



# Electronic reference images for flaw indications in welds and castings

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**Abstract.** Since decades the evaluation of flaw indications on radiographs from welds or castings are based on well accepted reference film catalogues from organizations like IIW (weldments), ASTM (castings) or DGZfP (D5 recommendation on heavy steel castings). Today, the transformation of classical film radiography to the digital world is in full progress. Some ASTM standards do not permit the evaluation of digital radiographs in reference to film catalogues. Therefore, these reference film catalogues have to be converted into the digital age too. BAM is supporting this transition by high definition film scanning. The result is a corresponding reference image catalogue.

The different standard organizations selected different ways to distribute the digital data. ASTM used high definition film scanning at 10 µm pixel size and distribution of a huge amount of high-res data via DVD. The user sub-samples these high-res data during catalogue import to the resolution of his system. The comparison is done by synchronized image viewing on the computer work station.

IIW recently decided to distribute their ISO 5817 reference images installed on tablets, which are used for image viewing too. The tablet image has to be compared with the digital image on the system monitor.

DGZfP transformed their D5 reference radiographs into a PDF for monitor viewing. This is the simplest and cheapest solution, but still allows the full usage of the catalogue in the digital era.

The status of ongoing work in progress will be discussed.

## Introduction

Digital radiography encompasses a range of technologies, including digital detector arrays (DDA) and computed radiography (CR) using imaging plates as film replacement. The marked improvement in technology of digital radiography in the past decade is opening up many opportunities for cost savings. In switching from traditional film radiography to digital radiography, the costs associated with purchasing film, processing film, and chemical waste disposal are eliminated. In addition significant savings can be realized through cycle time reduction and the ease of automation that digital radiography offers [1]. Finally, it has been shown that digital radiography even outperforms film radiography [2].

One of the major hurdles to the implementation of digital radiography for a number of industrial uses was the lack of digital reference images. The solution for this problem was the digitization of existing film reference radiographs. ASTM E 155, the Reference Radiographs for Inspection of Aluminium and Magnesium Castings, was the first catalogue

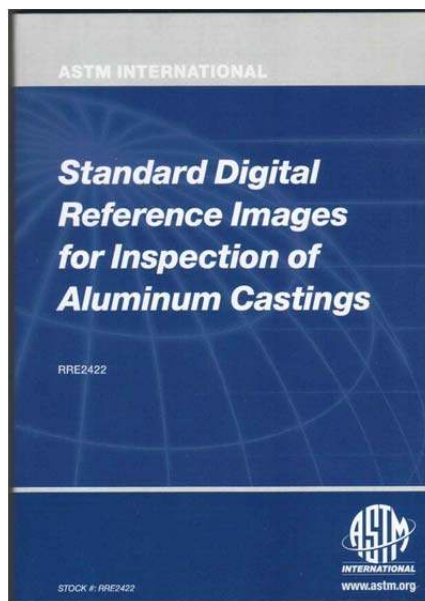


in a series of such conversions from film reference catalogues to electronic reference images, which started in 2003 and is still ongoing today [3].

### 1. Concept for conversion of ASTM reference radiographs to electronic reference images

The existing film based reference radiographs have been proven inadequate for comparison to digital images for two main reasons: (1) the difference in spatial resolution between radiographic film and the digital radiographic system, and (2) the difference in dynamics when displaying the film on the light box and an image of the digital detector on a monitor. The difference in dynamic range between film and many of the digital detectors is another reason that the use of ASTM E 155 reference radiographs has been proven unsuitable for the grading of the severity level of digital radiographic images of aluminium castings. Digital detectors with their wide dynamic range, coupled with the limitation on the number of grey level intensities that humans can differentiate, make it necessary to step through the data of a given image with a series of window level settings or to use appropriate image processing (e.g. high pass filtering) to reduce this dynamic range for viewing. The simplest approach is to adjust the contrast (window width) and then changing the brightness (window level) in a series of steps to view the data. The difficulty comes in adjusting the contrast of a production radiograph taken with a digital detector. When using a high contrast, the discontinuity looks worse (i.e. higher severity level). When using a low contrast, the discontinuity may not be visible at all.

