RADIOGRAPHIC EVALUATION OF CORROSION AND DEPOSITS: IAEA CO-ORDINATED RESEARCH PROJECT ON LARGE DIAMETER STEEL PIPES

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Abstract: The principle of corrosion measurement/monitoring by means of tangential film-based radiography is already known. Most of this experience, however, is limited to qualitative determination of internal defects. The ability to reliably measure remaining wall thickness in pipes has not yet been established.

The International Atomic Energy Agency has organized a Co-ordinated Research Project bringing together twelve Member States to study "validation of protocols for corrosion and deposits determination in large diameter pipes by radiography". The general scope of the project covers radiographic measurement of corrosion and deposits in straight and bent large diameter (>160mm) pipes made of carbon or stainless steel corroded/eroded on the outer or inner surfaces with or without insulation.

It is expected to define the limits of detection for each radiation source using the tangential method and to explore the double wall technique beyond this limit.

Introduction: The International Atomic Energy Agency (IAEA) promotes the industrial applications of radiation technology which include Non-Destructive Testing (NDT) under its various programmes. One of the ways for promoting this technology is through coordinated research programmes (CRPs) and research contracts. These are undertaken keeping in view the current status of the technology and the need for undertaking some research. Such research contracts and agreements are worked out between the Agency and universities, colleges, research centres, laboratories and other institutions in Member States.

Pipe is a common feature in industries. It provides the most economical, safe and efficient way of transporting chemicals in the form of liquids and gases from one point to another. However, pipe experiences degradation with time which if not detected might create problems such as leaks and bursts which finally can lead to catastrophe.

Corrosion, erosion, deposits and pipe blockage are some of the possible causes for this.

For years, many testing methods either destructive or non-destructive in nature were developed and applied on pipe to ensure integrity and reliability. Of many parameters, pipe wall thickness is considered as one of the most important to be monitored and measured with a high degree of accuracy.

Up to now, appreciable R & D efforts have been made to investigate this aspect. Measurement of wall thickness on long pipelines is accomplished with a number of established systems such as ultrasonic and eddy current 'intelligent pigs'. However, for plant piping, the existence of many bends and a variety of pipe diameters, some having insulation cover, do not allow the use of these systems.

A method, preferably non-destructive in nature, is required to precisely perform this measurement whose data will be used as a basis for determining whether or not the pipes need to be replaced. Theoretically, it is believed that radiographic method would be able to perform this function. It has the potential to be used to perform inspection without the need of costly removal of insulation material during operation of the plant. Furthermore, it offers an additional advantage of being capable to perform measurement in high temperature environments.

The principles of corrosion measurement/monitoring by means of tangential film-based radiography are already known. Most of this experience, however, is limited to qualitative determination of internal defects. The ability to reliably measure remaining wall thickness in pipes has not yet been established quantitatively and no standard is available.

It was based on these facts that an effort was undertaken by the Agency together with some Member States to organize a CRP on "validation of protocols for corrosion and deposits determination in small diameter pipes by radiography (CORDEP)" between 1997 and 2000. Member States involved in this three years project were Algeria, China, Costa Rica, France, India, Korea, Malaysia, Sri Lanka, Syria, Tunisia and Turkey. The general scope of the CRP covered radiographic measurement of corrosion and deposits in straight and bent small diameter pipes (less than 160 mm) made of carbon or stainless steels corroded/eroded on the outer or inner surfaces with or without insulation.

The results of various participating laboratories were reviewed and compiled. These are quite encouraging and demonstrate the capability of the radiographic technique for corrosion detection and measurement. A Technical Document (TECDOC) and an ISO draft were prepared and are under revision.

Encouraged by the results of previous CRP on small diameter pipes, a new CRP for the large diameter pipes has been initiated at the end of 2002 to extend the results to larger diameters. The participating laboratories this time are from Algeria, Canada, Germany, Hungary, India, Iran, Malaysia, Pakistan, Romania, Syria, Turkey and Uruguay.

Results: The scope of this CRP includes the evaluation of radiographic techniques (Ir-192, Co-60 sources and X-rays) to evaluate artificial defects and simulated or natural corrosion attack on carbon steel and stainless steel piping from 6 inches in diameter (168 mm) up to 20 inches (508 mm) with and without insulation.

