Trend Curves for IAEA Reference Steel JRQ

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Outline

- **Introduction**
- **Material description**
- **Material production**
- **Trend curves**
  - Results at different irradiation temperatures
  - Results MTR vs. WWER/PWR
- **Conclusions**

Material description

- **IAEA reference steel JRQ was prepared by Kawasaki Steel Corporation (Japan) as a sensitive material specially for the IAEA co-ordinated programme**
  - CRP-3 “Optimizing Reactor Pressure Vessel Surveillance Programmes and Their Analysis”
- **This steel has been used for several subsequent IAEA CRP programmes**
- **This steel is also used as a reference steel in several surveillance specimen programmes of reactor pressure vessels**
- **There exists sufficient stock of this material for future uses and purposes**

Material description

- **The steel was produced by the BOF-LRF (Basic oxygen furnace - Ladle refining furnace) process**
  - 2 blocks with dimensions 2300 mm × 3400 mm × 340 mm
- **After rolling, the plates were heat treated under the following conditions**
  - normalised from 900 °C
  - quenched from 880 °C
  - tempered at 665 °C for 12 hours
  - stress relieved at 620 °C for 40 hours

Material description

- **Plates A and B after rolling**
  - Dimensions – 3000 mm × 2000 mm × 250 mm

Plate A

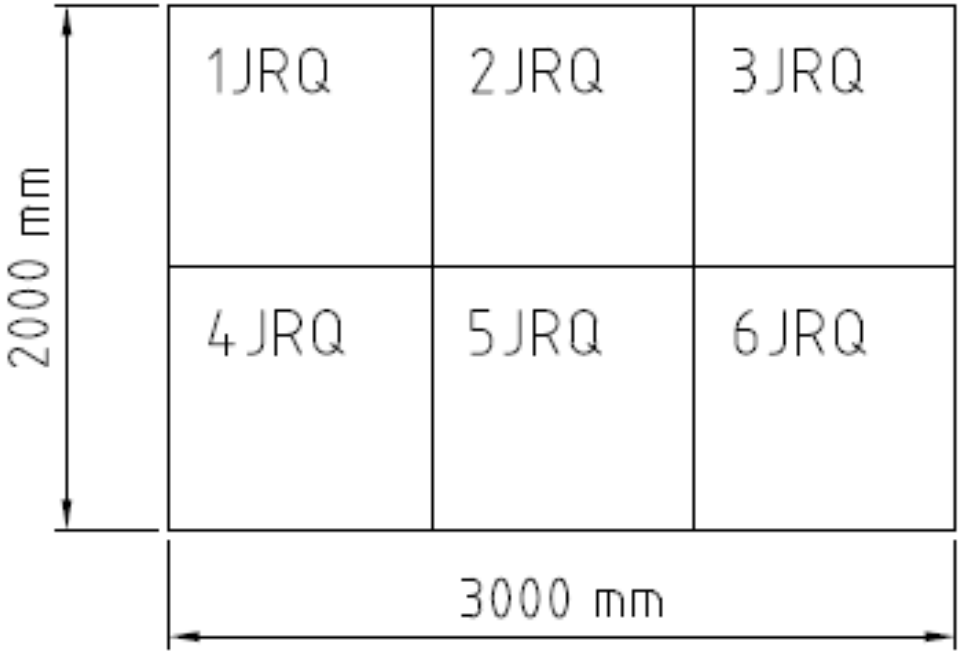
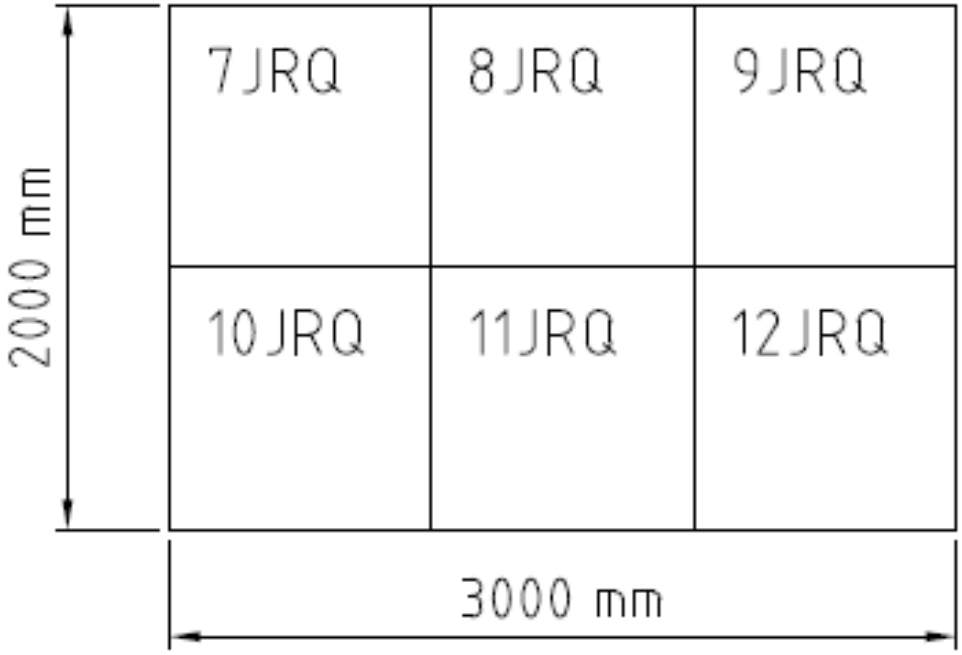
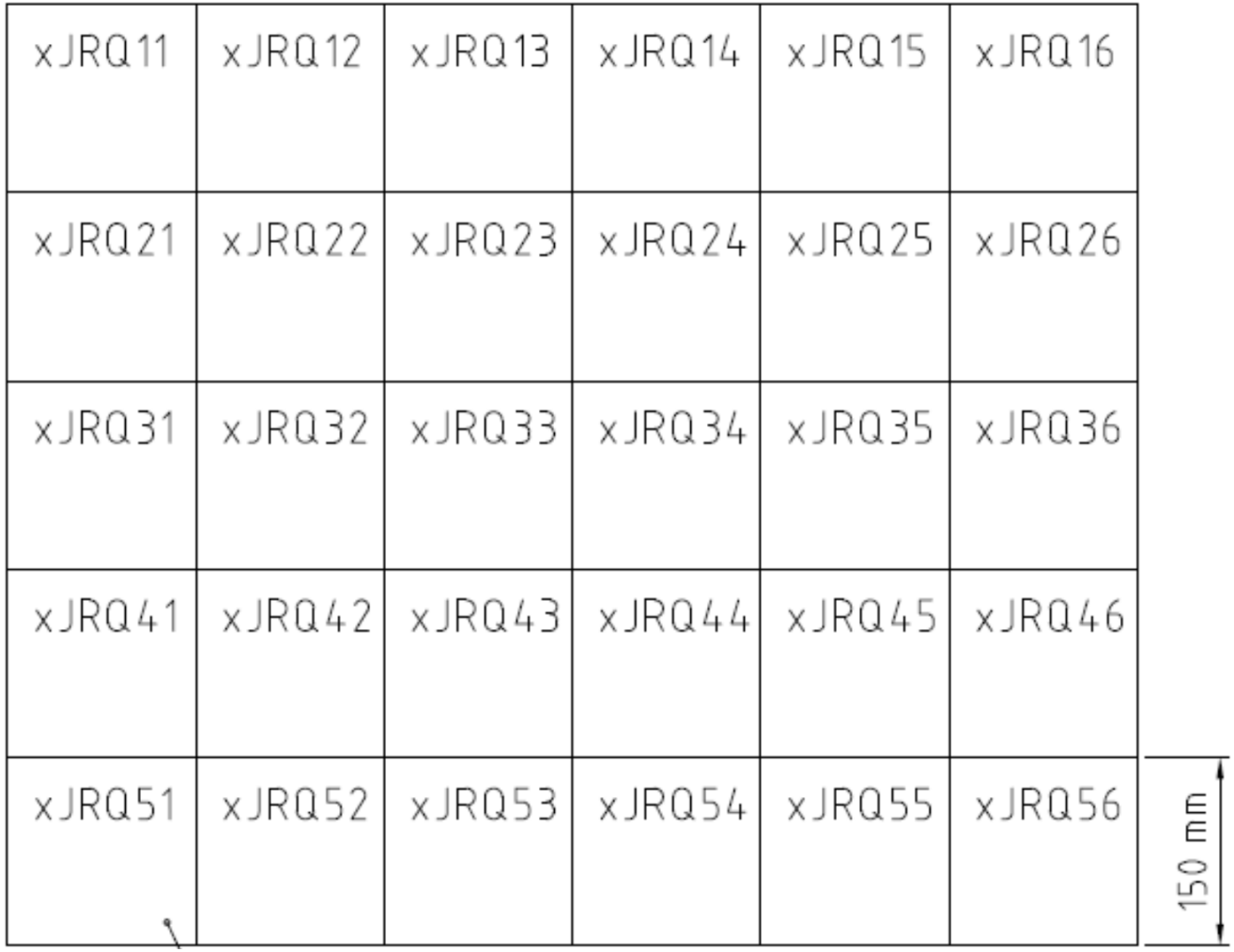