In an effort to overcome these difficulties, ASTM Committee E07 on Non-destructive Testing started with an industry team in 2003 to develop a set of digital reference images and a methodology to use them. These reference images and methods were published in 2006 as ASTM E 2422 (together with the adjunct RRE 2422 on DVD, see fig. 1) and have to be used in place of the ASTM E 155 reference radiographs when viewing digital radiographs of aluminium castings. The goal of this effort was to allow the use of digital radiography for aluminium castings without changing the classification of the castings as compared to the traditional film radiography using ASTM E 155 in a statistically significant way.



**Fig. 1.** ASTM RRE2422 Standard Digital Reference Images on DVD [3]. This DVD is the adjunct to ASTM E 2422, which contains digitized film data of part 1 of ASTM E155.

The approach of the team started with the ASTM E 155 hardware (flaw samples) and took new film radiographs of the hardware using the same techniques as used to create the E 155 reference radiographs. The only difference was the inclusion of a step wedge and two duplex line pair gauges according to ASTM 2002 and ISO 19232-5. The addition of the step wedge was essential to guide for the setting of the proper contrast by using known wall thickness differences. The addition of the line pair gauges served as a check on the basic spatial resolution (image unsharpness) throughout the process from radiographic exposure, via the digitized image, to the displayed image by a digital detector vendor's software. The critical step was to digitize these films at a very high spatial resolution (10 micro meter pixel size) and to a 16-bit dynamic range proportional to the optical film density (done at BAM Berlin in 2004 using the BAM high definition drum scanner from Linotype-Hell). This level of resolution was agreed on by the desire to have no visible loss in resolution against the size of the resulting file. The basic spatial resolution of NDT film systems with lead screens exposed at 100 kV is about 12  $\mu\text{m}$ . Since this result in a file size, close to a gigabyte per film after digitization, the team chose not to try for any higher resolution.

The concept in using these reference images is that by starting with an image with 10 micron pixels it is easy to reduce the resolution in steps of 10 microns by averaging to achieve the pixel size of detector considering also geometric magnification. For example, if a detector with a pixel size of 139 microns is operated with a geometric magnification of two, the reference images have to be shown with a pixel size of 70 microns. The average down function also considers for the improved SNR in the image when using larger pixel sizes.

If the resulting digital images shall become a useful standard, it is required to have a suitable documentation of when and how to use them. The team was addressing this with instructions covering such details as e.g. how the digital reference image files are to be sub-sampled, how to select the correct resolution for viewing and how to normalize the contrast between a production image and a reference image using known wall thickness differences in the reference and production radiographs. These instructions also include minimum hardware requirements for synchronized viewing of the images, instructions on how the brightness and contrast should be set using the step wedges of the reference images, and how to interpret what is seen. In addition, minimum software requirements were defined to cover the required operations to use the digital reference images. Finally, restrictions on the application range of the standard were addressed, i.e. limitations of the material thickness range and system resolution.

## **2. Status of conversion of ASTM reference radiographs to electronic reference images**

The procedure as described above was applied in the following years step by step to more catalogues of reference radiographs. In fig. 2 a list with all 15 sets of reference radiographs provided by ASTM is shown. Fig. 3 gives the status of available electronic reference images in 2016 generated by digitization of the film radiographs shown in tab. 1. Another catalogue derived from E 186 is under preparation and will be hopefully published in 2016. As shown in tab. 2, there are still 6 catalogues of reference radiographs of castings not yet available as well as the 3 catalogues of ASTM with welding flaws in steel and aluminium.







This work will be finalized in the next years, so it can be expected in about 5 years, that all classical ASTM film based reference catalogues will be available as electronic reference images too. But they will have new E xxxx numbers, designated arbitrary.

**Tab 1.** Overview on all film based ASTM Reference Radiographs.

There are 12 catalogues of casting flaws and 3 catalogues on welding flaws (steel and aluminium fusion welds), E 242 on welds is missing here, because not available.

