Fission-Suppressed Fusion Breeder on the Thorium-Cycle and Nonproliferation

Presentation to

FUNFI

Workshop on

FUSION FOR NEUTRONS AND SUB-CRITICAL NUCLEAR FISSION

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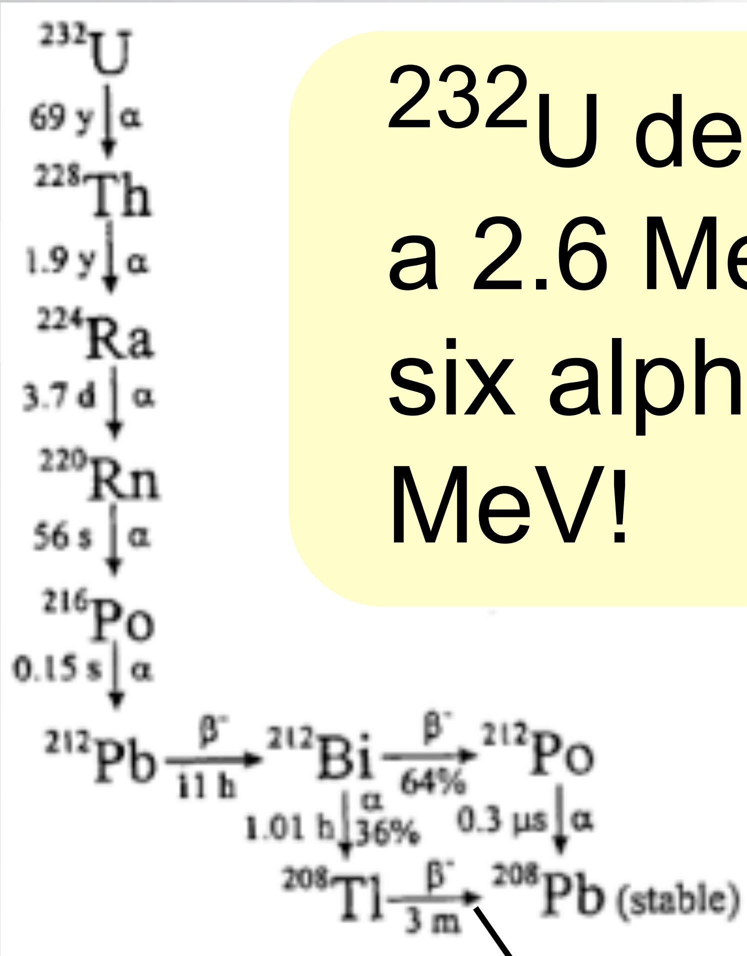
^{233}U is produced in the following reaction.

$$n + {}^{232}Th \rightarrow {}^{233}Th \rightarrow {}^{233}Pa + e^{-} \rightarrow {}^{233}U + e^{-}$$

^{232}U is also produced

Fusion is unique in that its high-energy 14 MeV neutron can generate up to 0.05 ^{232}U atoms for each ^{233}U atom produced from thorium, about twice the IAEA standards of "reduced protection" or "self protection."

What is ^{232}U?



2.6 MeV γ

^{232}U decays ending with a 2.6 MeV gamma and six alphas releasing 41 MeV!

- 69 year half-life
- ^{228}Th 1.9 y half-life hold up

^{232}U is produced in the following reactions

1 $$n + {}^{232}Th \rightarrow {}^{233}Th \rightarrow {}^{233}Pa + e^-$$

$$n + {}^{233}Pa \rightarrow 2n + {}^{232}Pa \rightarrow {}^{232}U + e^-$$ **Fast**

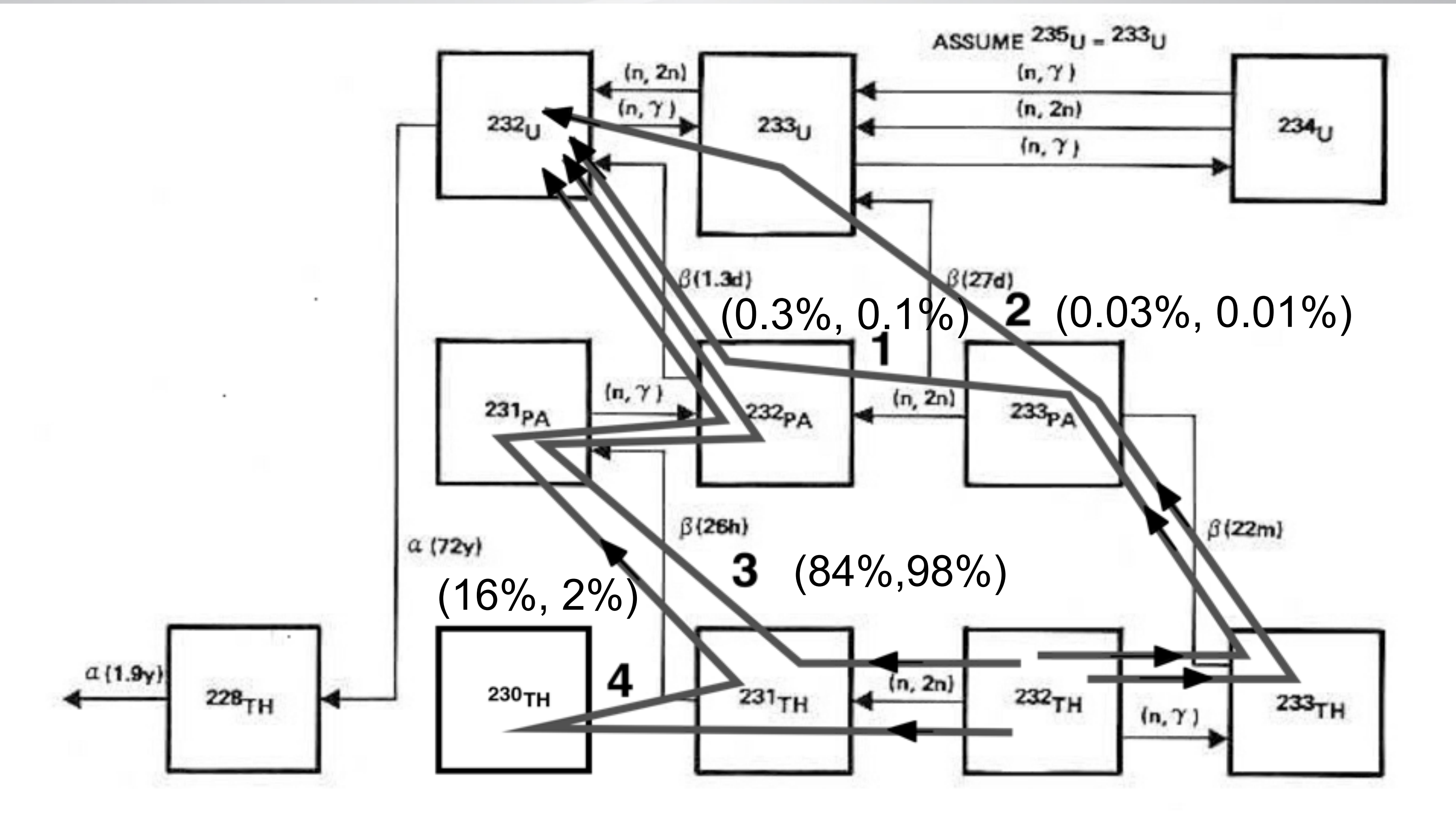
2 $$n + {}^{232}Th \rightarrow {}^{233}Th \rightarrow {}^{233}Pa + e^- \rightarrow {}^{233}U + e^-$$

