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# HTR FUEL
# MANUFACTURE, IRRADIATION AND ACCIDENT CONDITION TESTING

**By**

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# Source terms

**for fission products into the primary circuit of an HTR are:**

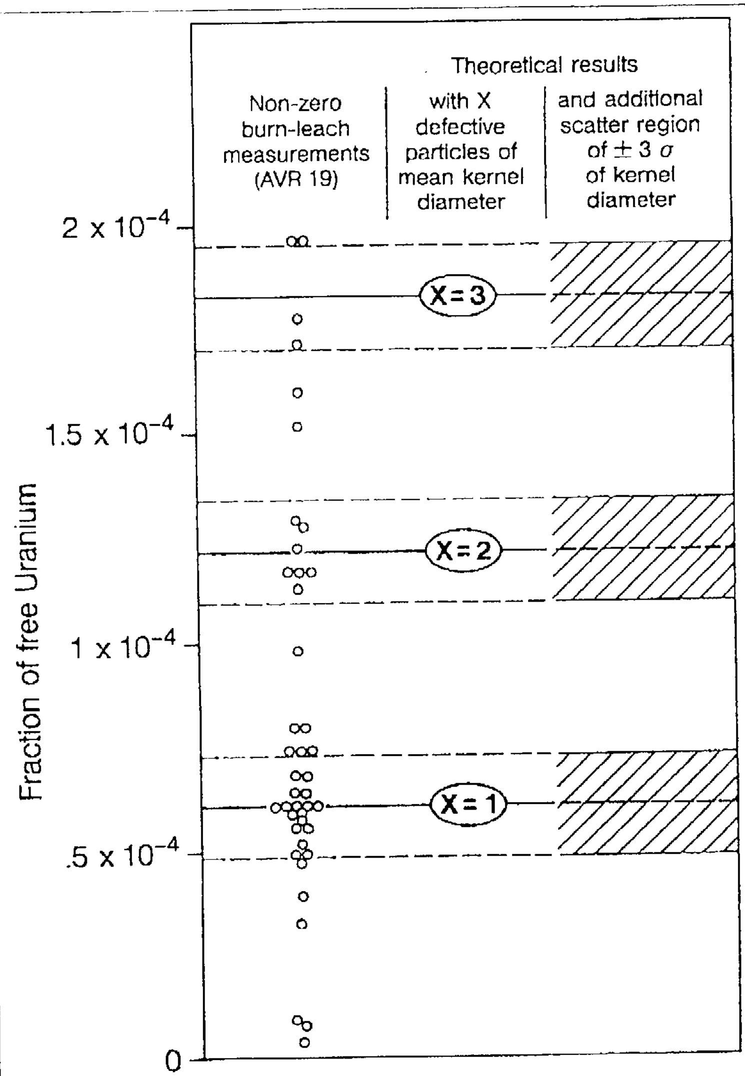
(i) heavy-metal contamination;
(ii) particle defect and/ or failure;
(iii) release from intact particles.

# Sequence of release is

$^{110m}Ag$, $^{137}Cs$, $^{134}Cs$, $^{85}Kr$, $^{90}Sr$, $^{106}Ru$, $^{95}Zr$

# HTR fuel: criteria required for ...

- Manufacture
- Irradiation tests ← normal operation conditions
- Heating tests ← off-normal conditions