Number	Title
E 155 - 14	Standard Reference Radiographs for Inspection of Aluminum and Magnesium Castings
E 186 - 10	Standard Reference Radiographs for Heavy-Walled (2 to 4-1/2 in. (51 to 114 mm)) Steel Castings
E 192 - 13	Standard Reference Radiographs for Investment Steel Castings for Aerospace Applications
E 272 - 10	Standard Reference Radiographs for High-Strength Copper-Base and Nickel-Copper Alloy Castings
E 280 - 10	Standard Reference Radiographs for Steel Castings, Heavy-Walled (4-1/2 to 12-in. (114 to 305-mm))
E 310 - 10	Standard Reference Radiographs for Tin Bronze Castings
E 390 - 11	Standard Reference Radiographs for Steel Fusion Welds
E 446 - 14	Standard Reference Radiographs for Steel Castings up to 2 in. (51 mm) in Thickness
E 505 - 01	Standard Reference Radiographs for Inspection of Aluminum and Magnesium Die Castings
E 689 - 10	Standard Reference Radiographs for Ductile Iron Castings
E 802 - 95	Standard Reference Radiographs for Gray Iron Castings Up to 4-1/2 in. (114 mm) in Thickness
E 1320-10	Standard Reference Radiographs for Titanium Castings
E 1648 - 95	Standard Reference Radiographs for Examination of Aluminum Fusion Welds

**Tab 2.** Overview on ASTM catalogues of Digital Reference Images. Beginning of 2016 there are 6 catalogues of Digital Reference Images available, in the right column the corresponding standard number of the film reference radiographs is given. All films where digitized at BAM, only E 2868 was digitized elsewhere.

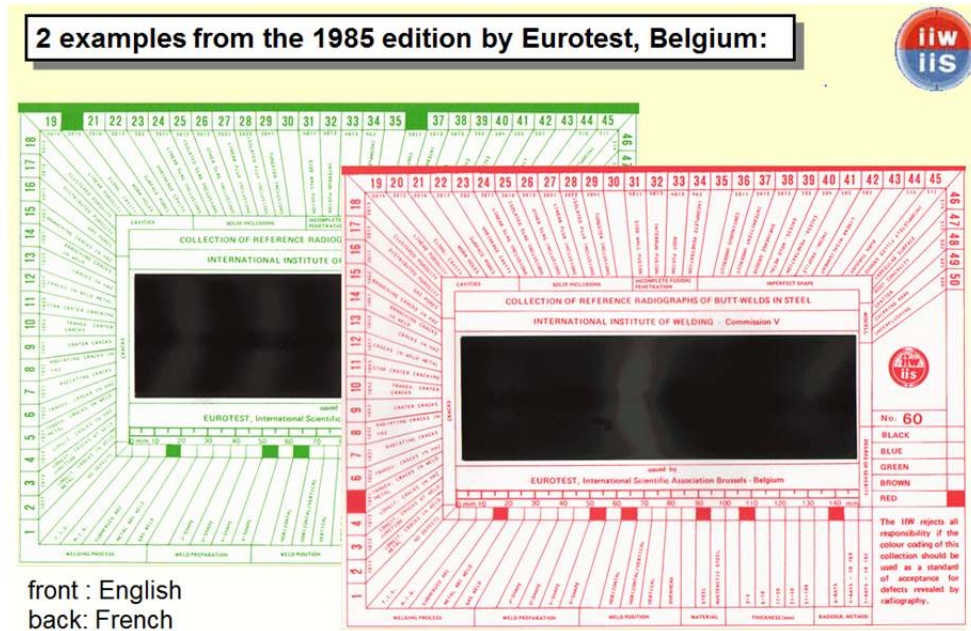
 E2422-05_Digital_Reference_Images_for_Inspection_of_Aluminum_Castings.pdf	E 155 Films
 E2660-10_Digital_Reference_Images_for_Investment_Steel_Castings_for_Aerospace_Applications.pdf	E 192 Films
 E2669-10_Digital_Reference_Images_for_Titanium_Castings.pdf	E1320 Films
 E2868-13_Standard_Digital_Reference_Images_for_Steel_Castings_up_to_2_in(50_8_mm)_in_Thickness.pdf	E 446 Films
 E2869-13_Standard_Digital_Reference_Images_for_Magnesium_Castings.pdf	E 155 Films
 E2973-15_Standard_Digital_Reference_Images_for_Inspection_of_Aluminum_and_Magnesium_Die_Castings.pdf	E 505 Films

