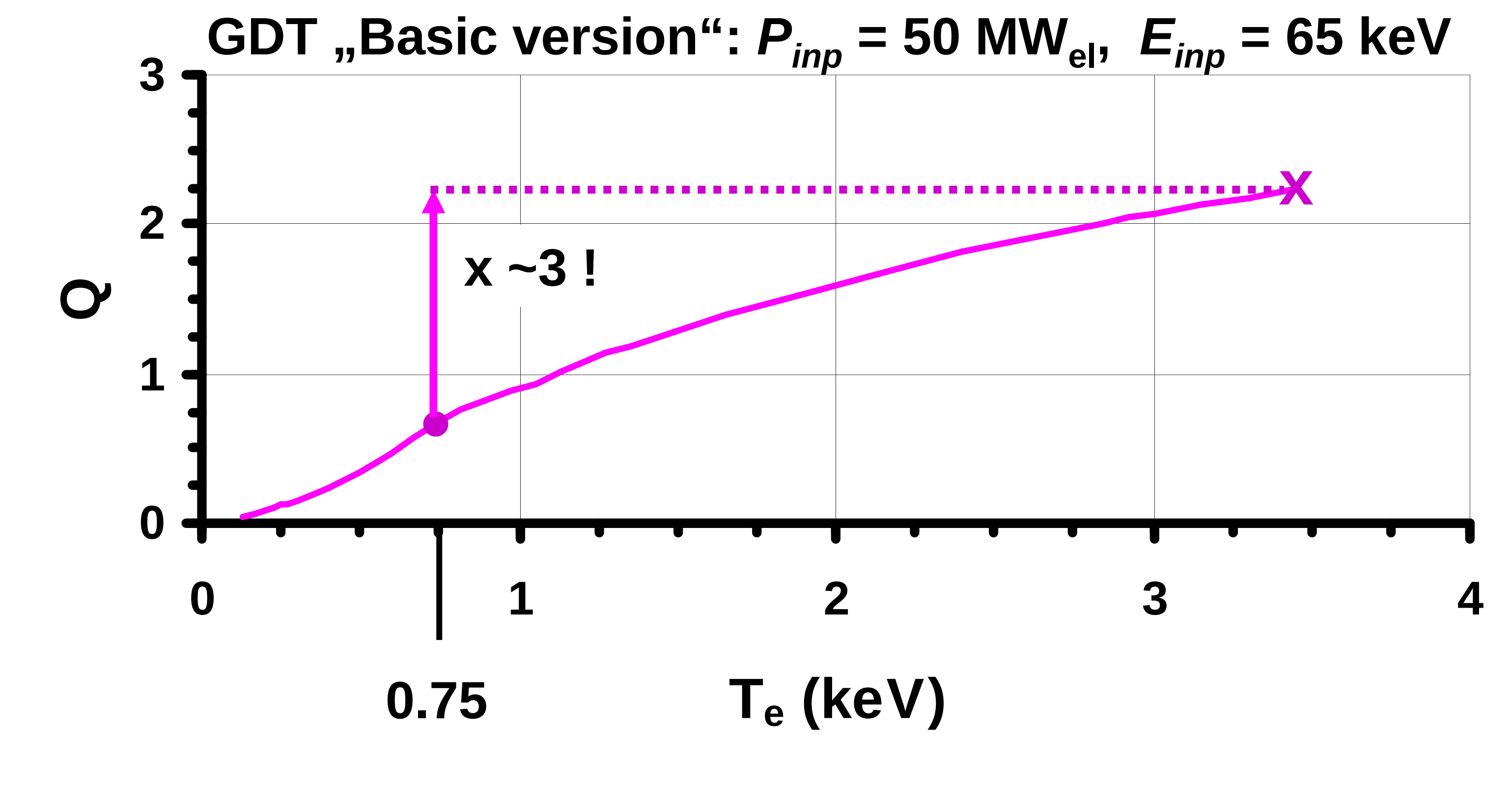
3. GDT-driven MA-burners (3/7)

➢ **Radial flux distribution (at nominal power):**



3. GDT-driven MA-burners (4/7)

➢ Improvement - Increase of the electron temperature T_e:



- T_e **should be increased up to the self-consistent value !**
  ➔: Study of plasma stability !

3. GDT-driven MA-burners (5/7)

➢ Improvement – Increase of the NBI-current:

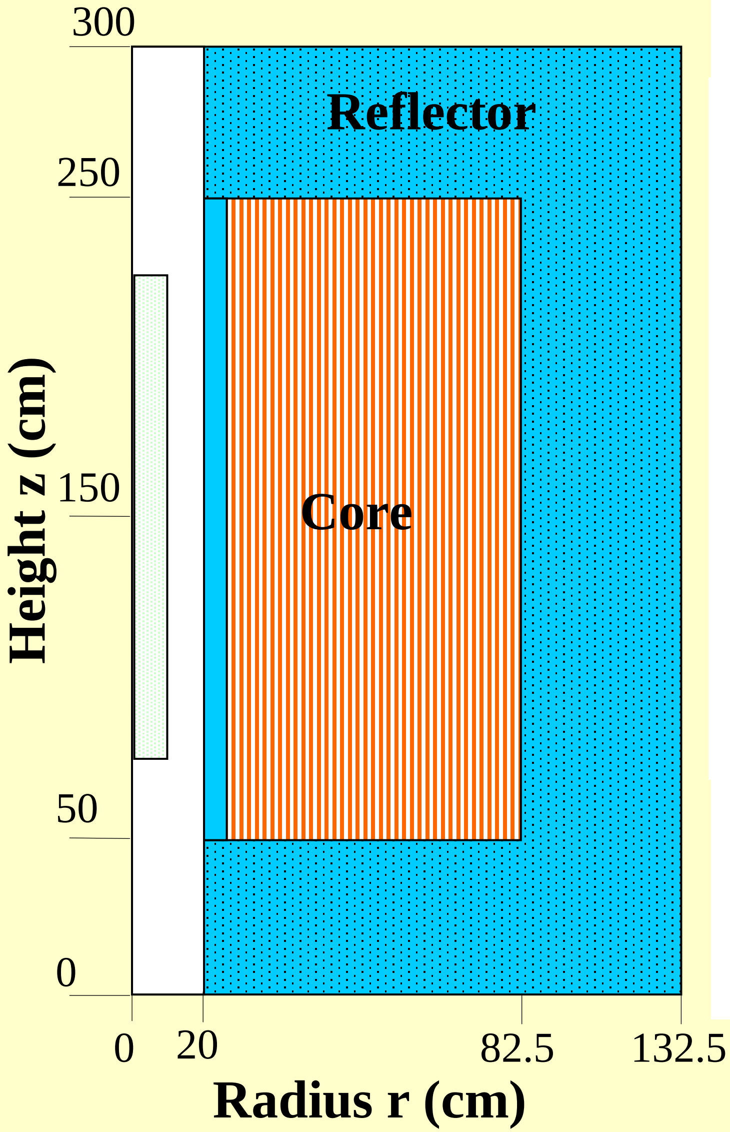
➔ **Problem of high electron temperature *Te* !**