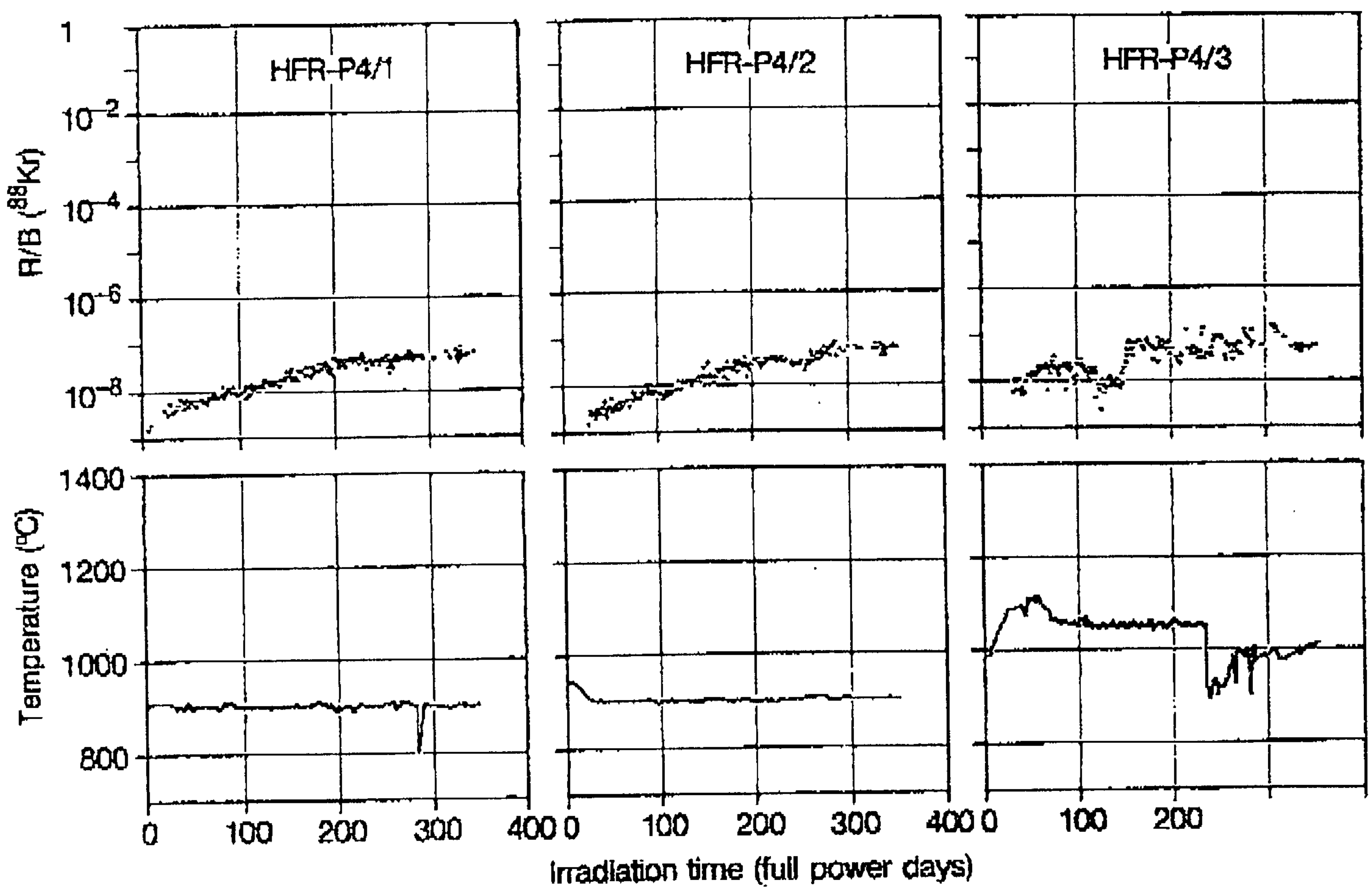

**Burn-leach with spherical fuel elements:**

1. **burn graphite and oPyC at 800°C**
2. **leach with $HNO_3$**
3. **determine U in solution**