### 3. Concept used for IIW reference radiographs on welding flaws

The collection of IIW reference radiographs of arc butt welds in steel has a long tradition. Commission V of the international institute of welding (IIW) compiled the first “blue” collection of 50 radiographs in 1953. More than 6000 catalogues were sold worldwide. The second edition of 1962 contained 86 radiographs in a wall thickness range of 6 to 50 mm steel. The third edition by Ron Halmshaw was released in 1985 based on 85 radiographs. Two examples of this collection are shown in fig. 2. Typical for these collections as shown in fig. 2 are the usage of colours for the severity of the welding flaws:

- Black: homogeneous weld with only a few scattered gas bubbles
- Blue: Very slight deviations from homogeneity (gas bubbles, slag inclusions, undercutting)
- Green: Slight deviations from homogeneity (gas bubbles, slag inclusions, undercutting, incomplete penetration)

- Brown: Marked deviations from homogeneity (gas bubbles, slag inclusions, undercutting, incomplete penetration, lack of fusion)
- Red: Gross deviations from homogeneity (gas bubbles, slag inclusions, undercutting, incomplete penetration, lack of fusion, cracks).



front : English  
back: French

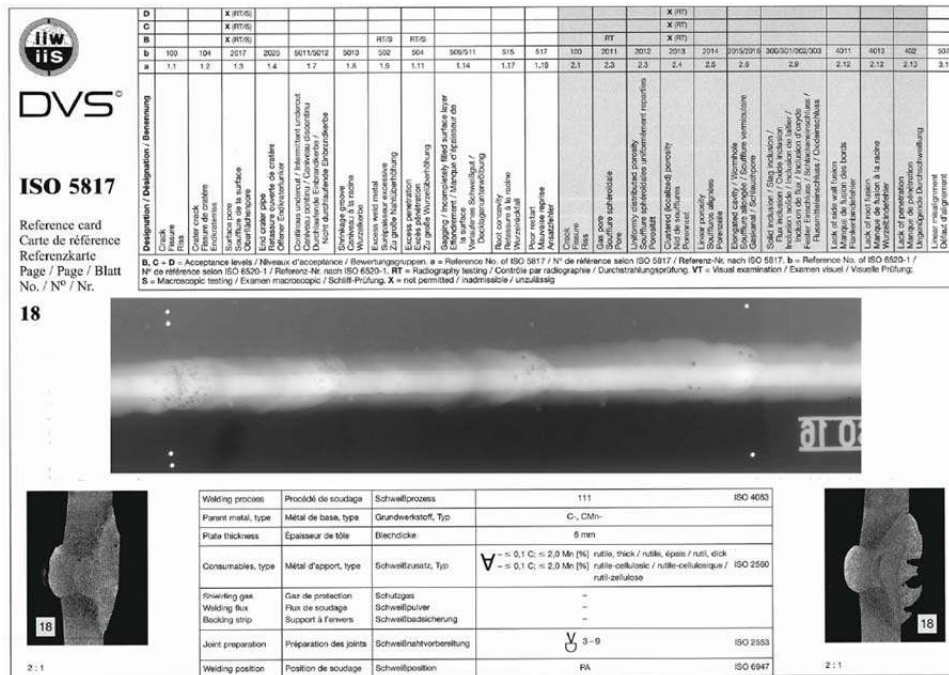
**Fig. 2.** 3rd revision of the IIW collection of reference radiographs of butt welds in steel, containing slight (green) and gross (red) deviations from homogeneity.

In 1995 the 4<sup>th</sup> edition was published in a totally different form using a different and more modern selection of reference radiographs. This 4<sup>th</sup> edition was based first time on the international standard ISO 5817, which replaced in Germany the old DIN 8563. The German collection of 67 reference radiographs according to DIN 8563 was used as the new IIW collection of reference radiographs. For worldwide distribution the production of reference radiographs was changed in 1999 to direct Laser printing at 630 dpi after a thoroughly film digitization of the original radiographs used for publication of this collection in 1998 with 50 µm pixel size.

