Neutron Radiography using the SINQ Experimental Set-up and Operational Experience

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History

- Neutron Radiography Station at PSI at the SAPHIR MTR
- Neutron Flux: 1 • 10^6 n/cm^2 sec
- Operation of SAPHIR was shut down on 20.12.1993
- Spallation Neutron Source SINQ was build
- NR equipment transferred to SINQ
- Start of SINQ Operation in 1996/97
- Neutron Radiography Station NEUTRA/NEURAP
- First Experiments with Unirradiated Fuel Rods in summer 1998
- First Experiments with Irradiated Fuel Rods in November 1998
- 8 Experiments with Irradiated Fuel Rod Segments or Activated Material carried out

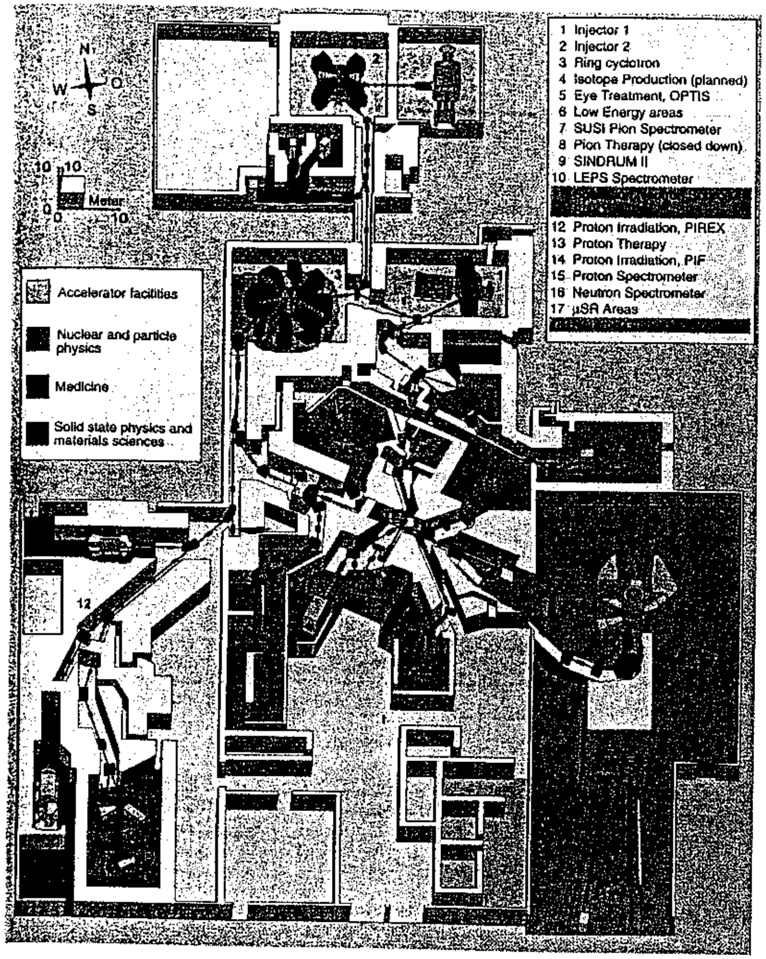
Operational Limitations

- SINQ is no nuclear facility and has only a low level radiation protection classification (zone-II)
- Stringent requirements with respect to handling of radioactive material and fuel in particular
- Safety assessment and operational procedures approved by PSI radiation protection and by HSK
- Notification of shipment 24 hours in advance
- Transport of cask according to PSI transport QS (similar to sending nuclear fuel outside PSI)
- Closure of road from PSI east to PSI west for all traffic
- Limitation in residence time of fuel segments at SINQ
- No contamination of transport cask and of components exposed during examination at the SINQ (< 4 Bq/cm^2) assured by QS exit and entrance checks

GF43/WG-Hotlab99/12.10.99

Comparison of neutron radiography facilities at PSI

	NR-Station @ SAPHIR	NEUTRA @ SINQ
thermal neutron flux at the experiment	$4 \cdot 10^5$ cm^{-2} s^{-1}	$3 \cdot 10^6$ cm^{-2} s^{-1}
mittlere n-Energie	36 meV	25 meV
Cd-Ratio	22	16
L/D	350	550
shape of the beam profile	bulked with asymmetry	flat over a wide range
usable beam diamter	250 mm	350 mm
gamma-background	24 mSv/h	1.5 mSv/h
exposure time film (AGFA -D4)	25 bis 35 min	4 bis 5 min
exposure time for CCD-camera	100s (estimated,not verified)	about 12 s
techniques available	Track-etch-foils with LiB, film with Gd- and Dy-converters	film mit Gd- und Dy-converter, CCD-camera system, Imaging Plates for neutrons und secondary radiation