The major objective is to define the limits of detection for each radiation source using the tangential radiography technique. Internal and external defects will be included in the experimental program. Only NDT film based inspection will be considered. The double wall technique will be further explored for application to the pipe sizes in this range. Results will be verified by other methods.

Tangential radiography technique (TRT) and double wall technique (DWT)

There is a certain geometrical set-up for pipe inspection and direct wall thickness measurement (Fig. 1). This method is called tangential exposure method. Here the parts of radiograph which lie below the tangential location on the pipe only are interpreted. The middle part of the pipe image is ignored. To get the proper image at tangential location, the energy of radiation used must be higher than that used for double wall inspection (DWT) at the middle of the same pipe. This is the effect of the maximal penetrated wall thickness L_{max} at the point of the inner pipe surface.

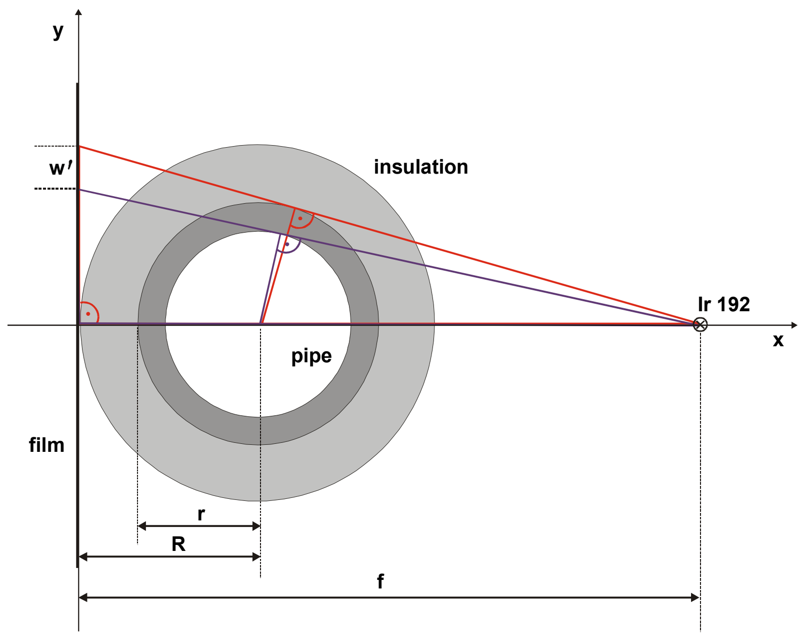

Fig. 1: Tangential Radiography technique (TRT)

The most important application of this method is in absolute measurement of the wall thickness of the pipe. This is because the wall thickness is seen in profile in tangential radiography, almost like a longitudinal section of the pipe. Care must however be taken to correlate only that part of the pipe wall which lies at the tangent. Minor rotation will bring a different segment in image.

It may be noted that the real traversed maximum thickness is much more than pipe-wall thickness while using the tangential radiography technique. Selection of irradiation source must therefore be according to the maximum of the transmitted thickness, L_{max}:

$$L_{max} = 2w\sqrt{\frac{D_a}{w} - 1} \qquad (1)$$

Where w = pipe-wall thickness, D_a = 2r = outside diameter.

Selection of higher energy radiation ray helps in reducing the contrast. Higher contrast would extend the low density zone corresponding to the wall much inside the diameter of the pipe. That makes the determination of wall thickness difficult. Lower contrast picture obtained at higher radiation energy has better delineation of the ID profile.

The technique of Tangential Radiography can be used for assessing the residual wall thickness in those segments of process pipelines where corrosion or erosion are likely to have occurred. It can similarly be used for assessing the scaling of ID or finding deposit inside the tubes. This CRP addresses the problem of determining effectiveness of application of technique determination in corrosion depth determination in the pipelines.