$$n + {}^{233}U \rightarrow 2n + {}^{232}U$$ **Fast**

3 $$n + {}^{232}Th \rightarrow 2n + {}^{231}Th \rightarrow {}^{231}Pa + e^-$$ **Fast**

$$n + {}^{231}Pa \rightarrow {}^{232}Pa \rightarrow {}^{232}U + e^-$$

The reaction paths that lead to ^{232}U with % for each route for the (Li/MS, Be/MS) blankets

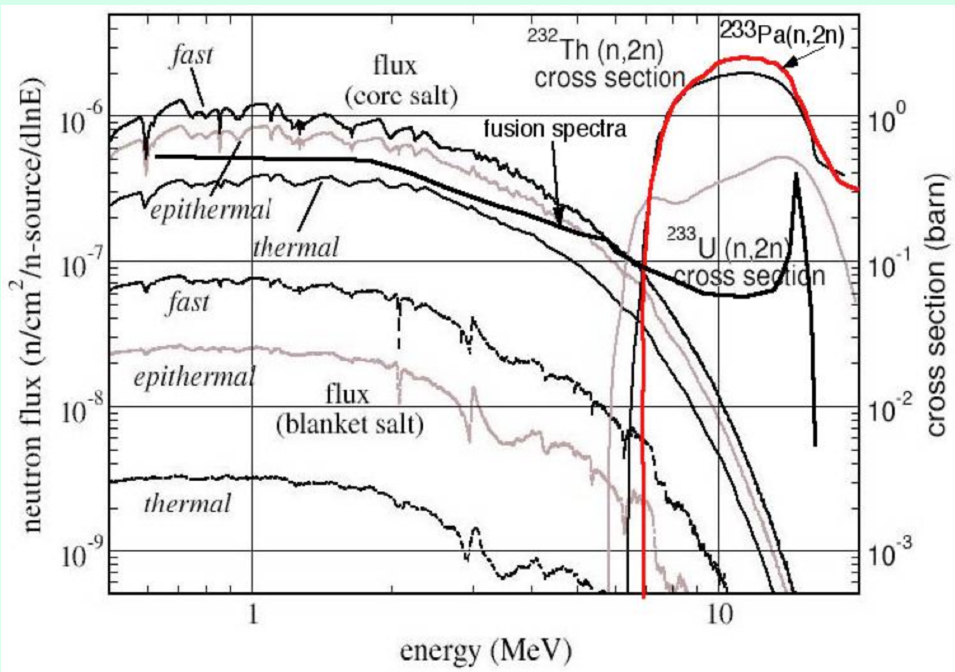


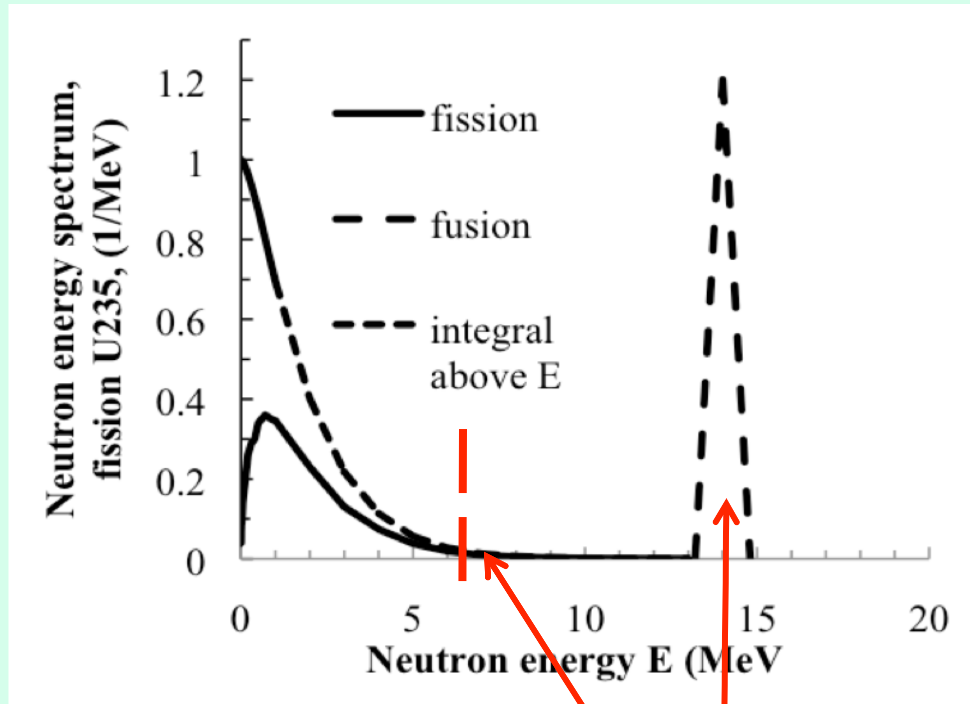
^{233}U is produced in the following reaction #2