Plate B



Material description

- **Cutting to smaller blocks**
  - Dimensions – 150 mm × 150 mm × 250 mm



Material main characteristics

Chemical composition (mass %)

	Location		C	Si	Mn	P	S	Cu	Ni	Cr	Mo	V	Al
Ladle	-		0.18	0.24	1.42	**0.017**	0.004	**0.14**	0.84	0.12	0.51	0.002	0.014
Plate A	Top	t/4	0.19	0.25	1.41	**0.017**	0.004	**0.14**	0.84	0.12	0.50	0.003	0.012
		2t/4	0.20	0.26	1.43	**0.019**	0.004	**0.14**	0.85	0.12	0.51	0.003	0.012
	Bottom	t/4 t	0.18	0.25	1.39	**0.017**	0.003	**0.14**	0.83	0.12	0.50	0.003	0.012
		2t/4 t	0.18	0.25	1.38	**0.019**	0.004	**0.14**	0.82	0.12	0.49	0.003	0.012
Plate B	Top	t/4	0.19	0.25	1.39	**0.019**	0.004	**0.14**	0.83	0.12	0.50	0.003	0.012
		2t/4 t	0.20	0.25	1.41	**0.019**	0.004	**0.14**	0.84	0.12	0.50	0.003	0.012
	Bottom	t/4	0.18	0.25	1.37	**0.018**	0.004	**0.13**	0.82	0.12	0.49	0.003	0.012
		2t/4 t	0.16	0.25	1.35	**0.019**	0.003	**0.13**	0.80	0.12	0.49	0.003	0.012

T = plate thickness (225 mm)

Acceptance test results

Tensile test results (Plate A) – room temperature

Location		Yield Strength [MPa]	Tensile Strength [MPa]	Elongation [%]	Reduction of Area [%]
Top	0/4 t	564	688	26	82
	1/4 t	487	635	25	77
	2/4 t	482	630	24	77
Bottom	0/4 t	548	678	27	81
	1/4 t	467	624	27	76
	2/4 t	465	611	27	77

Acceptance test results

Charpy impact test results (Plate A)

Orientation	Location		$T_{41\ J}$ [°C]	$T_{68\ J}$ [°C]	$T_{50\ \%}$ [°C]	KV(-12 °C) [J]
Longitudinal	Top	0/4 t	- 115	- 112	- 99	240
		1/4 t	- 28	- 15	2	75
		2/4 t	- 23	- 13	5	74
Transverse	Top	0/4 t	- 53	- 46	- 36	176
		1/4 t	- 23	- 13	2	69
		2/4 t	19	- 8	8	60

Steel characterization

- **IAEA reference steel JRQ was proposed as a correlation monitor - material with medium sensitivity to radiation damage**

