# Mobile Computer Tomography for In-Service Inspection in Nuclear Power Plants

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**Abstract**. COMPRA GmbH, a member of the RTD Group, developed together with BAM Berlin the TomoCAR system for the mechanized digital radiography and planar X-ray tomography. The system is able to accurately size cracks in welds with a COD (crack opening displacement) of only 25 µm independent of its orientation. The system has a very high reliability of recognizing planar defects and the integrated TomoCar software modules are able to produce a 3D-view of the cracks. It is the first time these kinds of results are achieved on site with radiography equipment.

## 1. Introduction

The TomoCAR system (Tomography *C*omputer Added Radiography) is a patented radiography system that allows a mobile tomography to be carried out on welded pipes. The system was developed to detect stress corrosion cracking in austenitic piping (Fig. 1), since practical experience in industrial environment with conventional radiographic tests showed that the cracks could only be detected if they penetrated at least 1% of the wall thickness in precisely the direction of irradiation. This susceptibility of austenitic materials to allow stress corrosion cracking is a widespread problem in safe and economic utilisation of structural materials. It limits the useful life of structural components and often the catastrophic break-down of expensive power plant technology can be traced to an unexpected fatigue failure.

**Fig. 1:** Example of an austenitic pipe with stress corrosion cracking.
These kinds of cracks start almost always from the surface and penetrate into the material.

## 2. Some historical comments on the system development

A close co-operation between operators, users and researchers over a period of more than seven years was needed before this system could be put to practical use. The rapid progress in data processing and in the field of detectors encouraged the researchers to try out new inventions whose improvement in turn affected the project. Consequently, several parameters were changed simultaneously in the course of the project which affected the assess ability of the system and called for a re-assessment.

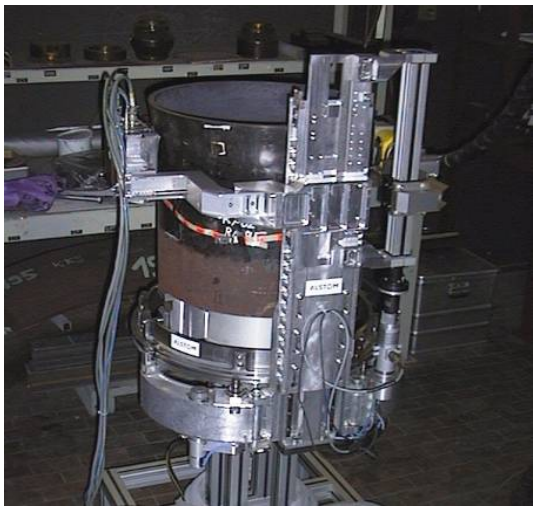

**Fig. 2:** View on one of the first manipulators that was used with the TomoCAR technology.

In the beginning a converted ultrasonic manipulator was used to test the advantages in the statement of the overlapping of radiographies from various irradiation angles in a dismantled pipeline from an atomic power station (Fig. 2).

The result amazed experts: cracks could be observed from all directions by means of radiography using tomography (Fig. 3) – and with a mobile system. Although this 3D representation was very effective it hampered the measurement of the displays.

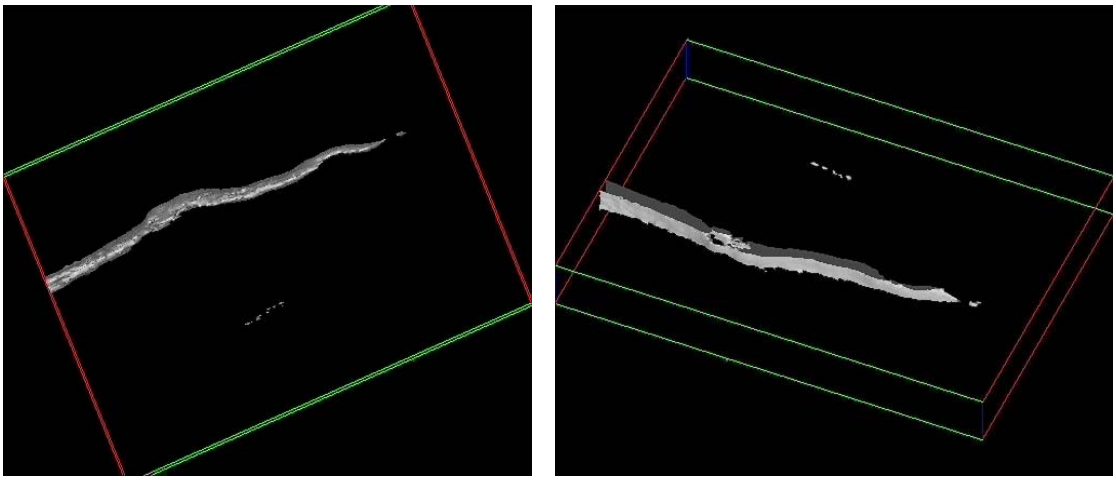

**Fig. 3:** Three dimensional view on the defects.
Note the details that can be imaged with such a mobile tomograph.

It was thus decided to fall back on a two-dimensional display, the so-called 'radiological section' (Fig. 4), in which the course of a display is shown like a certain part of a microsection. Yellow line in Fig. 4. The comparison with a microsection at the same point

(right part of Fig. 4) resulted in a dimensionally accurate representation and course of the crack.

