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X-ray endoscopy for inspection of tube to tube sheet welds in heat exchangers

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BASF
The Chemical Company

Tasks of heat exchangers
NDT of tube sheet welds

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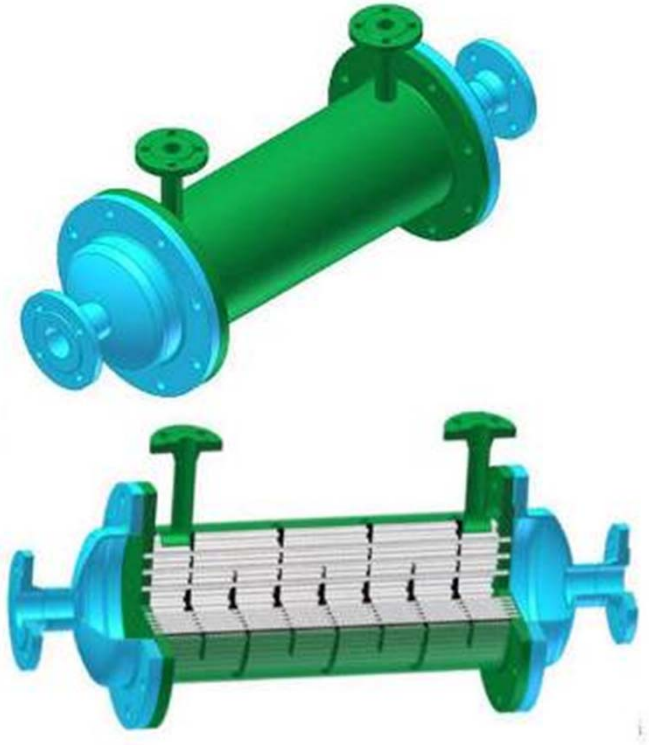
- Heat exchangers are central components in chemical processing industries
- Heat transfer from medium 1 to medium 2 without direct contact
- Considered here: tube bundle heat exchangers
- Leak-thightness of tube-to-tube sheet connection essential for safety and availability of chemical plants

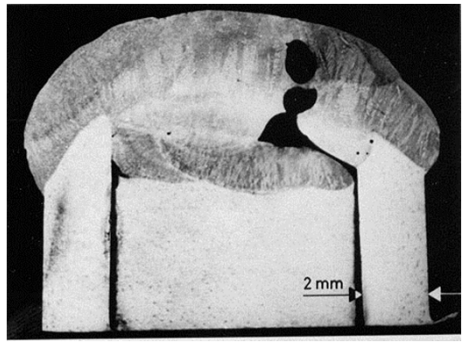


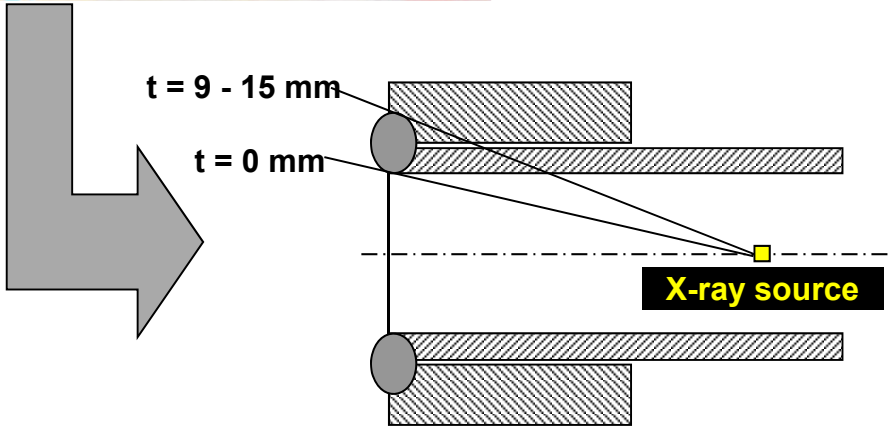
- <u>Minor problem:</u>
  No standards for NDT of tube-to-tube sheet connections available
- <u>But:</u> Considerable increase of application in a global scale!

Tube - to - tube sheet connection (TTS)
Inspection task

Aim of inspection:

Imaging of TTS weldment by one exposure with sufficient image quality and flaw visibility





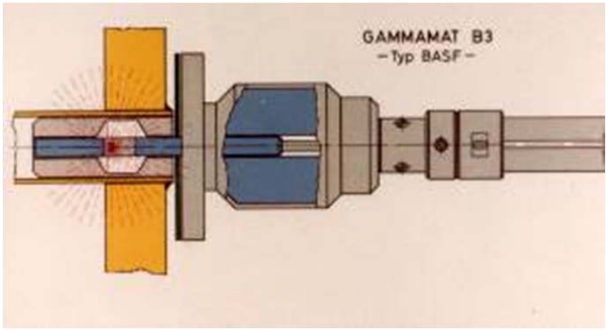
Scheme : TTS connection layout

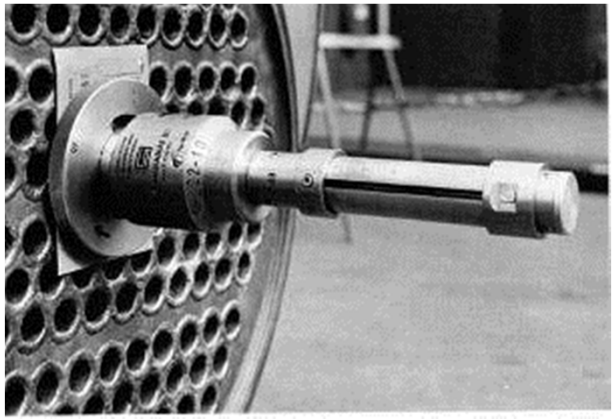
Solution:

- gamma- or X-ray source
- application of wall thickness compensators
- suitable detector - focus - distance depending on diameter and wall thickness of the pipes

NDT for inspection of TTS welds
History

- Introduction of gamma container with Isotopic source Ir-192 (1.0 x 0.5 mm²) **in 1975**
- Successfully application at the manufacturing site of the heat exchangers on request of chemical industry **until today** (film based)
- Constantly ca. 100 - 200 inspections per year by BASF only
- Influence on weld quality by NDT directly during manufacturing process at the manufacturing site
- Visibility of single pores starting from **0.5 mm** diameter
- Acceptance criteria in written practice of BASF





Continuous reports on inspections at conferences, working groups and committees of the German NDT society, e.g. by BAYER and BASF

NDT for inspection of TTS welds
Why a new inspection system?

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Facts:

- Inspection continuosly important for safe operation of heat exchangers
- Transport of radiactive containers requires more organizational efforts
- Usage and transport of isotopes on international scale nearly impossible

Aims:

- Increase mobility for BASF worldwide
- Reduce radiation exposure
- Inspection of different materials (Fe, Ti, Ni, …)
- Reduction of costs:
  - ommision of consumables like films and chemistry („greener world“)
  - constant and short exposure times
- Immediate evaluation of results on-site, therefore important contribution to process optimization

Step 1:
Development of rod anode X-ray tube

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MCTS 130A-0.6

rtw RÖNTGEN-TECHNIK DR. WARRIKHOFF GmbH & Co. KG

Step 2:
Developement of digital detector array

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- direct converting detector CdTe - CMOS
- 4 active tiles around rod anode
- pixel size 100 µm x 100 µm
- X-ray voltage 40 - 130 kV
- exposure time 10 - 30 s
- Image acquisition 20 frames/s
- inspection of **Pipe- Ø 20 - 30 mm**
- porosity detectable > **Ø 0,2 mm**

AJAT CdTe-CMOS X-ray Imaging

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Step 3:
Developement of software / user interface

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Image Evaluation by Isee!

Control of X-ray tube and image acquisition & storage:

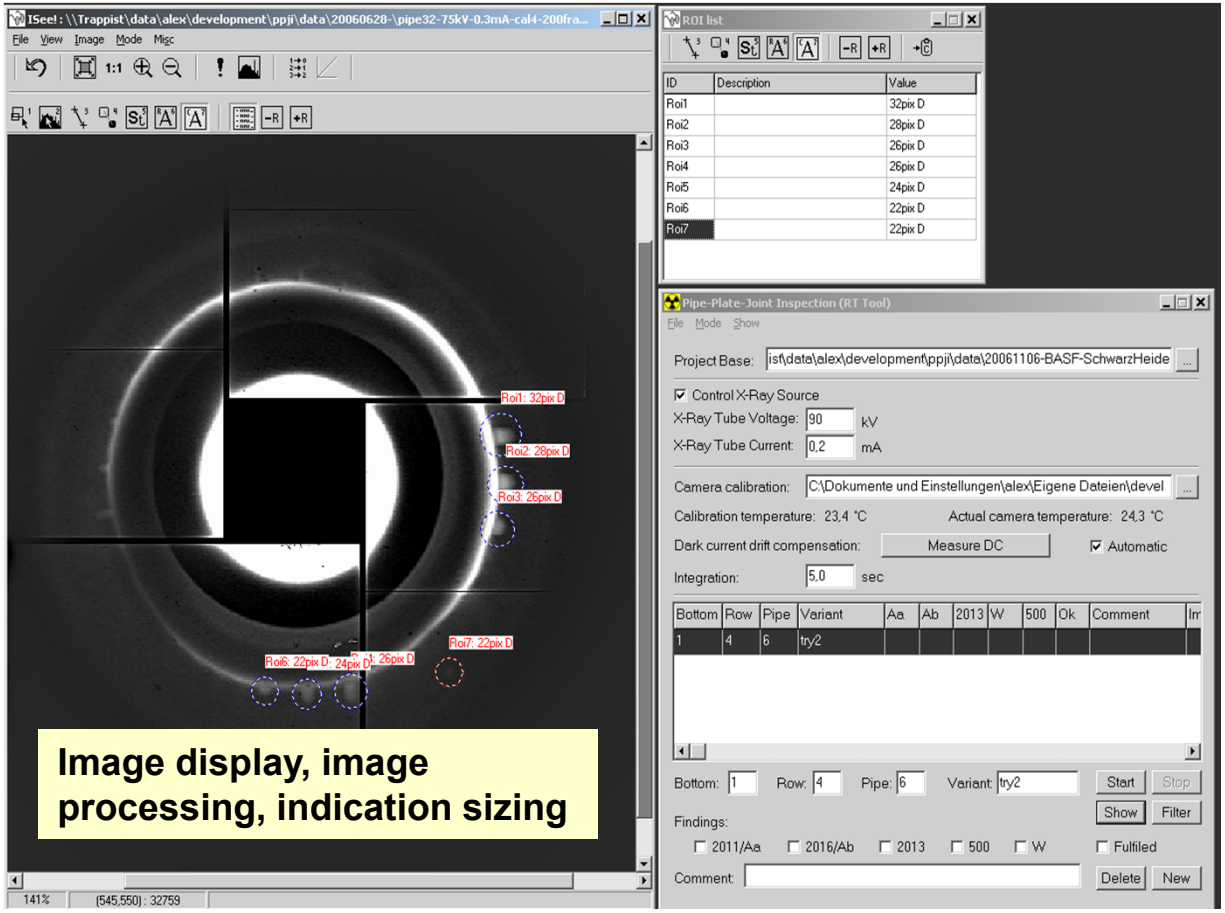

Image display, image processing, indication sizing

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BAM software for digital radiology, image processing and image analysis:

Isee!

http://dir.bam.de/ic

NDT for inspection of TTS welds
Chronology of inspection techniques

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Isotope Ir-192
NDT film based

Advantages:

- large wall thickness range
- easy applicable

Disadvantages:

- permanent radiation source
- radioactive container
- limited detail visibility
- low efficiency with DDAs

X-ray tube
NDT film based

Advantages:

- high detail visibility
- fixed exposure parameters
- easy transport

Disadvantages:

- lower wallthickness range
- electricity on-site required

X-ray tube
DDA based

Advantages:

- see X-ray tube
- lower radiation exposure
- immediately evaluation
- no consumables

Disadvantages:

- mechanically sensible system (connectors!)
- high investment costs

New TTS inspection system
Contribution of BASF (practical validation)

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- **Verification of detection sensitivity by**
  - test plates
  - modular reference blocks
  - real heat exchangers
- **Investigation of influencing parameters**
  - X-ray voltage, exposure time, image processing
  - pipe diameters, wall thicknesses, materials
  - Stability in practice on-site
- **Transfer of practical experiences to the TTS inspection system**
  - design changes at rod anode and digital detector (heat distribution)
  - modified instructions for radiation protection
  - **modified procedure for image evaluation and indication assessment by trained operators (validated acceptance criteria)**

New TTS inspection system
Verification of inspection sensitivity

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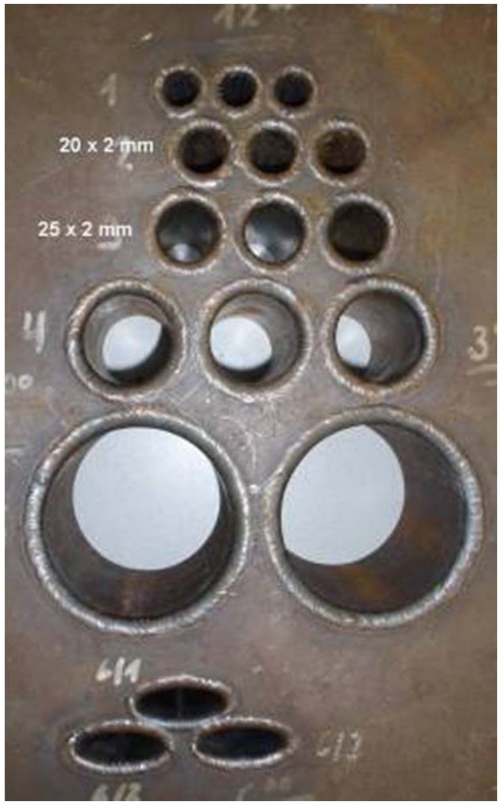
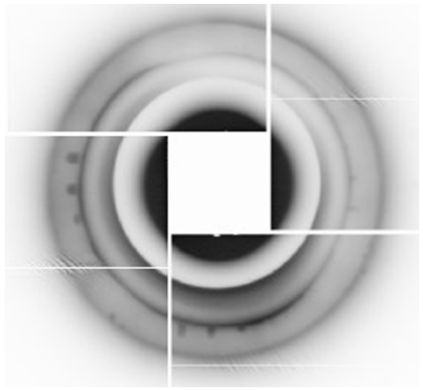
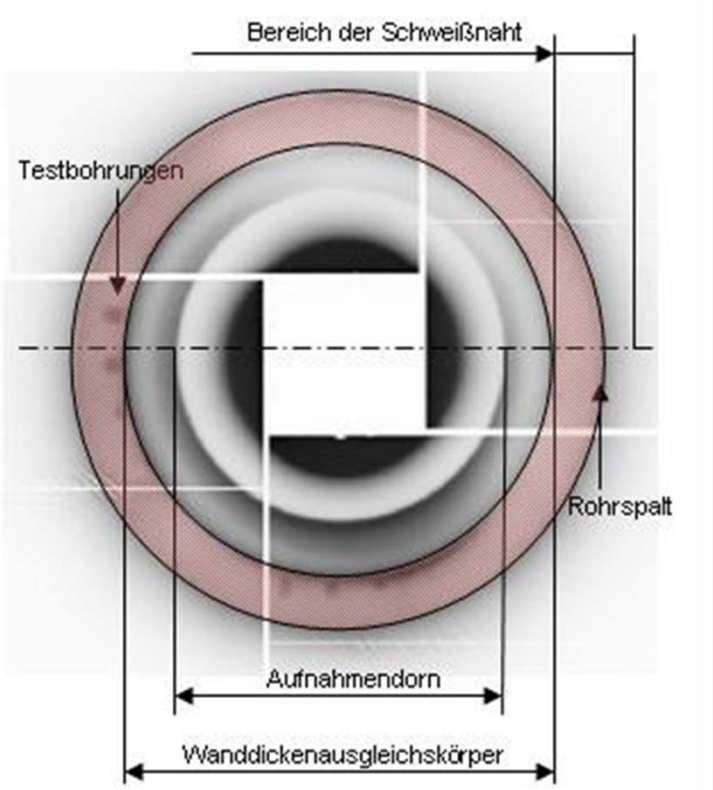
Test plate with TTS