Magnification correction

According to the geometrical set-up of the tangential exposure technique (see fig. 1) there is a magnification factor inherent to this set-up. To consider this, a correction on the estimated wall thickness must be done. The following correction can be applied. The true wall thickness is calculated according to /5/, a practical approximation is:

$$w = \frac{w' \cdot (f - R)}{f} \qquad (2)$$

Where w'is the apparent wall thickness, R is the pipe radius (including insulation) and f is the Source Film Distance (SFD).

Limits of tangential inspection technique

One of the main aims of the CRP is to establish the application limits of tangential inspection technique. As a starting point BAM provides a diagram (see fig. 2). It is based on maximum penetrable wall thicknesses of pipes (L_{max}) in depending on the radiation energy. L_{max} determined the maximum wall thickness which can be inspected at a given pipe outside diameter D_a.

If a given combination of outer pipe diameter and wall thickness is exceeding the limiting dashed line for the chosen energy, this energy can not be applied for successful tangential inspection, because the position of the inner wall cannot be determined from the radiograph. As alternative a higher radiation energy can be used (e.g. replace Ir-192 by Co-60), or the double wall inspection technique (DWT) in the pipe centre for the relative wall thickness measurement must be used. According to /6/ a wall thickness change can be calculated in this case from a ray dose change, recorded on the radiographic film as film density difference.

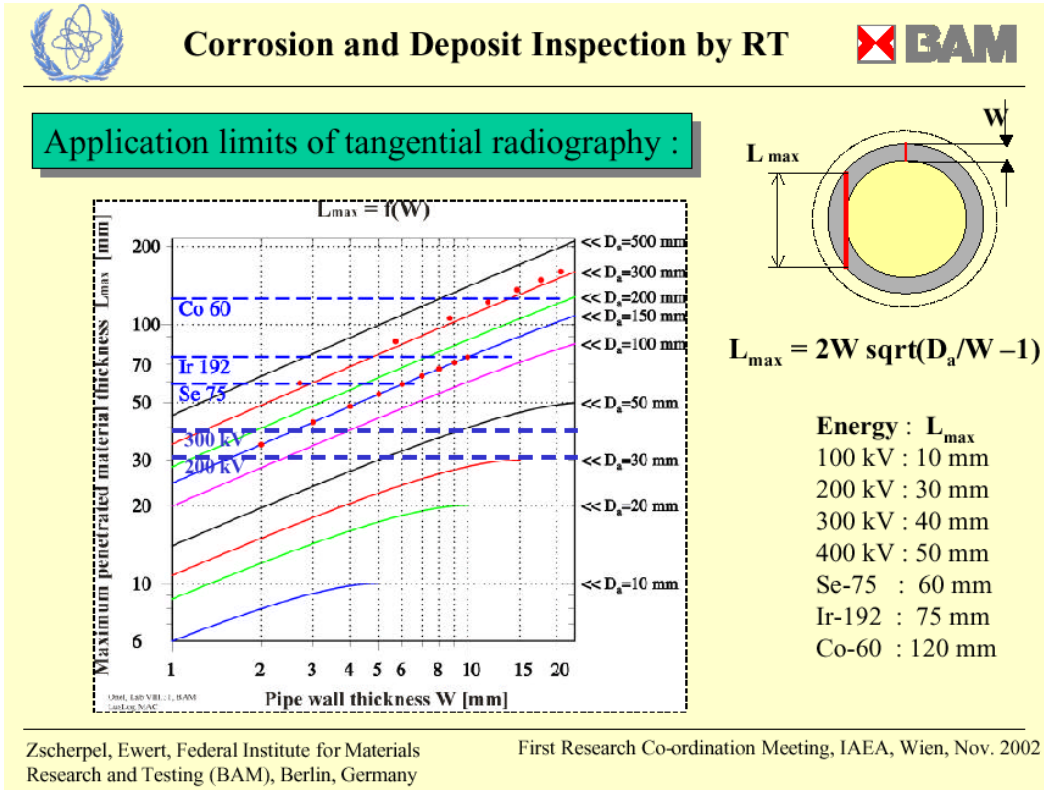

Fig. 2: Suggested application limits for tangential inspection techniques

General procedure for the current CRP

Each country shall manufacture at least 2 reference blocks with different pipe diameters, covering the diameters and wall thickness to be tested.