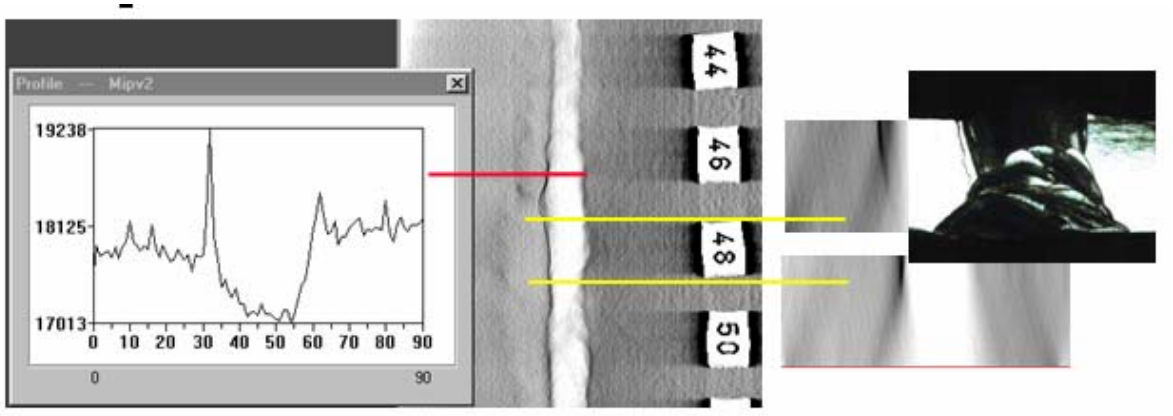


**Fig. 4:** The central part of this image shows the radiograph of one of the studied weld surfaces. The corresponding grey scale profile is on the left part and on the right of the image is the corresponding metallographic image.

Based on these positive results, the VGB (Association of German Power Station Operators) decided to set up the research project 'Mechanised radiography, or mechRAD for short' in cooperation with BAM, Cegelec and COMPRA. The objective was very clear defined: Development of a mobile unit that is able to identify and describe more exactly cracks through stress corrosion cracking in austenitic piping. Thanks to the establishment of this VGB project a special analysis manipulator (Fig. 5) could be built. During the course of the project several efforts were made to reduce the space requirement of the test system and realise the latest state-of-the-art. These additional efforts resulted in a new miniaturised X-ray unit and several detectors.

**Fig. 5:** View on the actual TomoCAR manipulator.

The system was initially tested on dismantled piping. It was hereby discovered that a reconstruction of the surface courses (example of a surface course in the area of a weld seam Fig. 6) and thus the wall thickness is needed in order to be able to identify precise crack lengths and undercuts. BAM developed an algorithm to determine the wall thickness curve on the basis of the absorption of the X-radiation, whereby an additional marking of the outer surface is necessary from which the course of the inner surface can then be reconstructed (Fig. 7).

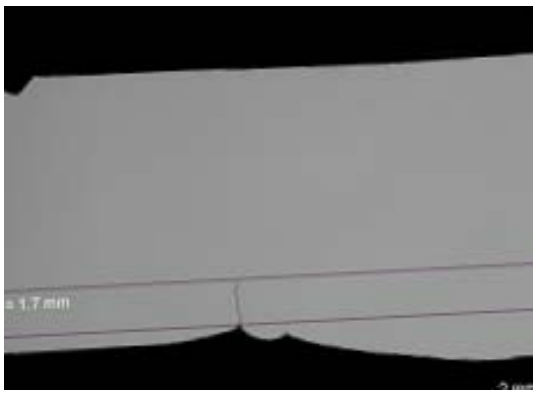


**Fig. 6:** Metallographic view of a stress-corrosion cracking on one of the investigated welds.

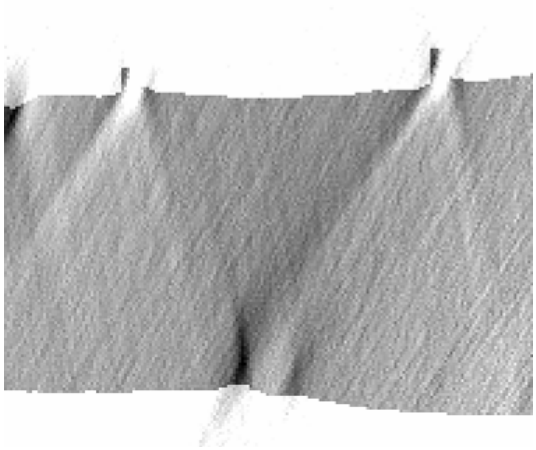

**Fig. 7:** Radiographic image corresponding to Fig. 6. The grey colors are related to the absorption coefficient.


**Fig. 8:** View on some documents of achieved during the ENIQ qualification.

In the course of the VGB project the power station operators expressed a wish that the project should be used as a pilot project for the first German qualification according to ENIQ (Fig. 8). The project was extended for a further year through the qualification processes and documents specified in ENIQ. Weld seams with natural faults on demantled piping were investigated in a power station as an additional qualification step (Fig. 9 and 10). The results showed that the readings could be displayed and described with an accuracy of ± 1 mm. The VGB project 'mechRAD' and the ENIQ pilot study could thus be brought to a successful conclusion.