TTS Ø25 x 2 mm



detector image Ø25 x 2 mm



New TTS inspection system
Comparison with test plate, pipe 25x2 mm²

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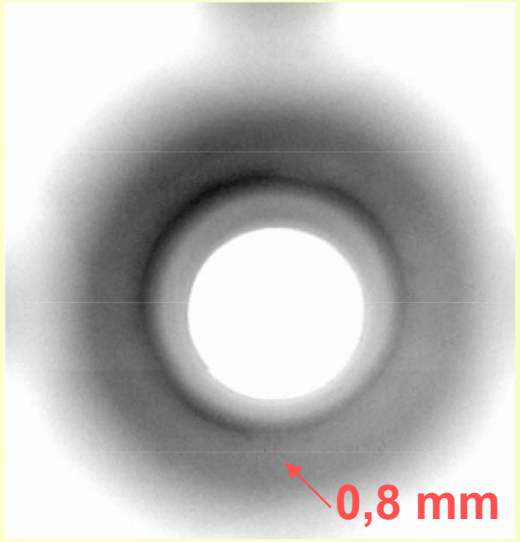
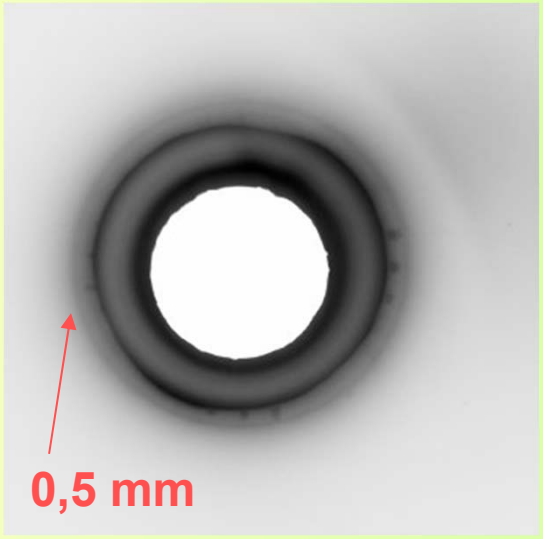
Ir-192 + film



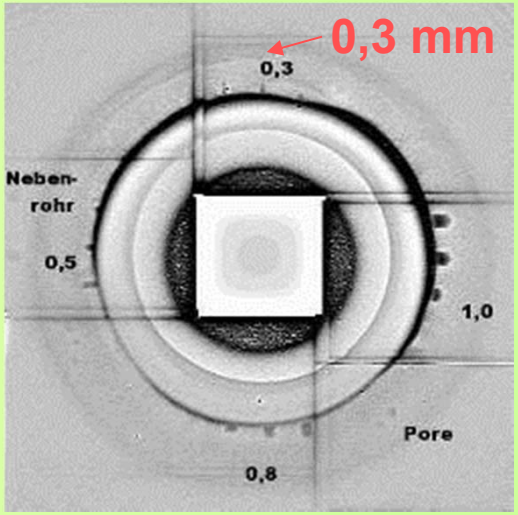
85 GBq, 1 x 0.5 mm², C3 film, 2 x 0,02 Pb screens
t_e = **1 min**

