OULUN AMMATTIKORKEAKOULU

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FULFILMENT OF FINNISH SAFETY REGULATIONS IN DESIGN, EXECUTION AND CONDITION MONITORING OF WELDED JOINTS IN NUCLEAR PRESSURE EQUIPMENT OF VVER-1200 REACTOR

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ABSTRACT

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In all phases of the Hanhikivi Nuclear Power Plant project, Finnish nuclear safety requirements shall be complied with. Finnish nuclear legislation and regulations set an acceptable safety level, largely based on western nuclear codes, conventional standards, and practices. For VVER-type reactor plants, including VVER-1200, Russian nuclear codes and standards have traditionally been applied both in Russia and abroad.

Application of standards and procedures other than those defined by the Finnish nuclear regulations is possible provided it can be convincingly demonstrated that it provides an equivalent level of safety. To justify the use of Russian regulations in the Hanhikivi Nuclear Power Plant project, these shall be assessed against the requirements set by the Finnish regulatory body in YVL-Guides.

The aim of this thesis has been to compare and assess the requirements applicable to the welded joints of nuclear pressure equipment, and lay the basis for further discussions on what might be the practical impact of the deviations identified, while refraining from bias the topic is highly susceptible to.

The thesis gives an overview of the regulatory framework and defines the applicable codes and standards, which may be used as a reference guide for a better understanding of requirements applied in the nuclear sector related to the integrity of welded joints.

Similarities and differences between Russian and Western codes and standards are discussed. Where feasible, comparison tables have been compiled and attached as appendices to the thesis. Also, risks caused by different approaches and practices, but also seemingly trivial issues, such as inconsistent technical terminology, have been highlighted.

It has been found that while regarding certain topics handled in this thesis, making conclusions on the fulfilment of Finnish regulations is straight forward, others are subject to dispute and deserve further discussion.

Keywords: VVER-1200, Nuclear Codes and Standards, Welding, Qualification, Quality, Testing

TABLE OF CONTENT

LIST OF ABBREVIATIONS

ASME BPVC	A nuclear code developed by American Society of Mechanical Engineers (Boiler and Pressure Vessel Code)
BW	Butt Weld
DAC	Distance Amplitude Correction Curve (referring to indication evaluation method)
DGS	Distance Gain Size (referring to indication evaluation method)
DSR	Disc Shape Reflector
DT	Destructive Testing
ERS	Equivalent Reflector Size
EPR	Pressurized water reactor developed by AREVA (formerly Framatome and Siemens)
FH1	Hanhikivi Nuclear Power Plant Unit 1
FW	Fillet Weld
GOST	Regional standards applied mainly in Commonwealth of Independent States
GOST R	Russian national standards
IAEA	International Atomic Energy Agency
IIW	International Institute of Welding
IQI	Image Quality Indicator
ISI	In-Service Inspections
ISO	International Standardization Organization (in this thesis referring to the international standards)
ITP	Inspection and Test Plan
L-scan	Scan for longitudinal indications using angle beam probes
MT	Magnetic Particle Testing
NB	Notified Body
NDT	Non-destructive Testing
NP	Series of Russian nuclear regulations (referred to as NP nuclear code in this thesis)
NPP	Nuclear Power Plant

PED	Pressure Equipment Directive 2014/68/EU
PNAE G	Series of Russian nuclear regulations (referred to as PNAE G nuclear code in this thesis)
PT	Penetrant Testing
QA	Quality Assurance
QC	Quality Control
RCC-M	A French nuclear code developed by French association for design, construction and in-service inspection rules for nuclear island components.
ROSTECHNADZOR	Federal Environmental, Industrial and Nuclear Supervision Service of Russia (*Федеральная Служба по Экологическому, Технологическому и Атомному Надзору*)
RPV	Reactor Pressure Vessel
RT	Radiographic Testing
RTPO	Recognized Third Party Organization
SC	Safety Class (in this thesis referring to safety classification according to Guide YVL B.2)
SDH	Side Drilled Hole
SSC	Systems, structures and components
STUK	Finnish Radiation and Nuclear Safety Authority (*Säteilyturvakeskus*)
T-scan	Scan for transverse indications using angle beam probes
UT	Ultrasonic Testing
VT	Visual Testing
VVER	Pressurized water reactor designed by OKB Gidropress (*Водо-Водяной Энергетический Реактор)*
WPQR	Welding Procedure Qualification Report
WPS	Welding Procedure Specification
YVL	Finnish Regulatory Guides on nuclear safety and security

1 INTRODUCTION

Hanhikivi nuclear power plant (FH1), planned to be built in northern Finland, will be the country's third NPP and sixth reactor unit in total. It will house a VVER-1200 type reactor (design designation AES-2006) developed and mainly manufactured in Russia. The existing safety requirements set by the Finnish nuclear authority (STUK), mainly based on western codes, standards, and practices, shall be followed in the FH1 project. The Finnish nuclear safety regulations are widely considered stringent, but they are, in nature, comparatively goals-based. Therefore, the fulfilment of these is assessed by the regulator based on reasoning and justification.

Nuclear industry for civil purposes in Russia has its roots in the 1950s making up several decades of experience and well-settled practices. The industry being strongly regulated and Russia understandably taking great pride in their engineering and manufacturing capabilities, changes to the existing design or any execution practices are not taken lightly. Drastic changes to established practices, if not thoroughly considered, carry a risk that safety is compromised despite noble intentions.

In order to assess the fulfilment of Finnish safety requirements and the necessity for improvements to existing practices, a systematic comparative analysis shall be carried out to determine the discrepancies between requirements of Russian and Finnish nuclear regulations and their safety significance.

1.1 Purpose and objective

The purpose of this thesis is to assess the fulfilment of welding-related requirements set by the Finnish regulator in the FH1 project. The objectives are to specify applicable regulations and practices in Russia and in Finland, provide a comparison between the essential parameters affecting the quality and structural integrity of welded joints and to identify potential risks and challenges. The aim is not, nor would it be feasible, to conduct a comprehensive quantitative comparison, but to provide a perspective on the Russian regulatory requirements in relation to those applicable in Finland. Requirements other than those set by regulatory documents, such as contractual requirements, are not handled in the thesis.

1.2 Scope

This thesis is focusing on the design, execution, testing, and ageing management of nuclear pressure equipment, that is, mostly primary circuit pressure vessels and piping which are considered significant in terms of nuclear safety. Such components include, but are not limited to, the main components of the reactor plant as shown in Figure 1.

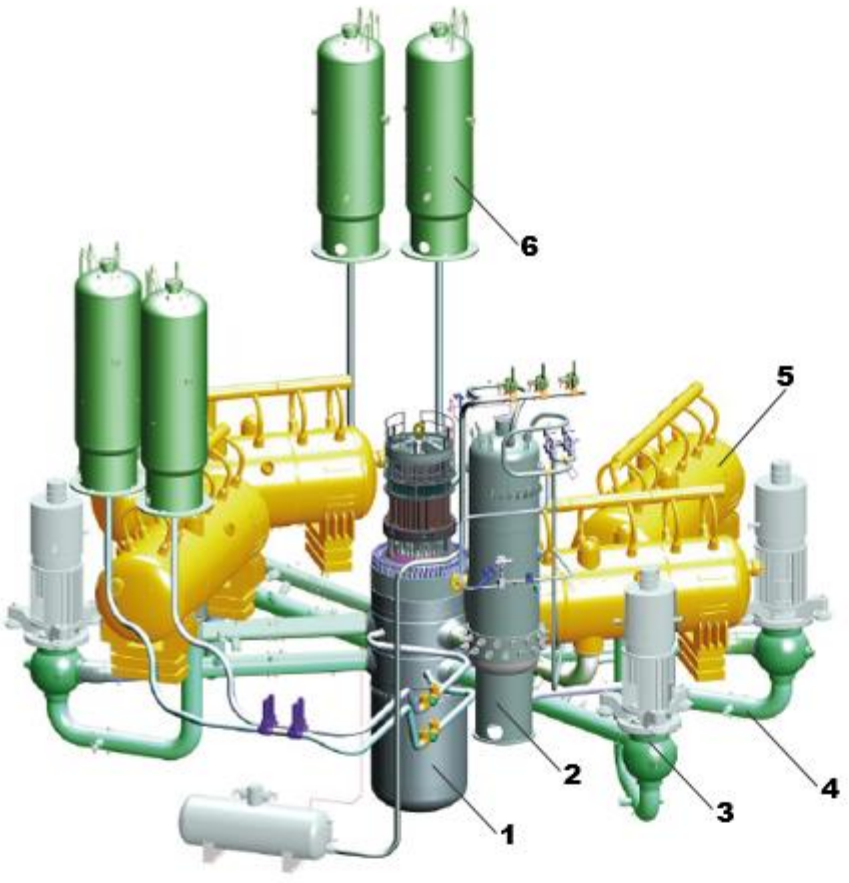

FIGURE 1. VVER primary circuit main components: reactor pressure vessel (1), pressurizer (2), reactor coolant pumps (3), main coolant pipeline (4), steam generators (5). Also showing emergency core cooling tanks (6). (Adapted from AEM-technology JSC. Equipment for nuclear power industry. p. 6)

2 NUCLEAR REGULATORY FRAMEWORK

2.1 General background

While nuclear safety regulations differ in different parts of the world, all of the world's countries applying or aiming to apply nuclear energy are to a larger or lesser extent committed to the mutual fundamental safety principles through membership of the International Atomic Energy Agency (IAEA). IAEA's set of Safety Standards, consisting of a collection of Safety Requirements and Safety Guides are not legally binding to the member states but do serve as a common general reference for development of national regulations (IAEA GSR-1 2016, pp. 13-16).

Within the EU, a nuclear regulation directive has been in force since 2009, setting the foundation for all EU members using nuclear energy, including Finland, for maintaining and promoting nuclear safety. Council Directive 2009/71/EURATOM and its post-Fukushima addendum 2014/87/EURATOM state, amongst other general safety requirements, that:

> *Member States shall establish and maintain a national legislative, regulatory and organisational framework (hereinafter referred to as the 'national framework') for nuclear safety of nuclear installations that allocates responsibilities and provides for coordination between relevant state bodies- -.*
> *- -*
> *Member States shall ensure that the prime responsibility for nuclear safety of a nuclear installation rests with the licence holder. This responsibility cannot be delegated. (2009/71/EURATOM Chapter 2, Article 4, para. 1; Chapter 2, Article 6, para. 1).*

In short, each EU member state is responsible for adopting its own national nuclear safety requirements taking into account the safety principles of the IAEA and Western European Nuclear Regulators Association (WENRA) and ensuring these are fulfilled by the responsible party - the licensee.

Significant differences exist between Finnish and Russian regulations and how they are established conceptually, but both follow the similar principle hierarchy (Figure 2).

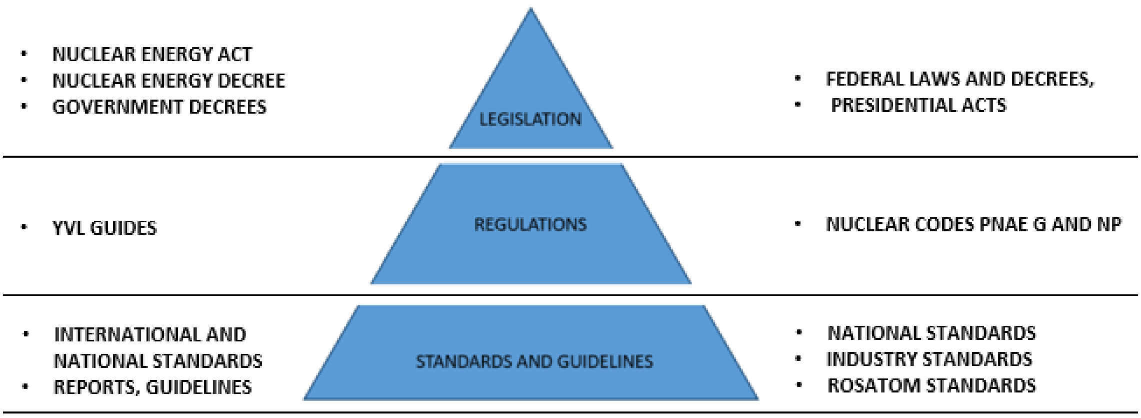

FIGURE 2. Nuclear Regulatory Pyramid as implemented in Finland (left) and Russia (right).

2.2 Applicable codes and standards in Russian Federation

The legal basis and principles of nuclear energy in the Russian Federation are set in federal law no. 170-FZ "Federal Law on the Use of Atomic Energy"[1] and in Russian Federation Decree no. 401 "About the Federal Environmental, Industrial and Nuclear Supervision Service", which specifies the tasks and responsibilities of the Russian nuclear regulatory body Rostechnadzor. Among these are the development and approval of codes and regulations.

In design and manufacturing of VVER-1200 reactor plant components, PNAE G nuclear code[2] has been followed together with a variety national standards GOST and GOST R, standards of Russian nuclear corporation Rosatom and industry documentation (OST, TU, TI, RTD, RD EO) developed by organizations licensed by the regulatory body.

PNAE G nuclear code was developed in USSR in the 1980s and, apart from minor updates, remained unchanged until inevitable necessity led to a wide restructuration and updating of nuclear code and standards in Russia.

1 Article 6 of 170-FZ includes an indirect reference to IAEA: „- - The above mentioned codes and standards shall take into account recommendations given by the international organisations in the field of the use of atomic energy, whereto the Russian Federation is a part. - - „

2 Due to inconsistencies in translations, other terms such as "rules" and "norms" are often used. For the sake of clarity, the term "code" is used in this thesis.

The aim of the still ongoing project has been to revise and, when necessary, to update the requirements, but, equally importantly, simplify and, by that, clarify the document hierarchy and improve readability. PNAE G has, in most parts, been replaced by the NP code, whereas more technical requirements are increasingly concentrated into state standards GOST R instead of numerous levels of documentation mentioned in the previous subchapter.

However, in case of FH1 project, for which the contract has been signed and a significant amount of upper-level project documentation has been developed before the replacement of PNAE G code by NP (and thus based on and referring to PNAE G), recent changes in Russian regulations cause a complex question of whether the new code and standards shall be followed in the project or not. As it is not conclusively solved by Russian nuclear regulator Rostechnadzor and corporation Rosatom, it is a subject for discussion and mutual agreement between the licensee and supplier (Decision no. 1-8/9 pr 11.3.2019).

In this thesis, the currently valid code (i.e. mostly NP)[3] is taken as the basis for Russian regulation. Comparison against relevant parts of PNAE G and applicable standards it refers to has also been carried out but only briefly addressed. The same applies to NDT standards. As for DT, the standards are currently not affected by the standardization project.

2.3 Applicable regulatory safety guides and standards in Finland

The founding principles of the use of nuclear energy in Finland are set by the Nuclear Energy Act 990/1987. It sets the general safety level and authorizes The Radiation and Nuclear Safety Authority (STUK) to specify the detailed safety requirements and to follow their fulfilment by the licensee:

> *The Radiation and Nuclear Safety Authority shall specify detailed safety requirements concerning the implementation of safety level in accordance with this Act. - - (Nuclear Energy Act 990/1987 7 r §)*

The safety requirements of the Radiation and Nuclear Safety Authority are binding on the license holder, but reserve the license holder a right to propose an alternative procedure or solution to that provided in the regulations:

[3] There are parts of PNAE G, which are still valid in Russia, even though the majority have been replaced by NP.

If the license holder can convincingly demonstrate that the proposed procedure or solution will implement safety standards in accordance with this Act, the Radiation and Nuclear Safety Authority may approve the procedure or solution (Nuclear Energy Act 990/1987 7 r §).

The goals-based nature of Finnish nuclear safety requirements is, thus, defined at the legislative level. This fact provides a good background as to why the collection of regulatory documents setting the detailed safety requirements, referred to in the Nuclear Energy Act, is called “Regulatory Guides on nuclear safety” (YVL Guides). Being guides does not render the requirements optional but rather refers to the concept of guiding the licensee on fulfilling the nuclear safety level set in legislation while allowing the licensee to propose its own solutions through reasoning and justification – a convincing demonstration.

Such philosophy may be difficult to grasp by suppliers used to rules-based requirements provided by nuclear codes. A thorough understanding of requirements set in YVL Guides is crucial for justifying alternatives. Suppliers with long experience in the industry may be tempted to take the justification lightly and lean solely on the experience aspect as justification. Not in all cases can experience be considered a convincing demonstration.

Applicable welding and testing related requirements are mainly concentrated into the following YVL Guides:

- YVL E.3 - Pressure Vessels and Piping of a Nuclear Facility
- YVL E.5 - In-Service Inspection of Nuclear Facility Pressure Equipment with Non-Destructive Testing Methods
- YVL E.12 - Testing Organisations for Mechanical Components and Structures of a Nuclear Facility

There are differences between requirements applicable to nuclear and to non-nuclear (conventional) pressure vessels. Knowing the key differences helps for a better understanding of Finnish nuclear regulations.

As Directive 2014/68/EU (Pressure Equipment Directive, PED) does not apply to nuclear pressure equipment, supervision over fulfilment of safety requirements is performed by STUK instead of Finnish Safety and Chemicals Agency (Tukes) (Directive 2014/68/EU Chapter 1, Article 1, para. 2(h); Decree On Pressure Equipment 1548/2016 2 § para. 8).