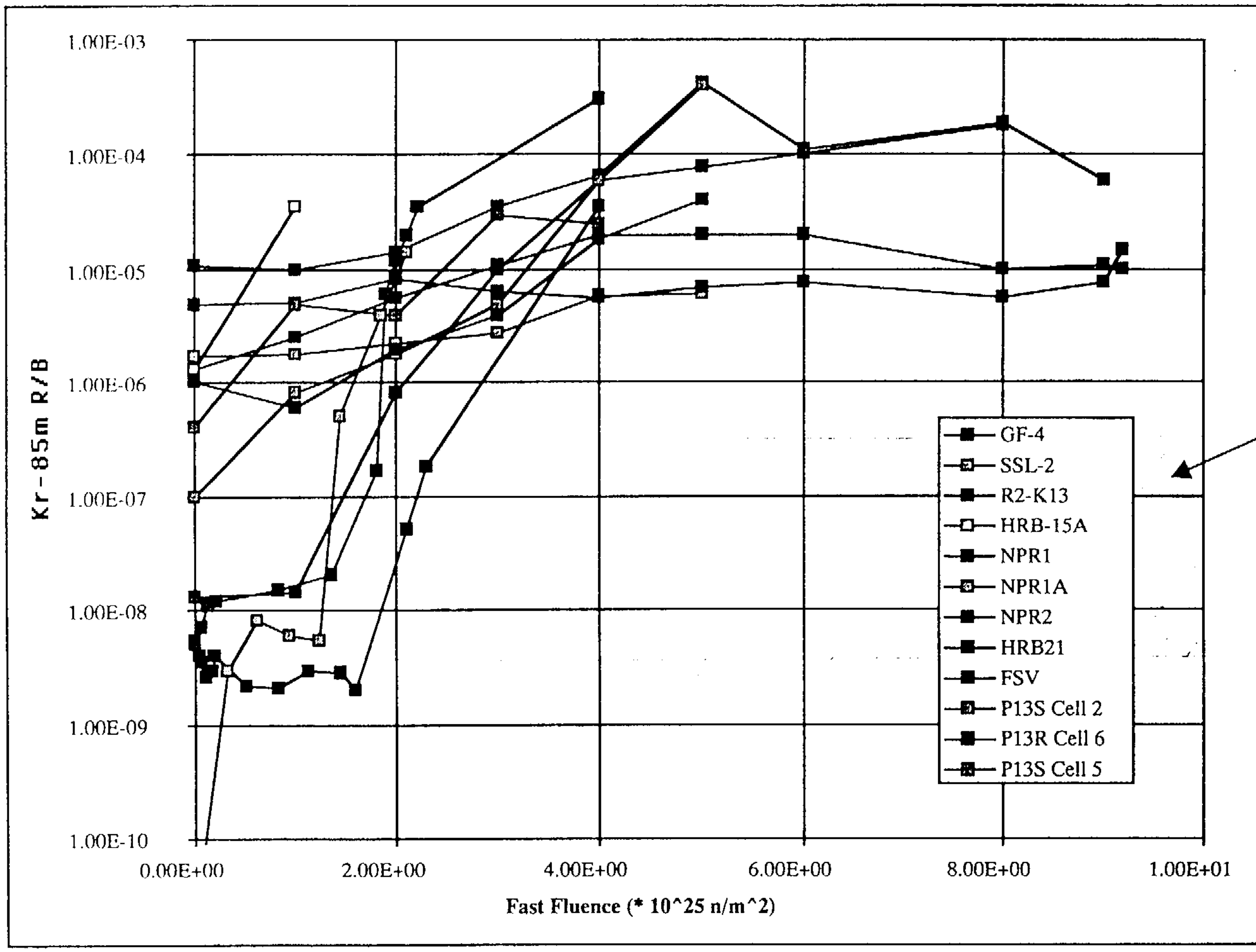
**Diagram shows non-zero free uranium measurements in the seventy burn-leach tests from NUKEM quality control of the AVR 19 (GLE 3) production of 24,600 AVR fuel elements. This is a destructive test on 5 FEs per lot from the 14 lots in this production.**

**Measured free uranium corresponds to the contents of an integer number of coated particles; here zero, one, two or three out of 16,400 particles in a sphere.**

# • Irradiation to near 15 % FIMA



# Compilation of US Gas Reactor Fuel Behavior Experience




Range of German data

# Criteria for irradiation testing in order of relevance

1. temperature
2. burnup
3. fluence
4. power/ temperature gradients
5. transients
6. real time

| Coated Particle Modelling | | |
|---|---|---|
| **Classical** | | **Alternate** |
| Pressure vessel models like PANAMA or STRESS3 | Geometry + material properties: failure when gas pressure exceeds strength | Goodin-Nabielek for 1500-1800°C off-normal conditions |
| | Chemical effects by thinning of coating layers | Ogawa et al. for 1800-2400°C extreme accidents |
| FRESCO | Set of diffusion coefficients determines release from intact, defect and broken particles | ... |

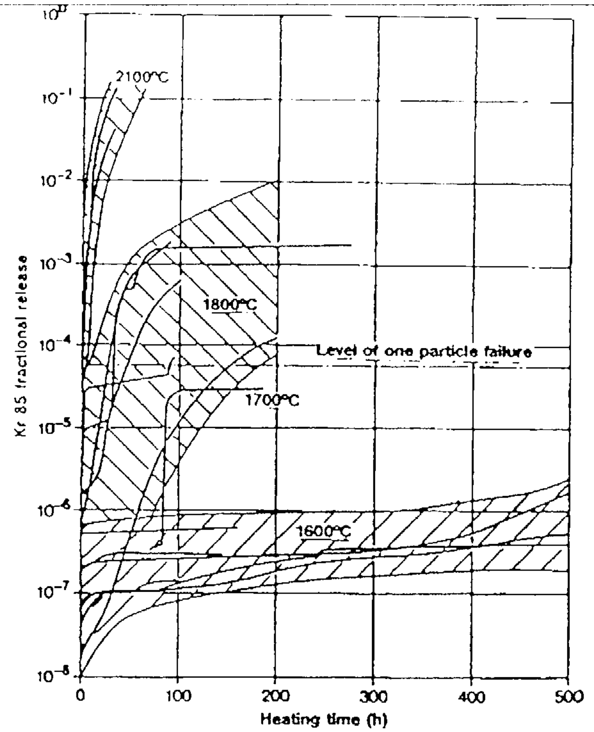
## Suggested HTR fuel work, to be discussed:

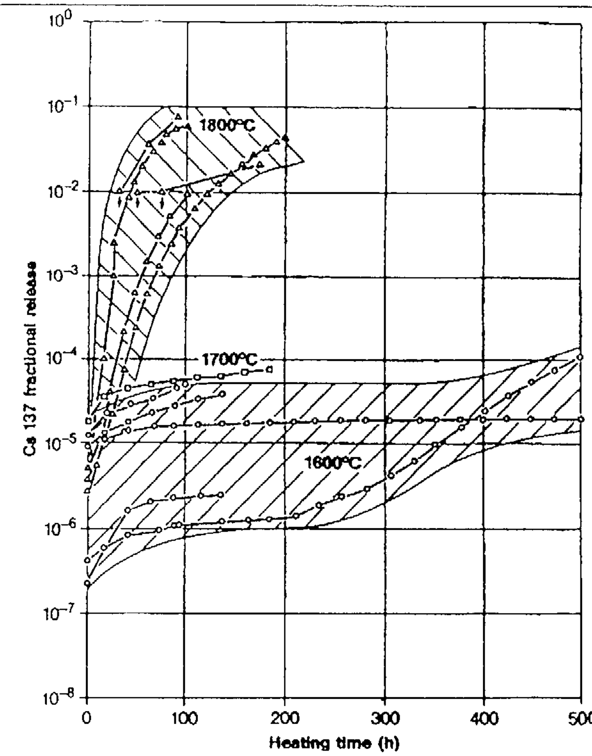
(i) $^{110m}$Ag: Re-evaluate release data during normal operations for better source term data base in direct cycle applications.

(ii) Determine influence of burnup > 10% FIMA on irradiation performance, in particular for potential reduction of 1600°C capability.

(iii) Analyse accident condition performance > 1600°C for an improved coated particle model.

# Heating tests at 1600-2100°C




**Krypton release during tests with irradiated spherical fuel elements at 1600 to 2100°C.**

**Caesium release from heated spheres as a function of heating times up to 500 hours.**

The Work of Dr Werner Schenk

# Accident simulation at 1600 – 1800°C

## Licensing procedure of MODUL

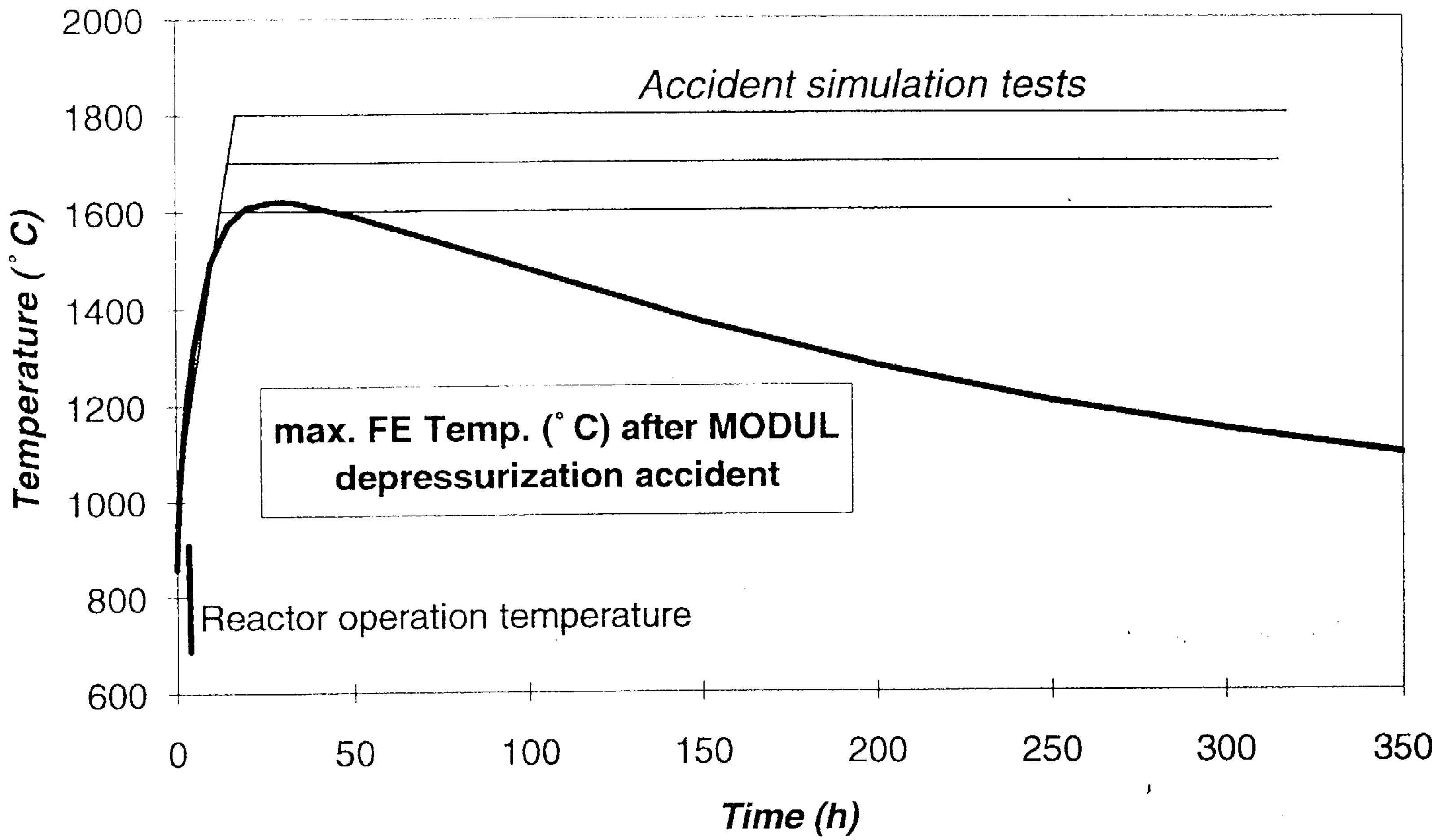
- **Heating tests with $UO_2$ TRISO FE with high burnup**
  - Particle failure fractions
  - Iodine release

