Idaho National Engineering and Environmental Laboratory

Irradiation of German Pebbles in ATR

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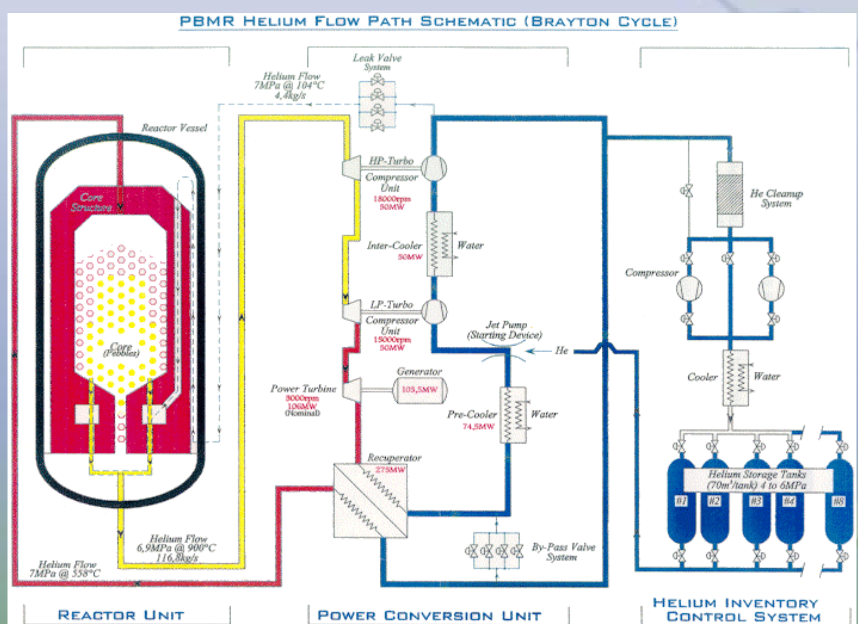
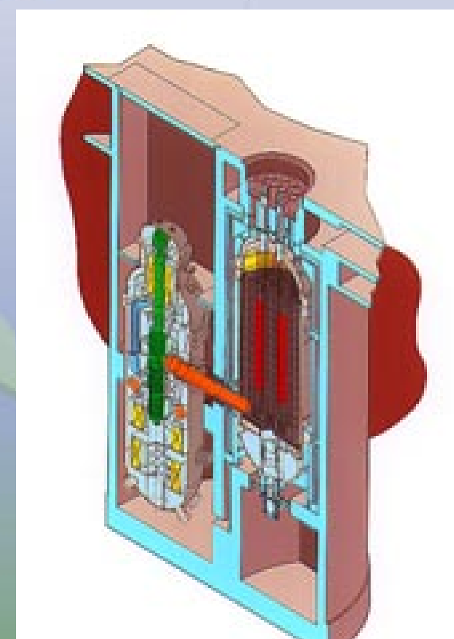
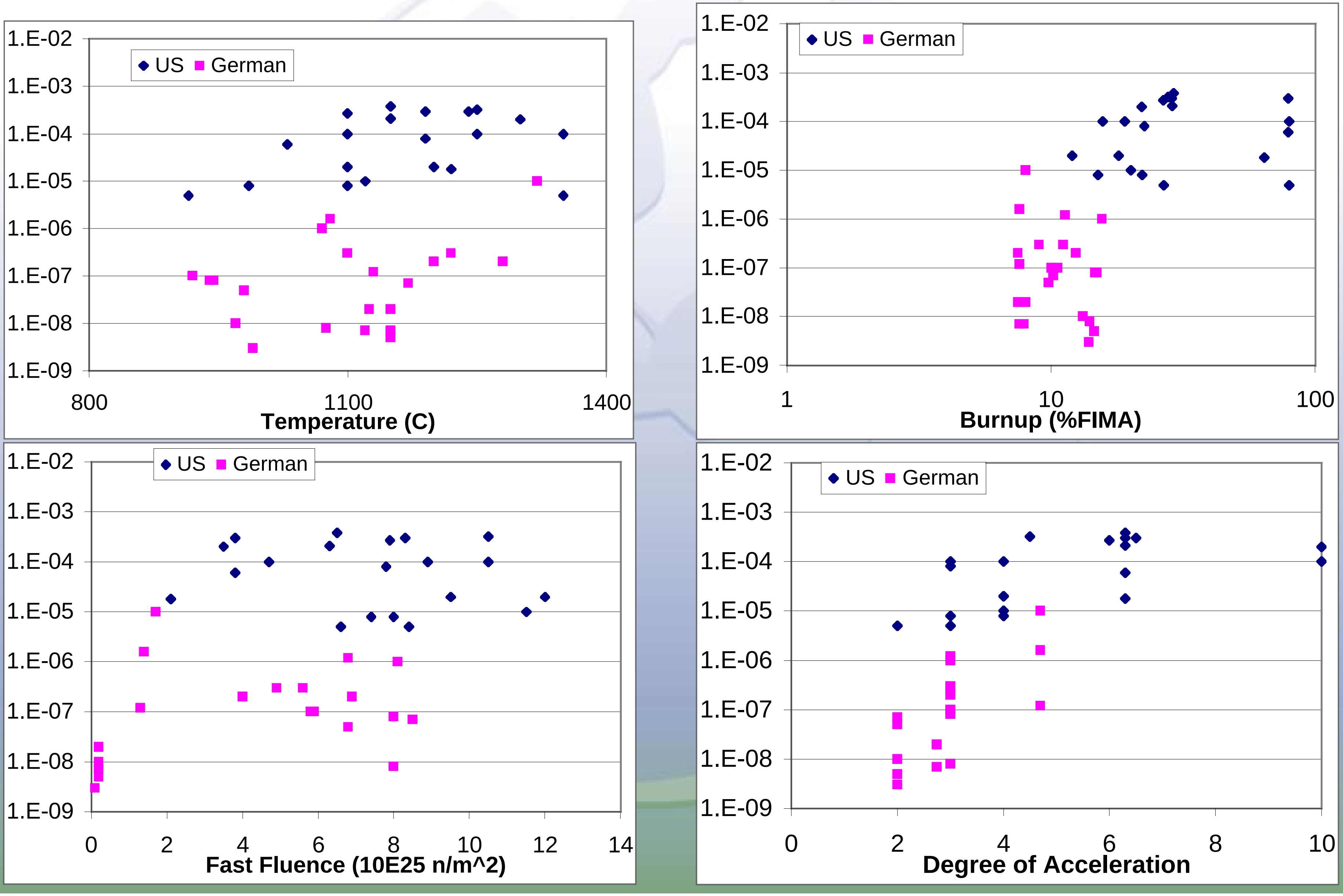
Service Conditions for PBMR and GT-MHR