Reference blocks shall be tested according to the defined procedure and for each radiographic arrangement. Results will be interchanged between participants working with the same diameters, establishing the limits of each radiation source and exposure technique.

Other probes will be tested, with artificially introduced natural defects, according to the established limits.

Standard reference blocks

Type and size of defects to be considered are as follows:

i. Step block with holes inside and outside (one pipe specimen with machined steps inside and outside)
ii. Each step will be chosen to range from 0 to 0.7 w in steps of 10% wall thickness rounded up to nearest half mm; 20 – 50 mm in length; precision in wall thickness shall be ± 0.1 mm.
iii. Hole diameter will be equal to remaining wall thickness, minimum of 2 mm.
iv. Hole depth shall be 10, 20 and 50% of the step thickness spaced at different circumferential positions (separated by 120°), holes shall be flat bottom.
v. Where steps are located at the inside surface of the pipe, material will be removed by grinding or machining to a depth of 15% of maximum wall thickness of the pipe, forming a flat surface. Length covering all the steps. 30° separation from closest holes. Precision shall be ± 1%.
vi. Where steps are located at the outside surface of the pipe, material will be removed by drilling with a 20 – 25 mm diameter tool, parallel to the pipes axis to a depth of 15% of maximum wall thickness of the pipe. 30° separation from closest holes. Length covering all the steps. Precision shall be ± 1%.

Pipe dimensions and kind of tests

24 specimens will be required to be machined by all twelve participants covering commonly used outside pipe diameters and suitable wall thickness ranges to reach the application limits of tangential radiography technique.

On every pipe size radiographic tests will be performed in 5 different positions for the tangential method and in 4 different positions for the double wall technique, exposing every artificial discontinuity to the tangential or centre position respectively. Each test will be performed with and without removable glass wool insulation of approximately 50 mm thickness and with and without simulated internal deposits.
Additional defects can be introduced in separate blocks or in the reference block, provided they do not interfere with the ones described before. These could be artificially induced to simulate shapes and sizes of natural defects. Samples for erosion, corrosion and pitting shall be selected in the same diameter and thickness ranges as above.