➢ Improvement – "stretching" of the n-zones:

- ***Stretching of the n-zones by appropriate magnetic field.***
- ***More fusion reactions in stretched n-zones.***
- ***<u>The same plasma conditions as for the „basic version" !</u>***

➔**Necessary: Elongation of the sub-critical system !**

3. GDT-driven MA-burners (6/7)



➢ Elongated GDT-driven MA-burner:

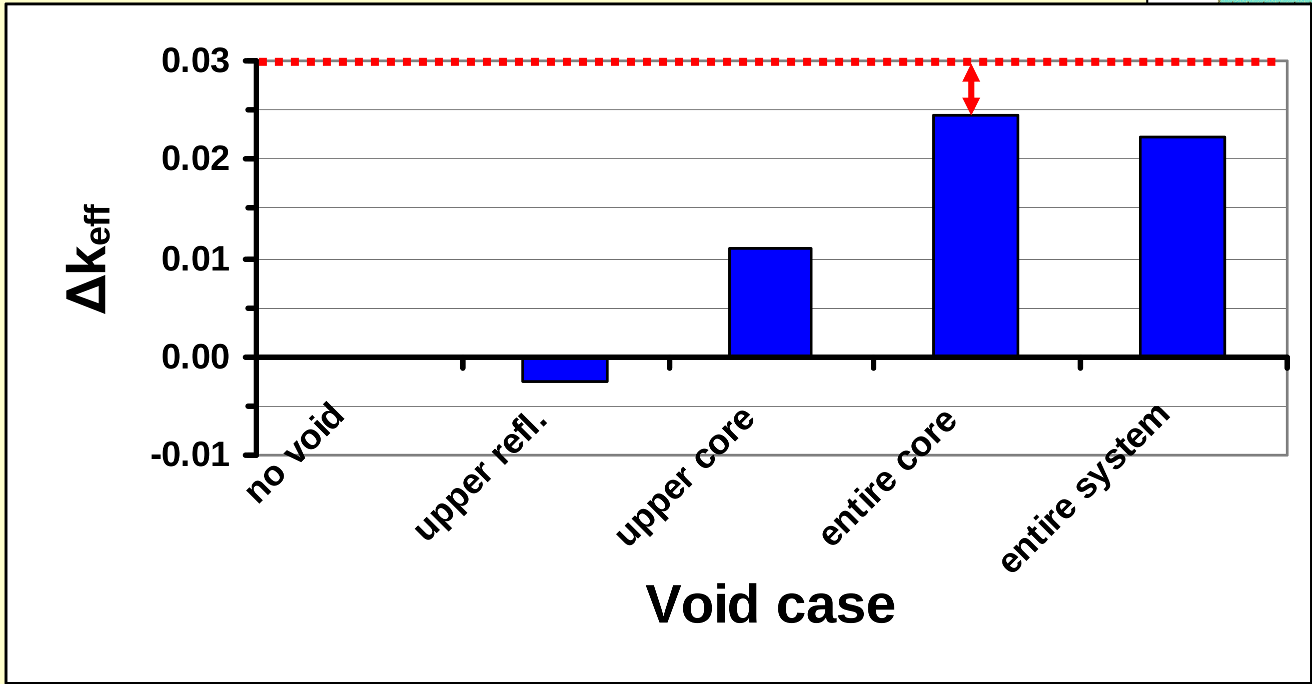
- **GDT „stretched version“**
  - $L = 1.5\ m$
  - $P_{inp} = 83\ MW_{el}$
  - $S_{GDT/2} = 3.43 \times 10^{17}\ n/s$ ↑ x ~3.5
  - $p_{GDT} = 1.2 \times 10^{-10}\ W/(n/s)$ ↓ x ~0.5
- **Elongated MA-burner**
  - Core height = 2 m
  - Inner core radius = 27.5 cm
  - Outer core radius = 82.5 cm, $k_{eff} \sim 0.97$