0.019 P + 0.14 Cu

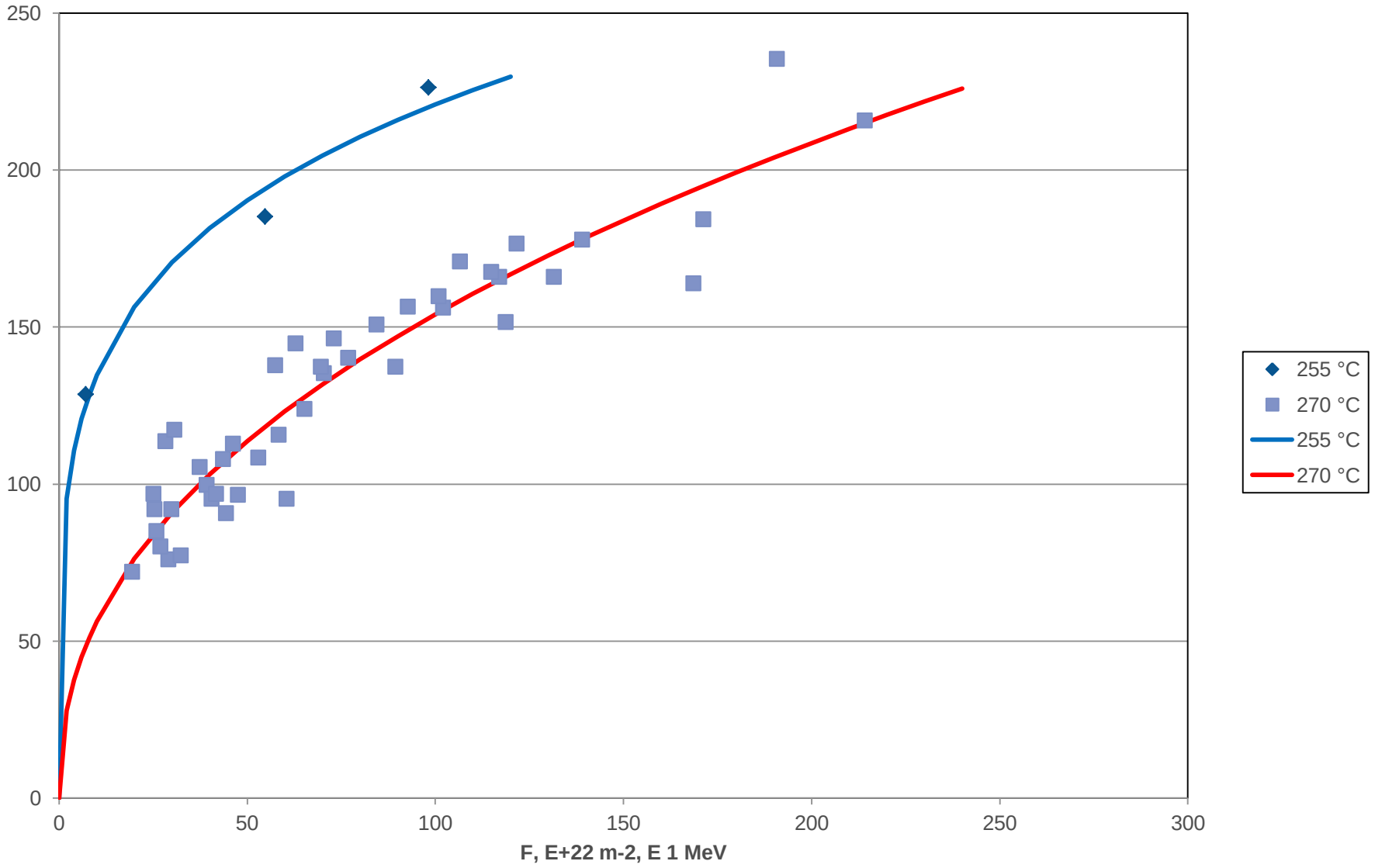
- **Specimens from middle half of the thickness are used**
- **Further information**
  - *IAEA-TECDOC-1230 - „Reference manual on the IAEA JRQ correlation monitor steel for irradiation damage studies“*