$$n + {}^{232}Th \rightarrow {}^{233}Th \rightarrow {}^{233}Pa + e^{-} \rightarrow {}^{233}U + e^{-}$$

Fusion is unique for producing ^{232}U

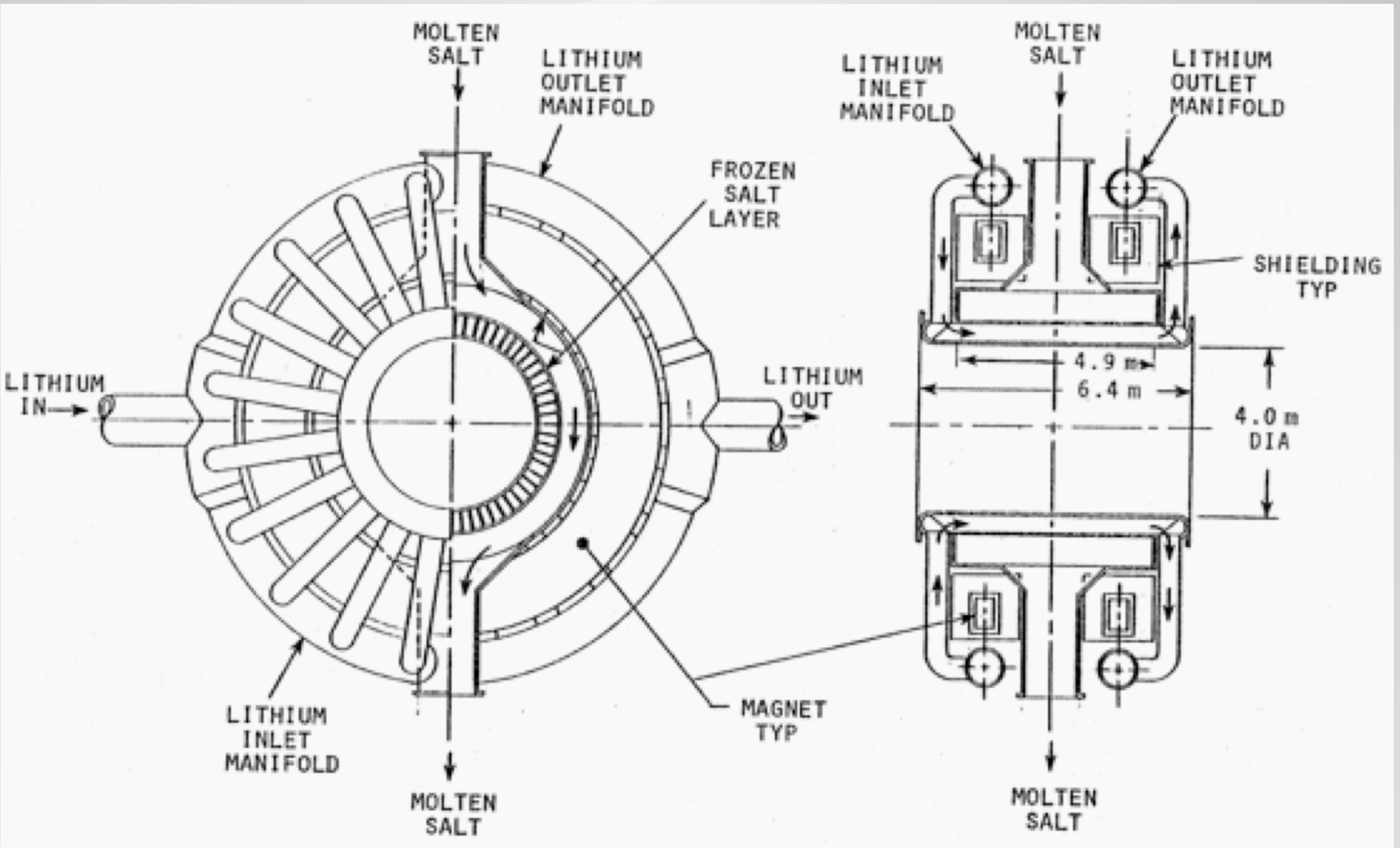
Threshold cross-sections for producing ^{232}U





Fusion (100% neutrons>6 MeV)
Fission (<3% neutrons>6 MeV).