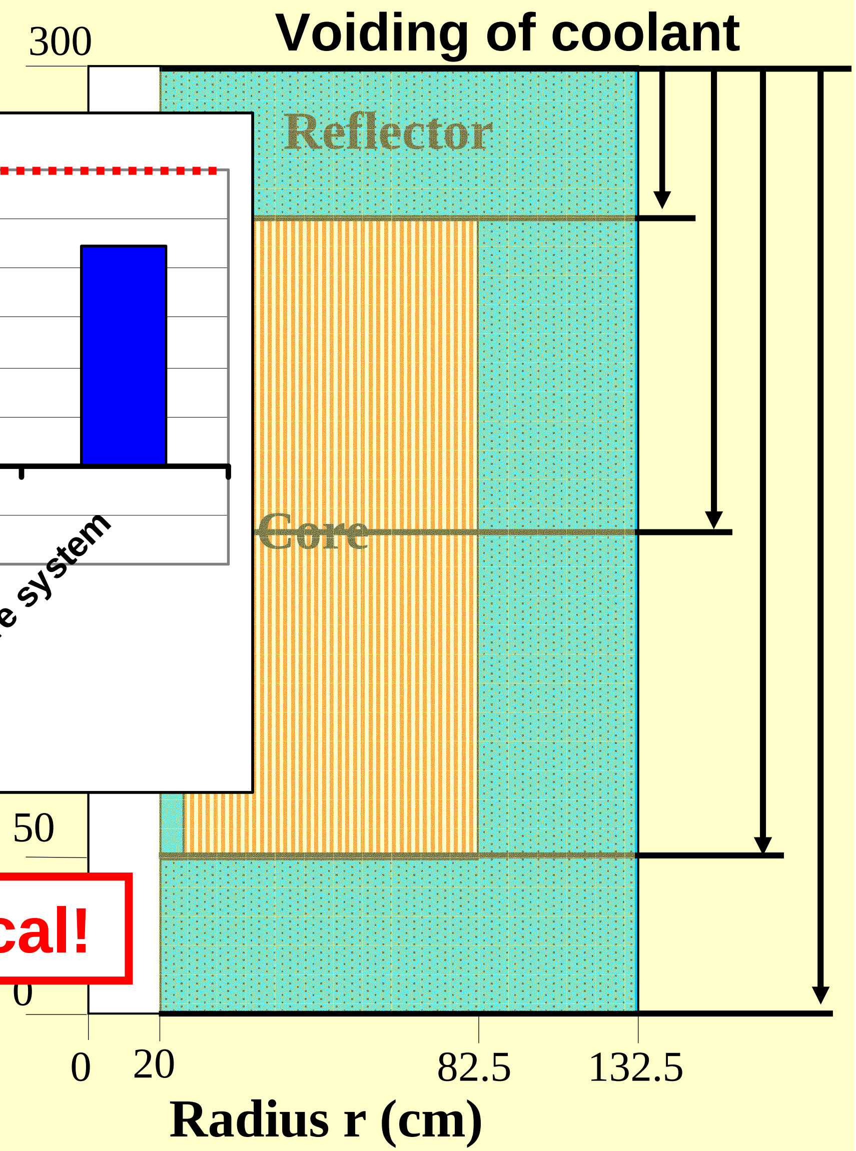
➔: $P_{fis} = 185\ MW$ (x ~4.3)

$Q = 1.78$ (x ~2.7)

3. GDT-driven MA-burners (7/7)

➢ Coolant void effect:





➔: The system remains sub-critical!

4. Conclusions (1/3)

1. Fusion vs. spallation neutrons as drivers

1.1. n,2n-reactions by fusion neutrons:

- For Pb&Bi eutectic as buffer/coolant:

$$\varphi^*_{GDT\text{-}DS} \cong 2 \times \varphi^*_{ADS}$$

1.2. Impact of the sources on the core flux spectra:

- **No noticeable difference in the spectra !**

➔: Transmutation rates per flux unit are nearly the same.

4. Conclusions (2/3)

2. GDT „basic version“

2.1. The neutron source

- **Source strength:**

$S_{GDT} \rightarrow 10 \; x$ **for proto-type MA-burner!**

- **Energetic price [W/(n/s)]:**

$p_{GDT} \cong 10 \; x \; p_{ADS}$

2.2. As driver of the benchmark MA-burner:

$Q_{GDT} < 1 \;\; \Leftrightarrow \;\; Q_{ADS} \cong 5$

- **Improvement:**

Increase of T_e up to the self-consistent value would yield a factor of ~*3*.

➔ **Plasma research necessary!**

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4. Conclusions (3/3)

3. GDT „stretched version“

3.1. Plasma physics:

- The same as in „basic version“!

3.2. Improvements of the neutron source:

- Higher source strength *S*
- lower energetic price *p*

are possible!

3.3. Improvements as driver of an „elongated“ MA-burner:

- Increase of *Q* up to ~*2*.
- Coolant void effect does not reach to criticality !

Thank you for your attention !

Spallation reaction: neutron yield per proton (Pb, Pb/Bi):