- **Post heating examinations**
  - Verification of release results
  - Fission product transport
  - Failure mechanisms

**Utilization for licensing and model verification**

Table 2: The fission products caesium, strontium and iodine are radiologically significant because, unlike the noble fission gases, they can be incorporated in the human body.

| Important fission products | | |
|---|---|---|
| ELEMENT | ISOTOPE | HALF LIFE |
| Solid fission products | | |
| Caesium | Cs 137<br>Cs 134 | 30 years<br>2 years |
| Strontium | Sr 90 | 29 years |
| Iodine | I 131 | 8 days |
| Fission gases | | |
| Krypton<br>Xenon | Kr 85<br>Xe 133 | 11 years<br>5 days |



Accident simulation tests
max. FE Temp. (° C) after MODUL depressurization accident
Reactor operation temperature
Temperature (° C)
2000
1800
1600
1400
1200
1000
800
600
0
50
100
150
200
250
300
350
Time (h)

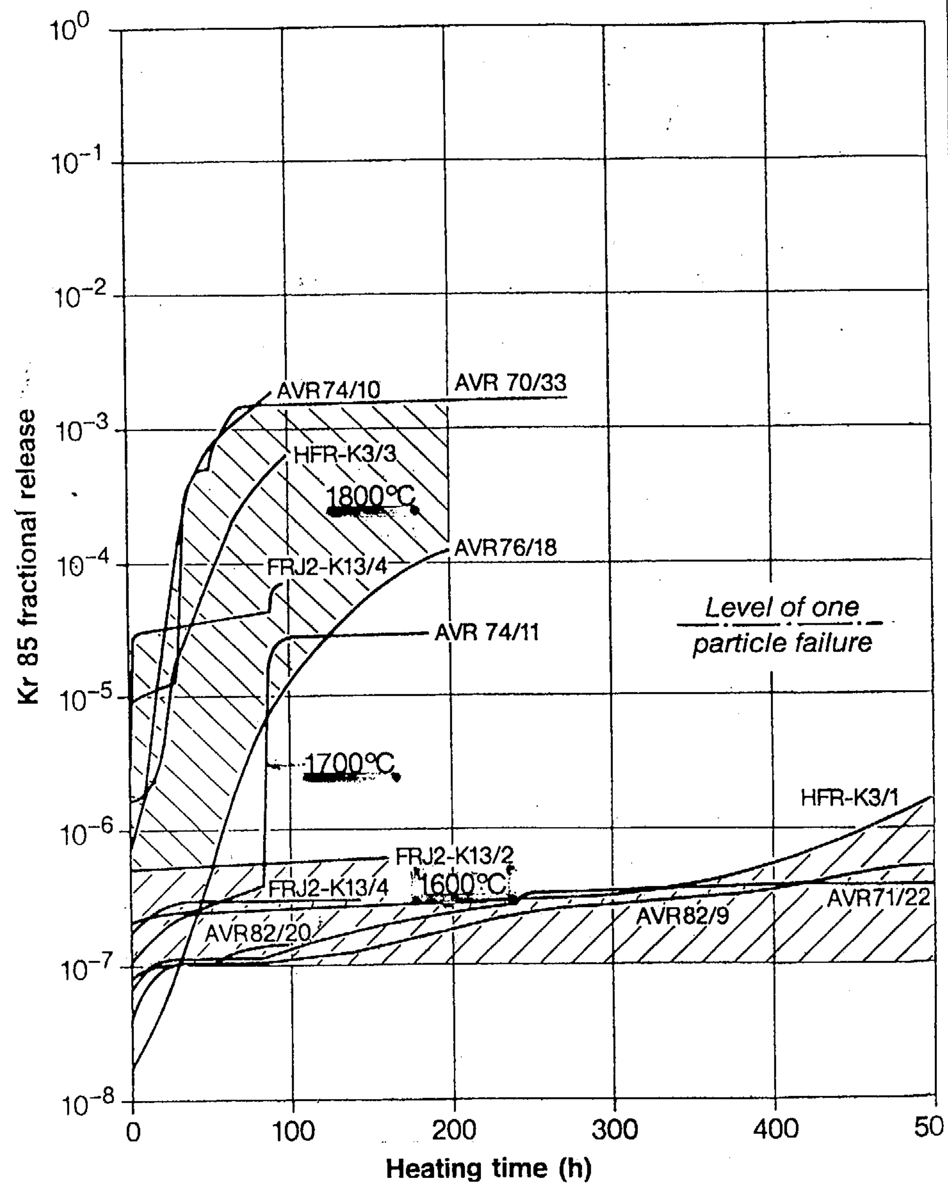
**F.p. release during depressurization accidents in small HTR (MODUL)**