Parameter	PBMR	GT-MHR
Fuel Kernel	UO2	UCO
Fuel form	pebble	compact
Temperature (Avg/Max) °C	800/1200(?)	1000/1250 (best estimate)
Peak kw/fuel element	3.4	590
Particle packing fraction in fuel element	10-15%	35-50%
Burnup (% FIMA)	11	20 fissile/6 fertile
Max. Fluence (>0.18 MeV) (10^21 n/cm2)	2.4	4

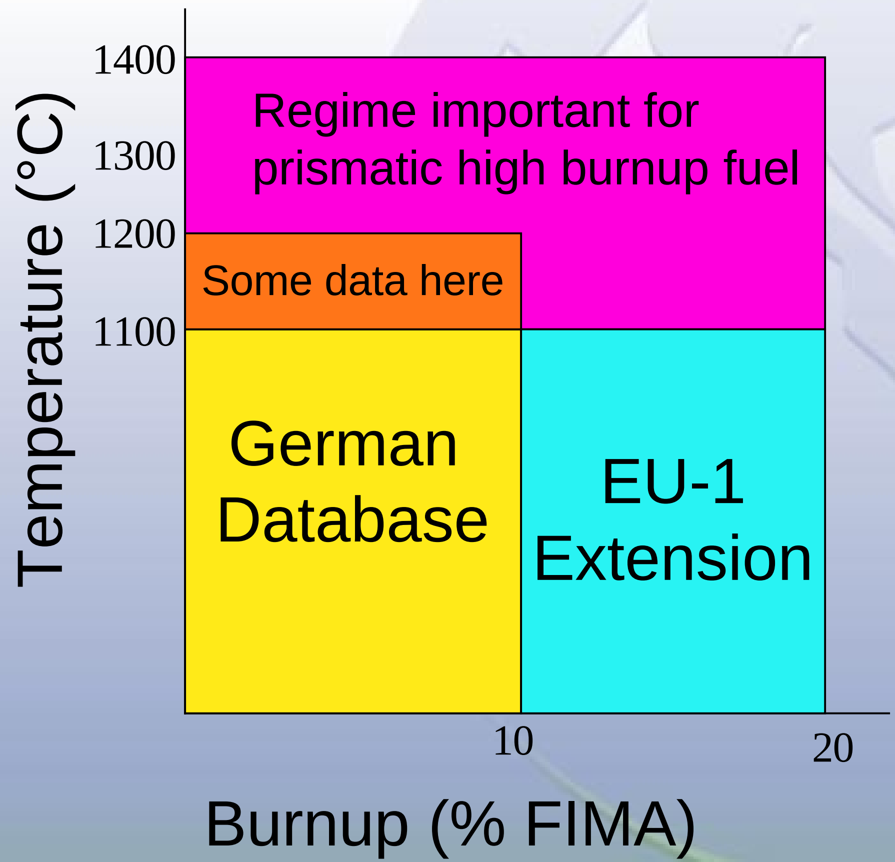


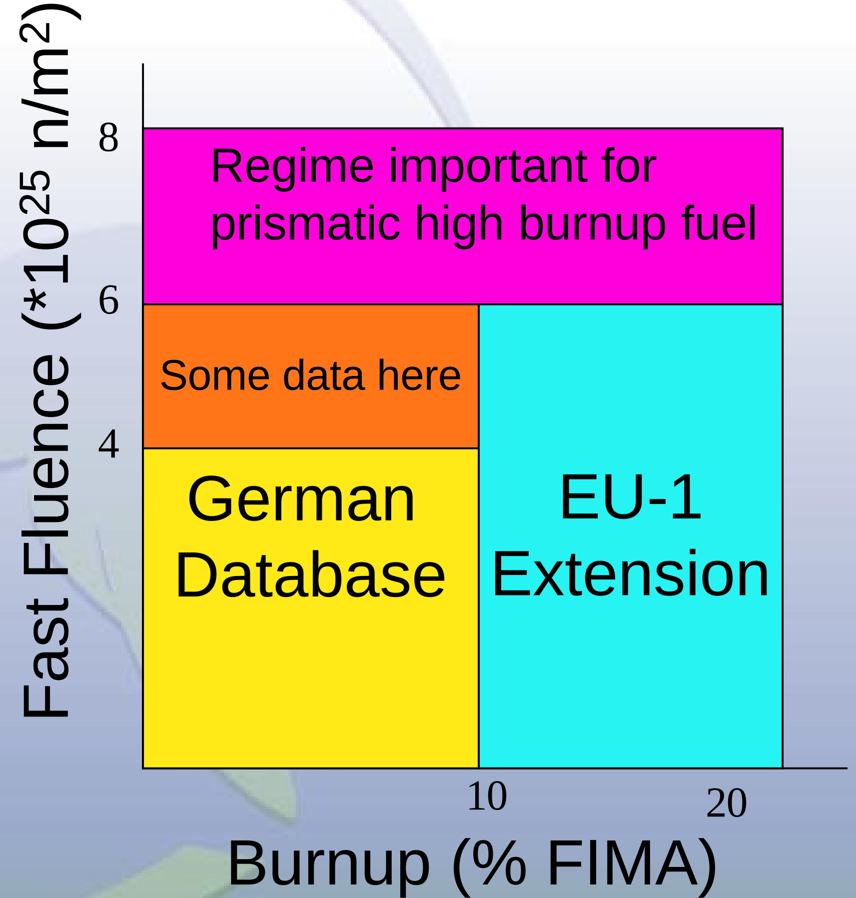


Gas Release (R/B) in US and German Irradiation Testing



Irradiation Test Map for LEU High Quality TRISO-coated Fuel





Testing Ideas

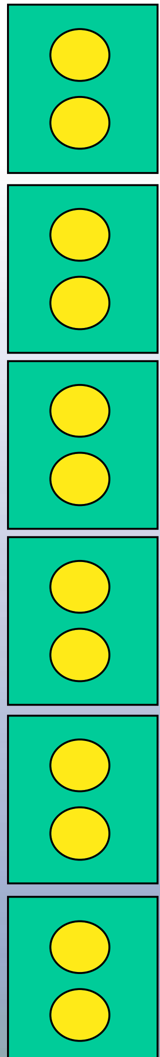
- Germans have basically demonstrated excellent behavior up to 9% FIMA, 1100°C, 4 x 10^{25} n/m^2
- Higher burnup (up to 20% FIMA),higher fluence (< 8 x 10^{25} n/m^2), higher temperature (1250-1400°C) regime has not been explored extensively
- Prismatic gas reactors run hotter than pebble beds (1250°C nominal max(?))
- High burnup will also push fast fluence
- Many international participants in recent IAEA meeting expressed desire to understand high burnup regime and limits of fuel under normal operation
- Limited German data indicate that higher burnup/higher fluence fuel will show greater releases in accident testing
  - Reason for this behavior is not well known
  - More testing and PIE would be very helpful here