Proton accelerator and research facilities

Properties of the NEURAP beam position

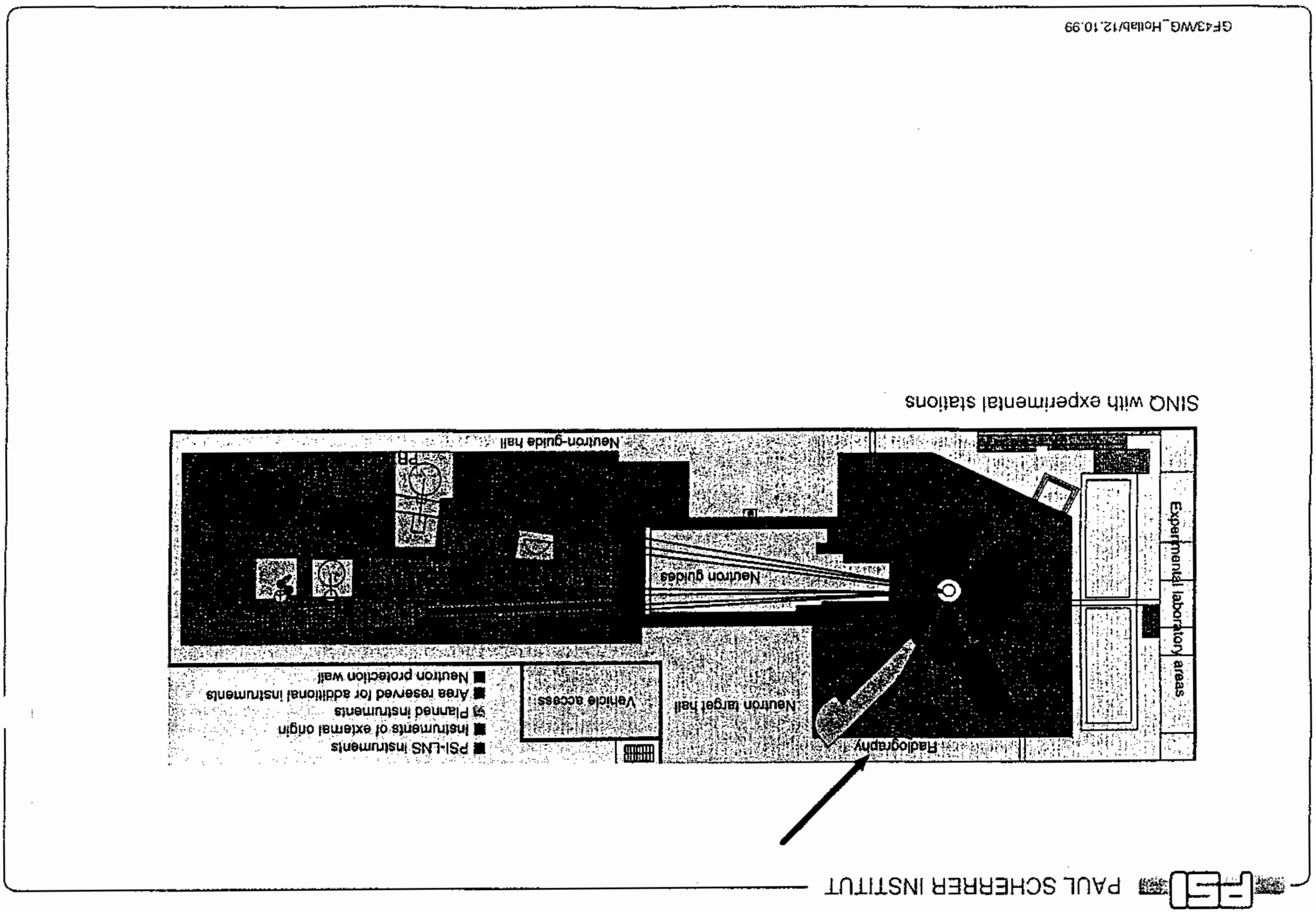
Distance from target	Distance from arperture blind	Beam diameter	Neutron flux	Collimator-ratio L/D
mm	mm	mm	1/cm² s mA	-
9876	7292	290	$5x10^6$	350

Experimental Capabilities:

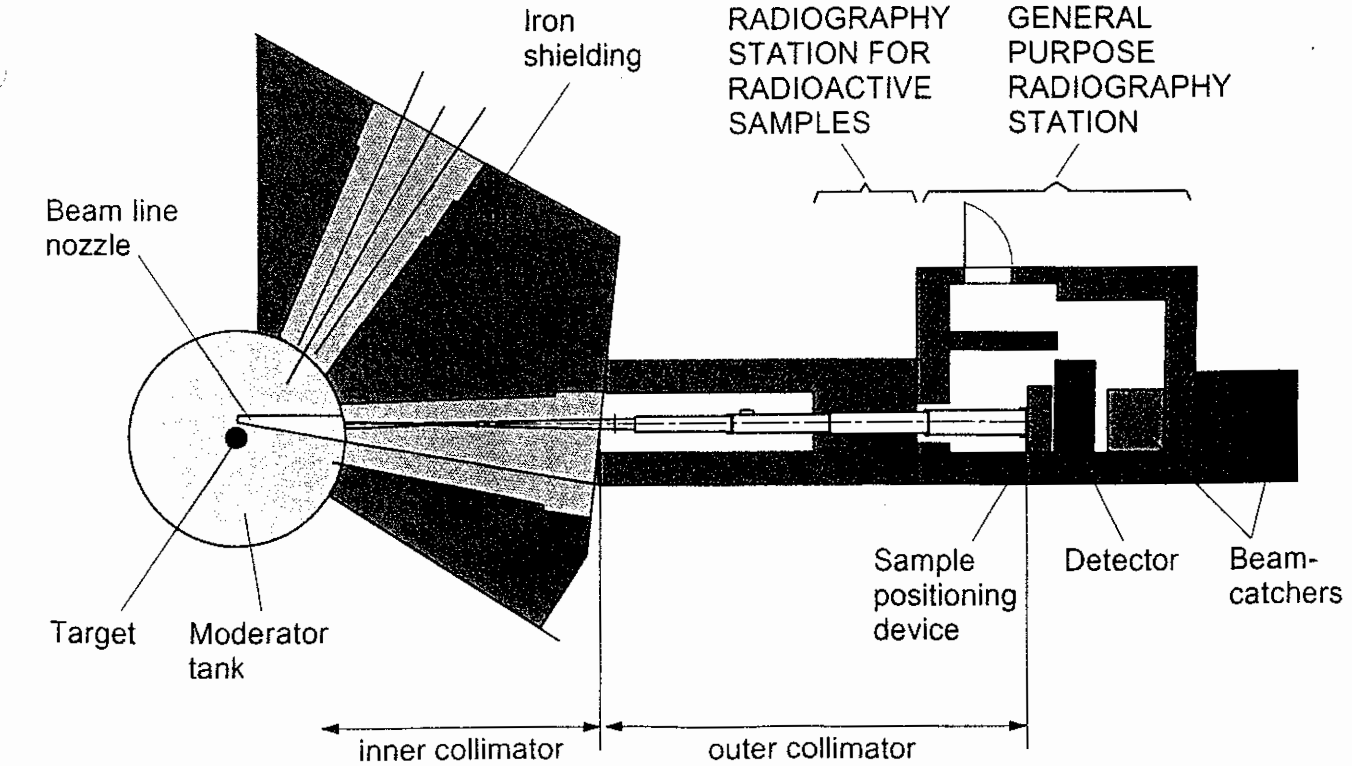
- 70 cm long fuel rod segments (3 images)
- axial and rotational displacement