As discussed previously, the requirements are given in YVL Guides, which, contrary to PED, does not assume the use of European harmonized standards nor is it assumed that by following the harmonized standards, safety requirements are met. Regardless of that, familiar principles and requirements can be recognized in the YVL requirements. Such examples are the approved design standards for safety classes 2 & 3 (see chapter 3), basic requirements to materials (though with additional requirements but also with options to justify the use of other than standardized materials), general base requirements to welding quality management, qualification & certification of procedures and welding and testing personnel (see chapter 5).

More distinct to nuclear safety requirements is the level of supervision – both the scope of inspections and the number of involved parties (see chapter 6). Although the requirements to third party inspection organizations are similar to Notified Body in PED, the role of the third party is not to assess the fulfilment of PED safety requirements but to supervise special processes and testing according to construction plans developed according to YVL E.3 requirements.

Requirements completely foreign to conventional pressure equipment can be found in YVL E.5 and regulate in-service inspections of pressure equipment (see chapter 7).

3 WELDED JOINT DESIGN PRINCIPLES

3.1 Design codes and general requirements

The standards for dimensioning of pressure vessels and piping are given in YVL E.3 requirements 632 and 651 as follows:

- ASME Code Section III (pressure vessels and piping of SC1)
- SFS-EN 13445-3 (pressure vessels SC2 & SC3)
- SFS EN 13480-3 (piping SC2 & SC3)

These standards form the basic requirement level. As described earlier, alternatively, other standards may be followed if justified that the same level of safety is achieved.

Nuclear pressure equipment of the VVER-1200 reactor plant has been designed in accordance with PNAE G-7-002-86. A comparison between PNAE G-7-002-86 and ASME Code Section III for strength calculations of main equipment has been provided by the designer and reviewed by STUK. The justification is based on a series of comparative calculations using both PNAE G and ASME codes. It is concluded that the differences found are not significant in terms of the structural integrity of the pressure equipment. Similar conclusions were drawn in the ASME in their Code Comparison Report STP-NU-051-1.

As an example of specifically welding-related differences, it can be pointed out that in PNAE G, coefficients are applied for the decrease of static and cyclic strength for the welded joints (PNAE G-7-002 1987, para. 4.3.3; Tables 5.8, 5.9). Such factors are not included in ASME (STP-NU-051-1 2012, p. 147).

ASME, by default, presumes the tensile strength of weld metal at least equal to that of base material while under-matching welding filler materials are commonly used in joining of VVER-1200 pressure equipment[4] (ASME BPVC III 2015, i. NB-2431.1; GOST R 58721-2019 2020, Table B.1).

[4] Example: Reactor pressure vessel base material 15Cr2NiMoVA-A: $R_{p0.2}$>490MPa @ 20°C / 440MPa @ 350°C
SAW welding wire Sv-08A, Sv-08AA for joining of RPV material: $R_{p0.2}$>353MPa @ 20°C / 314MPa @ 350°C

Differences between joint design requirements (weld type, joint preparation, geometry, tolerances, etc.) given in PNAE G-7-002 versus those given in ASME BPVC Section III, SFS EN 13445-3 and SFS EN 13480-3 certainly exist but are not analyzed in detail as the objective is not to fulfill each requirement of each code or standard but to achieve a satisfactory safety level. Combining design requirements from different standards is not desirable and, considering the entity, may be counter effective. As a general principle, the standards used for design, manufacturing, and testing should be of the same standard family (YVL E.3 2019, req. 304).

3.2 Classification of welded joints

Requirements related to welded joints, especially those governing QA/QC (inspection and testing scope, acceptance criteria, etc.) vary depending on the risk-significance of the component, part, or weld. In order to correctly allocate the requirements, it is important to understand how such classification is done in applicable codes and standards (see appendix 1).

As can be seen from Appendix 1, the approaches and terminology differ. Certain confusion can be caused by the fact that terms such as *category, class, group* are used in different codes and standards with different meanings. In order to compare the requirements, one shall acknowledge the approach and logic behind each classification system.

3.3 Irradiation embrittlement

The problem of degradation of mechanical properties, most notably fracture toughness, due to irradiation embrittlement is inherent to steels subject to strong neutron fluence, such as RPV wall. The phenomena cause a shift of transition temperature which could limit the operational lifetime of NPP or in worst cases could endanger the structural integrity of RPV. (NP-T-3.11 2009, p. 3; p. 22). First-hand experience with the phenomena in Finland dates back to 1980 when testing of the first set of surveillance specimens extracted from Loviisa NPP Unit 1 RPV showed the radiation embrittlement advancing more than twice the pace it was expected (ATS ydintekniikka 2/2011, p. 13). That finally led to reannealing the RPV in 1996.

With limited means available to mitigate the effect of irradiation embrittlement during NPP operation, practices are in place to influence the effects of the phenomena by material selection and quality[5], application of predictive models, and surveillance of material properties during operation by periodically extracting and testing material samples from the reactor core area.

Several methods for assessing the fracture toughness of RPV materials have been developed with significant differences between these concerning the reference transition temperature parameter (NP-T-3.11 2009, pp. 104-107). YVL E.4 requires the application of the Master Curve method described in ASTM E1921[6] (YVL E.4 2020, req. 604, 605; Explanatory memorandum 121/0002/2016 2020, pp. 4-5).

An essential parameter to the Master Curve method is the reference temperature T_o (ASTM E1921 – 17 2017, Chapter 5). Russian methodology, based on PNAE G 7-002-89, uses critical brittleness temperature T_k (or T_{k0} in the initial state) based on the Charpy V-notch transition temperature shift. T_0 and T_k differ principally in their concepts and methods of determination and thus cannot be directly compared. (ETSON/2018-001 2018, pp. 6-8; Technical Reports Series no. 249 2005, p. 3).

In order to demonstrate the suitability of base and welding materials or RPV for the intended 60-year service life, STUK has required an additional study on the embrittlement behavior of the VVER-1200 RPV materials based on testing material samples subjected to accelerated ageing (STUK quarterly reports September - December 2017 and September - December 2019). Accelerated ageing is performed by irradiating the samples in controlled conditions, such as in a research reactor. Implementing such an irradiation program is a demanding task which also reflects in the costs but will give valuable up-to-date data on the expected service life of RPV of VVER-1200.

3.4 Operational experience

With three VVER-1200 reactor units operational as of mid-2020[7], there is not sufficient operational data available to draw decisive conclusions about the track record of this specific reactor type. However, there is significant operational experience derived from 31 units of VVER-1000 in operation with over 500 reactor-years in total (The VVER today, p. 10). One vulnerability concerning

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[5] Impurities such as copper and phosphorus have significant effects on irradiation embrittlement (NP-T-3.11. 2009. p. 58-60)

[6] The effects and prediction of irradiation embrittlement have been widely researched by VTT. The master curve method, published as ASTM E1921, has originally been developed by VTT.

[7] Unit 1 of Leningrad NPP II was connected to the grid in 2018. Units 1 and 2 of Novovoronezh NPP II were connected to the grid in 2017 and 2018 respectively.

the structural integrity of welded joints has been widely discussed within the VVER community over decades. That is the degradation of steam generators' primary collector (mainly hot loop, but cracks have also been detected in the cold loop) to steam generator nozzle weld or weld number 111 as it has been designated.

Technical issues with NPP's are rarely discussed as publicly as the formation of cracks, some of which have resulted in leaks from the steam generator secondary circuit before detection, in weld 111 of VVER-1000 steam generators of several NPP units since 1998.

The issue has been regarded as one of the limiting factors for increasing the lifetimes of VVER NPP:

> *- - One of such components is the weld assembly between the hot header and the steam generator shell (WJ 111), in which formation and high-rate development of in-service defects is possible; the defects being systemic and affecting the operating safety of the entire power unit. - - The probability of intolerable defects in the WJ 111 area remains high, so measures are required to control their formation time and development process.- - (Netyaga – Saakyan – Povarov. 2017, p.1).*

There are several relevant publications available that cover the failure statistics, repair, possible causes and mitigation by the improvement of inspection systems for ISI (Adadurov – Velikodny – Podlatov – Antonov – Karyakin – Arzhaev – Makhanev 2019; Dub – Durynin – Razygraev – Razygraev – Harina – Lobanov – Mahnenko – Mahnenko – Saprykina – 2014; Povarov 2016).

No information is however publicly available if and how the issue has been solved for VVER-1200 for which the steam generator design does not significantly differ from VVER-1000.

3.5 Design for inspectability

It is an intuitive and general engineering principle that however low the failure probability is anticipated to be, if the consequences of such failure would potentially be severe (such as in case of NPP core damage or release of radioactivity), the risk cannot be disregarded. One of the mechanisms for managing such risks is performing in-service inspections (ISI) using non-destructive testing (NDT) periodically during the operational lifetime of components critical to safety (ISI is further discussed in chapter 8 of this thesis).

For NDT to be possible to be performed in an efficient, repeatable, and safe manner, inspectability shall be taken into account already in the design solutions. This means designing the components such that the material and geometry allow for reliable NDT during operation[8] and that the surrounding structures and clearances do not restrict access for performing the inspections on critical areas (e.g welds of primary circuit piping and components). This design philosophy is generally referred to as "design for inspectability" and in Finnish nuclear regulations concluded in YVL A.8:

> *- - It shall be possible to verify SSC's integrity. Provisions shall be made (in terms of geometry, selection of material and accessibility) for non-destructive material testing by means of which the SSC integrity can be periodically assured - - (YVL A.8 2019, req. 402)*

Recently, in 2019, STUK has pointed out inspectability and maintainability as challenges in the "Finnish report on nuclear safety"[9]:

> *- - Furthermore, ageing management for long construction periods, and realising the importance of ageing management aspects in design (e.g. inspectability and maintainability) in the new build projects were identified as challenges. (STUK-B 237 2019, p.75)*

Concerning VVER-type reactor equipment specifically, inspectability has been pointed out by IAEA as a potential safety issue as early as 1996 in a publication "*Safety issues and their ranking for WWER-1000 model 320 nuclear power plants*[10]":

> *- - There is also restricted accessibility of some vessel welds, vessel head, vessel head penetrations, piping welds, steam generator shell welds, and specific piping nozzles.- - (IAEA-EBP-WWER-05 1996, p. 49)*

Since then, significant development has been seen in the field of NDT techniques and inspection mechanization which has remarkably remedied the issue. However, as far as the design of critical components in the inspectability point of view is concerned, VVER-1200 is not an improvement to predecessors.

Figure 3 illustrates the geometry of RPV of VVER-1200 and locations of its circumferential welds, and in comparison, RPV of EPR (such as installed in Olkiluoto 3 NPP) as an example of a newer

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[8] Certainly, inspectability is critical also in the manufacturing phase, but inspectability during operation tends to be more complicated due to access limitations.
[9] Finnish report on nuclear safety is a periodical report published by STUK under the Convention on Nuclear Safety.
[10] Note: The abbreviation "WWER" as sometimes used in western literature is synonymous to VVER. VVER-1000 is the predecessor to VVER-1200.

design for which inspectability has been addressed in the design. The comparatively complex geometry of the nozzle area of VVER RPV affects the inspectability of circumferential weld no. 4 (weld between nozzle shells)[11] and weld no. 5 (weld between upper nozzle shell and flange) (figure 4).

Being a product of a long evolution process from VVER-440's, designed when inspectability was not omitted such importance as nowadays, some principle design features affecting the inspectability have not been and cannot be radically changed as it would affect reactor physics or would just not be economically feasible. This poses challenges to the designer of inspection systems for ISI.

[11] Note: the same weld is designated weld no. 5 in the first VVER-1200 designs, such as at LAES-2 NPP, because they pose an extra weld in the core area as compared to design intended for FH1.

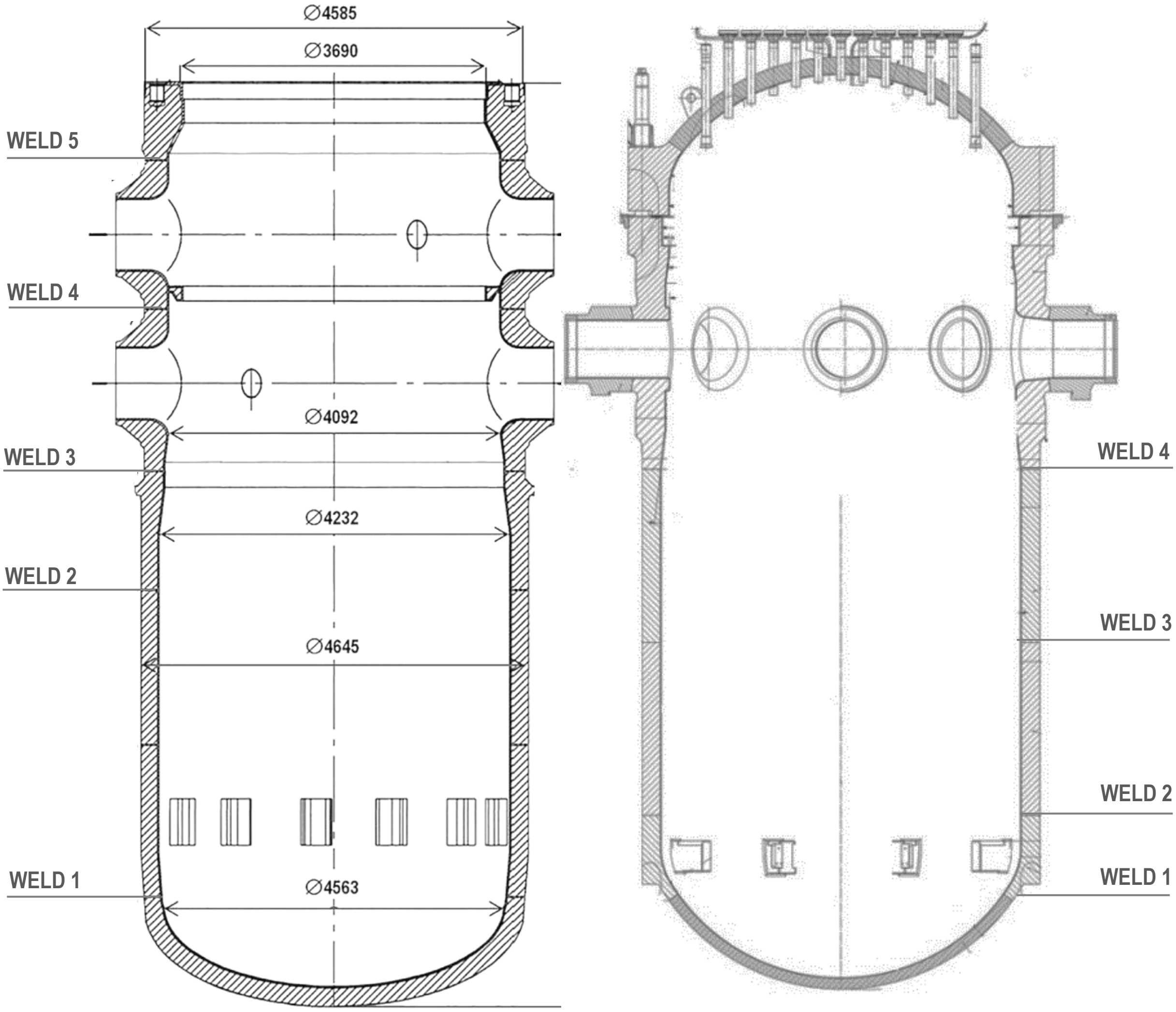

FIGURE 3. RPV of VVER-1200 (left) and EPR (right). Adapted from (Fig. 1. Arrangement of the VVER-1200 vessel welded joints. Urazov 2017; Figure 1: Diagrams of the Flamanville 3 RPV IRSN Report /2015-00010 2015).