K. van der Meer et al., Nucl. Instr. and Meth. in Phys. Res. B 217 (2004) 202-220

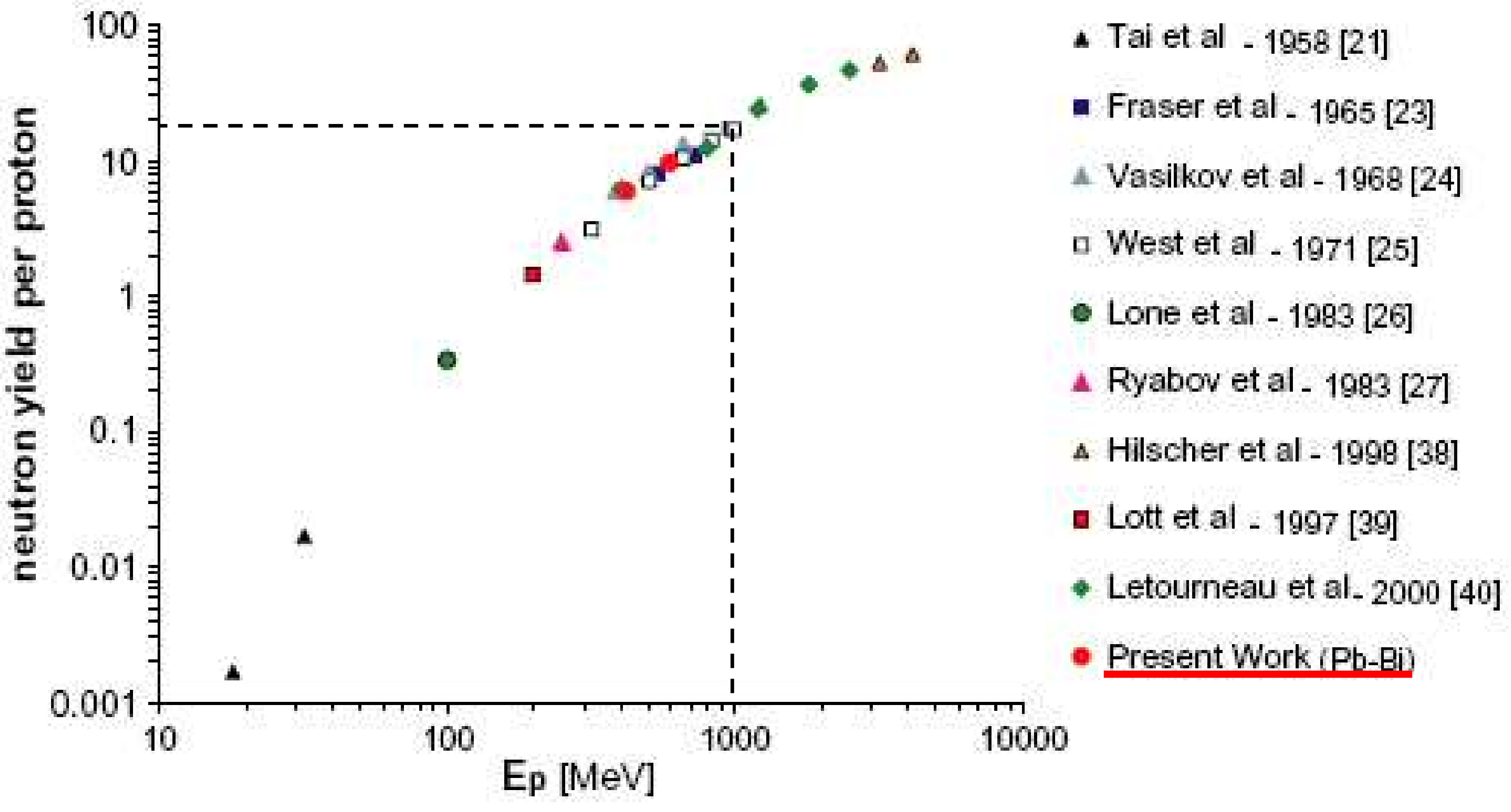
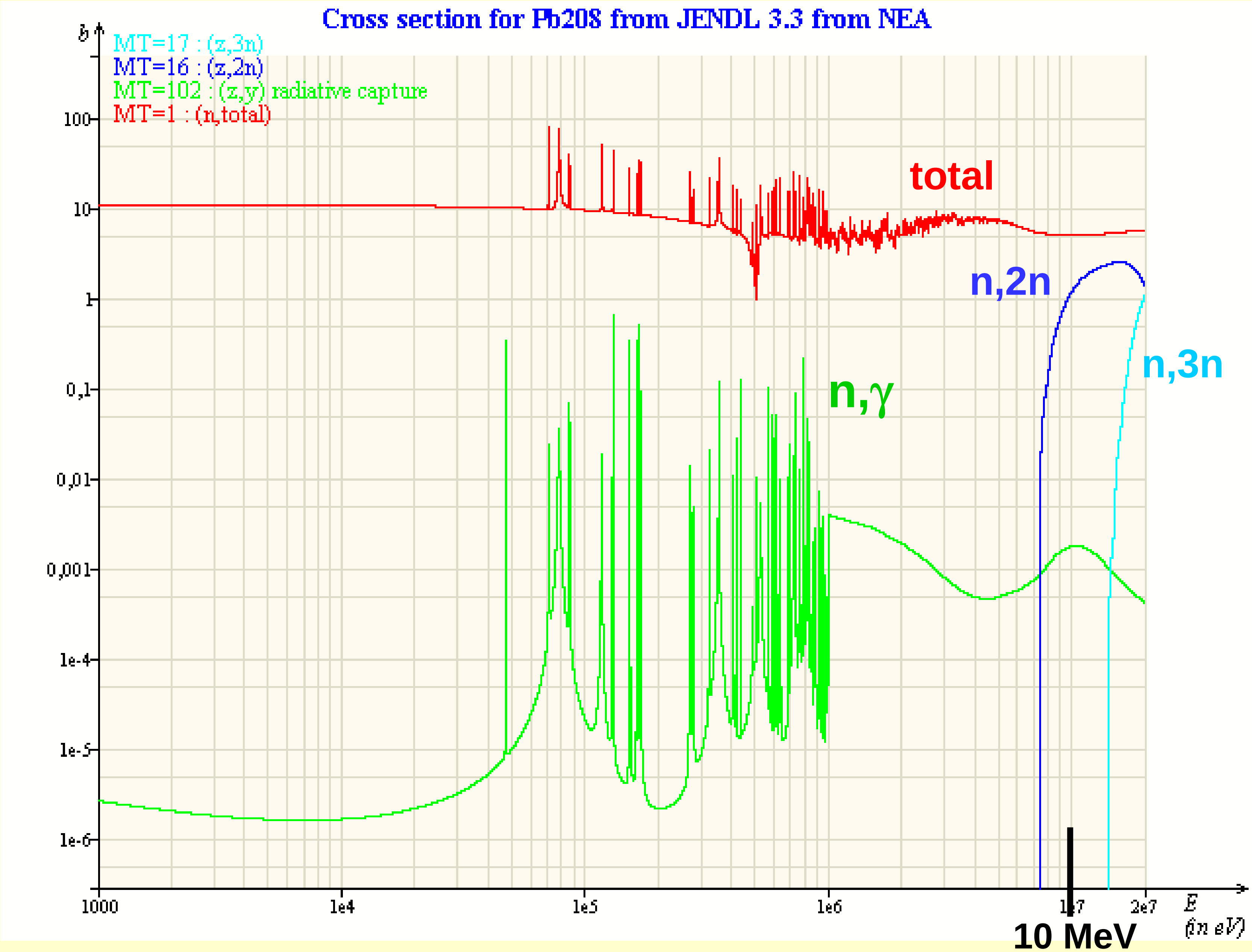