Irradiation conditions

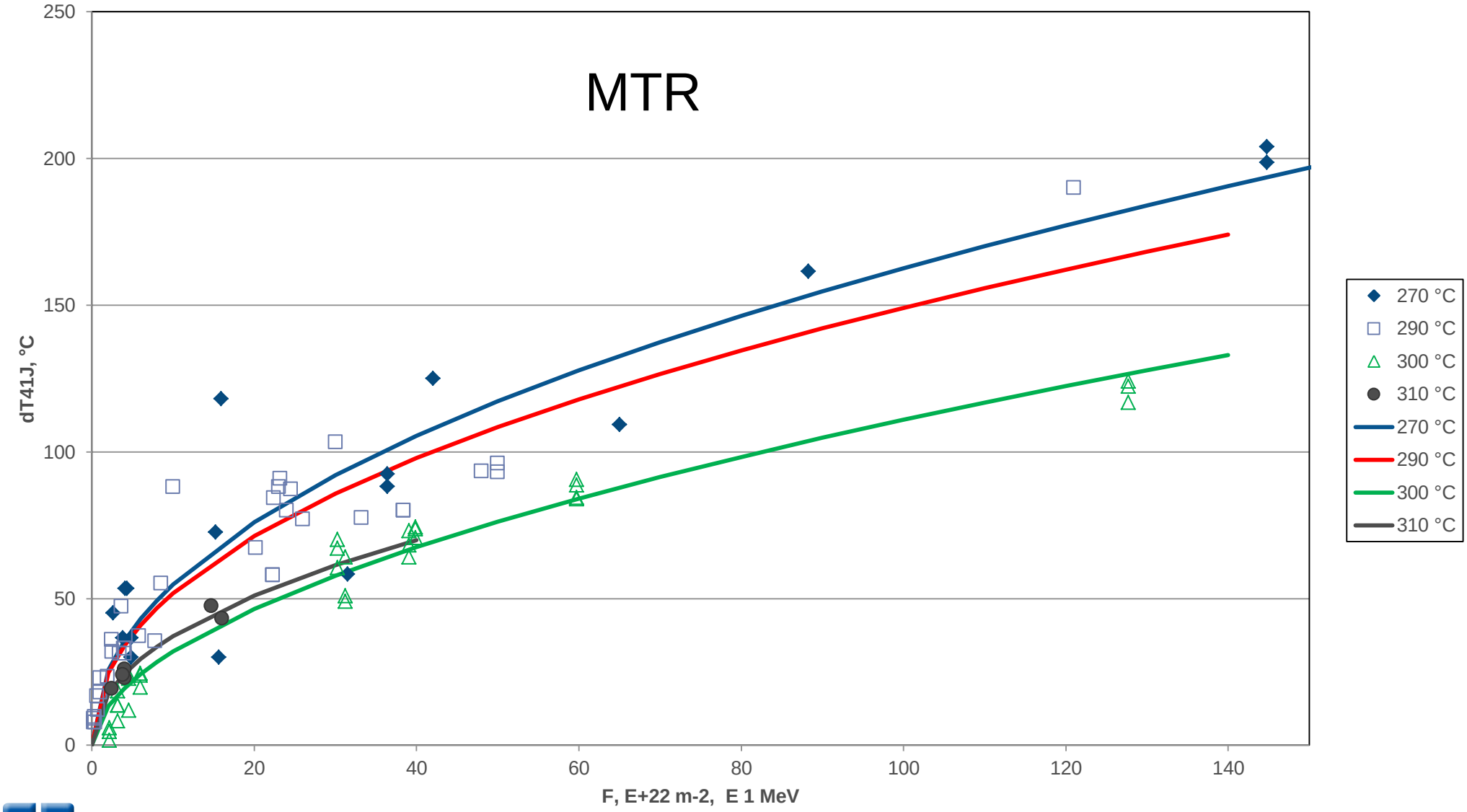
- **Irradiations were performed at different reactors**
  - WWER-440/V-213 surveillance position
    - Irradiation temperature – **270 °C**
  - at different experimental reactors within several IAEA CRPs + experimental programmes – RADAMO, IVAR etc.
    - Irradiation Temperatures – **255, 270, 290, 300** and **310** °C
- **Thus, comparison of irradiation at different temperatures in MTR and comparison of MTRs and WWER/PWR irradiations can be performed – flux effect**