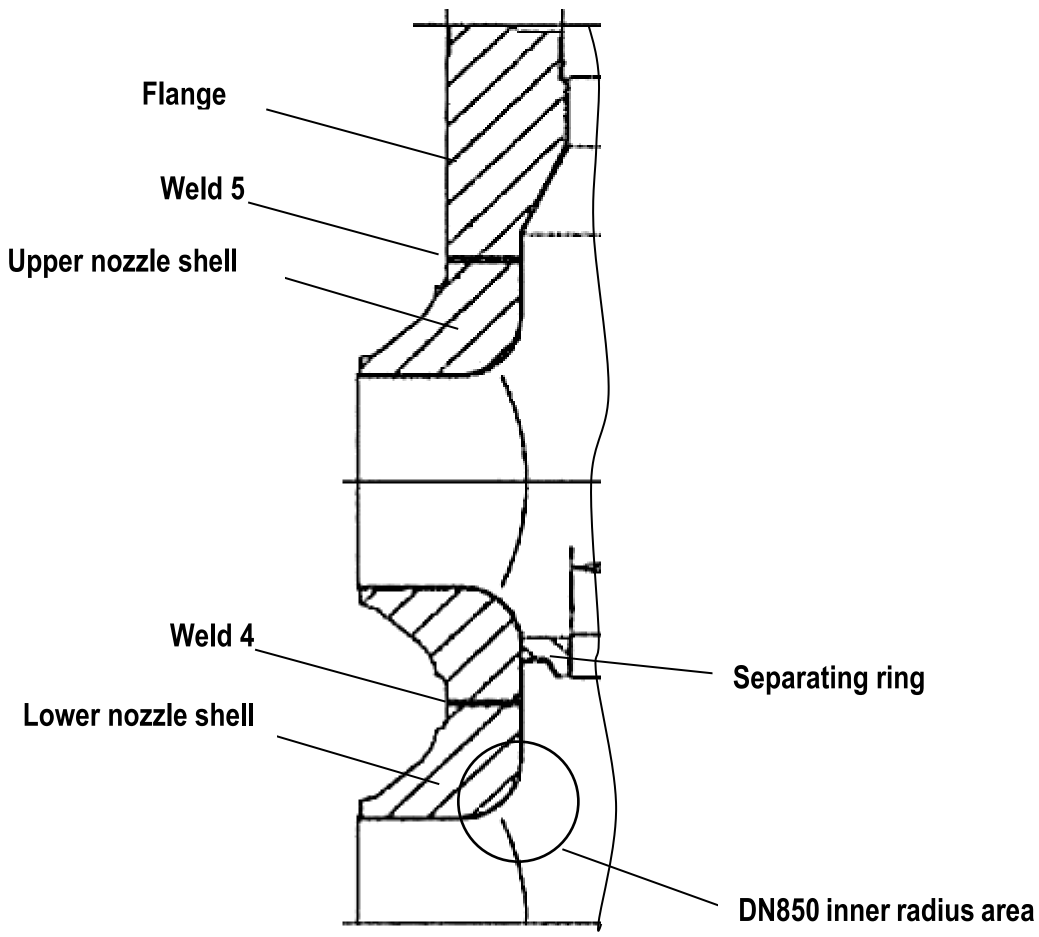

FIGURE 4. Nozzle area of VVER-1200 RPV (adapted from drawing 1.2 Корпус retrieved 12.6.2020 http://arthic.ru/vver1000/bezopas3.html)

It can be argued that "100% inspectability" is a relative term that depends on the anticipated defects, reliability of NDT methods & techniques, etc. For UT, the main volumetric testing method applied in ISI, the required testing volume for RPV circumferential welds may be considered fully covered when the when following conditions are fulfilled (interpretation of ASME BPVC XI 2019, articles I-2000; I-3300; ASME BPVC V 2015, Article 4):

- required volume is covered by 45 and 60-degree scans from at least one scanning surface;
- additionally, a 70-degree longitudinal wave probe is used to cover the volume near the scanning surface;
- the examination includes scans for longitudinal (L-scan) and for transversal defects (T-scan).

The required examination volume of RPV circumferential welds includes the full volume of the weld and adjacent base metal in width equal to half of base material thickness (ASME BPVC XI 2019, Figures IWB-2500-1, IWB-2500-4).

Welds 4 and 5 have thicknesses close to 300mm. Fulfilling the above-mentioned scanning requirements would require scanning areas of approximately 600mm both sides of weld center lines. Examination constraints close to welds in certain areas pose challenges to full volume testing by limiting the available scanning areas (figure 5).

Separating ring limits the scanning in the top-to-bottom direction in the full length of weld 4 resulting in deficiencies in testing coverage. DN850 nozzle radius areas limit scanning in bottom-to-top direction in four sections along the weld (figure 6). Similarily DN850 nozzle radius areas limit the scanning area for weld 5 in top-to-bottom direction (figure 6). For scanning in top-to-bottom direction, the slope of the scanning area affects the angles of incidence and significantly increases sound path lengths. During ISI, both welds are only accessible from inside the RPV meaning only a single scanning surface (ID) can be made use of.

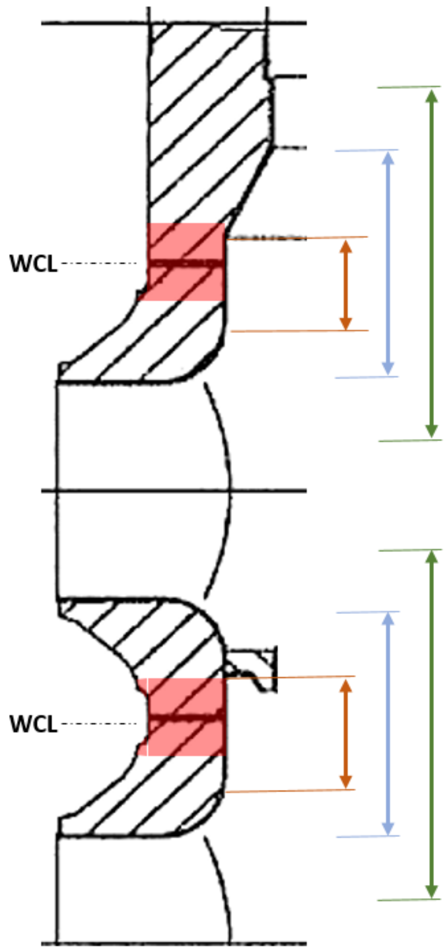

FIGURE 5. Nozzle area. Examination volume according to ASME XI IWB-2500-1 and IWB-2500-4 (red), available scanning area (orange), scanning area for 45º (blue), scanning area for 60º (green). (adapted from drawing 1.2 Корпус retrieved 12.6.2020 http://arthic.ru/vver1000/bezopas3.html)

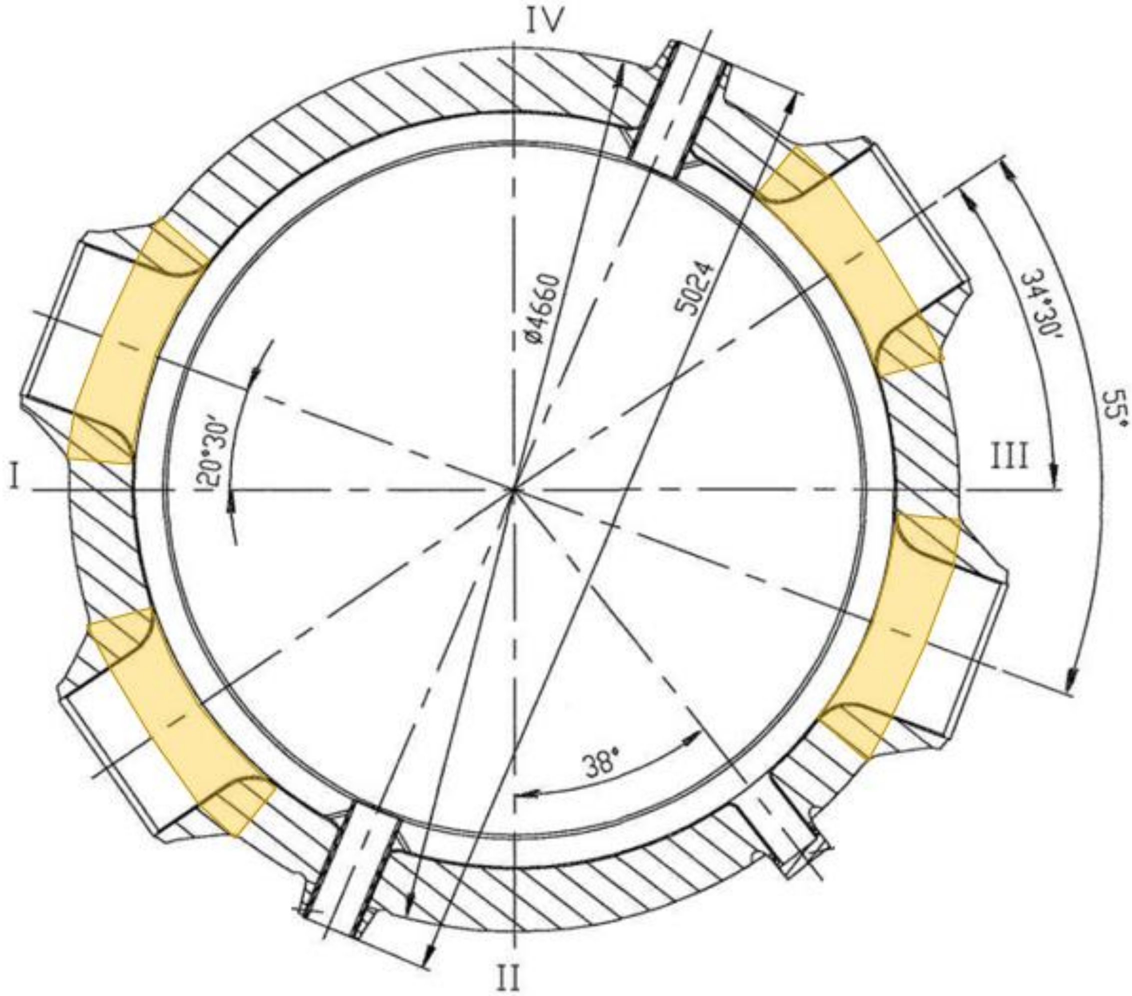

FIGURE 6. Sections of welds 4 and 5 for which examination is affected by DN850 inner radius areas. (adapted from drawing 1.4 Корпус (Поперечный разрез) retrieved 12.6.2020 http://arthic.ru/vver1000/bezopas3.html)

It can be concluded that both, welds 4 and 5, suffer from certain limitations for examination, especially in DN850 inner radius areas.

In addition to RPV circumferential welds, complex geometries pose challenges to the examination of emergency core cooling and instrumentation nozzles (figures 7, 8).

FIGURE 7. RPV set-on nozzles (pointed out with arrows) (adapted from VVER-1200 RPV retrieved 2.6.2020 http://www.omz.ru/en/company/project/project1/)

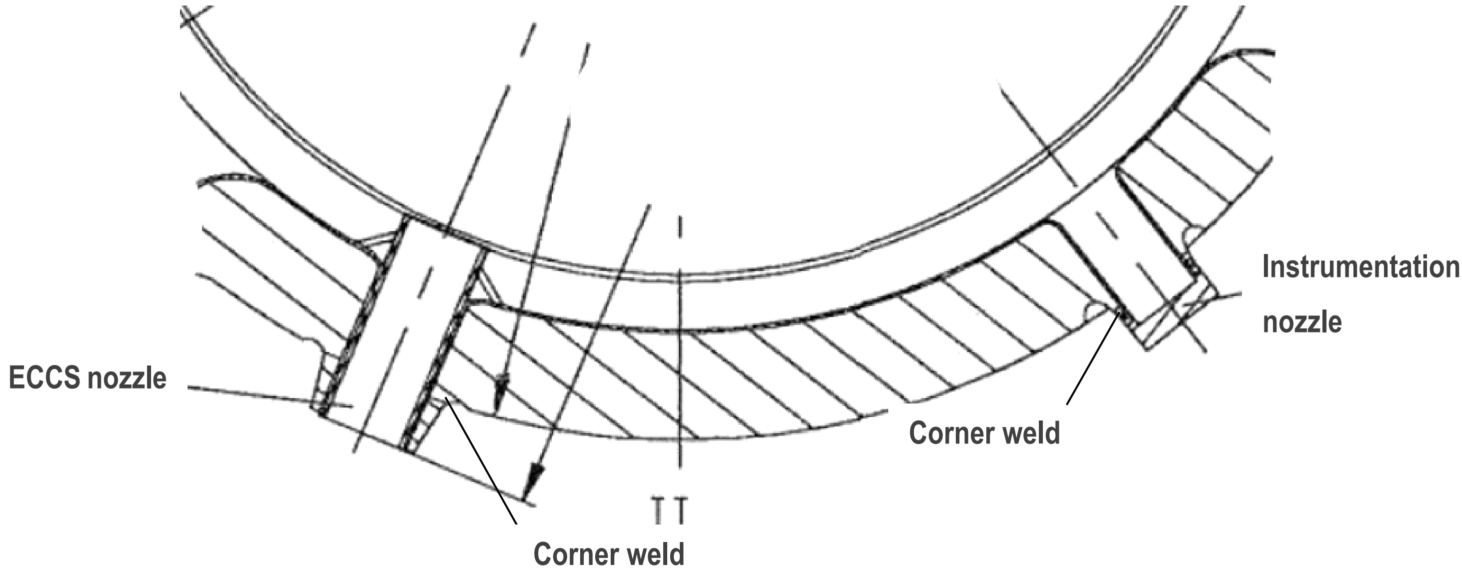

FIGURE 8. Set-on nozzles (adapted from drawing 1.4 Корпус (Поперечный разрез) retrieved 12.6.2020 http://arthic.ru/vver1000/bezopas3.html)

The nozzles are of set-on type (ASME XI Figure IWB-2500-7(c) applies as examination volume requirements). Challenges are caused by the fact that the nozzles are not accessible from inside and therefore can be scanned from outside surfaces only. Examination volume, according to ASME requirements, includes RPV shell inside radius areas, weld, and adjacent area of shell and nozzle in a width of ½ of the thickness of the shell. Fully covering the inspection volume required by ASME, which includes a significant volume of the base material, is challenging with conventional techniques due to large wall thickness of RPV, the geometry of corner welds, and unfavorable scanning surfaces.

The area which could be considered most prone to degradation, the root of corner weld, can, with certain limitations, be scanned. Reliable detection of transverse corner flaws in the radius area (ASME XI 2019, Figure IWB-2500-7(c)) is questionable.

It shall be noted that the coverage requirements presented above are largely based on requirements for examination during the manufacturing of components. Such requirements are aimed at providing a reasonable probability of detecting welding defects by implementing standardized testing procedures whereas the aim of ISI is detecting service induced defects. Hence, character, locations, and orientations of anticipated defects differ, and thus require different approaches to testing. For ISI, the efficiency of inspection systems, developed for specific examination object/area, are assessed case-by-case by a rigorous qualification process which includes practical trials on test pieces simulating the real examination object and including realistic defects. There is no direct relationship between the coverage of ISI and the safety it provides. In certain cases it may be acceptable that the examination areas are not tested in the full required volume or the testing is performed with limitations. Such are the examination areas where it can be justified that during operation the areas are not subject to any degradation mechanisms caused by stresses, environmental conditions, transients which may cause crack propagation and thus, testing would not provide any reduction in risk.

Being so, none of the discussed above shall be used to draw direct conclusions about fulfilment of safety requirements.

4 WELDING CONSUMABLES

4.1 Classification, selection and approval

As a principle, welding consumables used for welding nuclear pressure equipment shall be classified according to SFS-EN or ASME standards (YVL E.3 2019, req. 517). YVL does not rule out using Russian welding consumables that are not classified according to neither of these standards if reasons are justified. NP-104-18 appendix 2 lists welding filler- and auxiliary materials by grades, which are allowed by Russian authority and Russian material institute to be used for welding nuclear equipment. Having essential influence on strength analysis and ageing (that is, being fundamental for structural integrity), it can be perceived what consequences would changing the filler materials have. Together with long experience in manufacturing and operation, this gives a solid basis for justification of using the welding consumables specified in NP regardless of not being classified according to the acceptable standards, provided the thermal and irradiation ageing properties can be affirmed by the methods satisfactory to licensee and the Finnish authority.

Chemical composition and mechanical properties for weld metal are specified in NP-104-18 appendices 5 and 6 and, for welding the main base materials for main components (RPV, pressurizer, steam generators, main coolant pipeline), additionally in GOST R 58721-2019 (previously RTD 2730.300.02-91). The latter also refers to the applicable Russian standards or technical specifications issued (TU) by the material institute for each grade of consumable.

4.2 Quality assurance and testing

Quality assurance of welding consumables according to YVL E.3 is executed by a thorough specification of requirements (material specification), assessment of manufacturer's quality management system and testing of filler materials, and issuing of a certificate declaring conformance with specification (YVL E.3 2019, req. 519; Subchapters 4.1, 5.5).

Material certificates shall be in line with SFS-EN 10204; however, the type (level) requirements set by YVL are tighter than set for conventional pressure equipment by PED. Consumables used for welding main welds of main parts regardless of safety class and of coatings (cladding) and main welds of supports of SC1 equipment are required to have certificates based on specific inspection. For main welds of SC1, certificates shall be validated by a third party (YVL E.3 2019, Annex B).

This means that all-weld metal tests (EN ISO 15792 series) are carried out for each lot of filler material (size of which is for example defined according to ISO 14344:2010) to confirm that chemical composition and mechanical properties comply with the specification. As a result, the manufacturer issues a statement of compliance (material certificate) with test results for that specific lot. In cases when a type 3.2 certificate is required by YVL, such as main welds of SC1 or in case material manufacturer does not have a certified quality management system, the sampling and testing shall be supervised and the certificate validated by an accredited inspection body.

The practice does not differ from that used in conventional equipment manufacturing in Europe and is based on the concept that the responsibility of compliance with the order lies on the manufacturer. Presuming the manufacturer has a quality management system in place and, in case additional supervision is seen necessary, the inspection body is appropriately accredited, the material certificate provides sufficient assurance of the quality of materials.