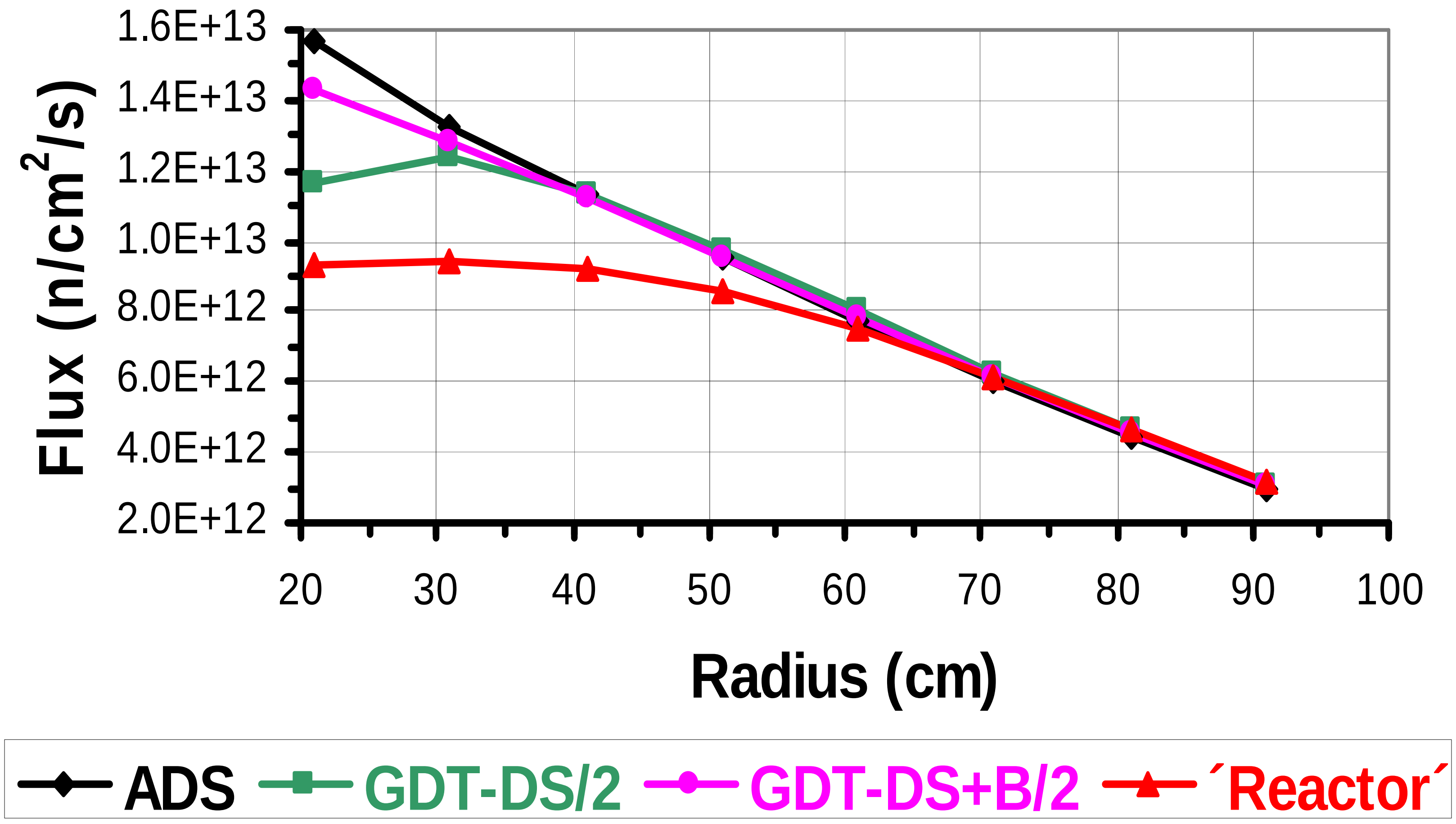
Fig. 10. Compilation of thick-target n/p values for p+ Pb and Pb/Bi measured to date at all incident energies.



Cross section for Pb208 from JENDL 3.3 from NEA
MT=17 : (z,3n)
MT=16 : (z,2n)
MT=102 : (z,y) radiative capture
MT=1 : (n,total)
total
n,2n
n,3n
n,γ
b
100
10
1
0,1
0,01
0,001
1e-4
1e-5
1e-6
1000
1e4
1e5
1e6
1e7
2e7
E
(in eV)
10 MeV

The MA-burners (2/2)

➢ **Radial flux distribution (at nominal power):**



Appendix (1)

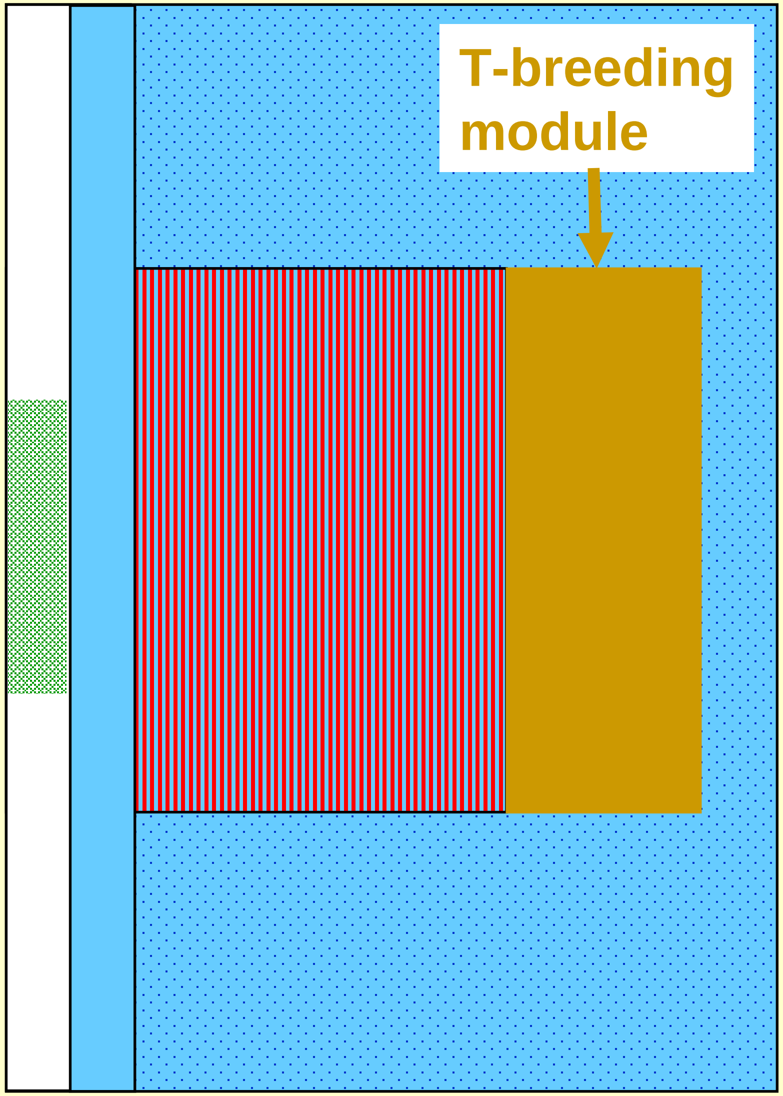
- **Tritium breeding:**
  - **T-breeding module:**
    - ITER inboard module,
    - He cooled pebble bed (Be and breeder pebble beds, breeder: Li_4SiO_4 with 40% Li-6)
    - FZKA 6763 (FZ Karlsruhe, 2003)
    - $^{6}Li + n \rightarrow {^{4}He} + {^{3}H} + 4.8\ MeV$