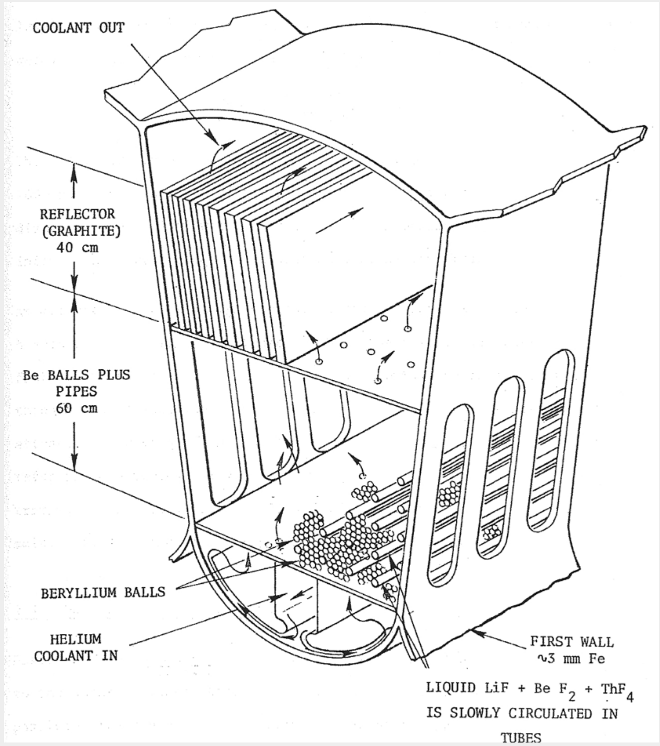
Fission-suppressed ^{233}U breeder blanket using a lithium neutron multiplier (Li/MS)

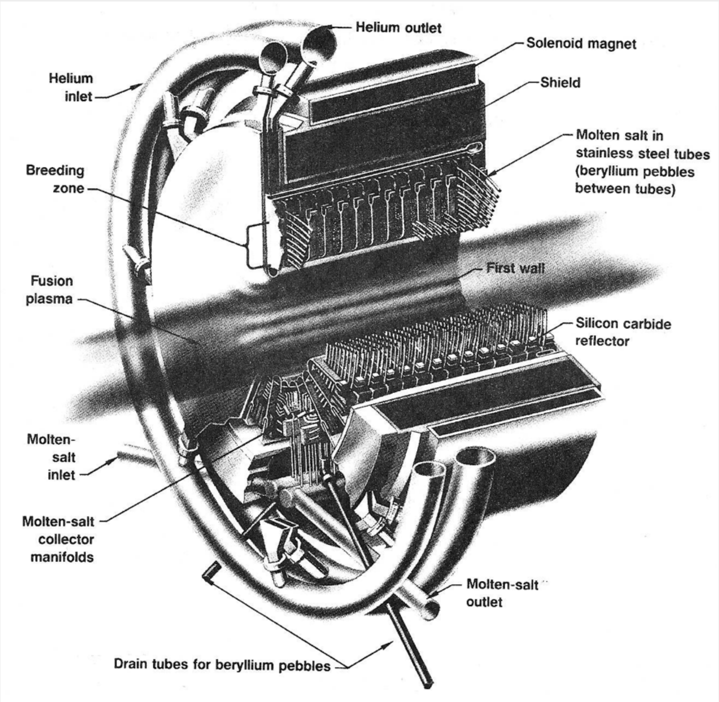


- Molten salt carries Li and Th to breed T and ^{233}U and ^{232}U
- Molten salt and liquid lithium cooling

Lee et al., UCID-19327 (1982)

Fission-suppressed ^{233}U breeder blanket using a beryllium neutron multiplier (Be/MS)