Russian requirements as described in NP-104-18 (identical to preceding PNAE G-7-010-89) do not include similar clauses for quality assurance by the material manufacturer. Instead, the manufacturer of equipment shall test each heat of welding wire and each batch of welding electrodes and fluxes and verify their properties before applying these in manufacturing (NP-104-18 2018, items 31-73; GOST R 58721-2019 2020, Chapter 11). For that, a butt weld with any kind of edge preparation may be used or testing of consumables can be omitted altogether in case production test weld joints are required for the joints the consumables are used for (NP-104-18 2018, items 45, 53). Thus, filler material testing according to NP-104-18 is in practice handled as a production test, not as an all-weld test. Technically, this does not necessarily verify compliance with the material specification, in which the chemical composition and mechanical properties are specified for undiluted weld metal, and thus does not in that sense, in principle, comply with the general concept of SFS-EN 10204. Furthermore, the production test weld testing scope may not be sufficient to verify all properties specified for filler material. From a practical point of view, analyzing the causes of failed tests likely is more complicated when testing of consumables and pre-production tests are combined because there are more variables involved.

There are arguments for and against whether the incoming inspection (testing) and quality documentation issued by the component manufacturer can be considered equal to testing and material certificate provided by the material manufacturer. Such quality document, provided that the testing fulfills requirements in other aspects, would in European practice be considered “intent of EN 10204” i.e. not a substitute to inspection certificate according to EN 10204. For reference, the topic is comprehensively covered in “Guidelines related to the Pressure Equipment Directive 2014/68/EU (PED)”[12] where a conclusion is made that *material manufacturer shall affirm compliance with specification* and further specifying:

> *Any entity who is not involved in the material manufacturing process cannot be considered as a material manufacturer. (Guidelines related to the Pressure Equipment Directive 2014/68&EU (PED) 2016, p. 181, guideline G-30).*

While not applicable directly, the principles of PED principles can also be recognized in YVL E.3:

> *The material certificate or other document shall include a confirmation from the manufacturer of the material or welding consumable that the delivered products are compliant with the requirements of the order and the product specification to which reference is made (YVL E.3 2019, req. 531).*

On one hand, the requirement is rather intuitive: manufacturer of a product affirms and takes responsibility that the product corresponds to what was ordered and by including reference to specification in the certificate, it can be confirmed that the manufacturer has indeed acknowledged the requirements. Even in the case of specific (lot) testing is done, questions can be raised whether it can be trusted for instance that the quality of consumables is consistent within the lot, are the batches defined correctly and with full traceability and who actually is responsible that filler materials fulfill specified requirements if testing is only carried out by the component manufacturer.

On the other hand, it can be argued that testing of filler material at the manufacturer’s premises significantly simplifies the process in practical aspects. For instance, it allows better control over the testing process itself as it is easier to organize supervision over the component manufacturer for which stringent YVL requirements apply anyway (including NDT and DT laboratories) than over filler material manufacturer that may not have similar readiness. Taking into account the prejudice about impartiality and certificates issued in Russia (whether this has any basis is not the subject of

[12] Guidelines addressing the topic are G-05, G-10, G-24, G-29, and G-30.

this thesis), this may actually lead to improved transparency as far as testing is concerned, however, it is up for discussion whether traceability, which does not fully extend to the actual manufacturing phase, will satisfy the licensee or authority.

5 MANUFACTURER QUALITY SYSTEM

Each manufacturer using special processes[13], including welding and heat treatment, for manufacturing of pressure equipment under YVL Guide E.3, in addition to approval by the licensee, shall be approved by STUK (YVL E.3 2019, Subchapter 4.2). A prerequisite for approval by either is manufacturer's sufficient competence, organizational and technical capacity, and capabilities. The manufacturer shall be able to convincingly demonstrate that it is capable of traceably and repeatedly producing products that are in conformance with specified requirements, that is - have an advanced quality management system. Assurance of that, to some extent, is provided by management system certification by an independent third party certification body as required by YVL A.3 (Subchapter 6.5) and E.3:

> *The manufacturer shall have in place a management system that is appropriately certified. - - (YVL E.3 2019, req. 401)*

"Appropriate certification" is defined by YVL E.3 as

> *- - certification of a quality system based on auditing in which the accreditation of the certification body has been done against the requirements of standard EN ISO/IEC 17021 and the accreditation is covered by the Multilateral Agreements (MLA) or Mutual Recognition Arrangements (MRA) entered into by FINAS. (YVL E.3 2019, definitions)*

In addition to above-mentioned requirements, an additional requirement applies to suppliers of SC1 and SC2 components. Such suppliers shall take into account the requirements for management system specific for the nuclear sector given in IAEA GSR part 2 (YVL A.3 2019, req. 629, 309). Being so, a common ISO-9001 certificate by itself is not a convincing proof of conformity with the YVL requirement for appropriate certification if not supplemented with IAEA nuclear sector specific requirements. SFS-ISO 19443:2018 has been developed for organizations supplying products and services important to nuclear safety to complement ISO-9001 with IAEA requirements. Certification according to SFS-ISO 19443:2008 is preferred, but not required. YVL, in its goal-based spirit, also gives the licensee the freedom to provide an alternative:

> *- - Otherwise, the licensee may apply for STUK's approval for other management system assessment performed by an independent third party. (YVL E.3 2019, req. 401).*

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[13] Special processes, as defined in YVL, are *"manufacturing processes, the results of which cannot be directly verified by means of a product inspection or testing after manufacture; instead, any shortcomings in the process may only appear later while the product is in use."*

In practice, the licensee would develop and apply approval for a procedure for assessment of manufacturer's management system in conformance with all applicable YVL requirements. An independent third party, chosen on licensee's discretion, would perform the assessment based on the procedure. Such a process would likely be longer and heavier in bureaucracy than a normal certification process but the assessment would be made against the same or more stringent requirements as it would be if certification was in question. The assessment, however, would not result in a certificate being issued, thus, using the alternative approach would not necessarily be rational.

The main Russian manufacturers for nuclear pressure equipment are certified by accredited certification bodies to fulfill ISO 9001 requirements. It is necessary to verify that the scope of certification is sufficient for the required application and, if needed, to complement the management system to fulfill the IAEA GSR and ISO 19443 nuclear sector specific requirements.

The management system requirements above apply to all manufacturers. In addition, manufacturers performing welding and heat treatment in connection with welding shall "take into account and observe" the requirements of ISO 3834-2 and ISO 17663 (YVL E.3 2019, req. 404). The expression "take into account" leaves room for interpretation as it does not specifically require certification to ISO 3834-2. However, one could argue that the most unambiguous method would just be that – implemented, for example, by integrating the requirements for special processes into existing ISO 9001 or ISO 19443 to extend the scope of certification also to cover ISO 3834-2 and ISO 17663 (SFS-EN ISO 3834-1 2006, Chapter 6).

In some cases, this may lead to improving existing practices but at minimum, this means describing the processes related to welding and heat treatment together with roles and responsibilities of personnel in written procedures. This includes activities before, during, and after the welding (review of requirements and technical review, personnel qualifications, procedure qualifications, inspecting, testing etc.) as well as more general elements for assuring the quality of welded components (equipment, materials, storage, traceability, etc.).

While certain Russian manufacturers do possess quality management system certificates that cover quality requirements of special processes, the same cannot be said about all main equipment manufacturers. Likely the main reason why ISO 3834 is not widely opted in Russia is that, in contrast to ISO 9001, ISO 3834 includes in addition to general principles of quality management, described in part 2, specific requirements for welding and testing procedure and personnel qualification. These are given in part 5 as a list of ISO standards that shall be complied with. As an alternative to adopting the ISO standards, conformity to ISO 3834-2 may also be claimed by:

> *- - adopting other documents that provide technically equivalent conditions to the ISO documents listed in 2.2; it is the responsibility of the manufacturer to demonstrate that the alternative standards selected have technically equivalent conditions to those in the corresponding International Standards when documents specified in 2.2 are replaced. (SFS-EN ISO 3834-5 2015, Subchapter 2.1)*

Demonstrating that alternative practices are technically equivalent presumes a good understanding of the requirements. However, it has been observed that the know-how of ISO standards and practices leaves to be desired in organizations manufacturing nuclear equipment according to Russian codes and standard. Limited practical experience on the application of ISO standards in the Russian nuclear sector and similarly limited experience of licensee concerning Russian practices bear a risk that requirements are not unambiguously specified.

It is acknowledged that having necessary certificates, by itself, unfortunately, does not guarantee the manufacturers ability to provide conforming products. All management systems of SC1 and SC2 manufacturers using special processes are audited by the licensee and audits supervised by STUK (YVL E.3 2019, req. 401a; annex A). Also that can only confirm whether the prerequisites are fulfilled but is not a substitute for comprehensive surveillance and supervision during the manufacturing process.

5.1 Procedure qualification

For procedures to fulfill their function of ensuring level quality by providing repeatability and traceability, procedures shall be fit for purpose and followed correctly by the personnel. Welding procedure qualification guarantees neither but provides a basis for both by providing information, whether the combination of welding parameters, materials, and joint configuration has prerequisites to produce satisfactory quality. In the case of critical applications, the suitability of specific welding procedure specifications are further verified in manufacturing conditions by production weld tests using the actual welding parameters.

YVL E.3 requires that procedures for special processes are qualified by procedure tests (YVL E.3 2019, req. 840) but does not set any distinct requirements for the qualification process. Therefore, the rules for welding procedure qualifications set in ISO 15607, ISO 15613 and ISO 15614 standard series, as referred to in ISO 3834-5, apply[14]. For reference, the same requirements are given by RCC-M S3000.

The essence of the ISO qualification scheme is the traceability and unambiguity provided by clearly defined phases and standardized output documentation: pWPS, WPQR, WPS (SFS-EN ISO 15607 2004, annex B).

While ISO standards or corresponding national GOST standards are acknowledged and widely applied in the conventional sector, they are not applied in the nuclear industry. For nuclear pressure equipment, Russian requirements are presented in nuclear standard GOST R 50.03.04-18 as referred to in NP-104-18 Chapter XIII. Neither recognizes the terms pWPS, WPQR, or WPS. NP-104-18 Chapter XI requires the welding parameters be specified in "technical documentation". Qualification results are formulated in "qualification report" and a decision on fulfilment of qualification requirements and qualification range is given in "qualification certificate" (GOST R 50.03.04-18 2018, items 11.1, 11.2, 11.3, 11.4, 11.5). This complicates communication as it cannot be assumed that the fundamental terms are understood similarly by all parties.

YVL E.3 requires that qualification of procedures is conducted under the supervision of an authorized third party supervisor (YVL E.3 2019, req. 842). This, in practice, means that an impartial third party verifies the welding and testing of test-pieces and issues a WPQR as a result. Third party is not authorized to set requirements but only to verify that requirements (for example such as given in ISO 15614-1) are fulfilled (third parties are covered in subchapter 6.2 of this thesis).

In Russian practice, the responsibilities differ significantly. In GOST R 50.03.04-18 qualification requirements and rules for grouping are given in much less detail. Instead, a "qualification committee" is formed by the "head material organization" which develops "qualification program" and "methodology" (or qualification procedure) for each case. The material organization is also responsible for verifying test results and issuing a qualification certificate. As GOST R 50.03.04-18 does not include all details to comprehensively cover all aspects of welding procedure qualification, it

[14] In this case, qualification based on experience, tested consumables, or using standard procedures is ruled out based on common sense and engineering judgment.

can be presumed that the qualification committee (which also includes representatives of the manufacturer) and the material organization have significant freedom to set requirements and interpret qualification results.

Appendix 3 presents the main features of GOST R 50.03.04-18 and corresponding YVL and ISO standard requirements. The appendix is intended to compare similar parameters, hence ISO 15614 requirements are presented in a reduced and simplified manner which also illustrates the difference in the level of detail provided by GOST R and ISO standards due to different approaches.

As for the information included in GOST R 50.03.04-18, it can be concluded that the qualification ranges are somewhat broader in the sense of material thickness ranges and joint types. Single qualification can be used to cover only interchangeable base- and filler materials fulfilling ISO 15614 clause 8.3.11 which clarifies material ranges in case materials are not grouped according to ISO/TR 15608. Notably, heat input is not an essential variable according to GOST R, and the scope of DT include neither impact test nor hardness measurement even though the materials in question normally possess strict requirements for toughness. It should be noted however that for the materials for which determination of Tk_0 (also see subchapter 3.3) is required, impact testing is carried out as part of Tk_0 methodology. Heat input is not considered in the welding position of the test piece. Execution and acceptance criteria of NDT and DT are handled in chapter 6 of this thesis.

Due to reasons mentioned above, a conclusion on Russian practices in relation to Finnish requirements for qualification of welding procedures can't be made solely by comparing standard requirements. However, the qualification ranges and testing scope described in GOST R bear resemblance to those specified in ISO 15614 for level 1 qualification based on ASME BPVC Section IX but do not completely fulfill the requirements for level 2 qualification which is considered a default by ISO (SFS-EN ISO 15614-1 2013, Chapter 1). As for PNAE G in comparison to NP and GOST R, no relevant differences between the codes have been identified.

Witnessing the qualification by an impartial third party certification body is an unambiguous requirement of YVL E.3. This can't be done solely by reviewing the documentation (such as qualification report) of already carried out qualifications (interpretation of YVL E.3 2019, req. 808, 810). This means that even in case the testing requirements would be fulfilled, existing welding procedures would likely have to be requalified under the supervision of an independent and impartial third party. Furthermore, it shall be noted that qualification is required for all welding works regardless of the application. This includes applications for which qualification is not carried out in Russian practice, such as temporary weld joints.

5.2 Personnel

5.2.1 Welding coordination personnel

Competent welding coordination personnel plays a central role in maintaining an efficient quality system. YVL E.3-429 requires that persons responsible for welding and related heat treatment have training equivalent to guidelines provided by the International Institute of Welding (IIW): IWS, IWT, IWE. The training is documented, and qualification verified by examination. While the latest revision of ISO 14731, due to anti-competition rules, does not anymore refer to IIW qualifications as the minimum competency levels expected from welding coordination personnel, the essence of the requirement remains the same and IIW qualification levels are still the most common and uniformly understood way to indicate one's qualification.

While IIW trainings are available in Russia[15], certification is not common for welding coordination personnel working in the nuclear sector. There is no reason to doubt the personnel has good technical competence and significant experience working with rules and standards they are used to. NP does not give clear requirements for the qualification of welding coordination personnel. It is therefore not possible to assess the level of personnel qualifications in comparison with IIW guidelines. The most transparent and clear way to fulfill requirement YVL E.3-429 concerning training being documented and verified by examination would be certification according to IIW guidelines but as the certification is not a definite requirement, it cannot be ruled out that existing qualifications (education, in-house training, experience) can be shown as equivalent. However, it is anticipated that fulfilling the points listed in ISO 14731 annex A concerning knowledge of ISO 3834 series and procedure and welder qualifications may require additional training.

In addition to general training and competence, it is critical that also project-specific requirements for transparency, supervision, and handling of nonconformities are acknowledged. Neglecting these (such as failing to follow qualified procedures, performing unauthorized repairs or non-documented welds) may have significant consequences (see also subchapter 5.3).

[15] Russia is a member of IIW.

Depending on the level of safety culture of manufacturer, a change in attitude may be required in terms of applying the quality statutes, written in quality manual and procedures, on the shop floor in practice. That is, understanding that actions shall be in line with documentation and vice-versa. Any temptation to “bend the rules” may result in harm not even comprehendible on floor level. The role and responsibility of welding coordination personnel shall be thoroughly acknowledged both by the coordinators themselves and, equally importantly, by the employer. The responsibilities of welding coordinators shall be defined clearly, and welding coordinators shall have the authority to fulfill their tasks without pressure from the manager level. Also, the criticality of review of requirements and technical review as described in ISO 3834-2 and involvement of welding coordinators in these is widely neglected not only in Russia.

5.2.2 Welders qualification and certification

YVL E.3 does not set any additional requirements to ISO 9606-1 (referred to in ISO 3834-5) but does specify that also annex B of ISO 9606-1 (included in the standard as a non-mandatory requirement) shall be applied:

> */…/ in addition to demonstrating the person’s practical skills, the qualification shall verify the job knowledge of the person to be qualified concerning joining technology /…/ (YVL E.3 2019, req. 418).*

Qualification shall be carried out under the supervision of a third party (YVL E.3 2019, req. 808; annex A).

As with procedure qualification, differences exist between the welder qualification practices applied in Europe and the practices applied in the Russian nuclear sector. Certain parallels can be drawn between differences of PNAE G-7-003-87 and ISO 9606 and corresponding GOST R and ISO for procedure qualification.

Welder qualification is described in PNAE G-7-003-87 in a less detailed manner than in ISO 9606 allowing the qualification committee more freedom in defining how qualification is performed. The qualification committee, according to PNAE G, is formed by the manufacturing organization basically allowing the qualification to be performed in-house (PNAE G-7-003-87 1988, items 1.2, 1.3, 1.4). PNAE G includes a requirement for theoretical examination, thus meeting preconditions for filling YVL E.3-418 referred above (PNAE G-7-003-87 1988, items 1.1, 5.7).

As appendix 3 shows, there are significant differences between the qualification ranges. Material ranges in PNAE G are defined by base materials, similar in principle to ISO 287-1 (superseded by ISO 9606) but not following the material groups according to ISO/TR 15608. Ranges for thickness, diameter, and weld type are wider than those given in ISO. Even though ISO 6947 is adopted as GOST R, PNAE G-7-003-87 does not recognize welding position designations according to ISO and does not include all positions in ISO 9606. Interestingly fillet welding may be covered by a butt weld test joint according to PNAE.