➔ **Result (sum of both sides):**

- **T-production = 355.3 g/fpy**

compared to

- **T-consumption = ~120 g/fpy**

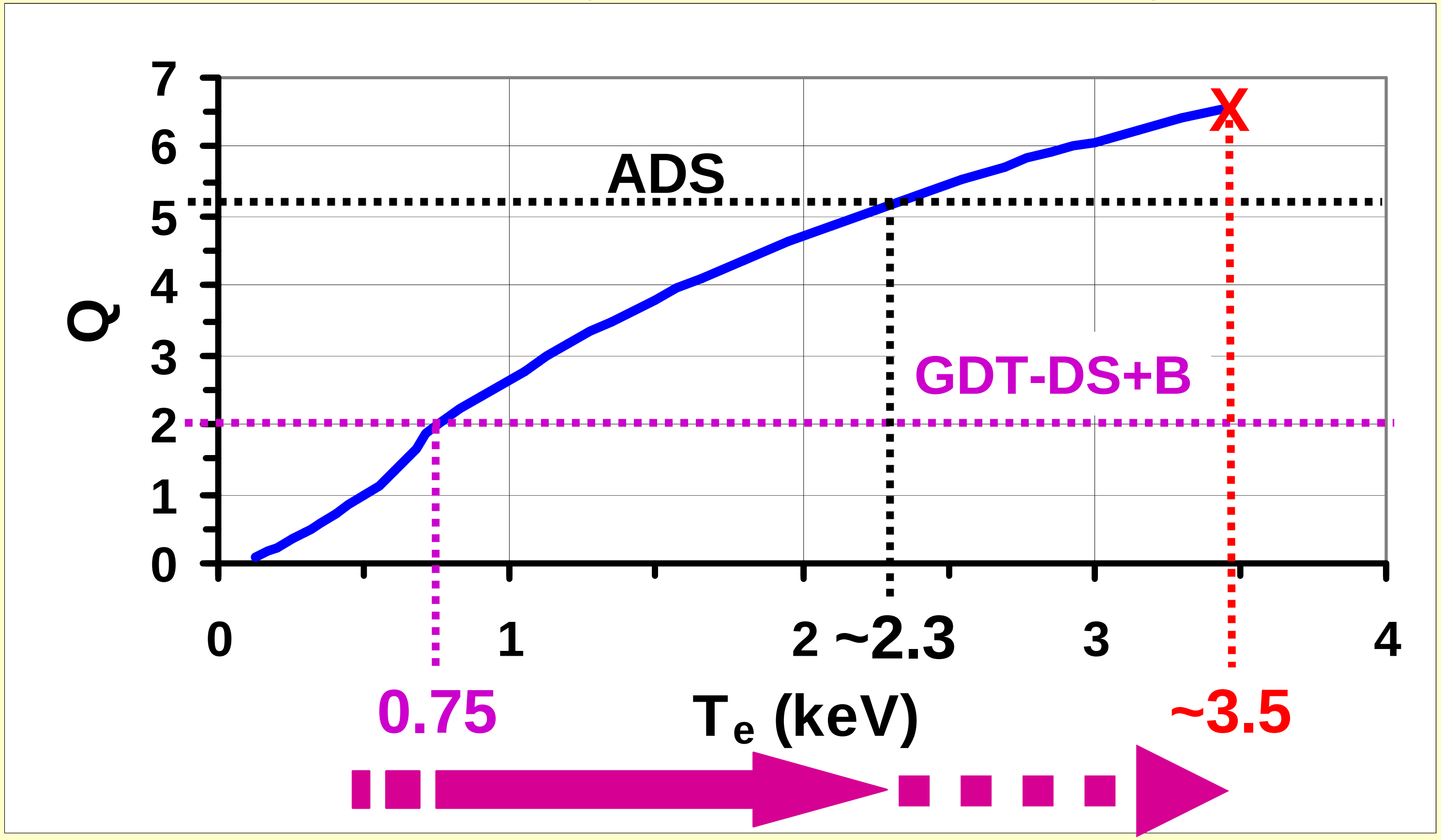


Conclusions (2/2)

 # Q-factor:

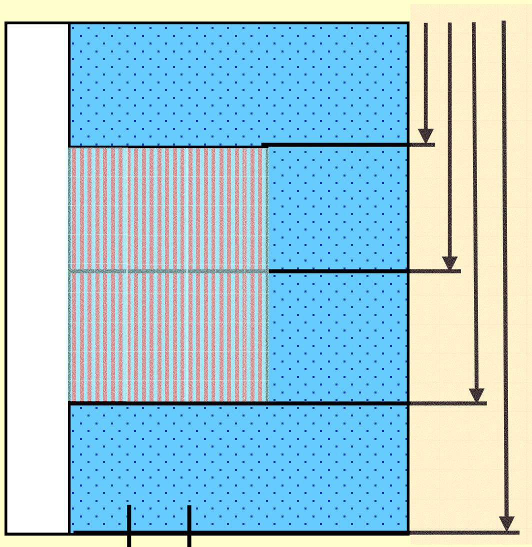
$$Q = \frac{P_{fis}}{P_{inp}} \propto \frac{S(T_e) \times M_{eff}}{P_{inp}}$$