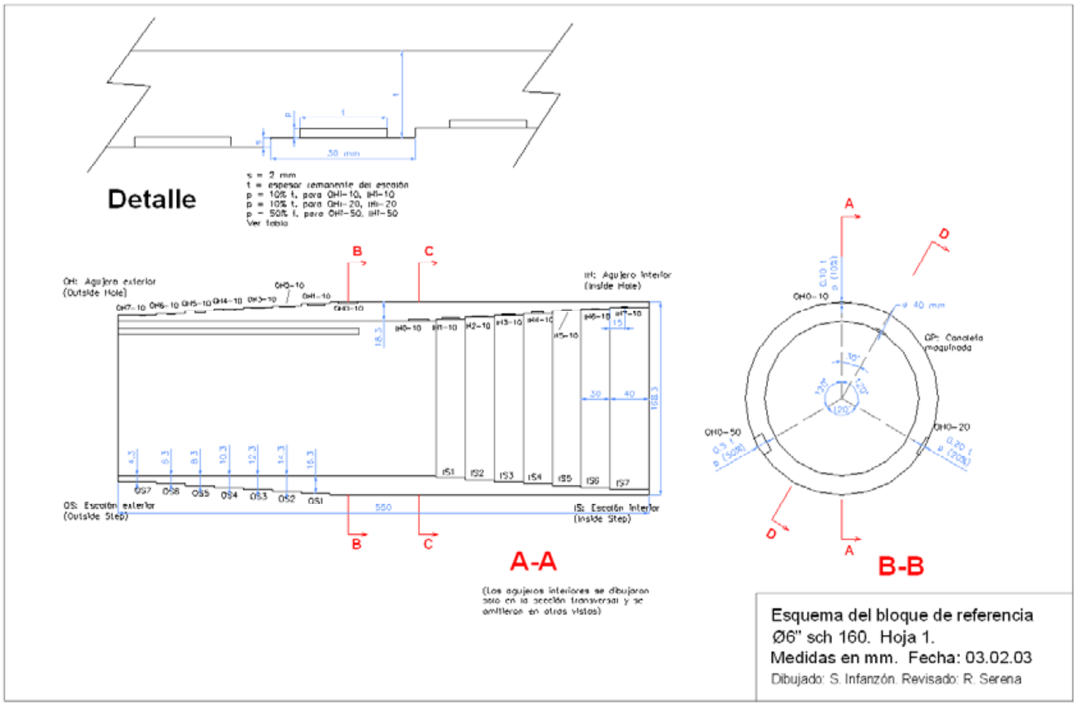

Fig. 3: Drawing of one of the reference blocks (6 inch diameter) machined in Uruguay.

Inspection set-up

Tangential projection technique (shadow shots) shall be used using Ir-192 and Co-60 radiation sources. The same specimens and reference blocks may be used for double wall technique.
Double wall technique should be used in the case, where tangential technique fails because of too high L_{max}. (wall thickness cannot be measured because inner pipe diameter cannot be detected).

Fig. 4: The finalized test specimen at BAM (8 inch steel pipe with inner and outer wall thickness steps separated for better handling, one 12 inch pipe at exposure arrangement ready for inspection, the other 12 inch pipe with outer wall thickness steps at the floor)

Fig. 5: Alignment of the radiation source (Co 60) for the tangential projection technique. Behind the 12 inch pipe is the film cassette. The pipe sits on a turn table for easy positioning of the different holes in relation to the film.

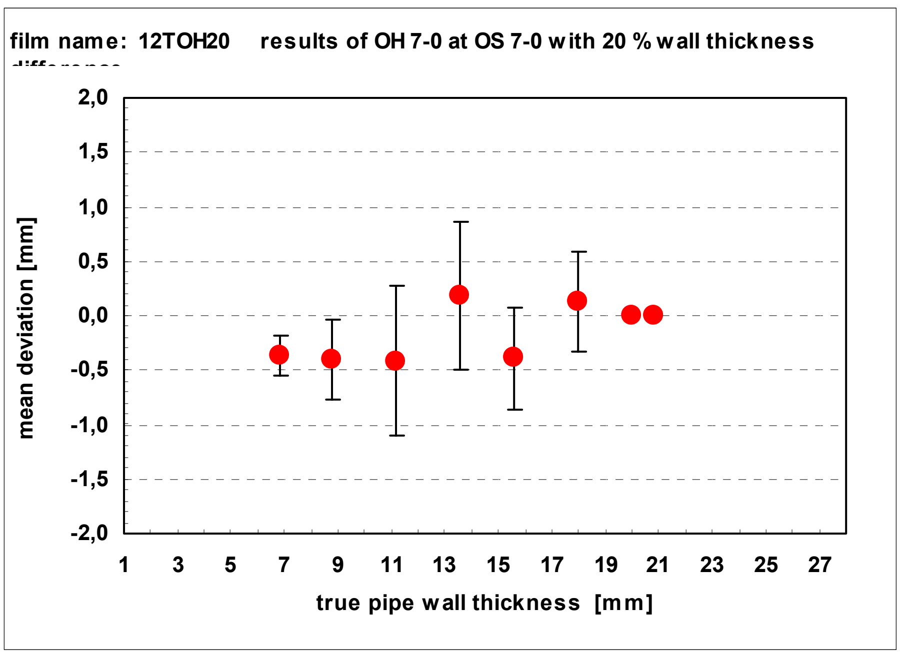

Fig. 6: Example of evaluation results for visual film evaluation of tangential projection technique as summarized in Excel sheets. The red points show the pipe wall thickness inspected, the bars the achieved accuracy (derived from 2 independent evaluations of 3 different inspectors).

Radiation sources can be X-ray (including 2 mm Cu pre-filtering), in most cases Ir-192 or Co-60. Limit energy for x-ray inspection should be 20 % higher than recommended in ISO 5579.
Many details about the radiographic procedure have been established to allow better comparison of experimental results, regarding radiographic arrangement, radiation sources, SFD, unsharpness, desired density range, exposure

time calculation, screen/film systems, magnification correction, shielding against scattered radiation, IQI, film processing and film evaluation procedure.