It is not possible to make conclusions about how the differences in qualification practices are reflected in the competence of welders. Judging one's skills solely based on the requirements of how the qualifications shall be demonstrated would lead to primitive and valueless results, especially because PNAE G is not comprehensive. In the construction phase the applicability of qualification certificates are regularly checked by several parties as part of welding supervision. In the least, the differences in how qualification ranges are defined and different materials and welding positions designated would cause confusion and significantly increase risk of misinterpretation.

As with welding procedure qualifications, the absence of a third party cannot be justified. Qualification could be performed according to a procedure developed to cover both ISO and PNAE G requirements, but ISO 9606 should be taken as a baseline, not PNAE G. Such an approach would be simpler to implement as ISO mostly covers PNAE G.

5.3 Temporary welds and repair welding

Failure to transparently document all welds, defects found and conducted repairs is an issue that tends to repeatedly occur both in the conventional and nuclear sector. In large scale projects supply chains may grow long which increases the risk that all requirements are not communicated to or are not thoroughly understood by the manufacturer. Cultural differences or previous practices certainly play a role. This can have significant economic consequences from investigation, delays in delivery, and reworking, or in the worst case, if undetected, can jeopardize equipment structural integrity.

Incidents in recent Olkiluoto 3 project, for instance, those described publicly in “STUK Investigation Report 1/06” (failure to comply with welding procedures and repair-welding without qualified procedures), STUK release from 15.10.2009 and attached request for clarification 4/G43KAA/2009 (welding without qualified procedures) and “The Radiation and Nuclear Safety Authority’s safety assessment of the operating licence application for the Olkiluoto 3 nuclear power plant unit 13/G42213/2016” (non-documented repair-welding) provide valuable lessons to learn.

Often such incidents can be considered intentional errors, where established procedures have been neglected, indicating deficiencies in safety culture and inadequate welding coordination. Incidents are more likely to occur if the approved practice has previously been different. Such is the case with welding of temporary attachments. During the manufacturing process of large equipment, several attachments for machining, lifting, and alignment are welded to pressure vessel walls.

FIGURE 9. Temporary attachments welded to main coolant pump spherical housing for fixing to positioner (AEM-technology JSC. Equipment for nuclear power industry. p. 12)

ASME BPVC, EN 13445, and EN 13480 unambiguously require that all attachments to pressure equipment, temporary or not, shall be welded by qualified welders using qualified procedures (ASME BPVC VIII 2017, i. UHT-85, SFS-EN 13445-4:2014, Subchapter 7.8; SFS-EN 13480:2017, para. 9.13.2). An identical requirement is given in RCC-M with exception to cases where it can be demonstrated that all base material affected by welding is removed subsequently (RCC-M 2015, i. S 7423).

NP does not require qualification of welding procedures for temporary attachments (referred to in NP as technological attachments). It has been observed that welding of temporary attachments is not considered to be a special process by some manufacturers. Curiously, some parties have not recognized that it is permanent joining in question, even though the joints are not permanent, thus not recognizing relevant requirements as being applicable. To bring an example, already in base material manufacturing phase (manufacturing of forgings for main equipment) a large number of welds are performed, which would be considered unauthorized according to codes and standards listed above, while at the same time the material manufacturer does not consider using special processes in its work.

NP does require that the number and location of temporary attachments, together with welding parameters, are given in manufacturing documentation (NP-104-18 2018, items 74g, 74e, 205d). Areas of base metal, where temporary attachments have been removed, shall be inspected by an NDT surface method (NP-104-18 2018, i. 206). However, it has been observed by reviewing manufacturing documentation of two separate manufacturers, that the locations of temporary attachments are not documented in such detail that would allow full traceability for example for repeatable testing.

6 SUPERVISION AND TESTING

6.1 Supervision of welding and testing

The level of supervision distinctive to the manufacturing of components for nuclear applications is considerably more thorough than normally applied for non-nuclear pressure equipment.

Inspections are carried throughout the manufacturing process according to inspection and test plans, developed as part of construction plans by the manufacturer and approved by licensee and STUK for each component or series of components (YVL E.3 2019, para. 7.9.1). ITP's are based on general inspection plans in which the minimum scope of supervision for each party is given (YVL E.3 2019, req. 308, 309, 310, 311, 312). The scope shall, as a minimum, fulfill the requirements of YVL E.3 annex A, as summarized in table 1. Inspections are indicated as either witness-[16] or hold points[17]. The parties include in addition to STUK, licensee, and third party inspection organization.

TABLE 1. Scope of supervision (adapted from YVL E.3 2019, annex A)

	Safety class	STUK	Third party	Licensee
Auditing of a pressure equipment manufacturer's quality management system				
	1	H	-	H
	2	H	-	H
	3	W	-	W
Auditing of a material manufacturer's quality management system				
	1	H		H
	2	W		H
	3	W		W
Approval of manufacturers, subcontractors, and NDT and DT testing organizations & approval of construction plan				

16 "- - inspection for which advance invitations have been sent to the parties defined in the inspection plan but whose supervision is not a condition for proceeding with the work." (YVL E.3)

17 "- - inspection - - whose supervision is a condition for proceeding with the work unless the parties have given written permission to proceed without their presence." (YVL E.3)

	1	H		H
	2	H		H
	3	H		H
Welding and heat treatment procedure qualifications				
	1	W	H	W
	2	W	H	W
	3		H	W
Welding and NDT personnel qualifications				
	1		H	W
	2		H	W
	3		H	W
Witnessing of welding filler material tests for main components				
	1	W	H	W
	2			W
	3			W
Welding and NDT of pressurized main components				
	1	W	H	W
	2	W	H	W
	3			W
Heat treatment				
	1	W	H	W
	2	W	H	W
	3			W
Production tests – welding and testing of production test joints				
	1	W	H	W
	2	W	H	W
	3			W
Construction inspection – inspection of manufacturing documentation (weld logs, reports, …), pressure test, inspection of equipment before and after pressure test				
	1	H		H
	2	H		H
	3	H		H

Although not specified in YVL, in practice ITP will also include corresponding inspection points for all relevant parties in the supply chain, that is - parties who are obliged to supervise their sub-suppliers. The scope for these may vary but plant supplier, being considered fully responsible for the delivery by the licensee, shall, in principle, provide control over manufacturing in at least the same scope as licensee itself.

The involvement of at least five to six parties and simultaneous manufacturing of a large number of components at several locations around the globe makes this a complex logistical task. The responsibility of handling the logistics lies mainly on the licensee and plant supplier but manufacturers shall ensure full transparency of the manufacturing processes to ensure that all relevant steps are described in construction plans and appropriately included in ITP's. Also, manufacturers shall, in its processes and scheduling, take into account the inspectability[18] aspect, meaning that inspections are considered in advance and integrated into the manufacturing process so that inspections are not made impossible or rendered more difficult as manufacturing progresses (YVL E.3 2019, req. 758, 914).

Witness point does not, however, mean that licensee will physically oversee each step, but does give that privilege when practical, meaning that provisions shall be made by supplier and manufacturer to ensure upcoming witness and hold points are notified well in advance. Notification times set by YVL as "not less than approximately two weeks" apply to request for inspection sent to STUK meaning the notification times in practice shall be longer taken into account the long way the notification travels through the supply chain (YVL E.3 2019, req. 901). Plant supplier shall ensure that procedures for handling the notifications (communication chain, advance times) are in place and followed throughout the supply chain.

The licensee develops its own approaches for performing its supervision based on a graded approach, taking into account the relevance of component and maturity of manufacturer's quality system.

Third party cannot sign off a hold point based on documentation provided by manufacturer or supplier alone – a relevant note specifically added to the latest revision of YVLE.3:

[18] Note that the meaning of "inspectability" in this context differs somewhat from that discussed in sub-chapter 3.5.

- - The third party shall verify the material before the removal of the samples to be tested and ensure the traceability of the samples to the product either by stamping or by other applicable methods. The witnessing person shall be present in the testing event that he/she is to witness, unless agreed otherwise in the approved inspection plan. (YVL E.3 2019, req. 808)

Having delivered several units to Asian and mid-eastern countries, supervision by foreign customers is not an uncommon practice for Rosatom but it is not known whether the level of supervision has previously been comparable to that practiced by Finnish authority and customer.

6.2 Third party

An accredited (MLA/MRA) certification body, a notified body (NB) or a recognized third party organization (RTPO) under PED may act as a third party within the scope of its area of qualification for procedure and personnel (welding, heat treatment, NDT) qualification (YVL E.3 2019, req. 418, 809, 1509; annex A, Table 3). EN ISO/IEC 17020 and SFS-EN ISO/IEC 17024:2012 apply for accreditation of qualification and personnel certification bodies, respectively.

The third party performing manufacturing control is recommended to be an NB under PED but YVL does not rule out other independent organizations if approved by STUK (YVL E.3 2019, req. 809; annex A, Table 3). NB's or appropriately accredited organizations do not require separate approval by STUK (interpretation of YVL E.3 2019, req. 809).

One may note that YVL requirements for third parties formally are less stringent than in PED which only recognizes NB and RTPO as third parties. This is a major change in the 2019 revision of YVL E.3 compared to previous in which the requirements were identical to PED. Motives for the change are presented YVL E.3 Explanatory memorandum 120/0002/2016, for example:

As part of an effort to reduce administrative burden, in addition to the previously accepted notified or certification bodies as referred to in the EU Pressure Equipment Directive (PED), the Guide also accepts other certification bodies with sufficient competence demonstrated by approved accreditation to provide qualifications for permanent joints of safety-classified equipment. The objective of the change is to make it easier to find an approved qualification body for objects where PED is not otherwise a binding requirement (120/0002/2016 2019, para.2.4.2).

This should in principle have no effect on the competency or impartiality of the third party since it is also a normal practice to prove the compliance of a Notified Body by having accreditation against relevant ISO 17000 series standards (Decision 768/2008/EC, annex I, article R17). Accreditation of a Notified Body does include certain specific requirements for accreditation scope; however, these requirements are specific to PED and thus irrelevant (EA-2/17 M: 2020, Chapter 3.2; annex B). The updated YVL E.3 thus provides some relief of requirements when manufacturing is mostly done outside the EU or outside any of the countries that have signed a corresponding MRA with the EU.

As Russian accreditation body, Federal Service for Accreditation (RusAccreditation), does currently not have MLA with International Accreditation Forum (IAF) for mutual recognition of accreditations issued to certification bodies, Russian manufacturers have a choice of either using the services of western certification bodies or local certification bodies accredited by western accreditation bodies. First of these options is rather widely used for QMS certifications and latter for personnel certifications.

Equally, local companies for providing welding procedure qualifications fulfilling YVL requirements exist.

RosAccreditation has joined the Multilateral Mutual Recognition Arrangement of the International Laboratory Accreditation Cooperation (ILAC MRA), meaning the accreditations of testing laboratories (ISO 17025) and inspection bodies (ISO 17020), issued by RosAccreditation, are recognized by western accreditation bodies.

It should be noted, however, that filler material testing and verification of material certificate shall still be performed by NB under PED (YVL E.3 2019, annex A, Table 3). Still, for most tasks, third parties, at least formally fulfilling YVL requirements, are available in Russia or alternative routes have been found by using western accreditation or certification bodies.

Especially in case of manufacturing control, it might be challenging to justify the impartiality and competence of a third party which is not an NB nor working under organization generally known in Europe.

6.3 Testing laboratories

6.3.1 Approval of laboratories

Testing laboratories performing NDT and DT are, as default, expected to be accredited against appropriate ISO standards in the scope which covers all applied methods and standards (YVL E.12 2019, req. 301, 302). In such cases, NDT laboratories for SC3 and DT laboratories for SC1, SC2, and SC3 are normally approved based on the accreditation, whereas NDT laboratories for SC1 and SC2 require additional approval from STUK (YVL E.12 2019, req. 413, 501, 401). To laboratories performing testing in SC1 and SC2, also general requirements for nuclear-specific QMS apply (YVL E.12 2019, req. 208).

Similarly to QMS certification, discussed earlier in chapter 5, in some cases non-accredited testing laboratories may be approved for justified reasons. Such cases include independent third party laboratories performing testing for SC3 components or manufacturer's own laboratories regardless of the safety class of the components. However, as discussed, such a scheme involves a third-party assessment according to requirements set by the licensee and approved by STUK. (YVL E.12 2019, req. 311, 314; Subchapters 4.2, 5.2)

As with QMS certification, it can be assumed that accreditation is the more feasible path to follow. In fact, laboratories known to provide testing to key manufacturers formally fulfill the accreditation requirement as is. However, it should be noted that audits conducted to certain accredited laboratories by the licensee have not shown compliance with basic ISO 17025 requirements.

It is common around the world for large manufacturing plants to have in-house testing laboratories. Manufacturers' own laboratories can be approved if justified and if interactions and responsibilities between the testing organization and parent organization are described sufficiently (YVL E.12 2019, req. 312). In other words, manufacturer's testing organization shall be fully impartial in its performance of testing and interpretation and documentation of results – as, by default, expected from any testing organization. Based on YVL requirements and observations, approval of main manufacturers' own testing organizations is not foreseen, in principle, to be an issue, provided the organizations can convince the licensee and authorities of their impartiality.

6.3.2 Personnel competence and certification

According to YVL, personnel performing NDT shall be qualified and certified according to ISO 9712 to at least level 2 or equivalent by a third party fulfilling requirements discussed earlier (YVL E.12 2019, Subchapter 4.3).

ISO 9712, preceded by EN 473, is a well-established qualification scheme recognized in most parts of the world in most industrial sectors. The standard establishes principles for levels of qualification: required working experience, general requirements for training[19] and examination, and respective authorizations for each of the three qualification levels. Assignment of roles and responsibilities (including impartiality) for involved parties - certification body, qualification body, examination center, and employer – is a fundamental feature of ISO 9712. In principle, ISO 9712 is a central qualification system as opposed to in-house qualification according to the laboratory's own written practice, such as often practiced when and where ASME is followed. ASME BPVC recognizes ISO 9712 as an equivalent to SNT guidelines or ASNT qualification standard, but ASME written-practice based qualification is not recognized by ISO 13445 or ISO 13480. YVL, however, does in certain cases allow the application of in-house qualification systems for NDT personnel qualification (YVL E.12 2019, req. 425b).

NDT personnel qualification in the Russian nuclear sector is described in standard GOST R 50.05.11-2018 (NP-105-18 2018, i. 7). The standard is relatively recent, but the general idea remains the same as in PNAE G-7-010-89 (preceding NP-105-18) chapter 4. That is, qualification is performed according to a procedure drawn up by the head personnel qualification organization (certification body). Training and examination are executed by authorized qualification body and examination body (GOST R 50.05.11-2018, paras. 4.5, 4.6).

GOST R 50.05.11-2018 specifies three qualification levels similarly to ISO 9712, although designated differently. Qualification levels according to GOST R, SPVZ, and BPVZ[20], correspond to levels 1 and 2 according to ISO 9712 as far as the authorizations are concerned. Minimum training duration for common NDT methods for direct access to higher of those (i.e direct access to BPVZ

[19] More specific guidelines for training programs are given in ISO/TR 25107.
[20] Abbreviated from Russian phrases meaning "without authority for issuing of results" and "with the authority of issuing results".

or level 2) are identical (SFS-EN ISO 9712 2012, Table 2; GOST R 50.05.11-2018, Table A.2). Curiously, the required number of training hours for upgrading the qualification to level SPVZ and from SPVZ to BPVZ summed is more than directly to level BPVZ. The third level of qualification according to GOST R, SPA[21], does not correspond to level 3 according to ISO 9712. A person is certified to qualification level SPA by external qualification body and may act as an examiner for other personnel of the testing personnel for lower qualification levels. This can be interpreted as in-house qualification, similar in its core principle to ASME.

GOST R does not specify the duration of additional training for level SPA. The number of questions in theoretical examinations in GOST R and ISO are comparable for all levels but GOST R does not include requirements for the number of specimens for practical examination.

Assuming the training scope is comprehensive, in principle approval may be sought for such a qualification system after independent assessment:

> *Use of the testing organisation's internal qualification system can be approved for a justified reason, and it must be externally and independently assessed. The external independent assessment may be, for example, ASME Stamp, an internal qualification system within the scope of accreditation, Nadcap accreditation or other reliable assessment (YVL E.12 Explanatory Memorandum i. 2.4.2).*

In practice, although ISO 9712 is not mentioned in Russian nuclear code, the qualification scheme is widely applied in Russia. In fact, also the testing organizations in the nuclear sector employ NDT personnel appropriately qualified according to ISO 9712 in addition to Russian practice. Being so, there is a readiness to fulfill YVL E.12 default requirement which means that there should be no rational reason to apply for approval for any other qualification system.

For DT personnel a standardized and internationally recognized qualification scheme does not exist and no specific requirements for DT personnel are given in YVL E.12. It is assumed that accreditation against ISO 17025 is sufficient proof the organization has procedures in place to assure the competence of its personnel. GOST R 50.05.11-2018 provides a good foundation for fulfilment of that requirement, as it also applies to the qualification of DT personnel, including requirements for training and examination. Being so, Russian qualification scheme for DT personnel may be considered more advanced in a sense.

[21] Abbreviated from Russian phrase meaning "with the authority to assess".