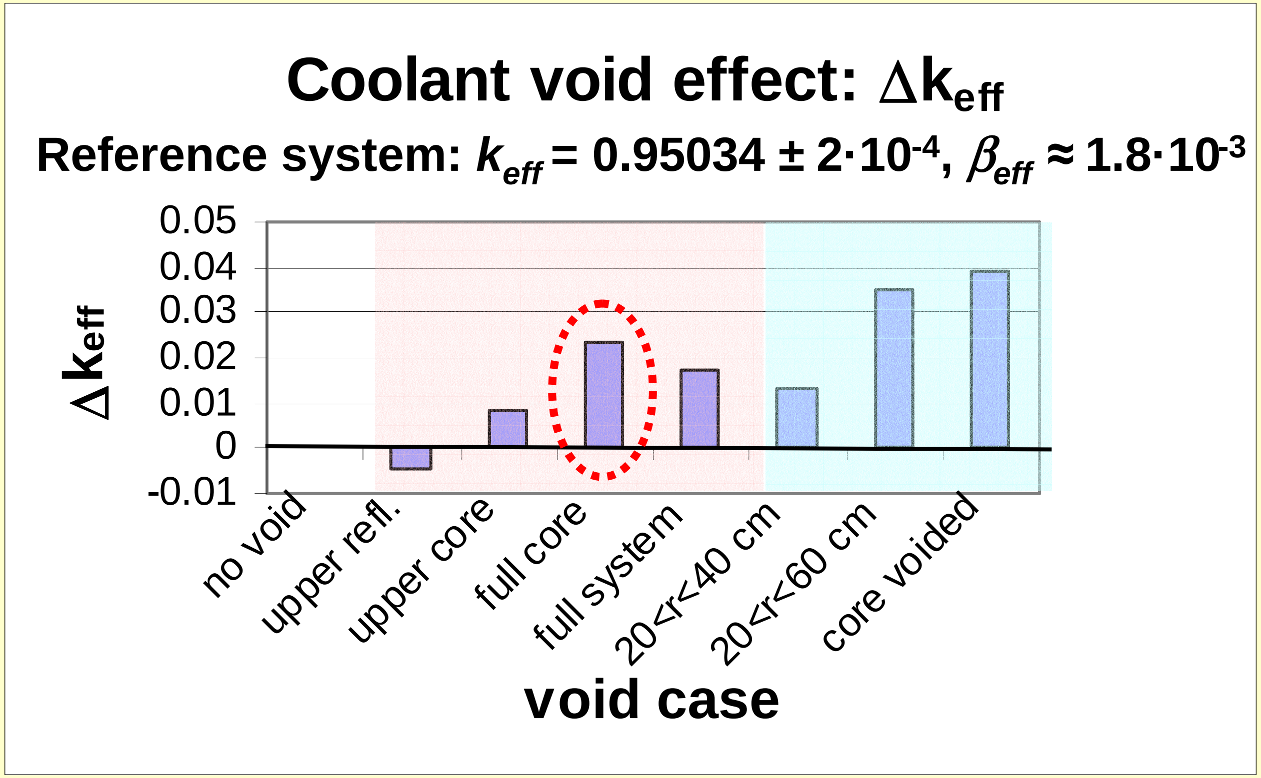
„GDT-DS+B“ : # P_{inj} = 60 MW (el.), # E_{inj} = 65 keV



Appendix (2)

