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The Classification of Weld Seam Defects for Quantitative Analysis by means of Ultrasonic Testing

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Abstract. The paper describes effective quality assessment of spent nuclear fuel storage cask. The ultrasonic testing method is considered. The classification of possible defects with corresponding dimensions limits is proposed. The database of defects of the spent nuclear fuel storage cask was created in compliance with the nuclear energy industry regulatory documents.

1. Introduction
Nowadays, nuclear energy is widely used all over the world due to the low level of fuel consumption, low price, and high capacity. It is the most promising way to produce energy [1–2].

However, all stages of the nuclear fuel cycle give rise to some nuclear waste that also requires specific storage conditions. There are two types of spent nuclear fuel (SNF) storage: dry and wet storage. Dry SNF storage is a current state-of-the-art technology. Mining and Chemical Enterprise (MCE) is one of the leading Russian companies that deals exclusively with the dry storage of SNF [3].

MCE has developed a special pressure-tight cask for the dry storage of SNF. It is a sealed container made of austenitic steel. In order to provide safety, an effective casks quality assurance method is required. At present, X-ray testing is used for this purpose. However, X-ray is a time consuming and risk bearing procedure due to potential radiation exposure. Nondestructive acoustic techniques can be applied as an effective nonradioactive method of monitoring. For example, ultrasonic method can provide proper evaluation of the degradation process of structural material of the cask and its weld seam [4]. Although ultrasonic testing is the relative method of measurement, it requires calibration block with relevant artificial defects to adjust the equipment [5]. It is important to analyze the structure and identify the parameters of an object of control before developing calibration block. Possible defects of the control object are to be determined. Therefore, the goal of this work was to create the database which contains SNF cask defects classification.

2. Object of control and defects classification
The cask for SNF dry storage was chosen as an object of control. It is the novel technology of nuclear power industry developed by MCE. This cask is intended for the storage of spent nuclear fuel of uranium-graphite channel type reactor RBMK [6].

Table 1 represents basic characteristics of the object of control.

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Table 1. Characteristics of the SNF storage cask.

Structural material	Dimensions [mm]	Types of seal welds	Welding
austenitic steel X10CrNiTi18-10	length – 1000 diameter – 635 thickness- 4	girth longitudinal	automatic argon-arc welding

Reliable quality assessment is achieved during weld seam testing. Welds are chosen as an inspection area due to flow growth which is most probable in this area. The cask consists of three main parts which are hermetically sealed. There are two types of seal welds: girth and longitudinal welds (figure 1).

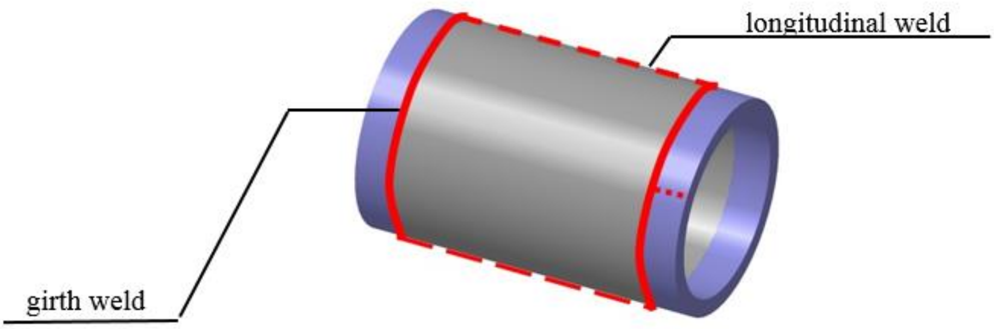


Figure 1. SNF cask`s body.

Quality control is applied to monitor the quality of the casks produced. The main purpose is flaw detection, determination of its size and orientation. There are two kinds of defects in respect to the time of formation: defects that occur during manufacturing process and those that occur during exploitation of the produced item.

Defects generated due to production are caused by breakdowns in the technological process. For welds, this group of defects comprises metal inclusions, blowholes and tungstic splashes. Another group of defects occurs due to the overload conditions (of exploitation nature only) or breakdowns in operating conditions.

This group of defects mostly comprises different types of cracks: fatigue cracks, stress cracks, overload-induced cracks, stress corrosion cracks and corrosion fatigue cracks.