The basic difference of the old (pre-1995) and the new (after 4<sup>th</sup> edition) IIW catalogue is the replacement of the 5 colours for the severity levels by the 3 grades B, C and D according to ISO 5817. In other words, when accessing welding flaws according to ISO 5817 the old IIW flaw catalogue showing coloured severity levels is NOT appropriate! This change about 20 years ago has been unfortunately very slowly communicated worldwide. Many educational organizations in welding technology on a worldwide scale are still using the “old” IIW catalogue which was replaced 20 years ago completely!

Finally, a 5<sup>th</sup> edition was released in 2005 with 60 reference radiographs to consider the latest revision of the acceptance levels of ISO 5817, due to the requirement using acceptance level B and C for pressurized equipment (PED) in Europe (see fig. 3). Since 2011 the wet Laser printing of the films was replaced by a dry film printing process, because the Mammographic Laser films used were no longer available. Overall, more than 350 catalogues were sold since 1995.

All these IIW catalogues are still film based and therefore, only usefully for film based radiographic inspection. In 2013, ISO 17636-2 was published for digital radiographic inspection of welds using CR with imaging plates or digital detector arrays (DDAs) as film replacement. Consequently, a digital IIW catalogue was requested.



**Fig. 3.** Card #18 out of 60 cards of 5<sup>th</sup> and actual revision of the film based IIW collection of reference radiographs of butt welds in steel from 2005 considering the latest changes in acceptance levels according to ISO 5817.

To consider the change of inspection technology away from classical film to modern digital detectors commission V A (headed by U. Ewert, BAM Berlin) suggested already in 2011 to apply the methodology developed for the ASTM reference catalogues also to the digital IIW catalogue. This was straight forward, because digital film data are already available since 1998 and are used to ensure the stable quality for the reproduction of the film catalogues on dry films “Drystar DT2 Mammo” from AGFA. This approach and also the copyright protection issue (the ASTM electronic reference images on DVD do not have any physical copy protection) started a broad discussion within IIW and also with the DVS Media printing house, which distributes already the IIW reference catalogue on ISO 5817 as film collection.

As final result, it was agreed in 2014 that the IIW electronic reference catalogue will be distributed first (phase I) as tablet app for Android, which was developed and tested meanwhile (see fig.4). The results were presented at the commission V meeting during the IIW annual assembly in Helsinki 2015 [4] and confirmed by the board of directors of IIW during the winter meeting in February 2016 in Paris.

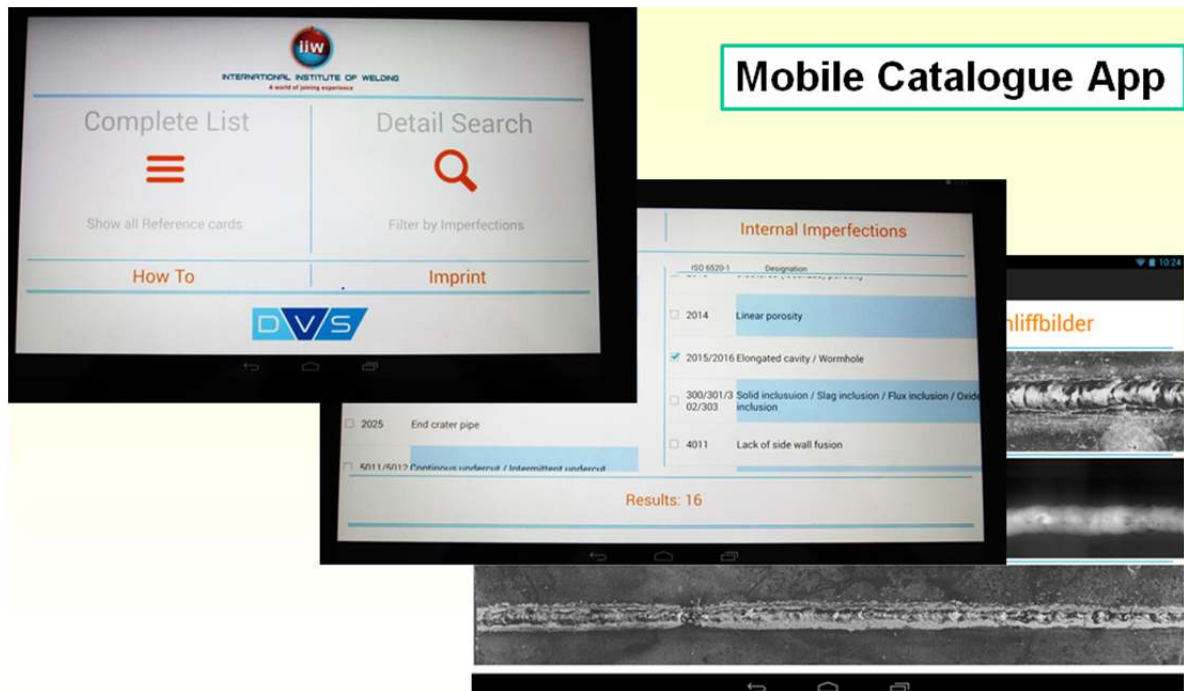
A demo version is available for free download (search for “IIW” at the Google Play Store), which is fully functional, but contains only the radiographic image #1. If the other images should be accessed, the complete version has to be purchased from DVS Media and downloaded from somewhere else, because the size of this app (873 Mbyte including all images) is too large and too expensive for Google Play Store. Also, directly from DVS a tablet is available with the already pre-installed app. Both versions, the film based catalogue and the electronic version are also available together on discount.