Table II: Irradiation targets of HFR-EU2 in comparison to respective conditions of HFR-EU1, HFR-K6 and HTGR designs

Parameter	HFR-EU 2	HFR-EU1	HFR-K6	HTR-Module	PBMR	Commercial GT-MHR
Fuel	UO_2 TRISO	UO_2 TRISO	UO_2 TRISO	UO_2 TRISO	UO_2 TRISO	U-C-O TRISO
Peak burnup [% FIMA]	<12	20	9.7	9.8	9.8	(20) fissile (6) fertile
Peak neutron fluence E>0.1 MeV [10^{25} m^{-2}]	4.5 (E >0.18 MeV)	6	4.8	2.4	2.4	4.0
Peak temperature						
Gas outlet [°C]	-		-	750	900	850
Fuel surface [°C]		950	650/850	926	1000	
Fuel center [°C]	1100-1150	1100	800(1) 1000(1) 1200(2)	1130	1100	(1250)(6)
Peak fission power per compact / fuel element [kW]	<1.5	<2.5	1.5(3) - 2.7(2)	1.6	3.4/4.5(4)	588.2 in 1020 graphite FE blocks
Maximum CP power [mW/CP]	< 400 at BOI	240	200	150	250/300(4)	27(5) (< 400 max.)
Irradiation time [efpd]	<350(7)	600	634		900	834
Simulation of number of passes	-	-	17	17	10	-

(1) 1/3 and 2/3 temperature of cycle, simulating one full pass of FE in the HTR-Module core
(2) Simulation of operational temperature transient of 5 hours, maximum temperature 1/////200 °C
(3) Maximum BOL power
(4) Equilibrium core / First core
(5) Average
(6) Temperature calculated on a best estimate (50% confidence) basis
(7) Peak burnup and peak neutron fluence is reached after about 300 full power days in HFR