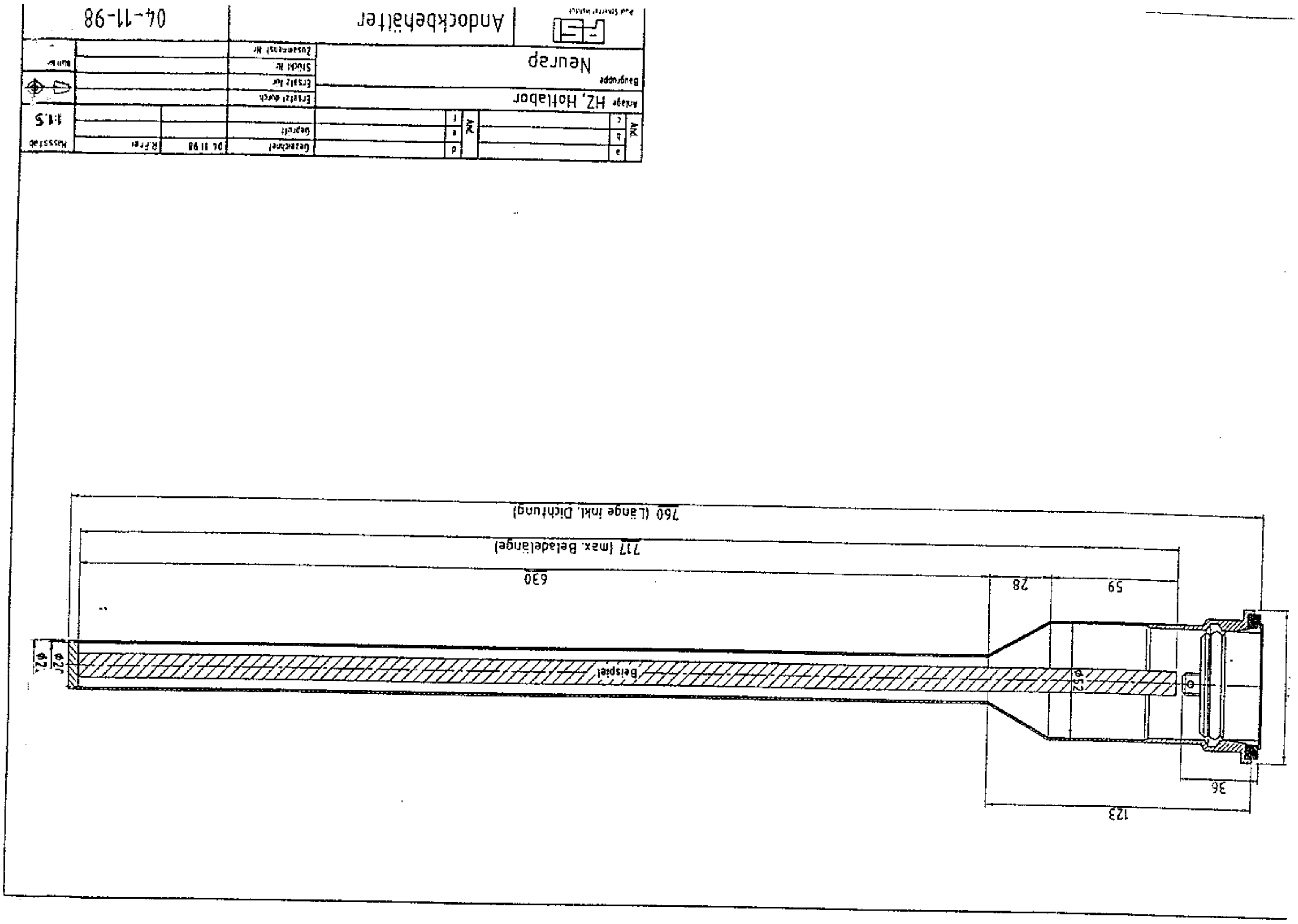
Imaging Techniques:

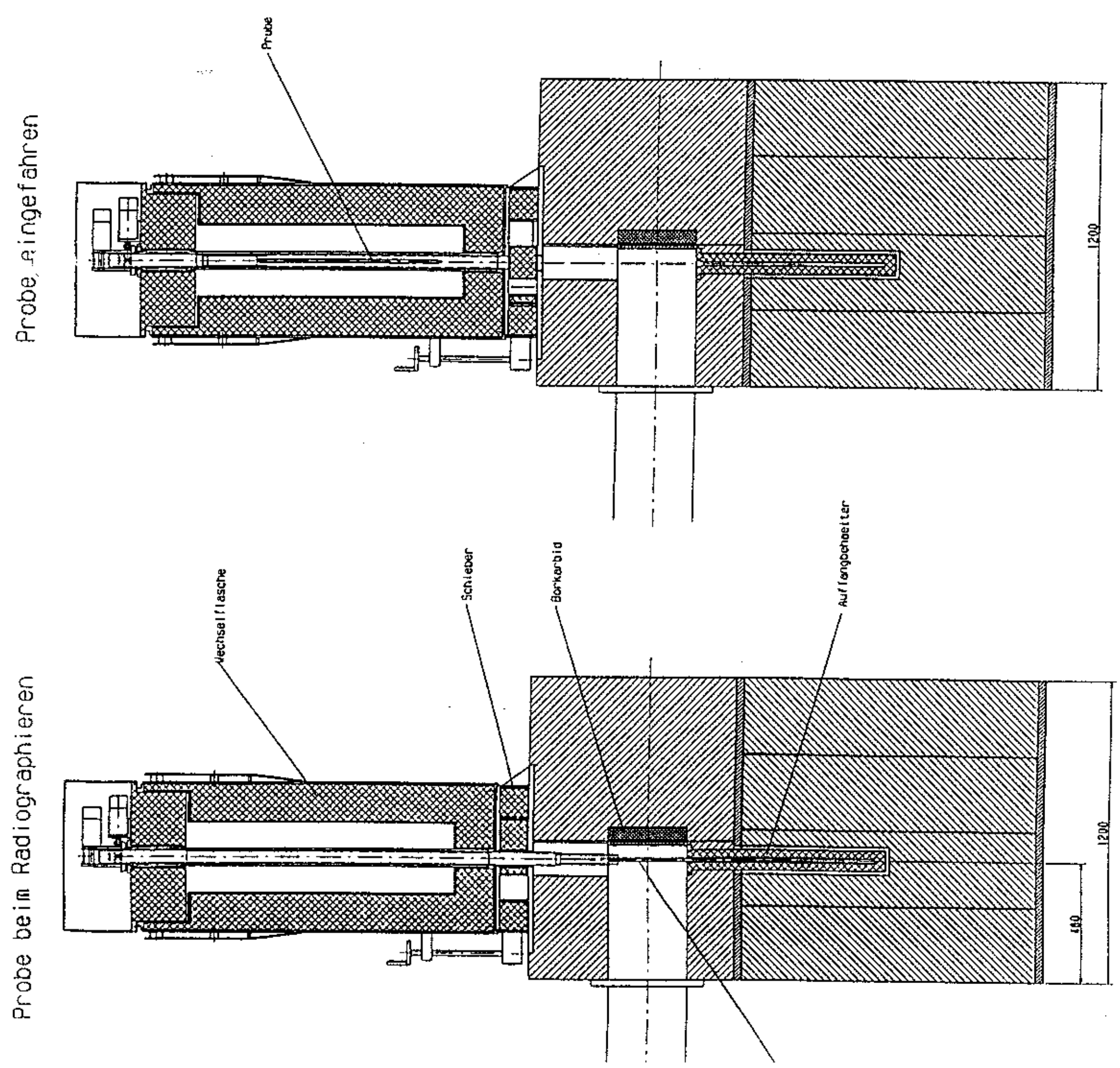
- Imaging plates with Fuji BAS 2500 scanner
  Dysprosium and Indium foils placed on β- or γ-sensitive plates
- X-ray films
- Track-etch method
  boron coated nitrocellulose film CN85 Type B
- Positives by conventional method
- scanning of films in the reflective mode with a b/w CCD camera and special darkfield illuminator
- scanning in the transmission mode (Scanmate F8plus scanner)
- Processing of images by AnalySIS and Picture Publisher



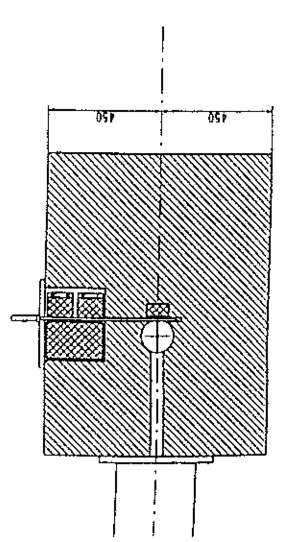
NEUTRA : Neutron Radiography Station at SINQ







Neurap
Konzept



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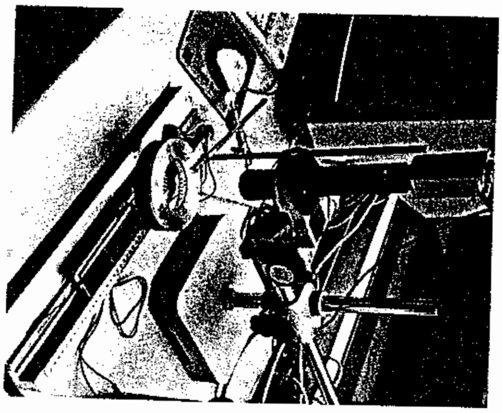
Transport of NR cask from Hotlab to SINQ