Experimental data and calculations show Cs, Sr, and other solid fission products are retained in FE and core

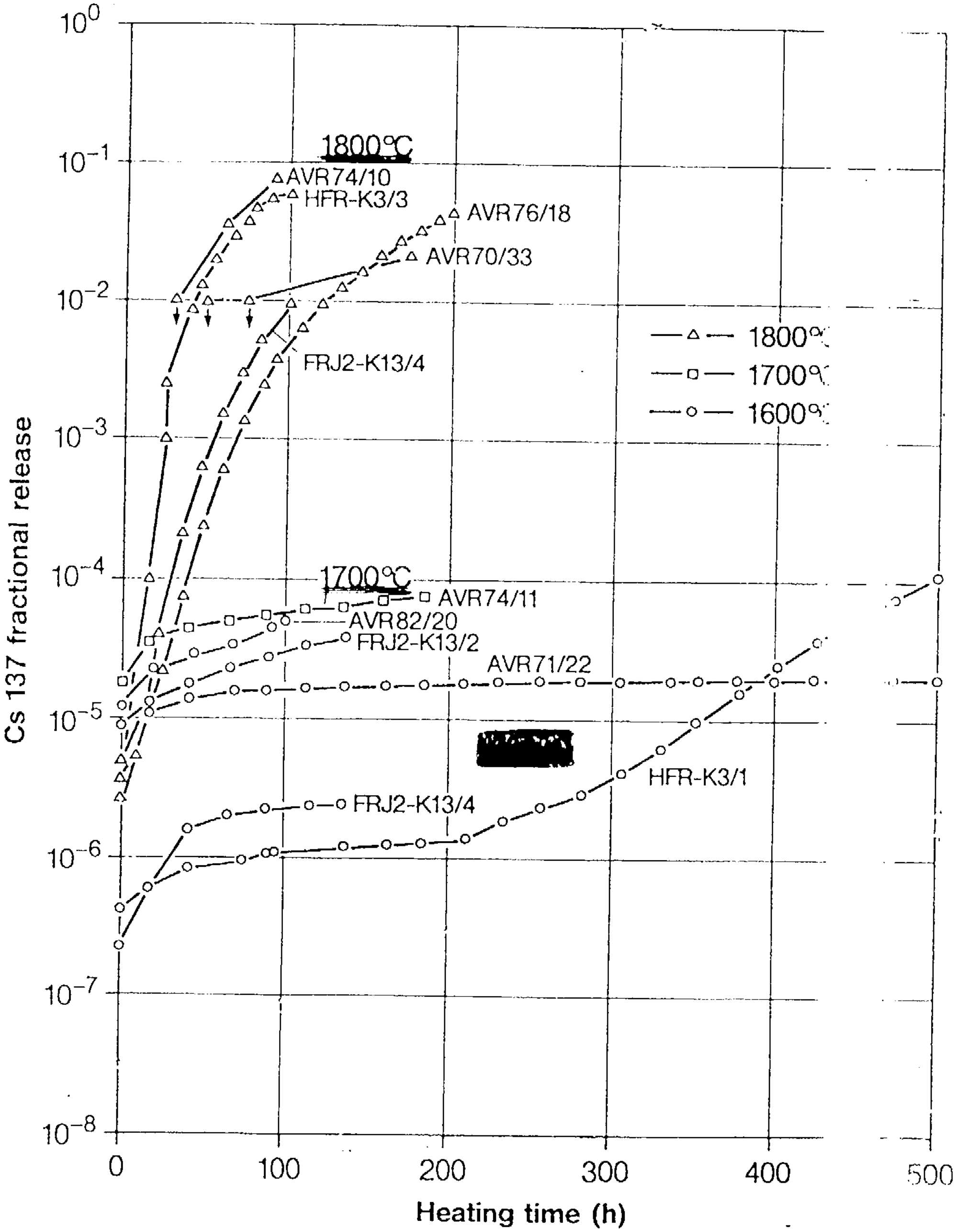
Most important is I release - I release depends on the number of failed particles