6.4 Non-destructive testing

Scope of testing, methods and techniques used, essential parameters involved in executing the testing, methods of assessing indications, and acceptance criteria form an entity, all parts of which have a certain effect on the effectiveness of NDT and ultimately – the integrity of welded joints.

The basis for acceptance criteria fundamentally is the dimensions and types of imperfections allowed in the weld joint without compromising its integrity. Method specific acceptance criteria are defined based on how, with reasonable certainty, flaw indication found by certain NDT method/technique is believed to represent the actual imperfection. Scope of testing and selected methods affect the probability of finding certain types and sizes of defects, in certain materials and locations. All above is a balance between the capabilities of NDT methods and techniques, which imperfections can be tolerated, what the safety margin is and how much assurance is considered sufficient and at which cost, keeping in mind that achieving a 100% probability of detection is not possible.

Testing requirements are intrinsically linked to the implemented design code. Codes and standards governing NDT in the nuclear sector differ significantly in their logic and structure due to different development paths and philosophies. Such differences in approaches can be seen when comparing the rather laconic NDT requirements set by ASME to those set by NP (figuratively speaking, RCC-M and ISO being somewhere in the middle). The latter can be considered highly theoretical, for instance in some cases presenting the acceptance criteria in such increments that could be argued to be less than the measurement uncertainty achievable in practice.

Due to the reasons above, the value of detailed quantitative analysis is questionable because it is not possible to quantify the impact of a single factor to the safety, that is, assess the differences in correct perspective. For instance, as can be noticed, the acceptance criteria set in NP tend to be more stringent for thin materials and less stringent for thicker materials than those set in RCC-M. At the same time, certain requirements set by RCC-M for the highest safety class components are less stringent than those set by conventional ISO standards for the highest quality level while the scope of testing is considerably higher than defined for the most stringent testing group in ISO design standards. Adding the supervision, manufacturer quality system, qualification and production test requirements, the equation is not solvable. Nevertheless, based on the analysis of western and Russian nuclear codes and standards, some relevant conclusions can be made using engineering judgement to provide a general overview of the requirements related to NDT. An attempt on comparing those is made in appendices 4-9. It is important to note that, as mentioned in chapter 3.2, the principles of how welded joints are classified differ between codes. This is essential to take into account when analyzing the information. ISO 13445-5 and ISO 13480-5 have been omitted from the comparison of required testing scopes (appendix 4) and are mainly intended for reference only in testing and acceptance criteria comparisons (appendices 5-9). Instead, RCC-M has been chosen to represent the implementation of ISO standards in the nuclear field. As mentioned earlier, requirements for testing scope given in RCC-M are more stringent than ISO, but, perhaps counter-intuitively, requirements for performance and acceptance criteria do not always meet requirements given in ISO standards for the highest (most stringent) quality class.

The basic principles of main NDT methods are universally understood and acknowledged and on the general level, the same well-established methods, with their strengths and weaknesses (in absence of better ones available), are applied in each code.

Russian code (as also ASME) does not clearly set the preferred surface testing method, leaving the selection between MT or PT to manufacturer's or laboratory's discretion whereas RCC-M clearly specifies MT as first preference. MT and PT are widely regarded as interchangeable (given the tested material and access allow for MT), but MT is more commonly implemented due to practical reasons. As for the probability of detection, a comprehensive round-robin study carried out in Nordic countries as part of Nordtest NDT-programme, taken part by Technical Research Centre of Finland VTT, has shown that PT is slightly more sensitive to small (short and shallow) defects and defects in welded samples but considers both methods reliable (*Kauppinen – Sillanpää 1991)*. Practical considerations include surface quality and effort. Less than ideal conditions and/or careless execution more easily lead to missing defects with PT than with MT. It can be expected that also the Russian manufacturers or laboratories choose the more practical method for a specific application.

For volumetric testing for ferritic welds, both RT and UT are implemented according to NP and RCC-M - a major difference from the conventional sector where normally (such as according to ISO 13445 or ISO 13480) either, but not both, of the methods, is applied following the general rules set in EN ISO 17635. Standard requirements for conventional equipment are a balance between the probability of defects occurring, possible consequences, and cost of manufacturing. Also, in nuclear sector economic factors cannot be ignored, but one could expect them to have less weight in the manufacturing of pressure equipment critical to nuclear safety.

Requirements for selection of volumetric testing methods can be considered somewhat more stringent in NP than in RCC-M as to for which welds and starting of which material thicknesses UT is applied in addition to RT. ASME specifies only RT during equipment fabrication (ASME BPVC III 2015, endnote 29) but it should be kept in mind that all critical equipment is subject to pre-service inspections (PSI) according to each of the three codes. For PSI, UT is the primary volumetric testing method. From that point of view, at least the differences between selections of testing methods can at least partly be attributed to different logic each code follows but not necessarily leading to different end-results. For austenitic steels, UT is not applied during the fabrication phase due to complications austenitic grain structure poses to sound propagation, but the topic is relevant in relation to ISI.

As can be seen in appendix 4, the scope of testing for category I welds[22], required by NP-105-18, for example, meets requirements for RCC-M class 1 welds and welds of ASME class 1 components and, at least formally, exceeds both of these in relation to the selection of volumetric methods. To avoid drawing false conclusions, especially for other classes or categories of components and welds, the above-mentioned differences in classification principles shall be considered and care taken when comparing the testing scopes. Regardless of that, a peculiarity can be noticed in testing scope requirements set by NP to category III welds – surface testing (MT or PT) is not required to be performed on ferritic welds. Category III is defined as such welds of group B components that are not in contact with (radioactive) coolant and welds of group C components (NP-105-18 2018, i.17). Thus, category III welds may include, for instance, welds to pressure-retaining parts (such as pressure vessel wall) of safety classified components. Not performing any surface testing to such welds is difficult to comprehend by engineering judgment. Yet another peculiarity has to do with UT of thin walled piping (t≤5mm): it is required for category III welds but not for categories I or II.

As for testing before and during welding, NP-105-18 requires surface testing on weld bevel surfaces similarly to RCC-M classes 1 & 2 and ASME class 1 (NP-105-18 2018, i. 79, 80; RCC-M 2015, i. S7710, S7720; ASME BPVC III 2015, i. NB-5130). It is not clear whether NP requires NDT during welding, for example after root pass. NP specifies RT for root pass for nickel-based materials (NP-104-18 2018, i. 209).

[22] Such testing scopes would be applied for example to pressure-retaining welds of main components of SC1.

One of the NDT methods, which have significant potential of causing misunderstanding between welding & NDT personnel working in the Russian nuclear sector and those used to working according to international standards, is VT. Standard ISO 6520-1, in which geometric weld imperfections are classified, can be considered a document that sets the common language for all welding and testing personnel in the industries where ISO standards are applied. ISO 6520-1 has also been issued as a Russian national standard GOST R ISO 6520-1-2012, but is not referred to in nuclear code nor in the standard for visual and dimensional inspection for nuclear applications, GOST R 50.05.08-2018. Thus, forming any understanding of what imperfection is in question involves reading the documents in their original language and based on judgment and best estimation, making the connections through the Russian version of ISO 6520-1, such as has been attempted in appendix 5 of this thesis.

As to which defects are not permitted, the NP mostly corresponds to RCC-M and ISO 5817 level B as far as defects most critical to the structural integrity of the welded joints are considered. Differing from RCC-M and ISO, NP allows some surface porosity (NP-105-18 2018, appendix 4, Table N4.1; RCC-M 2015, i. S7460; SFS-EN ISO 5817 2014, Table 1). For cases in which welds are not machined flush, RCC-M and ISO set requirements for the height of the weld cap. NP sets requirements for the depth of valleys between capping runs and for piping joints for root concavity and excess penetration. For other shape-imperfections, NP states the tolerances shall be given in technical documentation.

Curiously, also RCC-M does not fully succeed to present the acceptance criteria for VT unambiguously, referring to imperfections such as “weld collapse”, “shrinkage”, “spongy formations” and “flat defects”, “blistering” and “inclusions appearing on the surface” or referring to weld surface as “front” and root as “back”. (RCC-M 2015, i. S7460) In ASME, requirements for VT are vague and do not provide a good comparison. There is no definitive reason to doubt the requirements for VT set by NP are justified, but the harmonization of terminology in technical documentation by referring to international classification standard would significantly reduce the risk of misunderstanding and confusion over acceptance criteria, and thus would help avoid disputes during manufacturing.

As one could expect, no major differences in practices of performing surface testing (PT/MT) based on GOST R and ISO are identified. It deserves pointing out that while the term “sensitivity level” is used both in Russian and European codes and standards the levels are not defined the same way. Instead, either refer to their own methodologies how the sensitivity is determined. Being so, for PT detection media, sensitivity level II (GOST R) and sensitivity level 2 (ISO) are not equal. In practice, the few western products listed in GOST R appendix A, for which it can be confirmed, are classified as ISO 3452 sensitivity level 2 products by their manufacturers. For MT detection media, GOST R 50.05.06-2018 refers to sensitivity levels A, B, C while ISO 9934-2 does not define sensitivity levels. For those testing materials used, which are not tested in accordance with ISO practice, it could be appropriate to conduct a performance test using relevant ISO test sample (ISO 3452-2 or ISO 9934-2) to confirm the performance.

For thin materials (t<10mm) NP acceptance criteria for round indications for each weld category is more stringent than that given by RCC-M[23] or ASME. On the other hand, if detected and categorized as pores, these would not be permitted by RCC-M by VT requirements. For thicker materials and especially for weld categories II and III, the dimensions and number of indications (although methods for assessing multiple indications differ) permitted by NP is greater than in either of the western codes.

Comparing the execution requirements for RT, it can be noticed that image quality following the GOST R and NP requirements is not expected to be as high as required by RCC-M or ISO. For instance, GOST R generally permits using higher speed class films and requires lower densities resulting in grainier and lower contrast, that is, lower sensitivity, radiographs (GOST R 50.05.07-2018, annex B, Table B.1; RCC-M 2015, items MC 3312.4, MC 3161; GOST R 50.05.07-2018 2, para. 6.5.5; SFS-EN ISO 17636-1 2013, Subchapter 7.8; Table 3). Naturally, also image quality indicator requirements, especially for categories II and III, are significantly less stringent (NP-105-18 2018, annex 4, Table 4.18; RCC-M 2015, i. 3162.1; SFS-EN ISO 17636-1 2013, annex B, Table B.3). The IQI requirements set by NP for categories I and II are comparable to ASME (NP-105-18 2018, annex 4, Table 4.18; ASME BPVC III 2015, article 2, Table NB-5111-1). Radiographs fulfilling GOST R and NP requirements would be considered not acceptable for assessment according to ISO higher image quality class B, which RCC-M roughly corresponds to. Radiographs fulfilling requirements for weld categories II and III would also not fulfill image quality requirements for ISO lower image quality class.

[23] RCC-M requirements for single indications are comparable to ISO 23278 level 3X for MT but ISO 23277 level 1 for PT.

Comparing the acceptance criteria for volumetric testing is more complicated than the criteria for surface testing due to differences between Russian and western codes and standards in indication assessment techniques and how the acceptance criteria is defined.

NP follows a somewhat different logic in defining the acceptance criteria than ASME, RCC-M or ISO. NP distinguishes between small and large inclusions. No distinction between gas and solid inclusions is made[24], similarly to ASME.

Acceptance criteria for large inclusions (essentially elongated inclusions) are defined as permitted width and length, but also the number of allowed inclusions per 100mm of weld length. Permitted number or such inclusions is up to four, depending on category and thickness. In comparison to ASME and RCC-M considering only the maximum permitted length, as the acceptance criteria for elongated inclusions are only defined by the larger dimension in ASME and RCC-M, the acceptance criteria for elongated inclusions set by NP tend to be more conservative. In comparison to ISO, considering the width of inclusion, NP acceptance criteria for weld categories I, II, III are similar for low weld thicknesses (t<14…20) but allow considerably wider imperfections in thickness ranges applicable for most main component pressure-retaining welds than ISO for either level 1 or 2. On the other hand longer inclusions are allowed by ISO. (NP-105-18 2018, annex 4, Table N4.18; RCC-M 2015, items S 7714.3, S 7724.3, S 7734.3; ASME BPVC III 2015, i. NB-5320; mandatory appendix VI; SFS-EN ISO 10675-1:2016, Table 2).

In NP, the criteria for single round inclusions (essentially porosity) are defined by dimensions, the number of inclusions, and cumulative surface area per 100mm of weld (NP-105-18 2018, annex 4, Table N4.18). Considering the dimensions, NP acceptance criteria for categories 1 and 2, RCC-M class 1 and ISO acceptance levels 1 and 2 are in the same magnitude. ASME and RCC-M class 2 criteria allow larger round inclusions in all thickness ranges than NP or ISO.

Adding in the different rules how imperfections are summed, cumulative dimensions or area determined and in the case of NP, the number of inclusions allowed, the feasibility of a reasonable comparison is questionable.

[24] RCC-M and ISO distinguish between gas pores and solid inclusions such as slag, flux, oxide and metal inclusions but acceptance criteria differ.

Defects most critical to the integrity of welded joints, cracks and planar defects (lack of fusion and lack of penetration) are not permitted by any applicable code or standard, but it shall be kept in mind that there are considerable limitations for detection of such defects with, especially given comparatively low image quality permitted by GOST R and NP.

Detection of cracks and planar defects is more likely with UT. Execution of UT according to GOST R 50.05.02-2018 is comparable to RCC-M, ISO and ASME as to the number of scans (probe angles, scanning directions, and scanning surfaces). For thicknesses up to 60mm, GOST R does not include a requirement for performing the scanning from both surfaces of the weld such as required by RCC-M regardless of the thickness (GOST R 50.05.02-2018, para 6.2; RCC-M 2015, i. MC2634). Performing the scanning from both surfaces, if accessible, would slightly improve the reliability of testing. Similar differences can be observed for other weld configurations.

Comparing the acceptance criteria for volumetric imperfections between NP, RCC-M, ISO and ASME is complicated because each of these codes and standards refers to different amplitude evaluation techniques. GOST and NP rely on distance-gain-size (DGS) technique whereas RCC-M and ASME refer to distance amplitude curve (DAC) (RCC-M 2015, i. MC 2635; ASME BPVC V 3025, article 4, i. T-434.2). ISO includes criteria for both, but the criteria for DGS are given as the length of indication in relation to weld thickness and respective maximum permitted echo heights which are expressed as the difference in the amplitude compared to reference reflector (echo height in dB over or under reference reflector). NP, for weld thickness over 5mm, gives the acceptance criteria as equivalent reflector size and permitted number of indications per 100mm of weld length (NP-105-18 2018, annex 4, Table N 4.13). Probe-specific DGS curves could be used to make connections between the different echo height assessment techniques (amplitude in dB over or under reference FSR versus amplitude as ERS) but direct comparison between the acceptance criteria as a whole cannot be made.

For instance, for 60mm weld thickness, according to ISO (acceptance level 2), it is permitted to have indications over reference level (3mm FSR, H_0) up to +6dB (that is, 6dB over reference level), 30mm in length and indications -4dB up to reference level 60mm in length. Indications more than 6dB over reference level are not permitted. Indications 4dB under these respective acceptance levels shall be reported. (SFS-EN ISO 11666 2011, Table A.1).

For the same weld thickness, according to NP (weld category I), indications over 2,5mm ERS shall be reported and indications over 5,0mm ERS are not permitted. It is permitted to have seven indications over 2,5 and under 5,0mm ERS for each 100mm length of weld. (NP-105-18 2018, annex 4, Table N 4.13). The value of such comparison is, at a minimum, questionable.

RCC-M, ASME and ISO refer to DAC with side drilled hole (SDH) as reference reflector but the diameters of SDH differ, again rendering the criteria not directly comparable.

Linear indications (indicating a planar defect or crack) are not permitted by any of the applicable codes or standards, however, from a practical point of view, characterization of UT indications can be challenging and much dependent on the training, experience, and credence of individual testers.

It can be concluded, that while certainly not differing radically on the principal level, the approaches, especially for defining acceptance criteria for volumetric testing differ considerably between codes. While it shall be noted that certain differences in logic also exist for example between RCC-M and ISO, the relative complexity (from the perspective of someone used to European practices) of how acceptance criteria are presented distinguishes NP from other codes.

6.5 Destructive testing

As discussed earlier (see subchapters 4.2, 5.1, 5.2.2), certain differences exist in practices regarding which testing methods and methodologies are implemented in destructive testing of weld metal and welded joints. Compared to NDT, however, NP requirements for DT are simpler to put into perspective of European practices as the execution and assessment of results are less ambiguous.

It can be noticed that although NP does not refer to any ISO standards, comparatively many references to ISO standards are made in russian national standards for DT. General requirements for determination of mechanical properties of welded joints are set in GOST 6996-66 which includes ISO 4136-89 (transverse tensile test), ISO 5173-81 (surface and root bend test) and ISO 5177-81 (side bend test) as annexes (GOST 6996-66 2005, appendices 1, 2, 3). It shall be noted that the appendices are marked as recommendations use of which „is allowed“ (GOST 6996-66 2005, i. 1.4).