The next step for wider distribution is to include this electronic reference catalogue into the training materials of the SLVs in Germany, which carry out the education for European Weld Engineers (EWE). The distribution of the course material (about 2500 pages for each participant) was changed to PDFs on a tablet recently, so it is straightforward to include this catalogue for flaw evaluation too.

Finally, also a PC version for Windows 10 will be developed (phase II), which will allow also the synchronized image viewing like developed for the ASTM castings catalogues. This concept is well proven nowadays for castings with their wider dynamic range, but will be usefully applied for weldments too.

At the moment another development is ongoing establishing the IIW collection of reference radiographs in Aluminium and Aluminium alloys (51 radiographs in the wall thickness range 1 -16 mm) from 1962 as digital catalogue. This collection is no longer available since years and should be reintroduced using the existing tablet concept from the ISO 5817 collection of reference images. The original films have already digitized at BAM, but the re-evaluation of the weld flaws (grouped into 5 severity groups having 5 different colours) is not yet finalized after revision of ISO 10042 in 2005. A group of experts is formed which will evaluate the flaw indications of all 51 radiographs according to ISO 10042. On this on-going work will be informed at the next IIW general assembly in Melbourne 2016. If this new evaluation is accepted, the

worldwide distribution of the electronic collection of IIW reference radiographs according to ISO 10042:2005 by the DVS Media printing house can be started.



**Fig. 4.** Mobile catalogue app for interactive viewing of the radiographic reference images (including high pass image processing) as well as the visual photographs of the weld surfaces by synchronized image viewing on an Android tablet.

#### 4. Concept used for DGZfP guideline D5 on steel castings

A working group of the German NDT society DGZfP (within the technical committee radiation testing) developed in the 1990<sup>th</sup> a collection of reference radiographs showing typical casting flaws of grey iron castings and ductile iron castings [5]. This catalogue had 3 editions, the first in 1992 with additions in 1997 and 1999. For the copying of the last edition of 1999 all original films (64 exposures, exposed by Ir 192, Co 60 and LINAC at 9 MeV, 16 to 360 mm wall thickness) were digitized and Laser film printouts were used for the catalogue distribution. Unfortunately, this catalogue is not available since 10 years. So, a decision was recently made to enable this catalogue for worldwide distribution. In fig. 5 one of the 64 cards with casting flaws is shown. The presentation of these cards will be basically unchanged in the electronic version, as it will be generated as a PDF file containing all cards and the corresponding scans of the cross sections. It was proven, that the contrast of the indications on the reference films is sufficient to be easily recognized using an 8 bit PDF, displayed without any further image processing on an up-to-date monitor in 1:1 magnification in real size..

At the moment the process of generating all PDF pages is on the way. It is expected that the complete PDF is already available at the WCNDT in June 2016.