Scanning system

NR cask

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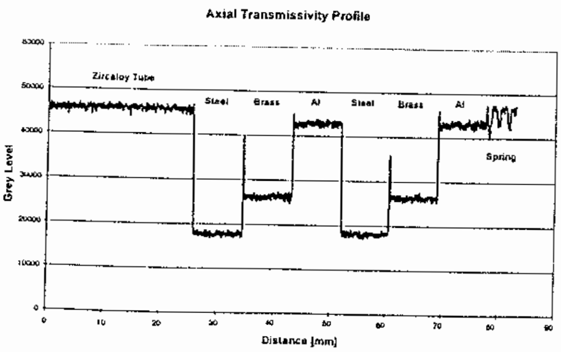
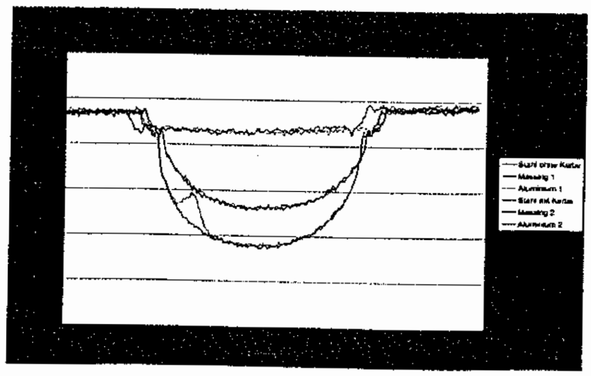
NR Calibration - Metal Dummy Pellets

notch 1x0.5 mm deep

Pellets
∅8.19 x 8.7 mm
Zry-2 tube
∅9.62 x 0.63 mm
Neutron Beam
2•10^{6}/cm^{2}sec, ~10 min

Imaging Plates (Dysprosium foil after 30 sec exposure)





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Depleted Uranium Oxide Pellets with Simulated Defects

- Depleted uranium oxide pellets (0.2% U-235)
- Neutron Beam : 2 • 10^6 n/cm^{2}sec (25 meV)
- Dysprosium Foil and Imaging Plates and X-ray Film
- ORIGEN-2 calculations to assess activation
- Verification by Gamma Spectroscopy

Imaging plate Fuji BAS 2500; exposure 30 sec

Detail after 90° rotation

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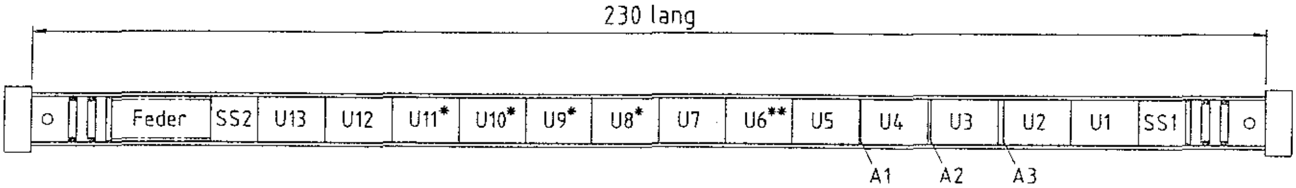
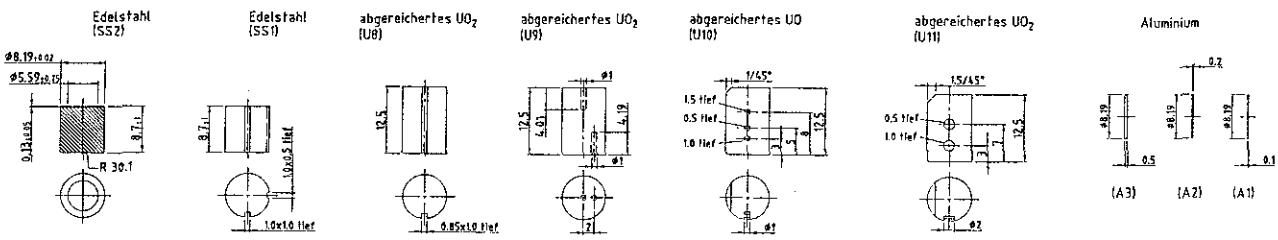
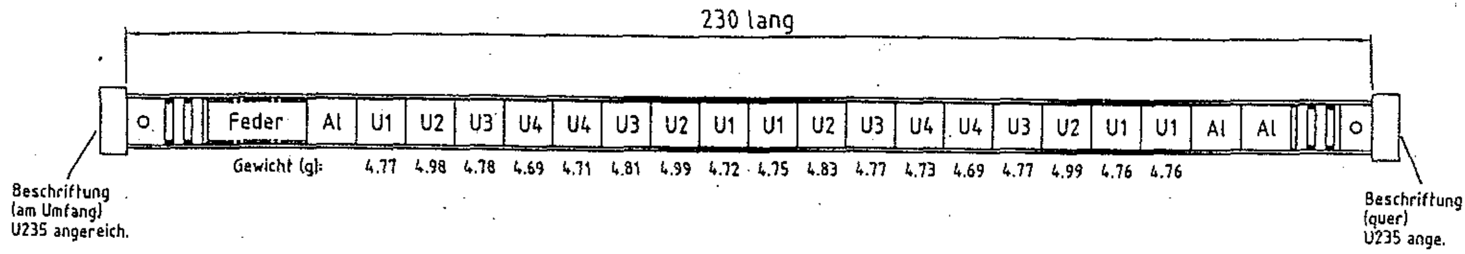