The number of defect particles from manufacturing and failed particles during irradiation and accident can only be determined by experimental work

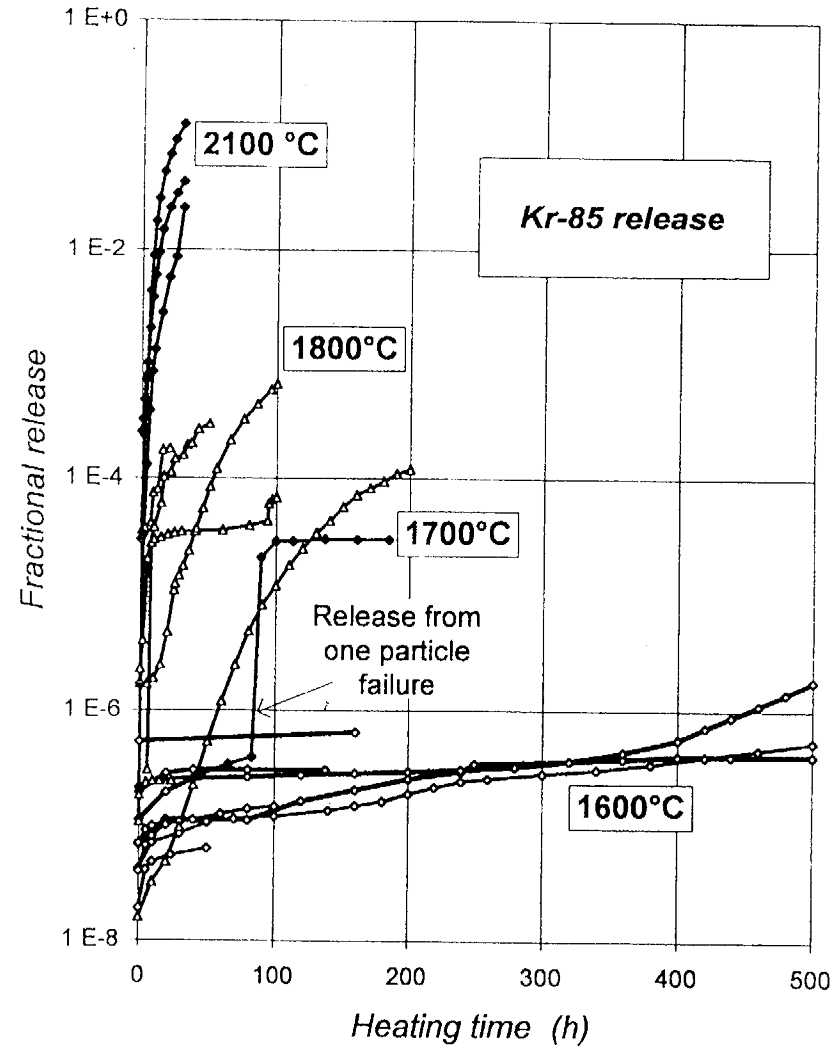
There is a high dependence of failure fraction from particle quality