For the considered object of control, there are several types of defects caused by the particular welding type of construction material. The cask is made of austenitic steel, X10CrNiTi18-10. This material has high resistance to embrittlement and corrosion, and good weldability. However, welding of X10CrNiTi18-10 steel may cause grain-boundary corrosion and transform into a defect during cask exploitation [7–8].

Furthermore, aqueous conditions at the surface, presence of aggressive species, heavy loads and changes of temperature cycles also give rise to material degradation processes that lead to penetration of a cask. As a result, there could be different failure modes such as porosity, cracks and others. The detectability is very important to enable the effective quality control for each failure mode and defect [9].

At the same time, all components of the nuclear power industry are made in compliance with the industrial standards. In accordance with these documents, the quality requirements for each type of the item depend on extent of the consequences in case of its failure. Usually, these requirements depend on the purposes of the item and thus specify frequency of inspections. For example, such parts as turbine blades, valve in the cooling system of NPP and SNF storage casks belong to the most critical groups according to the quality scale [10]. It is necessary to provide the effective quality assurance of these components to ensure that parts meet the requirements of specifications.

Quality control of mechanical structure of such components could be realized by means of nondestructive testing [11]. Ultrasound method of control was chosen for the present work. The main goal is to estimate if a component is still reliable in case of some discontinuity flaws.

Due to the technical regulatory documents [12], there could be different types of welding defects. The main parameters to determine the component reliability are quantity characteristics of discontinuity in accordance with the component quality group. Thus, for each component there should be a classification of possible defects that provides information about permissible imperfection size.

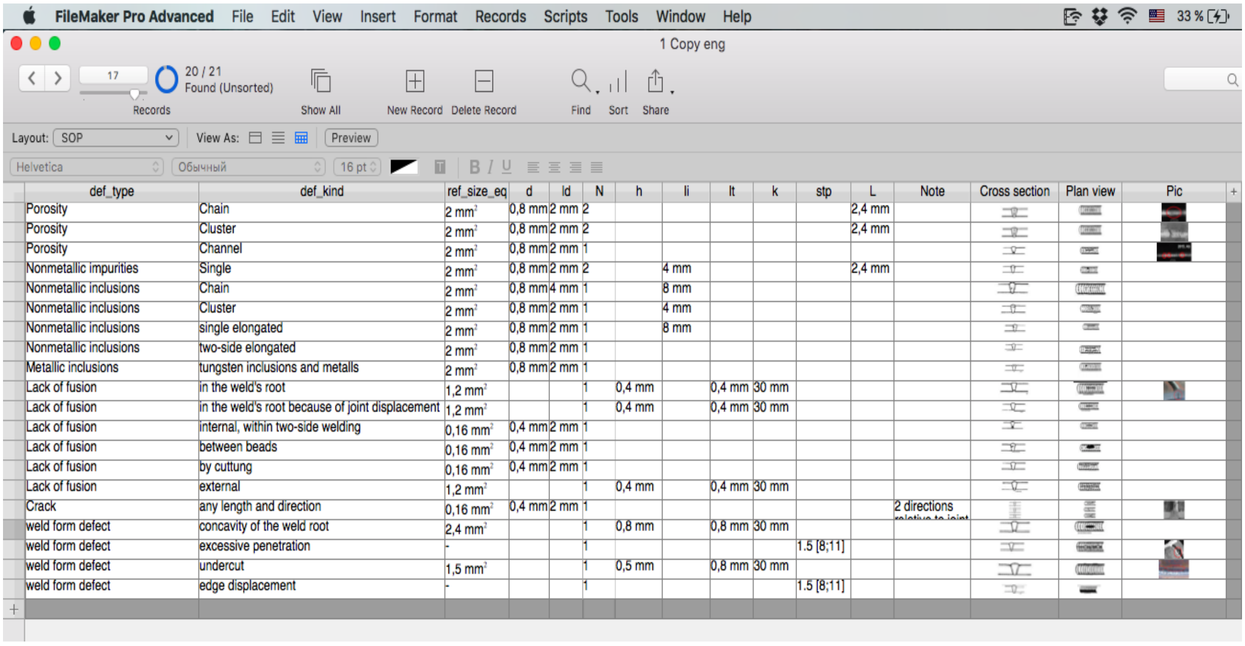
In the present work all typical defects of the SNF storage casks are classified. The classification comprises pores, non-metallic inclusions, lack of fusion, incomplete penetration, variations in weld geometry and others. According to this classification the database of possible defects was developed.