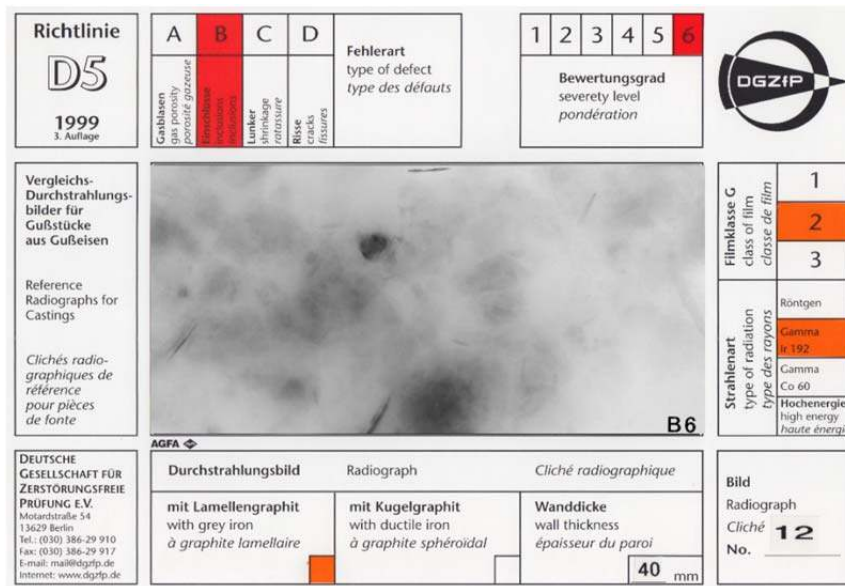


Fig. 5. Card #12 converted into PDF form of the DGZfP guideline D5 for grey iron castings and ductile iron castings.

## 5. Conclusions

Traditional film catalogues with reference radiographs, such as ASTM E 155 for Aluminium and Magnesium castings, should not be used in digital radiography due to different evaluation results by human operators. Therefore, the development of digital reference images was required to support the advantages and economic savings offered by the digital radiography technique. Many details of digital image processing and viewing were considered during development of the digital reference catalogues that will result in better classification results as compared to traditional film reference radiographs. They are successfully implemented by ASTM and other organizations will follow.

This presentation discussed the different approaches as used by the different standardization committees and organisations. All of them are based on the digitization of the available original reference films of the classical catalogues, but the final publication is different: ASTM prefers to sell collections of reference images on DVD for loading by suitable software of the manufacturer of the inspection hardware, IIW sells the electronic catalogues readily installed on a tablet and DGZfP plans to distribute the catalogue as PDF file, leaving the responsibility for adequate image viewing completely at the user.

## References

- [1] Bavendiek, Klaus; Zscherpel, Uwe; "Limits of radiographic testing - New high contrast sensitivity technique - Examples and analysis by system theory", MATERIALPRUEFUNG Volume: 49 Issue: 11-12 Pages: 610-616 Published: NOV 2007
- [2] Ewert, Uwe; Bavendiek, Klaus; Robbins, Jason; Zscherpel, Uwe; Bueno, Cliff; Gordon, Trey; Mishra, Debasish; "New Compensation Principles for Enhanced Image Quality in Industrial Radiology with Digital Detector Arrays", MATERIALS EVALUATION, Volume: 68, Issue: 2, Pages: 163-168 Published: FEB 2010
- [3] RRE2422: Reference Radiograph E2422 Standard Digital Reference Images for Inspection of Aluminum Castings + Active Standard, see <http://www.astm.org/BOOKSTORE/ADJUNCT/RRE2422.htm>
- [4] Ewert, Uwe; Zscherpel, Uwe, BAM Berlin; Horky, Mike; Kennedy, Jim; Hutchinson, Mike; Boeing USA; „A NEW COMPUTER BASED CONCEPT FOR DIGITAL RADIOGRAPHIC REFERENCE IMAGES”, NDT.net, Dez. 2002, Vol. 7 No.12; <http://www.ndt.net/article/ecndt02/268/268.htm>
- [5] DGZfP- Fachausschuss für Durchstrahlungsprüfung "Guideline D5 – Reference radiographs for gray iron castings and ductile iron castings" 3rd edition, January 2000, ISBN 3-931 281-15-3 0.025/2000