rod anode tube + film



130 kV, 0.5 mA, C3 film,
1 mm Sn filter, 2 x 0,02 Pb
t_e = **0.5 min**

rod anode tube + detector



75 kV, 0.5 mA,
t_e = **10 s**
digital high pass filter

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Further comparisons

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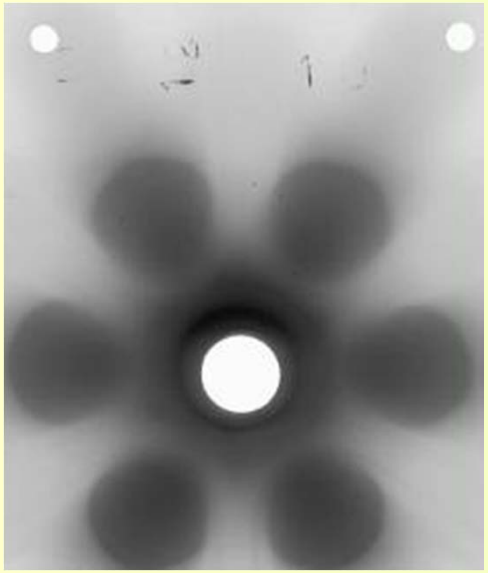
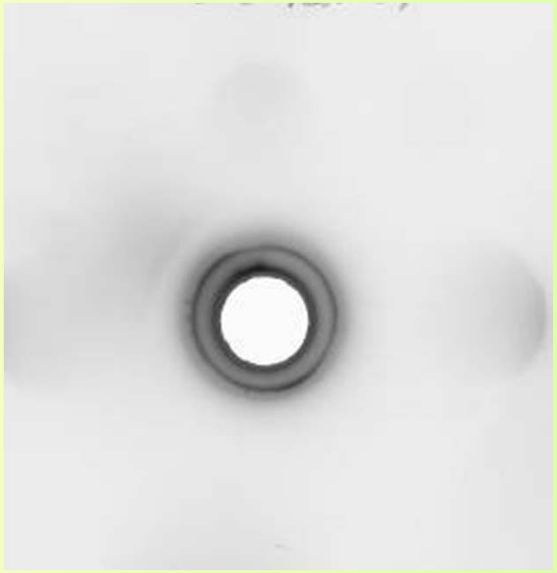
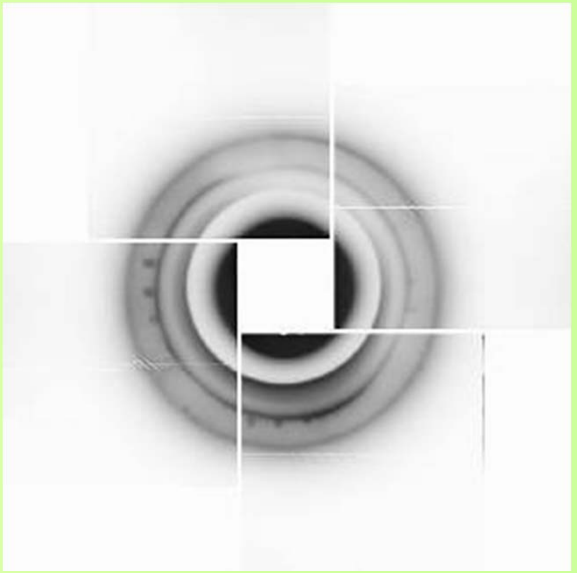


Gamma exposure with Isotope Ir-192 , f**ilm based**

High wall thickness range: evaluation of pipes in neighbourhood possible



X-ray exposure
130 kV / 0.5 mA / 30 s
f**ilm based**



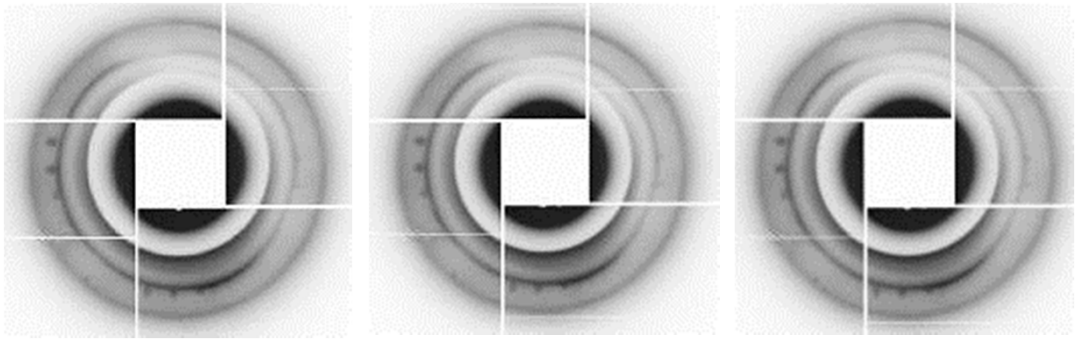
X-ray exposure with **digital detector array**
75 kV / 0.5 mA / 10 s