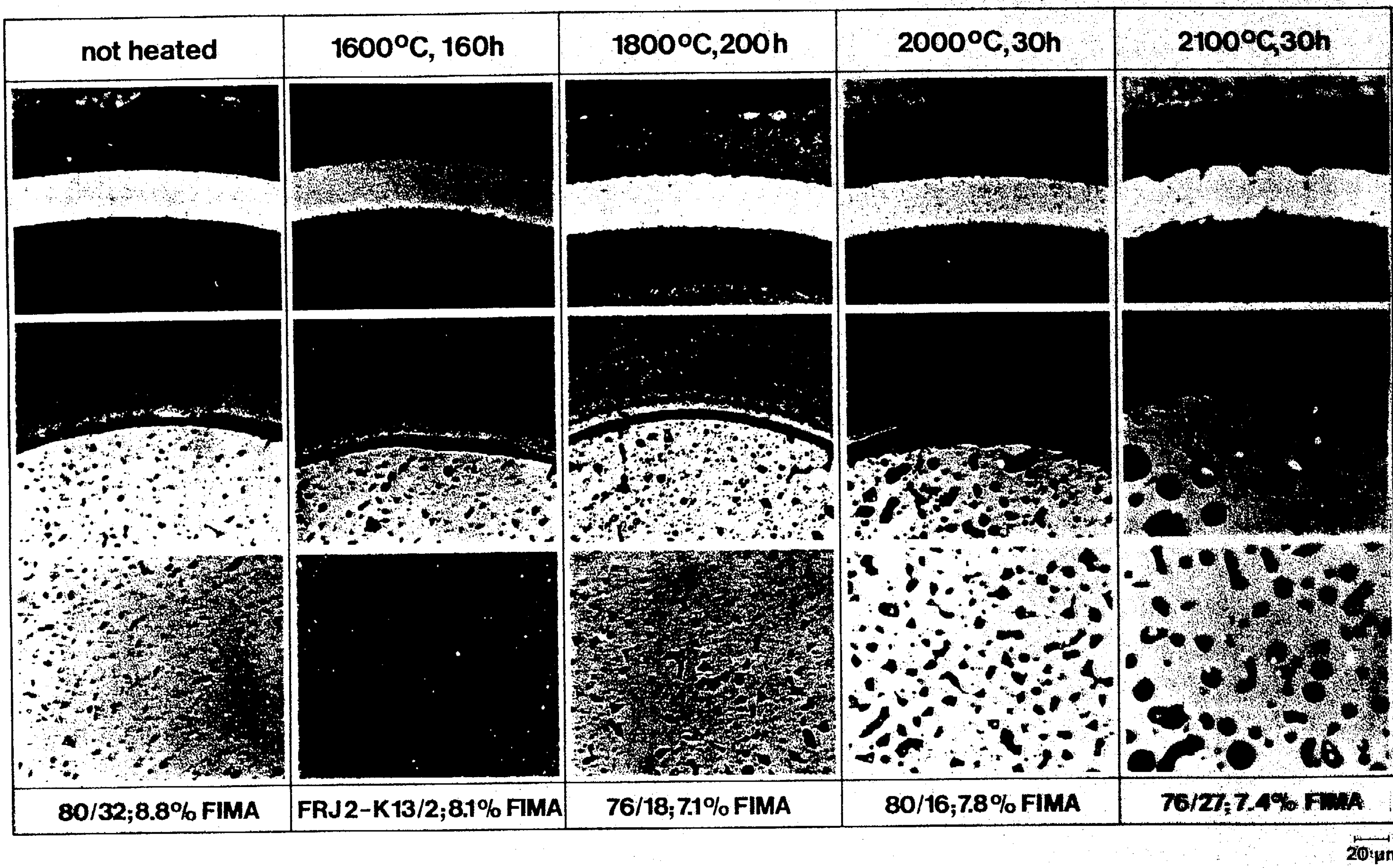



KFA Kr 85 release from fuel elements with $UO_2$ TRISO particles




## Kr-85 release during heating tests with spherical fuel elements (9% FIMA)






KFA Ceramographic sections through $UO_2$ TRISO particles

## Conclusions

### 1800 – 2500°C

- Increasing number of pressure vessel failure
- Additional to corrosion of SiC at 1800°C, above 2000°C SiC decomposition

**Cs** High release already at 1800°C, after heatup to 2500°C nearly total release

**Kr (I)** Release at 1800°C from single pressure vessel failures increases because of additional particle failures and diffusion through already destroyed SiC layer and still intact PyC layers up to 10% at 2500°C

## Conclusions of core heatup simulation experimen with FE with UO2 TRISO particles(small HTR)

***1600° C*** *F.p. release (except, Ag 110m) from <6E-5 free U from manufactoring*

*Changing of SiC structure only after >100h*

*Single pressure vessel failures only after extreme irradiation conditions*

***1800° C*** *Single pressure vessel failures and changing of SiC structure lead to increasing f.p. release in the order:*

*Cs*
*Sr*
*Kr / I*