3. The database of the SNF storage cask`s defects

The database was implemented using FileMaker Pro Advanced software. It is represented in the table that comprises all possible variables (figure 2). The operator can add new data to extend the database. This function is necessary if there is a new object of control which means the operator should consider other types of defects.

The table demonstrates all symbols used to identify type, parameters (def_type – type of the defect; def_kind – category of a defect; ref – reference sample), permissible dimensions (*h* – height, *d* – diameter; *I* – length; *L* – distance between two defects), schematic and realistic images of imperfections (figure 2).

The database can be used both for automatic and manual ultrasonic testing. This system comprises complete information about all possible defects and imperfections including their permissible dimensions depending on the required quality level of the weld.



def_type	def_kind	ref_size_eq	d	ld	N	h	li	lt	k	stp	L	Note	Cross section	Plan view	Pic
Porosity	Chain	2 mm²	0,8 mm	2 mm	2						2,4 mm				
Porosity	Cluster	2 mm²	0,8 mm	2 mm	2						2,4 mm				
Porosity	Channel	2 mm²	0,8 mm	2 mm	1										
Nonmetallic impurities	Single	2 mm²	0,8 mm	2 mm	2		4 mm				2,4 mm				
Nonmetallic inclusions	Chain	2 mm²	0,8 mm	4 mm	1		8 mm								
Nonmetallic inclusions	Cluster	2 mm²	0,8 mm	2 mm	1		4 mm								
Nonmetallic inclusions	single elongated	2 mm²	0,8 mm	2 mm	1		8 mm								
Nonmetallic inclusions	two-side elongated	2 mm²	0,8 mm	2 mm	1										
Metallic inclusions	tungsten inclusions and metalls	2 mm²	0,8 mm	2 mm	1										
Lack of fusion	in the weld's root	1,2 mm²			1	0,4 mm		0,4 mm	30 mm						
Lack of fusion	in the weld's root because of joint displacement	1,2 mm²			1	0,4 mm		0,4 mm	30 mm						
Lack of fusion	internal, within two-side welding	0,16 mm²	0,4 mm	2 mm	1										
Lack of fusion	between beads	0,16 mm²	0,4 mm	2 mm	1										
Lack of fusion	by cuttung	0,16 mm²	0,4 mm	2 mm	1										
Lack of fusion	external	1,2 mm²			1	0,4 mm		0,4 mm	30 mm						
Crack	any length and direction	0,16 mm²	0,4 mm	2 mm	1							2 directions			
weld form defect	concavity of the weld root	2,4 mm²			1	0,8 mm		0,8 mm	30 mm						
weld form defect	excessive penetration	-			1					1.5 [8;11]					
weld form defect	undercut	1,5 mm²			1	0,5 mm		0,8 mm	30 mm						
weld form defect	edge displacement	-			1					1.5 [8;11]					

Figure 2. Table of variables.

All the values used in the table were chosen in accordance with the regulatory government standards. The permissible dimensions depend on the type of defect chosen by the operator (figure 3).

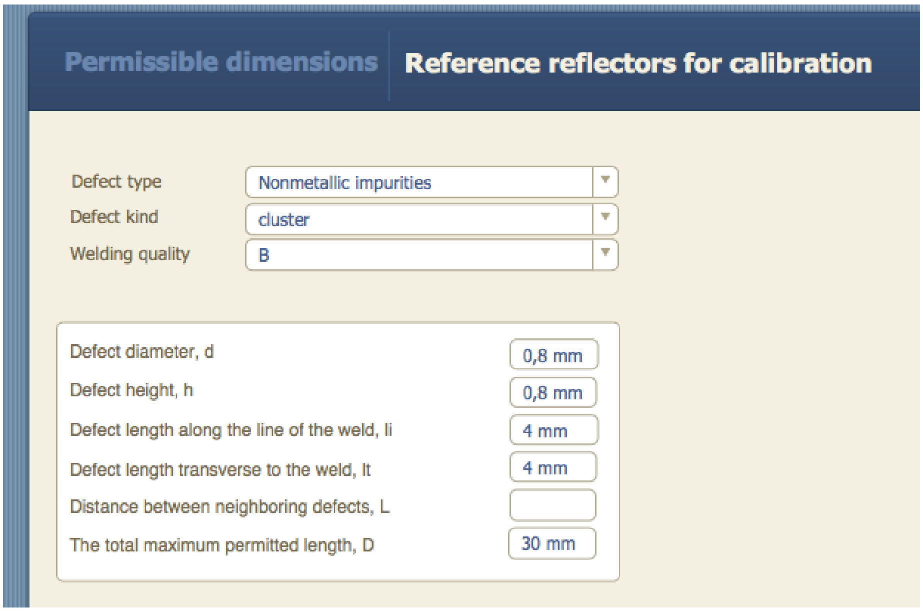


Figure 3. Operator`s report window.