New TTS inspection system
Exposures with X-ray tube and DDA

Influence of **exposure time** on image quality

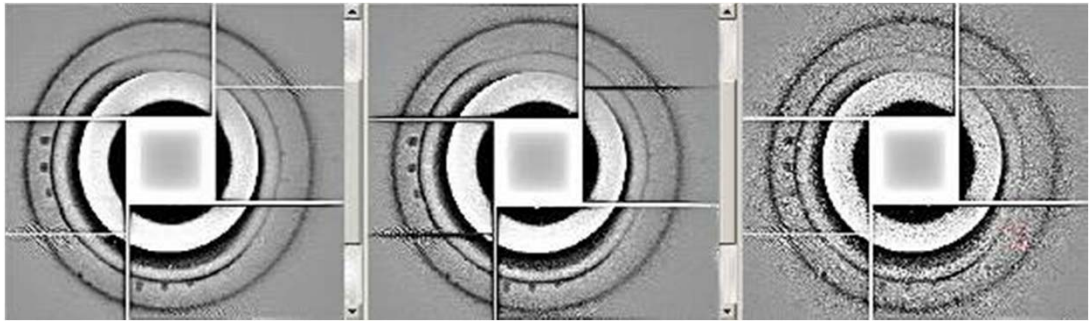
30 s 10 s 1 s

without image processing



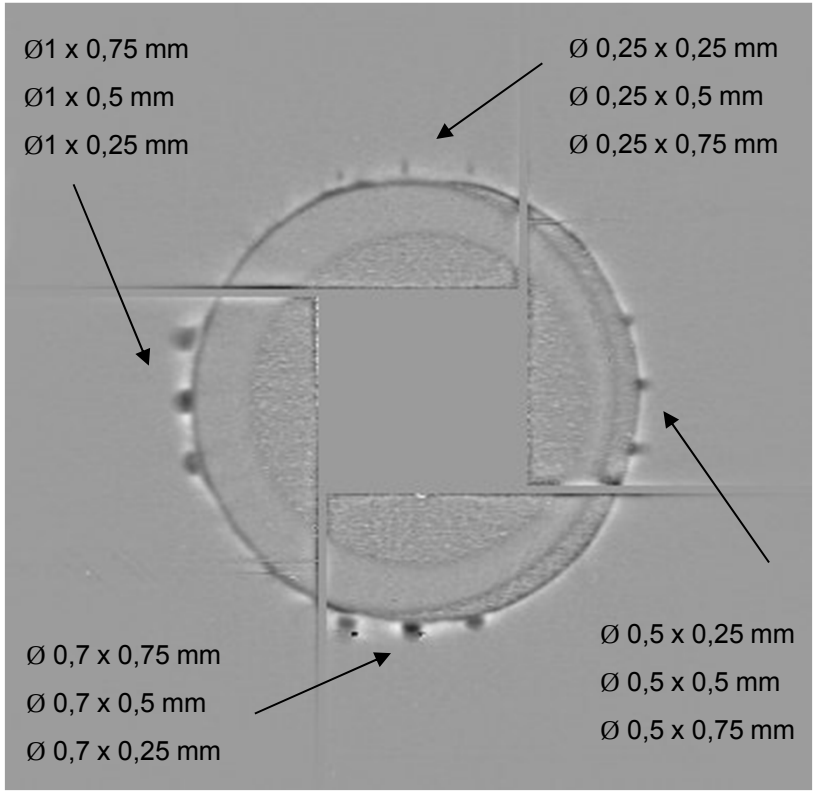
30 s 10 s 1 s

using image processing („Extract Details“ in Isee!)