➢ **Coolant void effect → Max(k_{eff})=?**

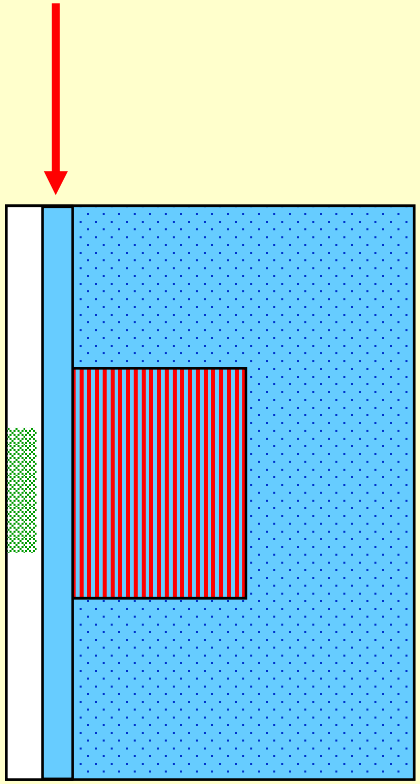


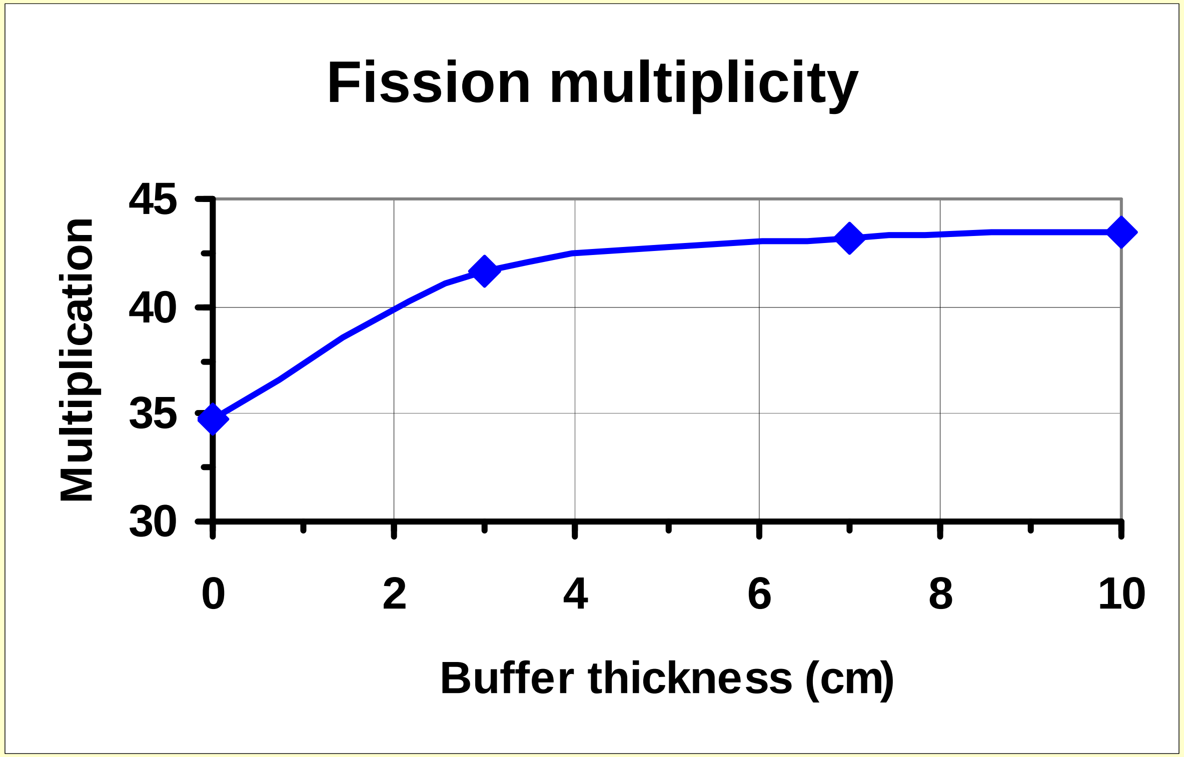


: This type of MA-burner could work with k_{eff} = 0.97 !

Appendix (3)

➢ **Optimum buffer thickness:**

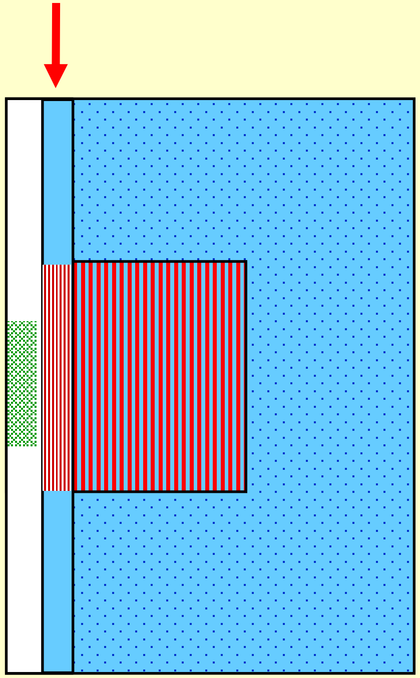




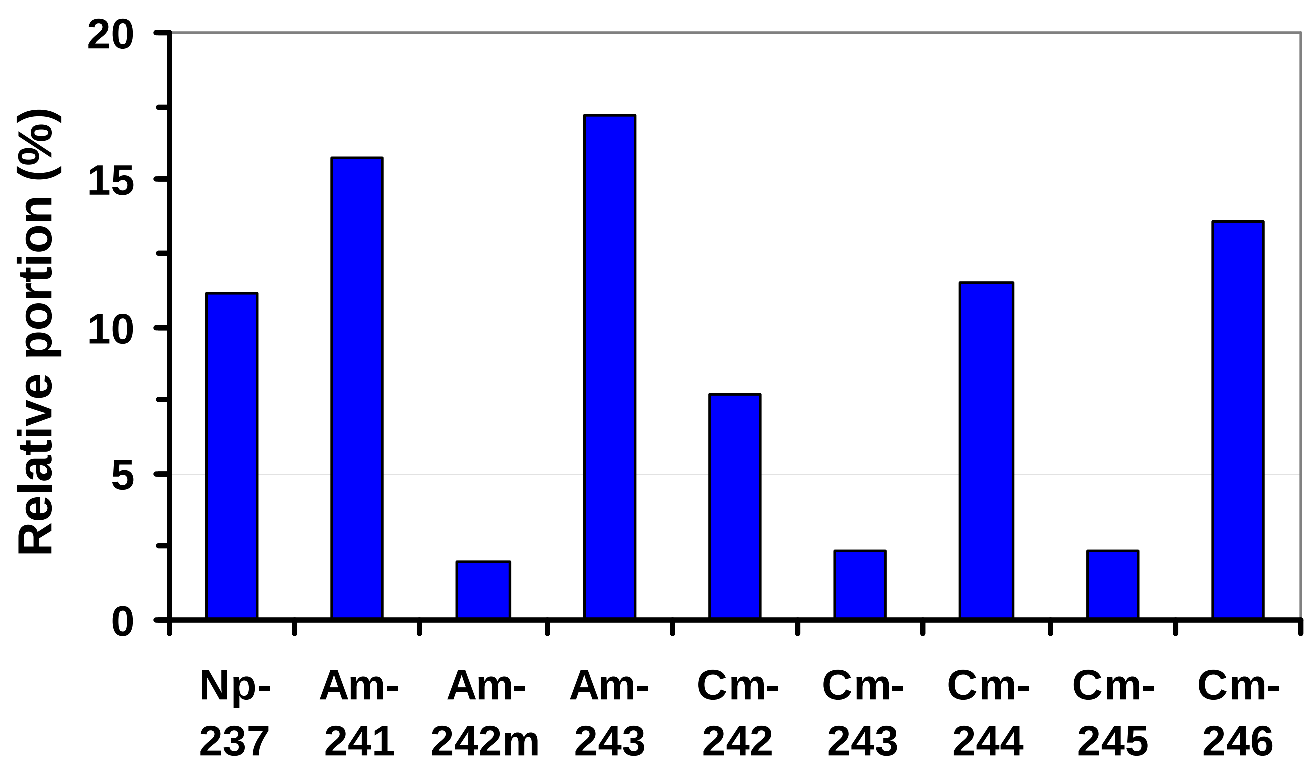
: Buffer thickness of 5-7 cm is ok.

Appendix (4)

➢ Is a MA-loaded, gas cooled buffer useful ?



Relative portion of fissions induced by fusion neutrons



Model:

Pu→MA

~~Pb-Bi~~

⇒ : No !

Appendix

- Spectrum effect of the coolant (→ gas cooled?):