SS1 Edelstahl
SS2 Edelstahl
U1 - U13 Abgereichertes Uranoxid
A1 - A3 Aluminiumscheiben
* simulierter Defekt
** natürlicher Abbruch (chip)

Änd. a b c	Änd. d e f	Gezeichnet	25.08.98	R.Frei	Massstab 1:1
		Geprüft			
Anlage HZ, Hotlabor		Ersetzt durch			
Baugruppe Neutronenradiographie		Ersatz für			
		Stückl. Nr.			Blatt Nr -
		Zusammenst. Nr.			
PSI Paul Scherrer Institut	Beladeplan f. Kalibrierpellets		4-178994_n		



Al	Aluminium (12mm).
U1	Uranoxid (2.34% U-235)
U2	Uranoxid (3.5% U-235)
U3	Uranoxid (4.74% U-235)
U4	Uranoxid (3.5% U-235 + 3.95% Gd)

Änd.	a		Änd.	d		Gezeichnet	25.08.98	R.Frei
	b			e		Geprüft		
	c			f				
Anlage HZ, Hotlabor						Ersetzt durch		
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PSI Paul Scherrer Institut		Beladeplan f. Kalibrierpellets					4-178994d	

Massstab 1:1

Blatt Nr. -

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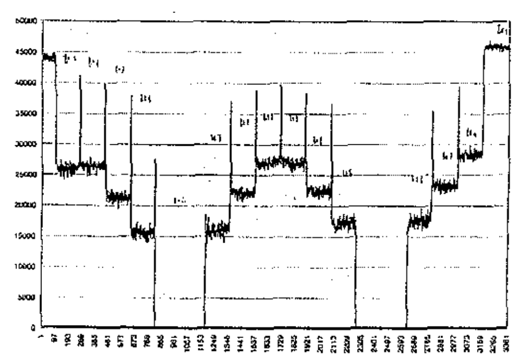
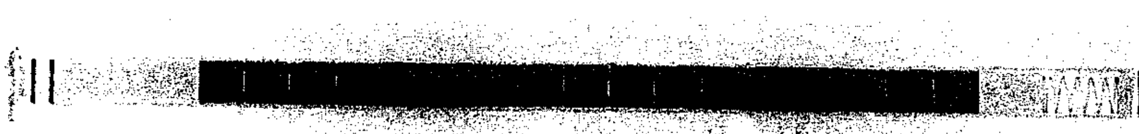
Uranium Oxide Pellets with Varying Enrichment

- Uranium oxide pellets
  (2.34 - 4.74% U-235 and 3.5% U-235 + 3.95% Gd)
- Neutron Beam : $2 \cdot 10^6$ n/cm^{2}sec (25 meV)
- Dysprosium Foil and Imaging Plates and X-ray Film
- ORIGEN-2 calculations to assess activation
- Verification by Gamma Spectroscopy



Transmissivity profile



X-ray film image

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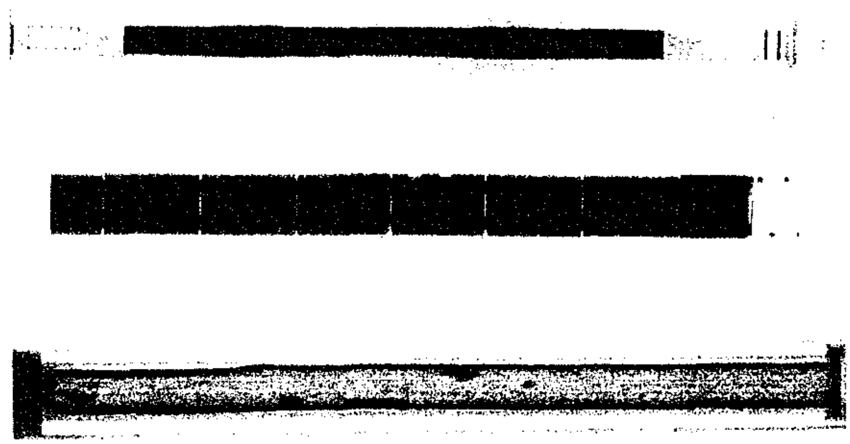
Neutron Radiography of Fuel Rod Segments