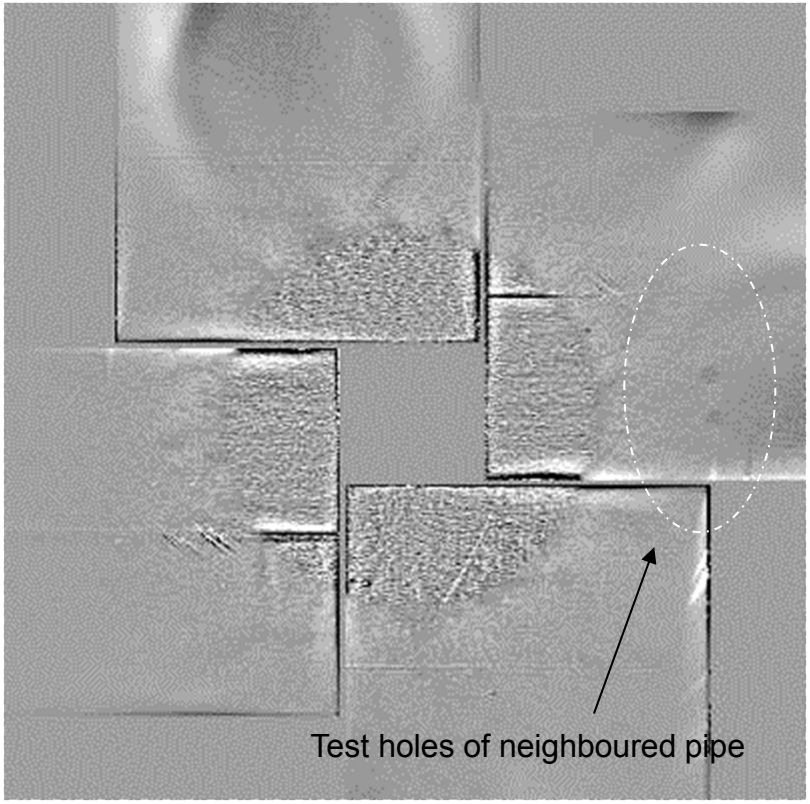


exposure parameters:
Ø 25 x 2 mm – **75 kV /** 0.5 mA / SDD = 37mm

New TTS inspection system
Exposures at TTS 20 mm x 2 mm



Detector exposure:
70 kV /0.5 mA / 30 s



Detector exposure:
85 kV /0.5 mA / 30 s

New TTS inspection system
Practical examples

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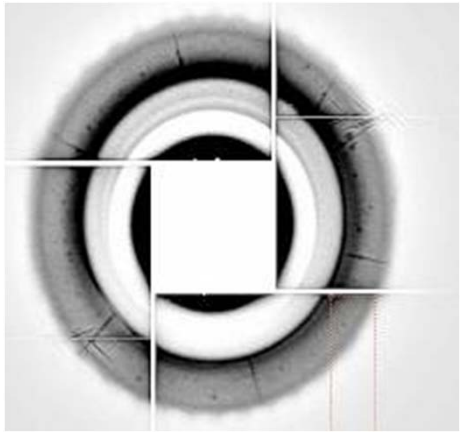
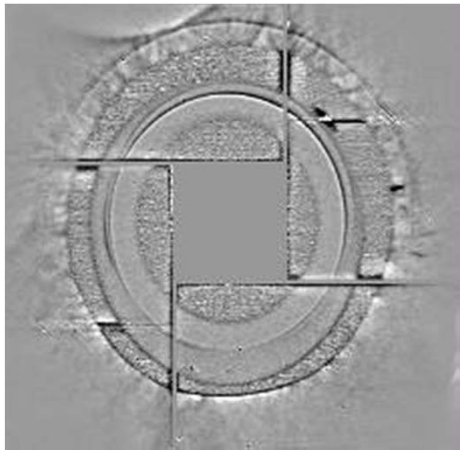
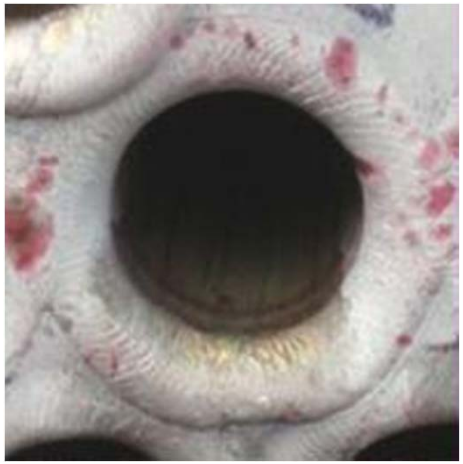
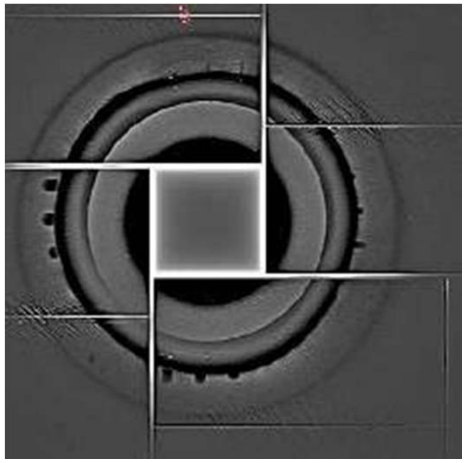



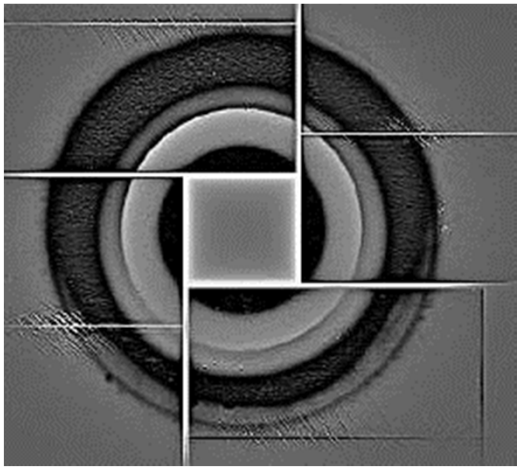



New TTS inspection system
Error sources

- **Important:**
  Positioning and **exact fitting of parts of equipment**
- **Therefore:**
  - application of suitable wall compensation pieces
  - correct exposure parameters and image processing
  - exact alignment of inspection unit relative to tube sheet plate



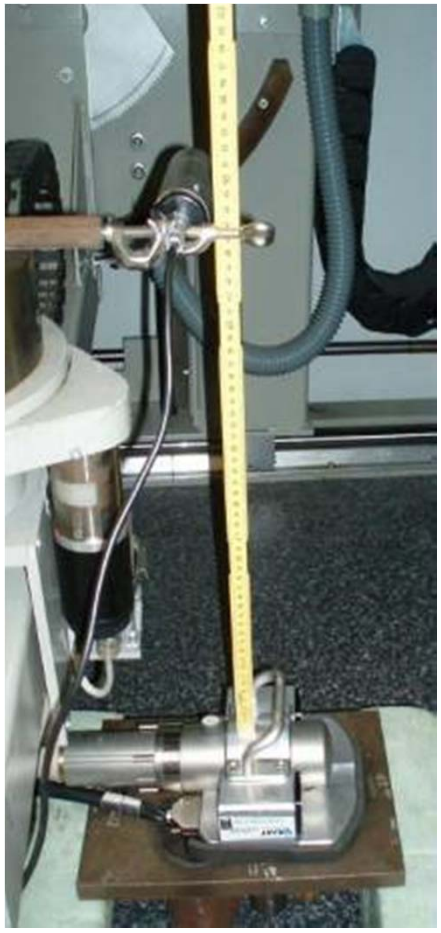
Inspection unit aligned



Inspection unit not aligned

Important image information is lost at improper alignment of the inspection unit, even when the correct exposure parameters have been used!