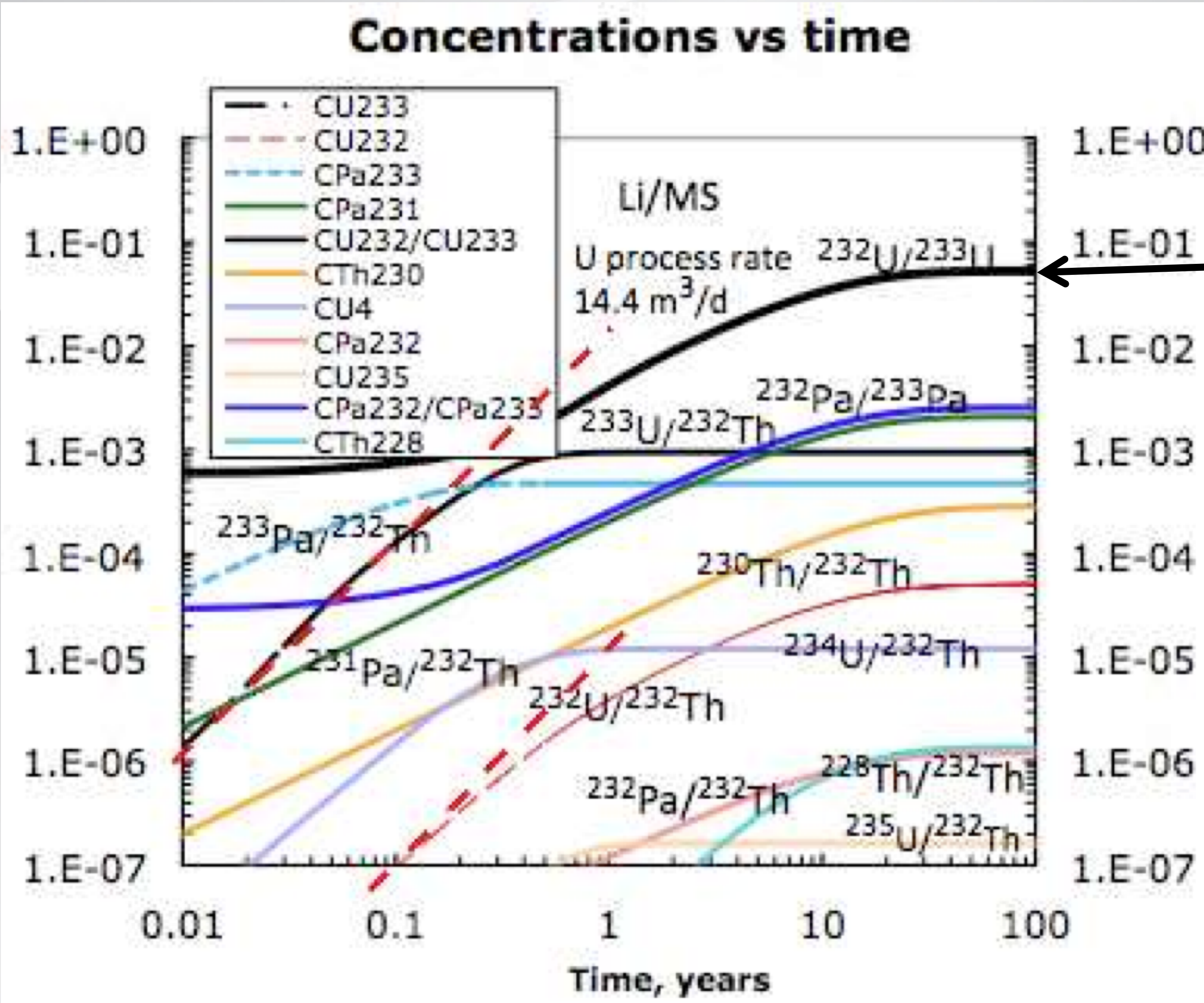




- Molten salt carries Li and Th to breed T and ^{233}U and ^{232}U
- Helium cooling

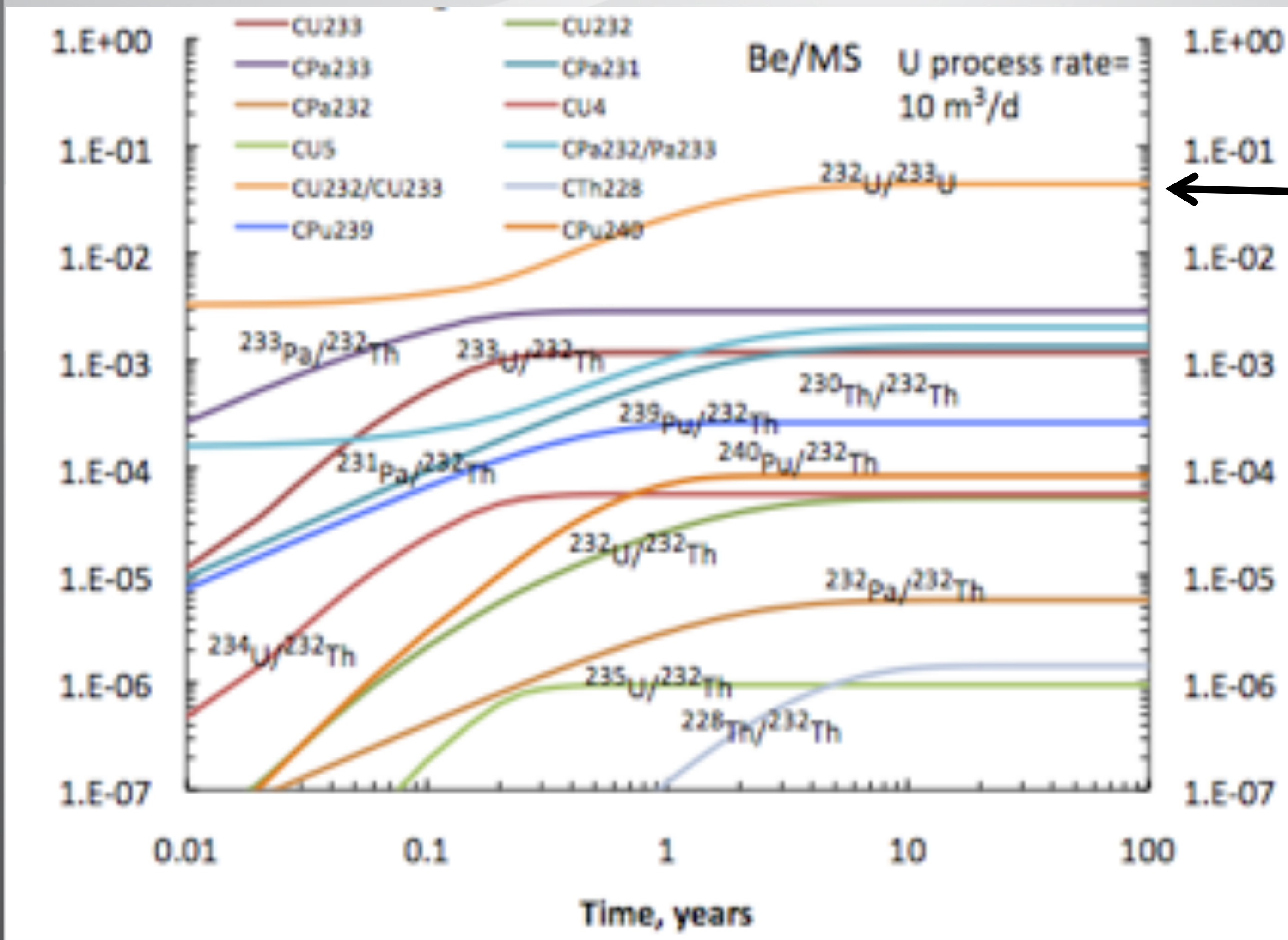
Moir et al., *Fusion Technology*, 8 (1985).

Concentration ratios versus exposure time for the Li/MS case.



^{232}U / ^{233}U >5%

Concentration ratios versus exposure time for the Be/MS case.