PBMR Irradiation of German Pebbles in ATR



1300°C	100 GWd/t	3.8×10^{25} n/m^2
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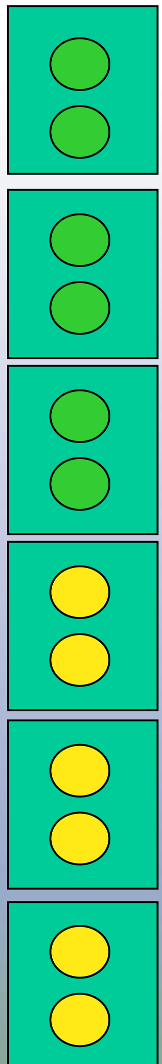
1300°C	100 GWd/t	3.8×10^{25} n/m^2
1300°C	50 GWd/t	$\sim 2 \times 10^{25}$ n/m^2

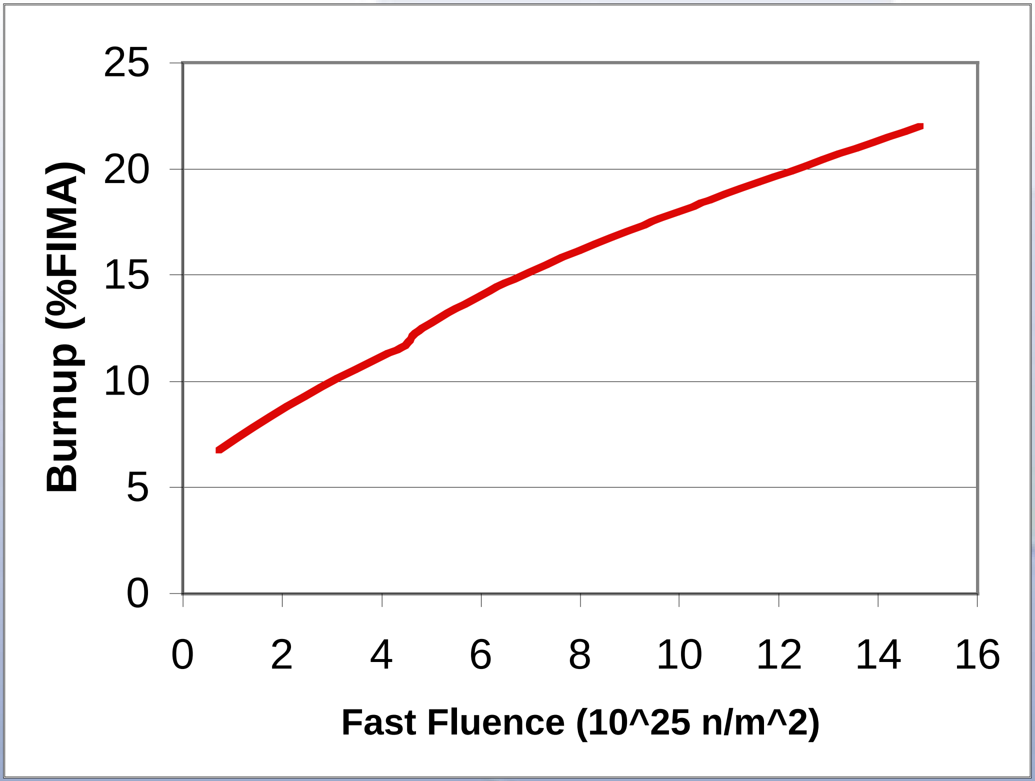
These are values based on PBMR design service conditions.