Assessment of pellet integrity and hydrogen accumulations in the cladding wall

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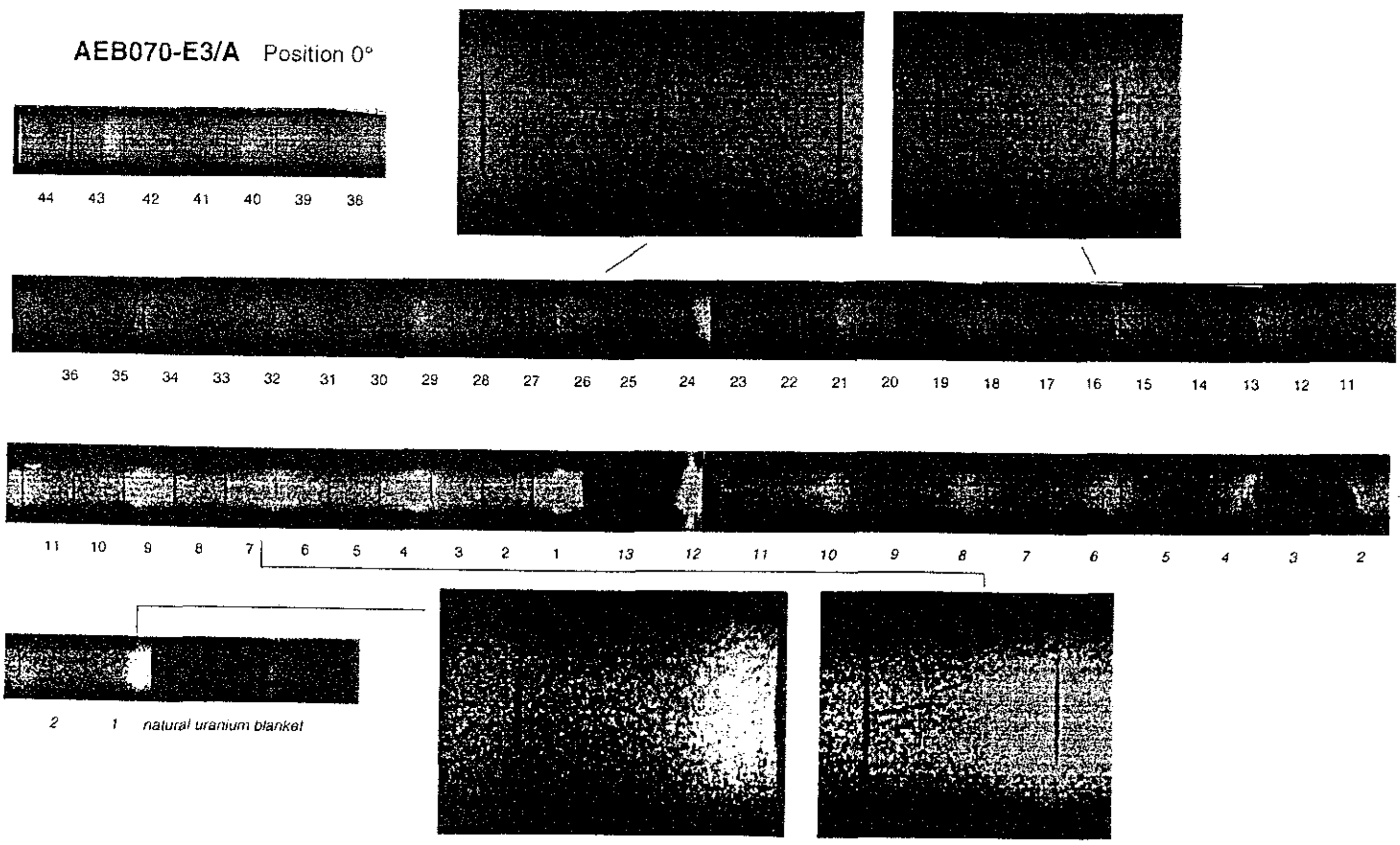
AEB070-E3/A Position 0°



Conclusions

- **Neutron Radiography is a useful method complementing the PSI hotlab capabilities**
- **Complex operation makes experiments expensive**
- **Improvements are still needed in optimizing**
  - ⇒ **imaging techniques**
  - ⇒ **image processing**
  - ⇒ **documentation**
- **Quality assurance and quality standards would be helpful**