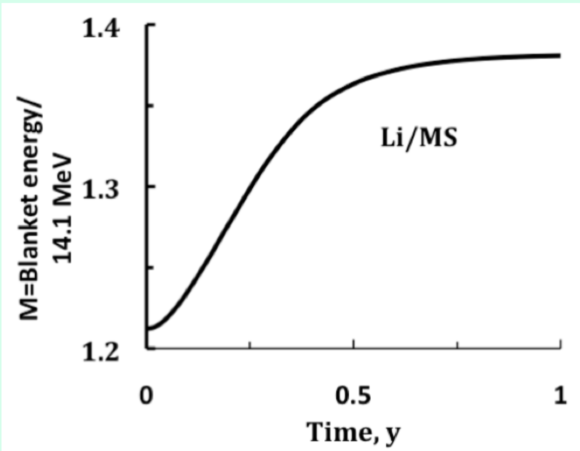


^{232}U / ^{233}U

>5%

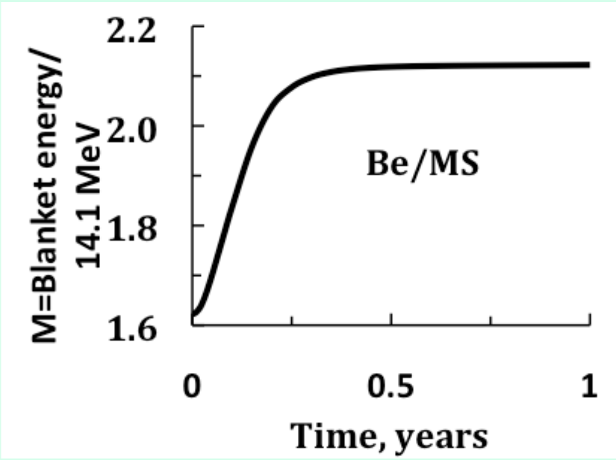
Fission is suppressed–blanket multiplication is low

Li/MS M=1.4



F=0.5 ^{233}U/fusion
2200 kg/1000 MW_F•y
1800 kg/1000 $MW_{Nuclear}$•y

Be/MS M=1.6



F=0.6 ^{233}U/fusion
2700 kg/1000 MW_F•y
1420 kg/1000 $MW_{Nuclear}$•y

How many molten salt thorium fission reactors can be refueled annually with one fusion breeder?

Molten salt thorium reactor
^{233}U, ^{238}U, Th fuel cycle; CR=0.8
74 kg $^{233}U/GW_{nuclear} \cdot y$