For the execution of testing, GOST 6996-66 refers to GOST 1497 and GOST 9651 (tensile test at room temperature and heightened temperature respectively) which are based on ISO 6892-84 and ISO 783-89. Even though the referred ISO standards are outdated, the fact that they are implemented as requirements for some of the testing methods considerably reduces risks of confusion compared to NDT. The base requirements for bend tests and tensile tests have not changed significantly in later revisions of ISO standards compared to those used (or allowed to be used) in Russian nuclear sector. Being so, the sampling locations, types and dimensions of specimens, execution and assessment of results implemented according to NP and GOST are similar than those practiced in Europe (GOST 6996-66 2005, appendices 1, 2, 3; SFS-EN ISO 5173 2011, Subchapter 5.6; SFS-EN ISO 4136 2012, Chapter 5; SFS-EN ISO 6892-1:2019, Chapter 6; annex D; SFS-EN ISO 6892-2:2018, annex A; GOST 1497-84 2008, appendix 2; GOST 9651-84 1993, appendix 1)

It should be pointed out, however, that a considerable discrepancy exists in acceptance criteria for bend test. GOST acceptance criteria for bend test is 5mm compared to 3mm required by ISO 15614-1 (GOST 6996-66 2005, i. 9.2; SFS-EN ISO 15614-1:2017, para. 7.4.2). Bend angle is not ambiguously defined in GOST nor in NP.

Certain incosistency can be observed as to how room temperature is defined in various standards. For tensile tests, GOST 1497-84 (ISO 6892-84), states that testing is carried out at 20^{+15}_{-10} °C. The same temperature range is given in newer revisions of ISO 6892 as the default testing temperature, additionally including temperature range for controlled conditions, 23±5°C (SFS-EN ISO 6892-1:2019, Chapter 5). ISO 4136 defines the latter as default testing temperature (SFS-EN ISO 4136 2012, Chapter 3). In this case, the requirements are not unambiguously defined in ISO. For bend test, GOST 6996-66 defines room temperature as 20±10°C, whereas in ISO standard it is 23±5°C (GOST 6996-66 2005, i. 3; SFS-EN ISO 5173 2011, Chapter 3). Similarly, for impact testing, the temperature range for room temperature testing is wider in GOST, 20±10°C than 23±5°C set by ISO (GOST 9454-78 2002, i. 3.3; ISO 6996-66 2005, i. 3; SFS-EN ISO 148-1:2016, para. 8.3.1).

GOST standard for impact testing, GOST 9454-78 is not based on an older revision of corresponding ISO standard but does not conflict with ISO 148-1 as to test specimen geometry, dimensions and tolerances or anvil and striker geometry and dimensions (ISO 148-1:2016, Tables 2, 3; GOST 9454-78 2002, i. 1.1; figure 4). GOST 6154-78 does only specify the 2mm striker but does allow the use of strikers with differing radius. It is important to note that according to Russian practice, impact test results are presented as impact toughness (J/cm^2), not as absorbed energy (J). According to both standard families, the value is determined as the arithmetic mean of three specimens (GOST 6996-66 2005, i. 3.2; SFS-EN ISO 15614-1 2019, para. 7.4.4). There are differences concerning how much one individual value is allowed to be below the specified minimum. According to ISO, the limit is 70% of that value whereas according to GOST, it is 5 J/cm^2 (GOST 6996-66 2005, i. 3.3; SFS-EN ISO 15614-1 2019, para. 7.4.4).

Comparing GOST 6996-66 and ISO 9015-1, hardness testing indentation patterns (indentation rows and locations) do not differ in principle (GOST 6996-66 2005, Chapter 7; SFS-EN ISO 9015-1 2011, Subchapters 6.1, 6.2). For welded joints, Vickers hardness testing with a 10kg load (HV10) is specified both according to GOST and ISO (GOST 6996-66 2005, i. 7.2; SFS-EN ISO 15614-1 2019, para. 7.4.5).

Concerning all DT methods, it is anticipated the designation of test specimens as to sampling location (weld metal, heat affected zone, face, root) and direction (longitudinal, transverse) may cause confusion if not further agreed and clarified in testing procedures.

It can be concluded that no major discrepancies have been identified concerning sampling and testing principles of commonly applied DT methods. It should not, however, be taken for granted that because references to ISO are made in GOST standard, the practices are identical to the details. While not necessarily detrimental to test results, it is beneficial to acknowledge such differences in the course of test procedure approval. Similarly, it should be kept in mind that general designer's and material organization's views on the selection of DT methods and sampling locations do not necessarily comply with GOST standard requirements or recommendations.

7 PRE- AND IN-SERVICE INSPECTIONS

In addition to inspections and testing carried out on NPP components throughout the operational lifetime as part of routine maintenance and ageing management, pressure equipment considered significant to safety is subject to in-service inspections (ISI) with NDT methods according to requirements of YVL Guide E.5. That means, in essence, that the areas considered to be subject to degradation mechanisms, that would, even with minute probability, lead to failure due to operation induced defects (predominantly welded joints) and by failure pose a risk to nuclear safety, are methodically and periodically inspected under authority supervision using inspection systems demonstrated to be effective for the specific inspection area in question - that is, capable of detecting the type and size of defects critical for that specific inspection area. Results of pre-service inspections (PSI), performed before NPP is put in operation, using the same inspection systems as later periodically in ISI, serve as a reference to ISI. The conception of PSI and ISI is well recognized by utilities around the world but the application of PSI and ISI differ, including principles of selection of inspection areas in the ISI program, testing methods and volumes, and inspection system qualification.

According to YVL E.5, the basic requirement level for ISI shall be the requirements of ASME BPVC Section XI, Division 1 (YVL E.5 2019, req. 302). YVL further specifies that for piping systems, risk-informed selection principles, such as described in ASME XI non-mandatory appendix R, shall be applied as opposed to pressure vessels for which the inspection objects and areas are selected by deterministic principles (YVL E.5 2019, req. 201; Chapter 4). For vessels, in general, the inspection areas required by ASME mostly match with those required by NP-084-15 and further defined by Russian nuclear utility Rosenergoatom in the standard program for VVER-1200 TPRG 1.1.3.09.1504-2019 which the individual plant operators apply in drawing up their plant-specific ISI programs. Discrepancies can be noticed in testing methods and testing volumes. For instance, RPV weld-on nozzles (discussed in subchapter 3.5) are included in standard ISI programs but for instrumentation nozzles only surface methods are applied, whereas volumetric testing is required by ASME (TPRG 1.1.3.09.1504-2019 2019, Table 7.1; ASME BPVC XI 2019, Table IWB-2500-1 B-D). Also, the requirements for examination volume differ greatly, ASME requiring a much larger area of the base metal adjacent to weld being inspected.

Risk informed in-service inspection (RI-ISI) programs, such as required for piping by YVL, are not yet applied in Russia. However, a GOST standard has lately been released which largely is an interpretation of ASME XI appendix R method B[25]. Being a rigorous multidisciplinary process, development of an RI-ISI program for VVER-1200 can be expected to be challenging due to limited experience in Russia.

The basic principle for defining the periodicity (when and how much) of performing ISI lies on the concept of dividing the operational lifetime of NPP into inspection intervals, such as 10 years[26], and further dividing each interval into three inspection periods, such as 3 or 4 years. By the end of each interval, the inspection areas shall be inspected in full. By the end of each inspection period, a certain amount of inspections of each area shall be done. Also, upper limits are set as to how much inspections can be credited for each period to ensure the inspections are divided evenly within the interval. (ASME BPVC XI 2019, Article IWB-2400).

NP-084-15 introduced a 8-year interval into Russian nuclear regulations with a requirement that the inspections shall be divided within the interval without further specifying how[27] (NP-084-15 2015, Table 1). Until the release of NP, the requirements for ISI were given in PNAE G-7-008-89 and were based on the number of operating hours, translating into roughly 4 years for group A, after which the components would have to be inspected (PNAE G-7-008-89 1990, Subchapter 7.6). It can be noted the standard program for VVER-1200 still follows the 4-year inspection interval instead of a 8-year interval allowed by NP-084-15. Feasibility of changing the inspection periodicity has been questioned by All-Russian Research Institute for NPP Operation VNIIAES, part of Russian nuclear utility Rosenergoatom (Mikhalchuk - Getman 2013).

Paramount to the effectiveness of ISI is using such inspection systems that are proven to be able to detect the anticipated defects, for instance by performance demonstration, such as practiced according to ASME XI Appendix VIII or inspection system qualification, as commonly practiced in European countries. As in several countries around the world, according to YVL E.5, acting as guidelines for the qualification process in Finland is the European Methodology for Qualification of Non-Destructive Testing (EQMD) and recommended practices (RP) issued by European Network

[25] Also referred to as the EPRI method after the original developer, Electric Power and Research Institute of USA.
[26] In the case of Finland, possibly 8 years to fulfill Pressure Equipment Act 16.12.2016/1144 and YVL E.3 chapter 12 requirements for internal inspection of pressure vessel.
[27] Examination schedule according to NP-084-15 bears a vague resemblance to ASME XI periodicity rules up to 2006 as to variable interval length but does not specify the minimum and maximum percent of examinations completed.

for Inspection and Qualification, ENIQ (YVL E.5 2019, req. 507). Implementation of EQMD and RP guidelines in fulfilling YVL E.5 requirements is described in Finnish Methodology for Qualification of PSI/ISI NDT-Inspection Systems according to STUK YVL E.5 scheme (FIMEQ, 2019).

Qualification of inspection systems is a time-consuming and complex process which starts from defining the input information including location, orientation, depth and length of defects that shall, with high probability, be detected and results in an assessment on the performance of inspection system based on theoretical justification (technical justification,) and practical trials on test pieces containing defects simulating the postulated defects ((YVL E.5 2019, Subchapters 6.3, 6.5, 6.6; ENIQ RP 5 2018; ENIQ RP 2 2018). The process is overseen and assessment is done by an impartial Qualification Body (YVL E.5 2019, Subchapter 5.3, annex D; ENIQ RP 7 2018). Differing from requirements set to third parties and certification bodies in YVL E.3, YVL E.5 states the qualification body shall be accredited by the Finnish Accreditation Centre FINAS without the possibility of recognizing any foreign accreditation bodies (YVL E.5 2019, req. 520).

General principles of the ENIQ qualification scheme were introduced to Russia by IAEA in the publication “Qualification of In-Service Inspection Systems for WWER Nuclear Power Plants” in 1998. Just comparatively recently, based on Rosenergoatom technical document RD EO 1.1.2.25.0487-2015, a standard GOST R 50.04.07-2018 has been issued describing the qualification process in Russia, which in general follows the ENIQ scheme. In fact, one can recognize that GOST requirements for the contents of input information, technical justification, and specification of test pieces for practical trials originate from respective ENIQ RP’s (GOST R 50.04.07-2018, appendices A, B, G; ENIQ RP 2 2018; ENIQ RP 5 2018). GOST R does not recognize the concept of qualification body. Instead, the tasks which would be in the scope of qualification body according to YVL E.5, are allocated to the qualification committee and head material organization Cniitmash - a practice recognized also from welding procedure and personnel qualification discussed earlier.

It is known that certain practical experience in conducting qualifications of in-service inspection systems following the ENIQ general principles has lately been gained in Russia, but it is not known how the process relates to that in Finland in practice (Razygraev – Razygraev – Skorobogatykh – Kunavin – Evtushenko – Primkov – Tsukanov – Abutalipov - Mikhailov - Starodubtsev 2019).

The impartiality, division of responsibilities between parties, and the requirements for qualification body are unambiguously defined in YVL E.5. It is not likely that an alternative could be convincingly justified.

8 CONCLUSIONS

The safety of pressure equipment and the integrity of its welds relies on several interlinked factors. Quantifying the relevance of each parameter is not possible and thus making irrefutable conclusions on the fulfilment of safety requirements is complicated.

In certain aspects, the requirements of YVL guides are straightforward and should not cause dispute. Such are the requirements for supervision over qualification, certification, and manufacturing. In other words - how and to which extent it shall be ensured that the requirements and procedures defined in the documentation are followed in reality and how testing results are validated. A statement that less impartial control over processes is as good as or better than more would not be convincing. This, for instance, poses an issue regarding the welding procedure qualifications, since, even should Russian qualification practice be considered acceptable in other regards, the existing procedure qualifications are not performed under third party supervision, and thus do not fulfill YVL requirements. Similarly, though not indisputably, testing scope and applied methods generally are well comparable, taken the requirements are defined correctly considering the differences in weld classification principles.

Other aspects require a more qualitative approach to assess and are less ambiguous. Such is fulfilling the quality management system requirements generally - demonstrating the equivalence of Russian code and standards to those listed in the international welding quality management standard including standards applicable to procedure- and personnel qualifications and testing.

One could claim that picking and combining the most stringent requirements from each available code and standard would certainly guarantee the fulfilment of each of these. Such an approach, In addition to being difficult to justify economically, would lead to detachment of requirements from the design code and introduction of new practices which would not necessarily serve the purpose of assuring safety. Furthermore, the determination of which is the more stringent requirement, in many cases, is not ambiguous. With certainty, it can only be concluded that the practices differ. NDT acceptance criteria is a good example of a topic that may tempt into making superficial quantitative comparisons but in fact, comprises an array of problems.

Statements on the superiority of one code or standard over another should be treated with reservations as due to differences in approaches as it is rather easy to support any pre-determined results and convictions one might have.

There is no simple and definitive answer to the question of whether applicable Russian practices conform to corresponding Western codes and standards. The complexity of the problem lies in comprehending the entity and the dependencies between its parts - design, execution, quality management, testing. Adding to the complexity, Russian code and nuclear standards give relative freedom to the designer, material organization, and manufacturer in defining the requirements, rendering any comparison between codes and standards inconclusive. Hence, a critical factor, but perhaps the most difficult to assess beforehand, is how exactly are the requirements and procedures applied in practice.

Based on all above, while a comparison of requirements is essential for perspective, the need for effort-consuming case-by-case assessments remains, the outcome of which relies on multidiscipline expert discussions without losing focus on the entity or caving into bias. Challenges posed by historical and cultural differences shall not be underestimated. It is, however, evident that even though the experience of supplier and track record of VVER type reactors are well acknowledged, fulfilment of Finnish safety requirements requires a more tailored approach than in most projects in the supplier’s portfolio.

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APPENDICES

APPENDIX 1 – Comparison of codes and standards – classification of welded joints

APPENDIX 2 – Comparison of codes and standards – welding procedure qualification

APPENDIX 3 – Comparison of codes and standards – qualification and certification of welders

APPENDIX 4 – Comparison of codes and standards – NDT: scope of examination

APPENDIX 5 – Comparison of codes and standards – VT: execution and acceptance criteria

APPENDIX 6 – Comparison of codes and standards – PT: execution and acceptance criteria

APPENDIX 7 – Comparison of codes and standards – MT: execution and acceptance criteria

APPENDIX 8 – Comparison of codes and standards – RT (plate arrangement): execution and acceptance criteria

APPENDIX 9 – Comparison of codes and standards – UT (Pulse-Echo, ferritic BW): execution and acceptance criteria

APPENDIX 10 – Applicable DT-standards

<table>
<tr><th>YVL</th><th>ASME</th><th>RCC-M</th><th colspan="2">EN</th></tr>
<tr>
<td>Component safety classes 1, 2, & 3

Main welds of main parts
Welded coatings and main welds of supports
Other welds

(YVL E.3 2019, Annex B, Table 2)</td>
<td>Component classes 1, 2 & 3

Weld categories:

Category A – longitudinal welds of shells, transitions heads, nozzles. circumferential welds connecting heads and nozzles

Category B – circumferential welds of shells, transitions heads, nozzles

Category C - Welds connecting flanges or tubesheets, to main shell, to formed heads, to transitions in diameter, to nozzles.

Category D - Welds connecting nozzles to shells, transitions, heads.

(ASME BPVC III 2015, i. NB-3350)</td>
<td>Weld classes 1, 2, 3

Further divided by joint types.</td>
<td>Testing groups

Groups 1, 2 & 3 - as selected by designer.

Two subgroups each depending on material crack-sensitivity

Groups 1c & 3c – parts subjected to creep (additional requirements in Annex F)

Group 4 – as selected by designer but limited to low pressure and group 2 fluids.

Weld groups M, C, E, TS, T, S, F, N, B based on joint type.

(SFS-EN 13445-3:2014, annex A; SFS-EN 13445-5:2014, Subchapter 5.7; annex A)</td>
<td>Piping category 0
Piping category I
Piping category II
Piping category III

Further divided by weld types:

Circumferential welds
Branch welds
Socket/fillet welds
Seal welds

(SFS-EN 13480-1:2017, Table 5.1-1)</td>
</tr>
<tr><th colspan="5">NP*</th></tr>
<tr><td colspan="5">Component groups A, B & C

Weld category I - welded joints of equipment and pipelines of group A;

Weld category II - welded joints of equipment and pipelines of group B, working in contact with a radioactive coolant;

subcategory IIa - welded joints operating under pressure above 5 MPa;

subcategory IIv - welded joints operating under pressure up to and including 5 MPa;</td></tr>
</table>

Weld category III - welded joints of equipment and pipelines of group B that do not work in contact with a radioactive coolant, as well as welded joints of equipment and pipelines of group C. subcategory IIIa - welded joints operating under pressure above 5 MPa; subcategory IIIv - welded joints operating under pressure above 1.7 MPa up to and including 5 MPa; subcategory IIIs - welded joints operating under pressure from 1.7 MPa and below atmospheric (under vacuum). (NP-105-18 2018, Chapter III; i. 17 & 18)

Notes:

* There are no differences between relevant classification principles of NP-105-18 and PNAE G-7-010-89.