New TTS inspection system
Radiation protection



Dose rate $\dot{H}$ at 0.5 m

behind X-ray tube

kV	mA	s	µSv/h
70	0,5	30	**0,4**
75	0,5	30	**2**
80	0,5	30	**5**
85	0,5	30	**18**
90	0,5	30	**60**

Advantages:

- **Lower radiation exposure for inspection personnel**
- **Restricted access area smaller than 2x2 m²**
- **No influence of production processes at the manufacturing site**

New TTS inspection system
Detail visibility

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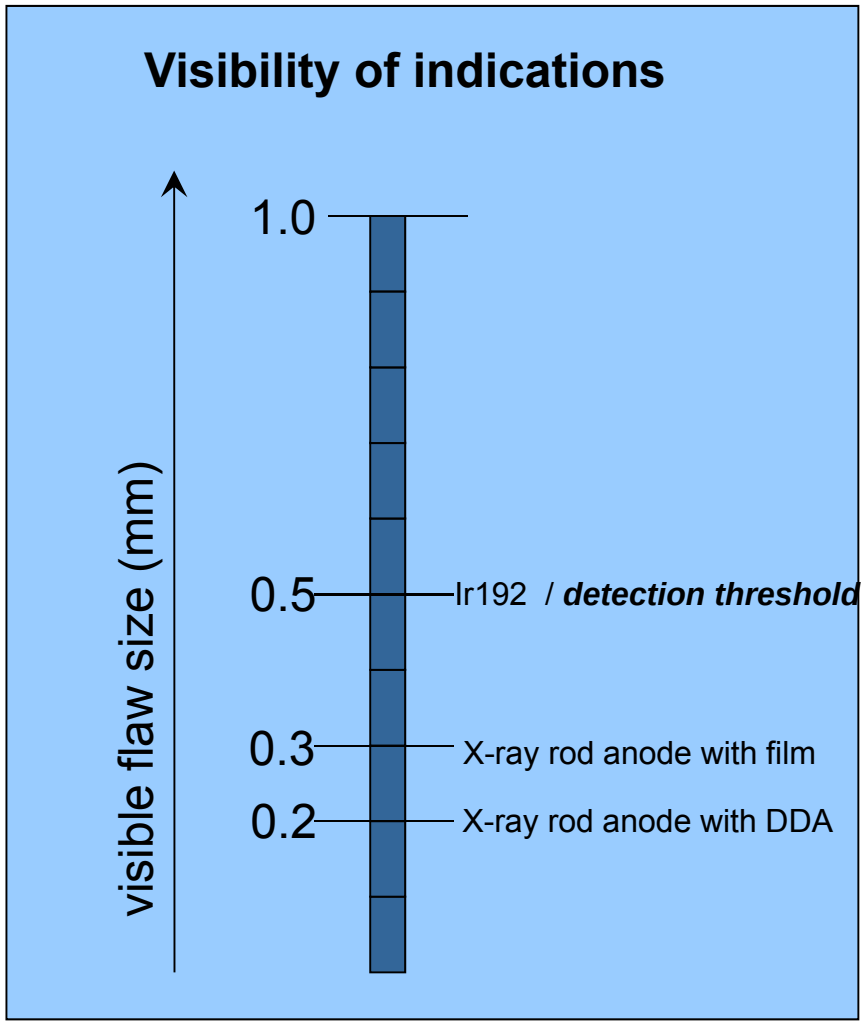
Radiographic inspection of TTS:

- **Gamma radiation (Ir-192)**

  back radiation technique (d=1x0,5 mm²)
  or penetration technique (d=2x1 mm²)

- **X-ray tube + film**
  (rod anode tube, d = 0.6 mm), back radiation technique with filmsystem C3

- **X-ray tube + detector**
  (rod anode tube, d = 0.6 mm)
  back radiation technique mit CdTe detector



New TTS inspection system
Summary - Advantages

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- No transportation of dangerous goods
- Global applicability
- Reduced exposure times
- Radiation protection:
  - Small controlled area at 75 kV
  - No disturbance of production processes at manufacturing site
- Visual defect assessment (image processing / defect sizing)
- Improved defect detection
- No consumables (cost reduction)
- Process optimization by onsite evaluation

New TTS inspection system

Excellent co-operation between:

Peter Rost, Markus Schmid and Team

Alexander Warrikhoff and Team

Prof. Uwe Ewert , Dr. Uwe Zscherpel,

Dr. Oleksandr Alekseychuk

Dr. Konstantinos Spartiotis and Team


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