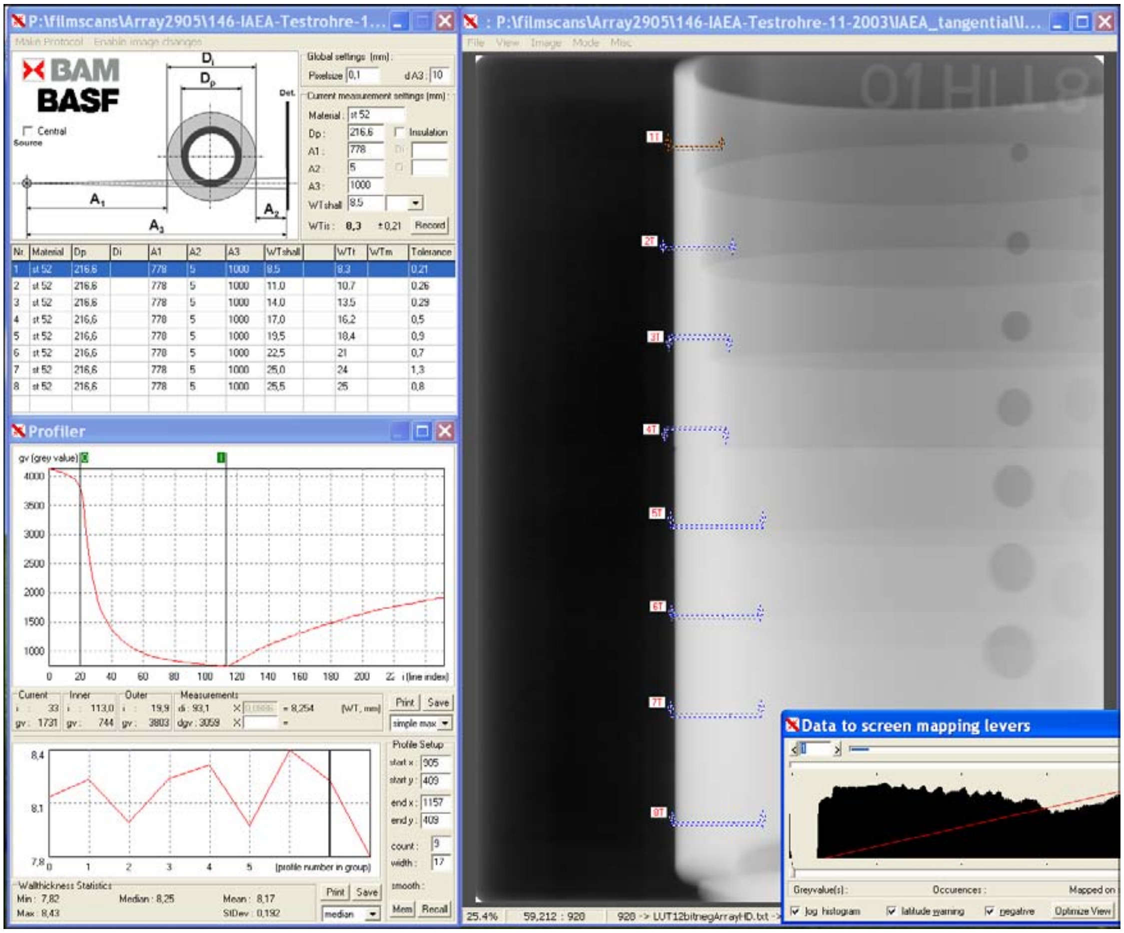

Fig. 7: Example of evaluation results of computer based film evaluation of tangential projection technique. The digitized film is shown, the positions of the measured profiles, the active profile and the neighboured ones, the geometrical set-up and a table with the results of the wall thickness measurements.

Discussion: An example of an inspection result in tangential projection technique (12 inch pipe with 8 to 25 mm wall thickness and 20% outside wholes, exposed with Co 60) is shown in fig. 6. This is one resulting diagram of the developed Excel data sheets exchanged for data collection between all of the participants. The deviation of the measured wall thickness on the film is compared with the true wall thickness determined mechanically after reference block production. The limiting wall thickness in this case is 20 mm, the achieved accuracy about 0.5 mm using the standard procedure for film evaluation in the CRP, without digitalization of films.