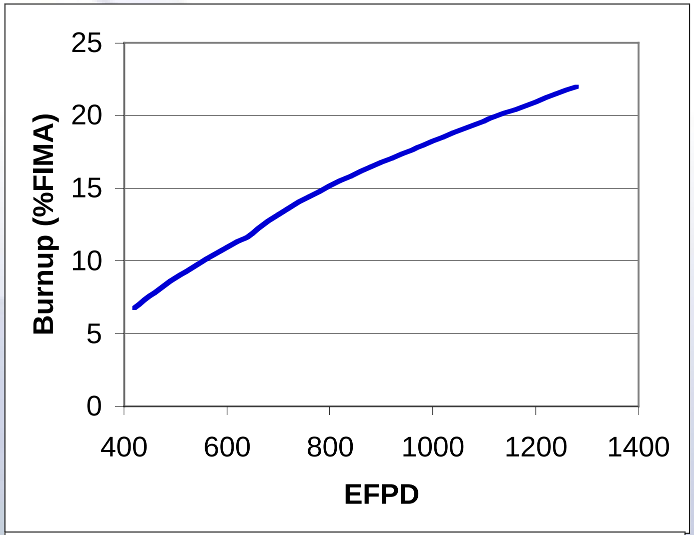
Proposed Irradiation of German Pebbles in ATR - Test Limits of High Quality TRISO-Coated Particles

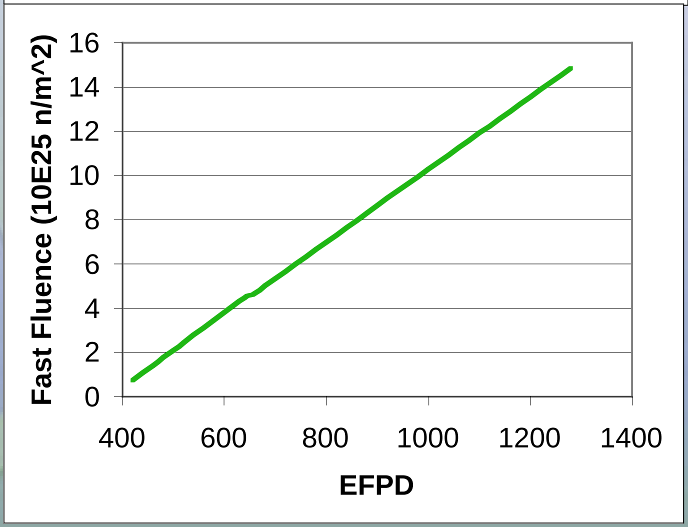


1400°C	130-150 GWd/t	6-8 $x10^{25}$ n/m^2
1300°C	130-150 GWd/t	6-8 $x10^{25}$ n/m^2
1300°C	130-150 GWd/t	6-8 $x10^{25}$ n/m^2
1200°C	130-150 GWd/t	6-8 $x10^{25}$ n/m^2
1100°C	130-150 GWd/t	6-8 $x10^{25}$ n/m^2
1300°C	65-75 GWd/t	~4 $x10^{25}$ n/m^2

Burnup/Fluence/Time Maps for Irradiation of German Pebbles in the ATR NE Flux Trap







What if we have less than 12 pebbles?

- If we have six
  - 4 at 1300°C,three to meet NRC needs for follow testing, one for PIE (?)
  - 2 at 1400°C, one to meet NRC needs, one for follow-on testing (heatup or PIE?)
- If we have eight
  - Add two pebbles at 1200°C
- If we have ten
  - Add two more pebbles at 1100°C
- If we have twelve
  - Add two more at 1300°C and lower burnup

Summary

- Higher burnup and high temperature irradiations address Gen IV needs and is relevant to GT-MHR
- NRC wants three pebbles at max. operating temperature and one pebble at max + 100°C
- This matrix provides:
  - 10 pebbles at 130-150 GWd/tU and 6 to 8 x 10^{25} n/m^2
  - 4 pebbles at max operating temperature (1300°C). Three for NRC safety testing and one for DOE to do PIE
  - Two pebbles +100°C above max operating condition (1400°C)
  - Two pebbles - 100°C below max operating (1200°C)
  - Two pebbles at 1100°C to provide modest overlap with EU program
  - 2 half burnup pebbles at max operating temperature
- The test is also complementary to EU HTR-TN irradiations planned in Petten
- The push to higher fluences/burnups will indirectly address margins