1 Li/MS Fusion breeder
F=0.5, M=1.4
2200 kg/1000 $MW_{fusion} \cdot y$
1700 kg/$GW_{nuclear} \cdot y$

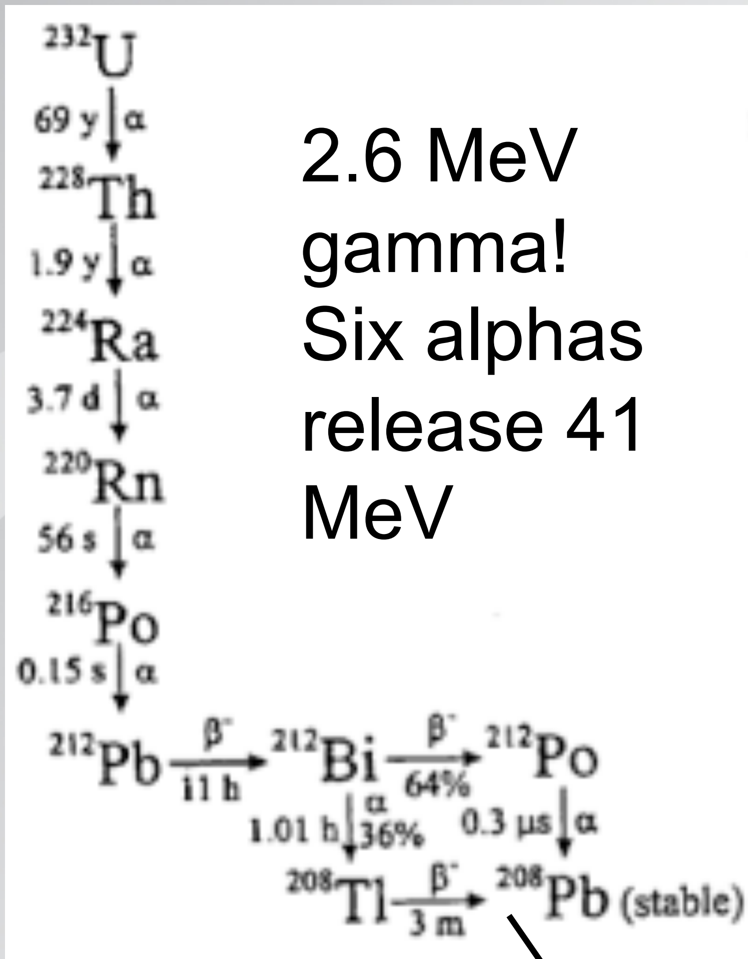
Support ratio

23

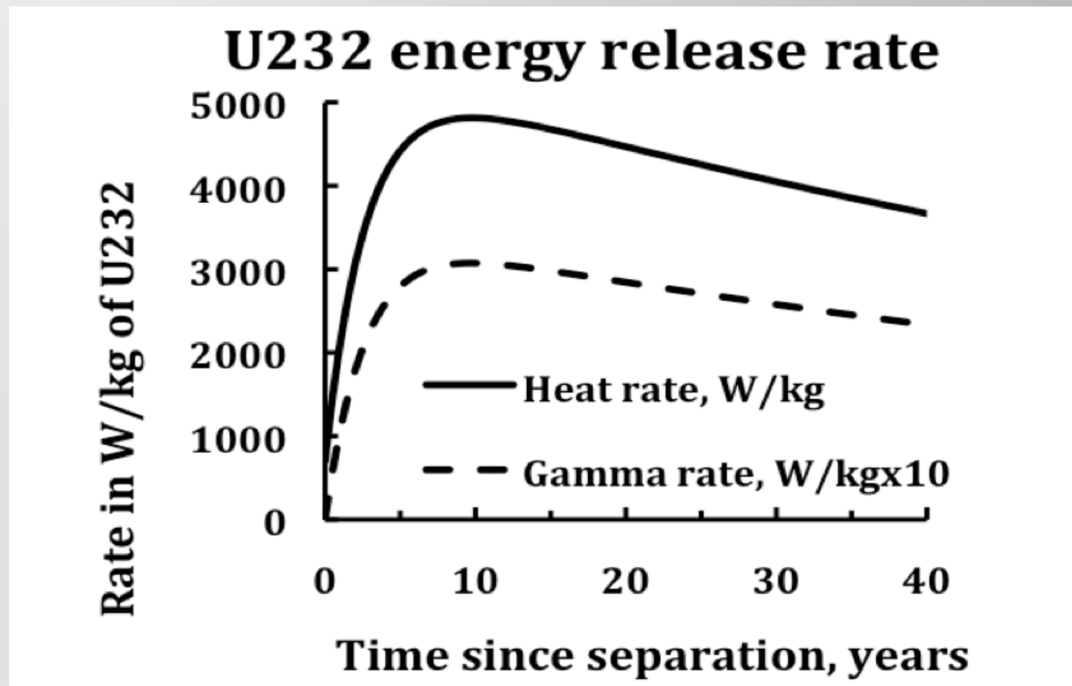
1 Be/MS Fusion breeder
F=0.6, M=1.6
2660 kg/1000 $MW_{fusion} \cdot y$
1420 kg/$GW_{nuclear} \cdot y$

19

Nonproliferation features



2.6 MeV gamma! Six alphas release 41 MeV

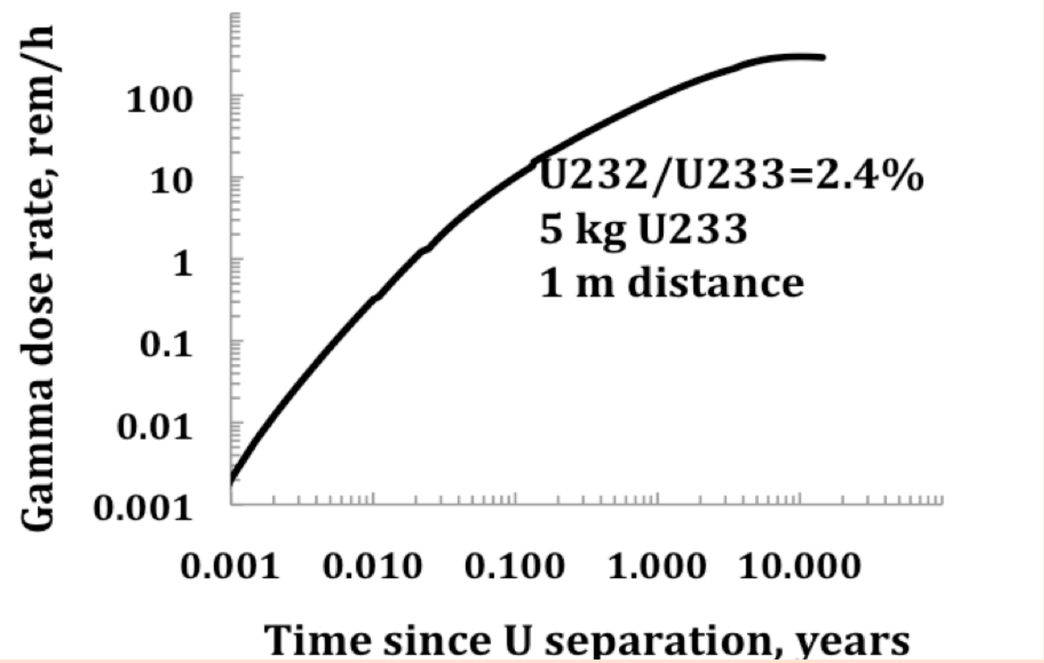


2.6 MeV γ

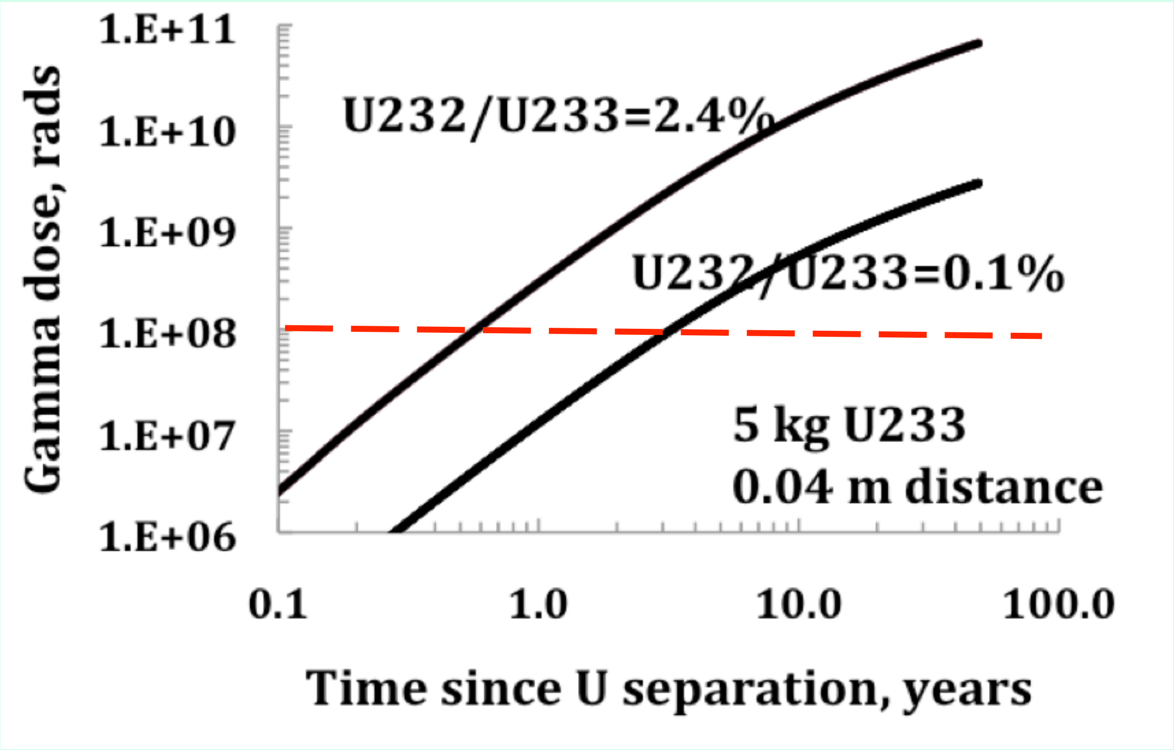
- 69 year half-life
- ^{228}Th 1.9 y half-life hold up