Comparison 255 °C vs. 270 °C

- Irradiation were performed in WWER reactors



Comparison of irradiation tempeatures

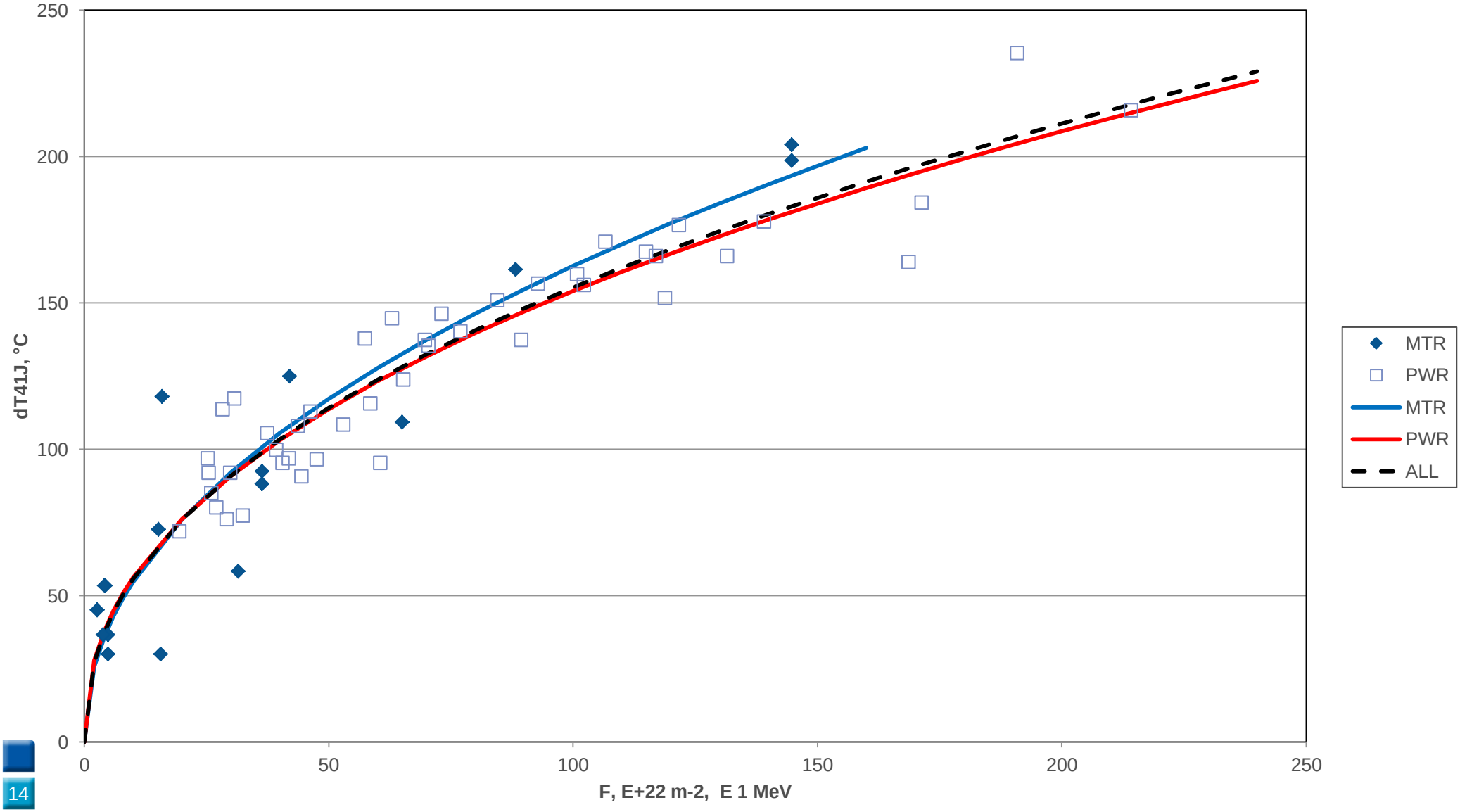


Comparison of irradiation tempeatures

- Some scatter of data exists after irradiations at MTR
- Effect of irradiation temperature is clearly seen even for small differences in temperatures
- No saturation effect is seen even for high irradiation fluences