In addition, Germany digitized films at BAM and developed together with German industry software for computer based inspection of TRT and DWT /7/. The developed computer algorithms /3-7/ ensure a higher accuracy compared with visual film evaluation on light boxes.

Another example for the pipe inspection in double wall technique (DWT) is shown in fig. 8. From film density differences at the measurement and reference points and with a known attenuation coefficient the relative wall thickness difference of the holes can be calculated and the accuracy of this method tested.

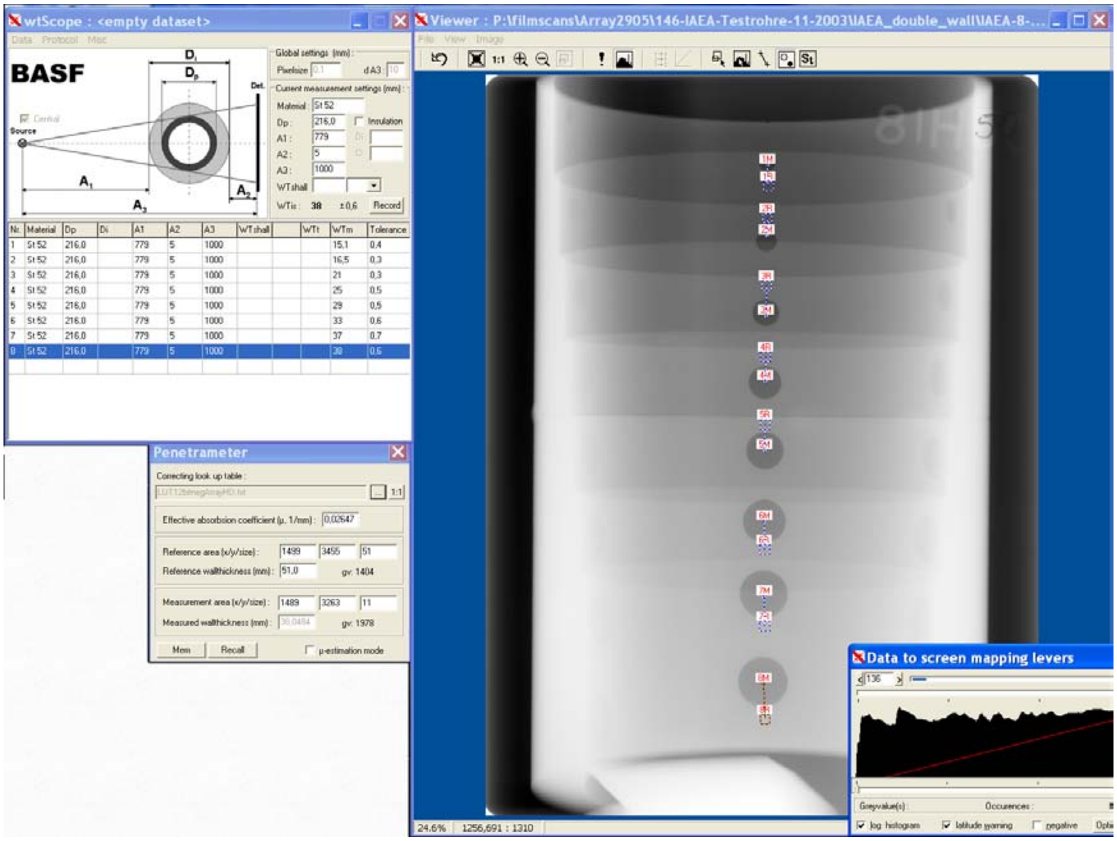

Fig. 8: Example for evaluation of the double wall image in penetration direction. The measurement points are indicated in the image, the table (left side) summarized the geometry and measurement results.

Conclusions: The current CRP is well underway with experiments being carried out in all of the participating countries. With this level of co-operation, the major objective of defining the limits of validity of the technique will be achieved, the results will be published in a TECDOC, and an ISO document produced which will make it available to all.

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