The nonproliferation feature of "Self protection" is satisfy at 2.4% $^{232}U^{233}U$. We have 5%.

IAEA standards of "reduced protection" or "self protection" set at a dose rate of 100 rem/h (1 Sv/h) at 1 m =dose rate from 5 kg of ^{233}U with 2.4% ^{232}U one year after chemical separation of daughter products.



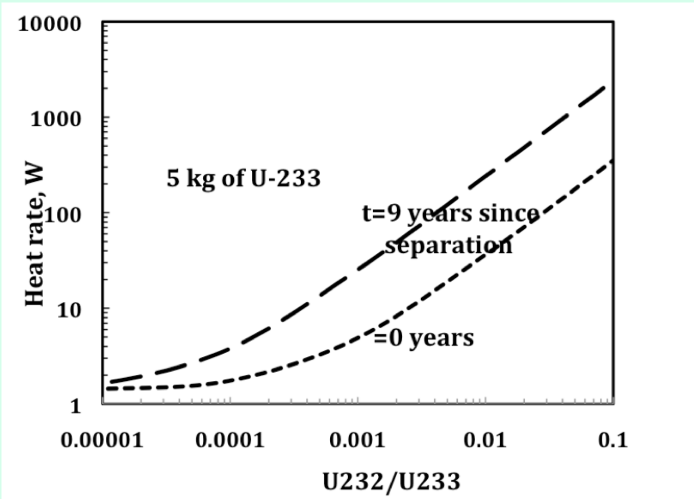
More nonproliferation features—high explosive damage

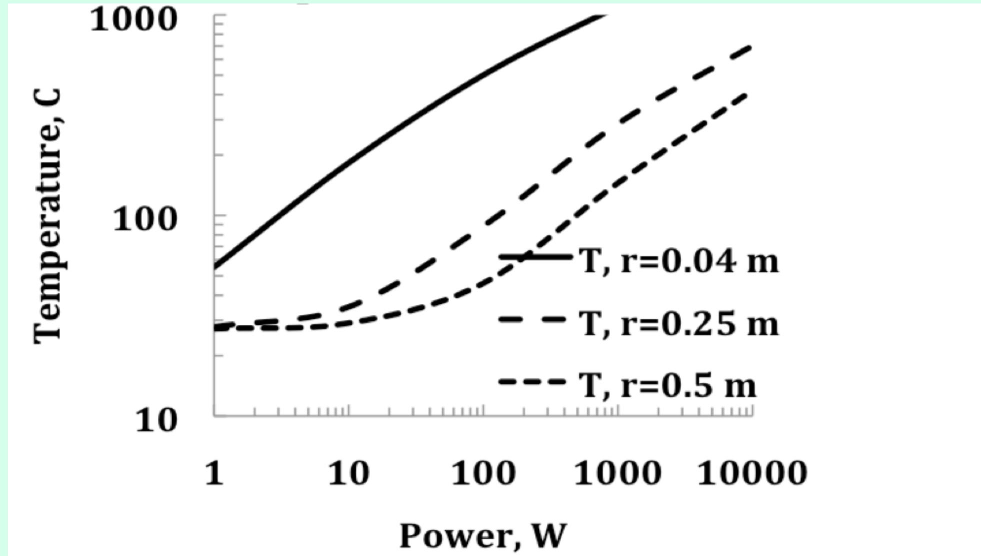


High explosives damage at 10^8 rads.

More nonproliferation features—Alpha decay heating produces high temperatures

Heat from a critical mass





On a sphere of 0.25 m radius
5 kg of U-233
77 W 50° C at t=0
600 W 200° C t=9 y after separation

Conclusions

- Fusion's 14 MeV neutron, being well above the 6 MeV threshold for producing ^{232}U makes it unique in enabling the thorium cycle with strong nonproliferation features.
- This radiation argues against ^{233}U from thorium use in nuclear weapons because of the dose to workers near the explosive.
- The allowed time of exposure is 300 hours for a fatal dose at ^{232}U /^{233}U =2.4%.
- Not so well known is the damage to high explosive material placed near the critical mass owing to ionizing radiation.
- The estimated shelf life for high explosive damage is about ½ year after separation for ^{232}U /^{233}U = 2.4%. The heat generation at the time of separation is 77 W and rises in nine years to 600 W.
- The temperature rise owing to this heat generation rate for a bare sphere is estimated to be 84 °C and 450 °C at time of separation and after 9 years, respectively.
- The radiation associated with the thorium fuel cycle is well known and is one of the reasons it is not used in nuclear reactors, especially since hands on fabrication of solid fuel is precluded.
- Fusion's first and early application could be to produce fuel to start up ~3 thorium cycle molten salt fission reactors yearly or supply annual makeup fuel for more than 20 reactors.