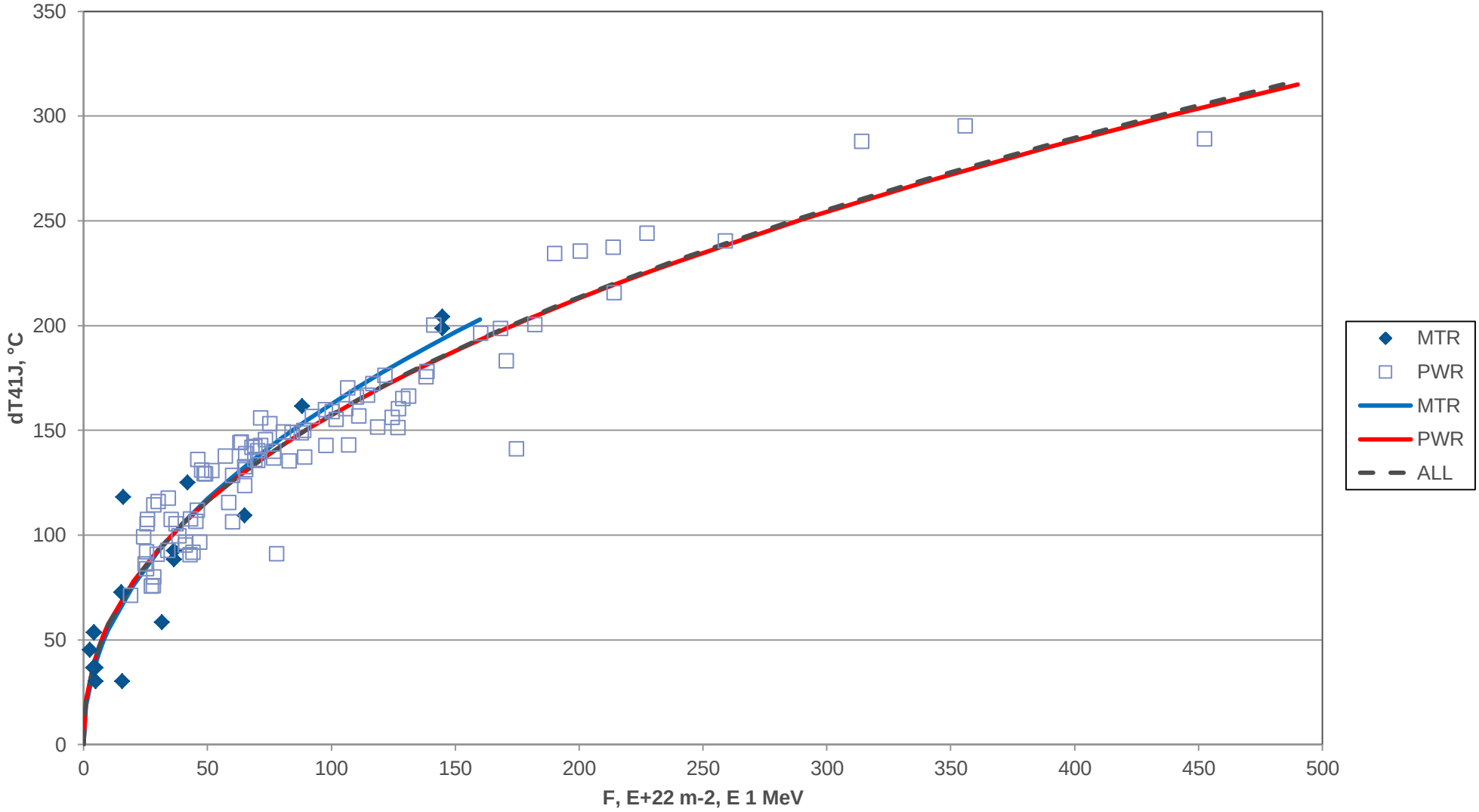
Comparison MTR vs. WWER/PWR

- **Irradiation Temperature – 270 °C**

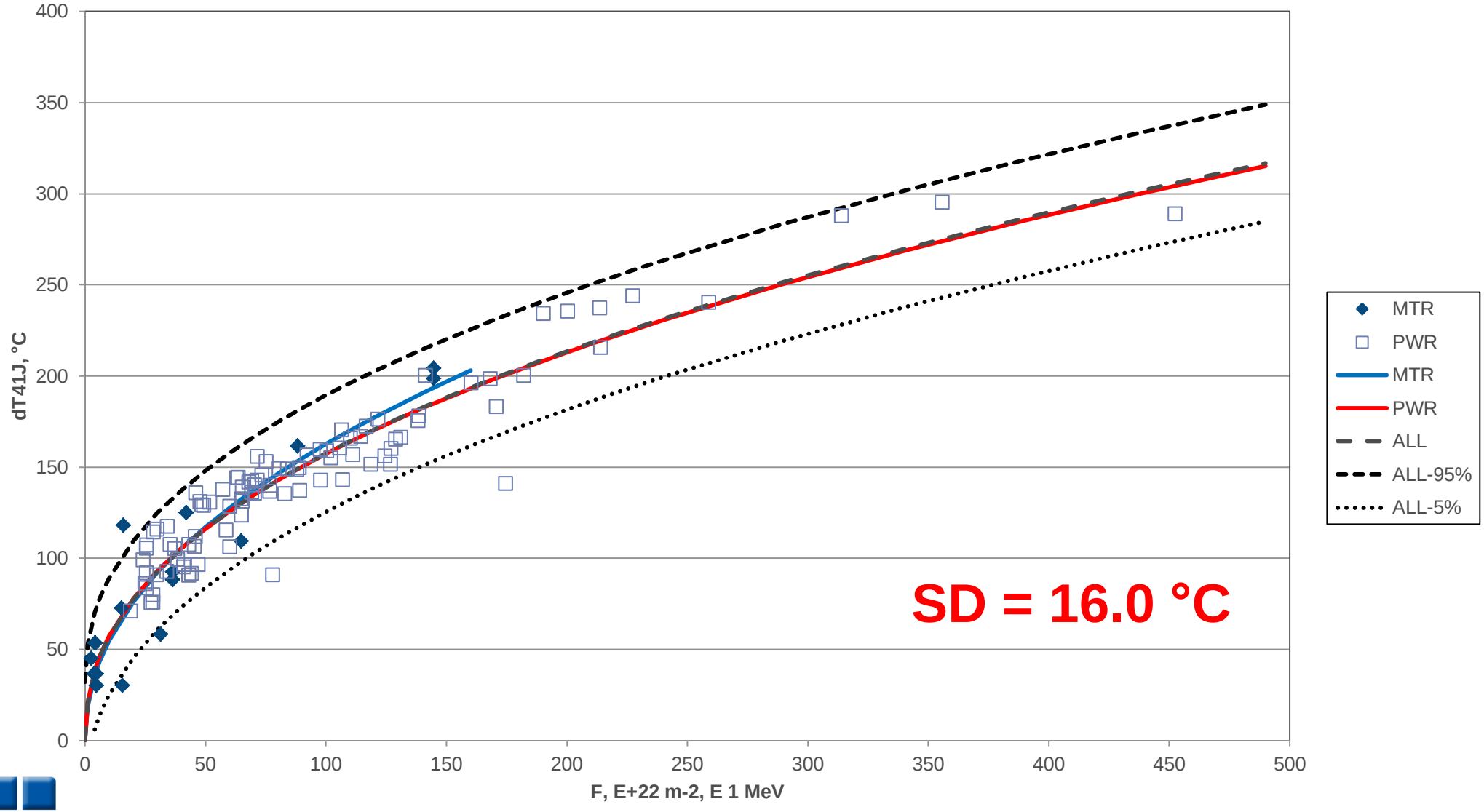


Comparison MTR vs. WWER/PWR

- Irradiation temperature – 270 °C
- Extended set of surveillance data



Comparison MTR vs. WWER/PWR



Comparison MTR vs. WWER/PWR

- Trend curves from irradiations at 270°C in MTR and WWER/PWR are practically identical in the whole fluence region
- Thus, practically no flux effect can be seen for this material and irradiation conditions – lead factor is approx. up to 100
- Exponent of power function in the trend curve is equal to n = 0.44

JRQ trend curves

ΔT_{41J} (270°C) = 20.77

[$F*10^{22}.m^{-2}$, E > 1 MeV]

n=0.44

SD = 16.0 °C

ΔT_{41J} (290°C) = 20.06

[$F*10^{22}.m^{-2}$, E > 1 MeV]

n=0.44

SD = 15.9 °C

- **There is only a small effect of irradiation temperature**
- **There is no effect on exponent in trend curves**

Conclusions

- **Irradiation embrittlement of JRQ steel is characterized by transition temperature shift**
- **Irradiations were performed at different reactors**
  - WWER-440/V-213 surveillance position
- **Trend curves for these temperatures have been evaluated**
  - Relatively small scatter of data (SD = 16.0 °C)
  - Does not show any tendency for saturation even at fluences over 2×10^{24} m^{-2} (E > 1 MeV)= 3.5×10^{24} m^{-2} (E > 0.5 MeV)
  - JRQ can be used as a reliable reference/ correlation monitor for irradiations at 270 °C as well as 290 °C up to these fluences (only – transition temperature shift for higher fluences can be higher than the irradiation temperature itself)
  - No flux effect is seen in irradiation embrittlement of this JRQ steel
  - UJV Rez serves as a custodian for the JRQ material – there is still enough for users

Thank you very much for your kind attention