**Fig. 9: and 10:** Installation of the mini-scanner.

In order to now prove the practical serviceability of the process, the team was commissioned to take part in a power station inspection. The operative austenitic piping chosen here was to be tested for operational damage in the weld seam area in addition to the ultrasonic test.

The thickens to be radiographed as 50mm, and thus in the upper range fort he performance of the test with the X-ray energy of 240 KeV that was available.

Not all piping sections displayed the necessary clearance of 200 mm around the piping with the given outer diameter of 270 mm so that in these cases he tests could only be performed with restriction (e.g. piping course Fig. 11). Because of the 20 m feeding pipes to the casing heads and manipulator the control units could be installed 15 m away from the objects in the reactor's sump (Fig. 11).

**Fig. 11:**Typical pipes investigated by the TomoCAR unit

**Fig. 12:** Adjustment of the TomoCAR unit on a client installation.

The 4-man team needed one working day to assemble the system, to transport this to location and protect it against contamination. The manipulator adjustment and system calibration on site to the actual dimension ranges took a further 4 hours (Fig. 12).

**Fig. 13:**The TomoCAR unit mounted on a pipe of a nuclear power plant.

**Fig. 14:** Evaluation. During ENIQ qualification the evaluation was carried out by experts from TÜV, BAM and COMPRA.

On completion of the preliminary work, the weld seams can be tested virtually in an hourly rhythm if the dimensions are the same (Fig. 13). Preliminary tests should serve to define an analysis range in which a general digital plot is taken. The evaluating parties define the exact co-ordinates for the points of analysis in the general plot. Over 500 projections with the various angles of irradiation are plotted transverse to the direction of welding and then overlapped so that the tomography that is performed allows the inspection and evaluation of the weld seams and neighbouring areas from all directions and in layer intervals of 0.1 mm. The various interesting pictures and viewing directions can be compiled and viewed on the PC and the cracks can be measured and interpreted (Fig. 14 and Fig. 15).

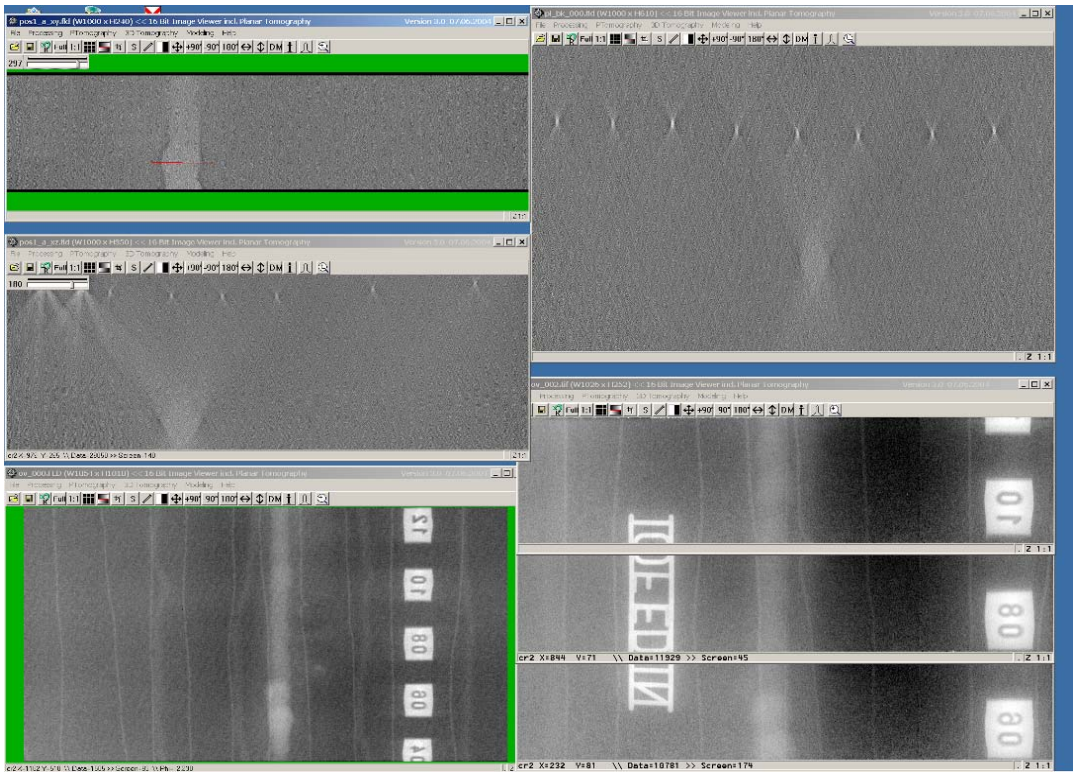

**Fig. 15:** Typical view on the display during the evaluation of the measurement results