There is a particular reference reflector for each type or category of defects. The dimensions of these reflectors should correspond to the parameters specified in the regulatory documents. Thus, using the created database the operator can estimate whether the detected imperfection is permissible for a given level of weld quality. Moreover, the operator can select appropriate reference reflector for the SNF storage cask. Reference reflectors are used for calibration and setting the ultrasonic testing system. The operator should use the type and category of a defect in order to get necessary information about reference reflectors for designing of a calibration block (Fig. 4). The developed database makes this process highly effective. Moreover, it provides images that demonstrate location of each particular type or category of defects.

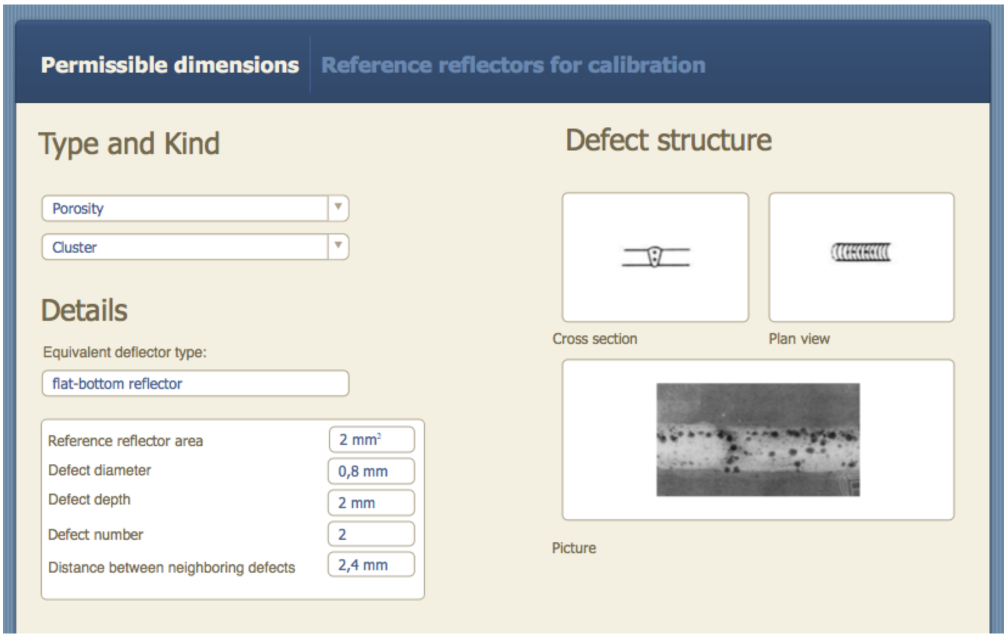


Figure 4. Characterization of calibration block.

4. Conclusion

The developed database provides all necessary information about defects that occur in the SNF storage cask. It includes information about defect type, its category and permissible dimensions in compliance with the technical regulatory documents.

In order to provide an effective quantitative analysis, a calibration block should be designed. It should contain reference reflectors inside. These reflectors are to relate to the real defects of the SNF storage cask. The defect database allows selecting appropriate parameters of reference reflectors for each level of weld quality.

Due to implementation of quantity estimation ability, the results of the present work provide the same level of measurement accuracy of ultrasonic testing as the level of X-Ray testing. Furthermore, ultrasonic testing is much safer and less time-consuming method of control. These facts emphasize the advantages of ultrasonic testing and within advanced techniques of ultrasonic industrial tomography enable to significantly increase the capacity of SNF cask manufacturing.

Within ongoing research in this project, it is planned to extend the developed database. The images of control of real SNF cask with indications corresponding to particular defects will ensure higher reliability of ultrasonic testing. It will provide simpler and more accurate identification of detected flaws.

Acknowledgements

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