Applicable code / standard	YVL E.3 / SFS-EN ISO 15614-1:2017	NP-105-18 / GOST R 50.04.03-2017*
Certification body and supervision of qualification	Certification body accredited against EN ISO/IEC 17020. Accreditation shall be covered by the Multilateral Agreements (MLA) or Mutual Recognition Arrangements (MRA). YVL E.3 2019, annex A, Table 3)	General material organization and a qualification committee approved by the material organization. Committee may include representatives from design organization, nuclear authority, operator and other interested parties. (GOST R 50.04.03-2017, items 5.1, 5.2; GOST 50.04.01-2018, i. 6.2.9)
Range of qualification	Classification of weld is not relevant. Same requirements apply for all welds.	**Weld classification** Qualification of weld of higher category covers welds of lower categories. Qualification of weld of specific component or piping may cover other similar welds provided that other rules for qualification range are fulfilled. (GOST R 50.04.03-2017, items 6.4.2.11; 12.2; 12.8)
	Parent material group: Ranges of qualification based on material groups according to ISO/TR 15608 according to Tables 5 & 6 of ISO 15614. Separate welding procedure qualifications are required for each parent material or parent material combinations not covered by the grouping system. (SFS-EN ISO 15614-1:2017, Subchapter 8.3.1)	**Parent material grade** qualification covers base materials for which same welding consumables are used according to NP. (GOST R 50.04.03-2017, i. 12.1)
	Filler material, manufacturer/trade name, designation Qualification covers filler materials if, according to the designation in the appropriate international standard for the filler material, they have equivalent mechanical properties. SFS-EN ISO 15614-1:2017, Subchapter 8.4.4)	**Welding consumable grades** qualification covers consumables that can be used to weld the same base materials according to regulatory documents. (GOST R 50.04.03-2017, i. 6.4.2.3)

<table>
<tr>
<td></td>
<td>
Thickness, butt welds:
<table>
<tr><td>Test piece thickness</td><td>Single run</td><td>Multi-run</td></tr>
<tr><td>t ≤ 3</td><td>0,5 t to 2 t</td><td>0,5 t to 2 t</td></tr>
<tr><td>3 < t ≤ 12</td><td>0,5 t (3 min) to 1,3t</td><td>3 to 2 t</td></tr>
<tr><td>20 < t ≤ 40</td><td>0,5 t to 1,1 t</td><td>0,5 t to 2 t</td></tr>
<tr><td>40 < t ≤ 100</td><td></td><td>0,5 t to 2 t</td></tr>
<tr><td>t > 100</td><td></td><td>50 to 2 t</td></tr>
</table>
Thickness, fillet welds:
<table>
<tr><td>Test piece thickness</td><td>Material thickness</td><td>Throat thickness</td></tr>
<tr><td>t ≤ 3</td><td>0,7 t to 2 t</td><td rowspan="3">0,75 a to 1,5 a (single run, no restrictions for multi-run)</td></tr>
<tr><td>3 < t < 30</td><td>3 to 2 t</td></tr>
<tr><td>t ≥ 30</td><td>≥5</td></tr>
</table>
(SFS-EN ISO 15614-1:2017, para. 8.3.2.2)
</td>
<td>
Thickness

t ≤ 3 mm;
3 < t ≤ 10 mm;
10 < t ≤ 50 mm;
t > 50 mm.

Qualification of 10 < t ≤ 50 mm also covers 3 < t ≤ 10 mm.

For T-joints, thickness ranges may be disregarded for the piece being welded to (equivalent of t2 in ISO 15614 figure 3.

Standard does not include ranges for fillet welds.

(GOST R 50.04.03-2017, items 6.4.2.4, 12.3)
</td>
</tr>
<tr>
<td></td>
<td>
Pipe and branch connect diameters:

Range of qualification

≥0,5 D (D is diameter of test piece)

D >500 mm is covered by qualification on plate.

(SFS-EN ISO 15614-1:2017, Subchapter 8.3.3)
</td>
<td>
Radius of workpiece

≤ 12.5 mm;
12.5 < t ≤ 50 mm;
50 < t ≤ 250 mm;
> 250 mm (including flat parts).

(GOST R 50.04.03-2017, i. 6.4.2.5)
</td>
</tr>
<tr>
<td></td>
<td>
Type of joint/weld

Full penetration butt welds qualify full and partial penetration butt welds and fillet welds in any type of joints. Fillet welds shall be qualified separately if predominant in production.
</td>
<td>
Type of joint

T-joint, fillet weld and lap joint are covered with a single qualification except for nozzle and branch joints.
</td>
</tr>
</table>

	Fillet welds qualify fillet welding only; butt welds in T-joints with full penetration qualify full and partial penetration butt welds in T-joints and fillet welds; (SFS-EN ISO 15614-1:2017, Subchapter 8.4.3)	Joint preparation: bevel angle up to 8 included bevel angle over 8 (GOST R 50.04.03-2017, items 6.4.2.6, 6.4.2.7)
	Preheat and interpass temperatures and post-heating (8.4.8, 8.4.9, 8.4.10) Recorded preheating temperature shall not be decreased more than than 50 °C Recorded interpass temperature shall not be increased more than than 50 °C except for material groups 8, 10, 41, 48 for which the highest interpass temperature reached in the welding of procedure test is the upper limit. Post-heating temperature and duration shall not be reduced. Post-heating may be added. (SFS-EN ISO 15614-1:2017, Subchapters 8.4.8, 8.4.9, 8.4.10)	**Pre- and post-heating** Same pre- and post-heating is applied as defined in “technical documentation” (welding procedure). (GOST R 50.04.03-2017, i. 8.3.8.4)
	Heat-treatment Addition or deletion of post-weld heat-treatment is not permitted. (SFS-EN ISO 15614-1:2017, Subchapter 8.4.11)	**Heat treatment** Qualification for materials subject to heat treatment covers qualification of materials not subject to heat treatment. (GOST R 50.04.03-2017, i. 12.7)
Test-piece	welding procedure test:– standardized test piece, plate, T-joint (thickness range according to or pipe branch pre-production welding test - non-standard test piece representative of the production conditions (SFS-EN ISO 15614-1:2017, Subchapter 6.3)	Test pieces are not standardized. Test piece is specified in qualification program developed by the GMO for specific application. Dimensions of test piece shall allow for conducting all testing twice in case re-testing is required. (GOST R 50.04.03-2017, i. 8.3.8.1)
Conditions for welding the test-piece	In case requirements for impact toughness and hardness apply, welding two test pieces in different welding positions is required – one in lowest and one in highest heat input position. Vertical down welding is qualified by specific test piece.	Test-piece shall be welded in similar conditions as production weld and in position that is considered most difficult. Conditions are determined by the committee.

	(SFS-EN ISO 15614-1:2017, Subchapter 8.4.2)	(GOST R 50.04.03-2017, i. 8.3.8.3)
Scope of NDT**	Methods and acceptance criteria defined in ISO 15614-1. Acceptance criteria: quality level B (ISO 5817) and respective method specific levels according to ISO 17635. Exceptions apply to certain geometric imperfections. **Butt joint and T-joint, full penetration** VT RT or UT MT or PT **Fillet weld:** VT MT or PT (SFS-EN ISO 15614-1:2017, Subchapters 7.1, 7.5; Tables 2, 4)	Same methods and acceptance criteria as for the welded joint for which the procedure is being qualified. Example: **Category I butt weld** VT RT or UT MT or PT **Fillet weld** VT MT or PT (GOST R 50.04.03-2017, i. 10.4)
Scope of DT**	**Butt joints, full penetration** Transverse tensile test Transverse bend test Impact test Hardness test Macroscopic examination **T- joint, full penetration and fillet weld**: Hardness test Macroscopic examination (SFS-EN ISO 15614-1:2017, Subchapter 7.1; Table 2)	**Butt joints:** tensile test at 20C and, if required, at elevated temperature bend test determination of resistance to intergranular corrosion (austenitic steels) **Fillet welds:** macroscopic examination (GOST R 50.04.03-2017, i. 10.7.3)

Notes: * There are no relevant differences between the qualification principles and ranges of GOST R 50.04.03-2017 and PNAE G-7-010-89 chapter 3 and appendix 1.

** Applicable ISO and GOST R testing standards are referred to in respective qualification standards, thus, execution and acceptance criteria differ (see chapter 6 and appendices 5-10).

Applicable code / standard	YVL E.3 / SFS-EN ISO 9606:2017	PNAE G-7-003-87
Certification body and supervision of qualification	Certification body accredited against EN ISO/IEC 17024. Accreditation shall be covered by the Multilateral Agreements (MLA) or Mutual Recognition Arrangements (MRA). (YVL E.3 2019, annex A, Table 3)	Qualification committee consisting of specialists in the field of welding and inspection. Committee is formed by the manufacturer itself. (PNAE G-7-003-87 1988, Chapter 1)
Validity of qualification certificate	One of the following: a) Retesting every 3 years b) Two welds tested volumetrically every 2 years c) Continuous, documented and satisfactory working for a manufacturer which is certified according to ISO 3834-2 or ISO 3834-3. (SFS-EN ISO 9606-1:2017, Subchapter 9.3)	Requalification every 2 years (PNAE G-7-003-87 1988, i. 5.4)
Range of qualification	Classification of weld is not relevant. Same requirements apply for all welds.	**Weld category** Welders are qualified for each category separately. Qualification for welding higher category covers welding of lower category welds. (PNAE G-7-003-87 1988, i. 2.2.2)
	Welding processes Each test normally qualifies only one welding process. (SFS-EN ISO 9606-1:2017, Subchapter 5.2)	**Welding processes** Welders are qualified for each welding process separately. (PNAE G-7-003-87 1988, i. 2.2.3)

	Base material is not an essential variable for qualification.	**Parent material groups** Welder qualification scope is determined by material groups. Material groups: 1 – Perlitic steels, yield strength up to 315MPa, without pre-heating 2 - Perlitic steels, yield strength up to 315MPa, with pre-heating 3 - Perlitic steels, yield strength over 315MPa: 4 –Steels with high Cr content, martensitic or martensitic-ferritic 5 - Steels with high Cr content,ferritic 6 – Austenitic stainless steels 7 – NI-alloys and NI-based steels 8 – Al and its alloys 9 – Cu and its alloys 10 – Zr and its alloys 11 – Ti and its alloys Qualification for groups 2...5 also covers numerically lower groups and combi-nations of these. Qualification for group 6 also covers group 1 and welding of group 6 materials to groups 1…5 materials. (PNAE G-7-003-87 1988, Table 1; i. 6.2)
	Filler material Qualification scope is determined by filler material groups. FM1 - Non-alloy and fine grain steels FM2 - High-strength steels FM3 - Creep-resisting steels Cr < 3,75 % FM4 - Creep-resisting steels 3,75 ≤ Cr ≤ 12 % FM5 - Stainless and heat-resisting steels FM6 - Nickel and nickel alloys	Filler material is is not an essential variable for qualification.

	Range of qualification for groups are given in Table 3. Additionally qualification scope is determined by filler material type (type of covering for electrodes, type of wire/rod) Range of qualification for filler material types are given in tables 4 & 5. (SFS-EN ISO 9606-1:2017, Subchapter 5.5)	
	Thickness, butt welds: Deposited thickness — Range of qualification s < 3 — s to 3 mm or s to 2s, whichever is greater 3 ≤ s ≤ 12 — 3 mm to 2s t ≥ 12 — ≥ 3 mm **Thickness, fillet welds:** Test piece thickness — Material thickness t < 3 — t to 2t, or 3, whichever is greater t ≥ 3 — t ≥ 3 (SFS-EN ISO 9606-1:2017, Table 6)	**Thickness** Thickness ranges t ≤ 3 mm; 3 < t ≤ 10 mm; 10 < t ≤ 50 mm; t > 50 mm. Qualification ranges depend on process. MAW: Qualification for 3 < t ≤ 10 mm also covers thicknesses 10 < t ≤ 50 mm. Qualification for > 10 mm covers all thicknesses > 3 mm TIG: Qualification for 3 < t ≤ 10 mm also covers t ≤ 3 mm and welding of root pass. SAW: Qualification for > 10 mm covers all thicknesses (PNAE G-7-003-87 1988, items. 6.4-6.8)

	Pipe diameters Diameter of the test piece — Range of qualification D ≤ 25 — D to 2D D > 25 — ≥ 0,5D (25 mm min.) D > 25 mm covers welds in plates; Qualification on plate covers D > 500 mm. (SFS-EN ISO 9606-1:2017, Table 6)	**Diameter of workpiece** Diameter ranges ≤ 25 mm; 25 < D ≤ 100 mm; 100 < t ≤ 500 mm; MAW: Qualification on pipe covers all larger diameters. Qualification on pipe covers plates Qualification on plate covers D > 500 mm. SAW: Qualification on any diameter pipe covers all pipes and plates. (PNAE G-7-003-87 1988, i. 2.2.5)
	Type of joint/weld Butt welds do not qualify fillet welds or vice versa. Qualification in combination is possible. Pipe welds qualify branch welds > 60 degrees (SFS-EN ISO 9606-1:2017, Subchapter 5.4)	**Type of joint** Qualification test weld butt joint covers fillet welds. (PNAE G-7-003-87 1988, items 3.1, 6.13)
	Welding positions According to ISO 9606 tables 9 (BW) and 10 (FW). (SFS-EN ISO 9606-1:2017, Subchapter 5.8)	**Welding positions** According to PNAE G-7-003-87 table 2. (note also above “type of joint”) (PNAE G-7-003-87 1988, items 6.12)
Test-piece	Standardized test piece – plate, T-joint and pipe Length for plate and T-joint at least 200mm.	Quantity, dimensions and configuration of test piece is determined by the qualification committee.

	Specific test-piece may be required if standardized test pieces are not applica-ble. (SFS-EN ISO 9606-1:2017, Subchapter 6.2)	Length of plate test piece shall be at least 200mm for manual welding and 400mm for mechanized welding. Number of pipe test pieces shall be at least 5 for D≤ 25 mm; 2 for 25 < D ≤ 100 mm and 1 for D > 100 (PNAE G-7-003-87 1988, items 3.6; 3.6.1; 3.6.2)
Conditions for welding the test-piece	At least one stop and restart in the root run and in the capping run. Removing minor imperfections is allowed except for capping run. PWHT may be omitted at discretion on manufacturer. (SFS-EN ISO 9606-1:2017, Subchapter 6.3)	For material groups 2 & 3 pre- and post-heating shall be applied. For material groups 4 & 5 pre- and post-heating shall be applied if necessary. Not further specified. (PNAE G-7-003-87 1988, i. 3.5)
Scope of NDT	**Butt joint, plate or pipe:** VT RT (may be replaced by bend or fracture test except for processes 131, 135, 138 and 311.) or UT (≥8 mm and ferritic steels only) **Fillet weld and branch joint:** VT (SFS-EN ISO 9606-1:2017, Subchapter 6.4)	VT RT or UT (except t ≤ 5,5mm and material group 6) RT or UT may be replaced by macroscopic examination. MT or PT (except category III welds) (PNAE G-7-003-87 1988, items 4,1; 4,2)
Scope of DT	**Butt joint, plate or pipe:** Bend test or fracture test (may be replaced by RT) **Fillet weld and branch joint:** Fracture test (may be replaced by macroscopic examination or, for pipes RT, if applicable) (SFS-EN ISO 9606-1:2017, Subchapter 6.4)	Not mandatory. (PNAE G-7-003-87 1988, Chapter 4)

Notes: * Applicable ISO and GOST R testing standards are referred to in respective qualification standards, thus, execution and acceptance criteria differ (see chapter 6 and appendices 5-10).

<table>
<tr><td>RCC-M class 1</td><td></td><td colspan="4">Ferritic steels</td><td colspan="2">Austenitic steels</td></tr>
<tr><td>ASME Class 1</td><td></td><td colspan="2">surface</td><td colspan="2">volumetric</td><td>surface</td><td>volumetric</td></tr>
<tr><td>NP category I</td><td></td><td>PT</td><td>MT</td><td>UT</td><td>RT</td><td>PT</td><td>RT</td></tr>
<tr><td rowspan="3">BW
plates</td><td>RCC-M Table S 7710.1 & S 7710.2</td><td></td><td>X</td><td>X (plate t≥10mm)</td><td>X</td><td>X</td><td>X</td></tr>
<tr><td>ASME NB-5210, NB-5221, NB-5222</td><td colspan="2">X</td><td>-</td><td>X</td><td>X</td><td>X</td></tr>
<tr><td>NP-105-18 Tables N2 & N3</td><td colspan="2">X</td><td>X (t>5,5mm)</td><td>X</td><td>X</td><td>X</td></tr>
<tr><td rowspan="4">Piping, nozzles, pipe branches, flanges</td><td>RCC-M Table S 7710.2</td><td colspan="2">X</td><td>X (d≥114mm, main scanning surface t≥20mm)</td><td>X</td><td>X</td><td>-</td></tr>
<tr><td rowspan="2">ASME NB-5231, NB-5241</td><td colspan="2" rowspan="2">X</td><td>-</td><td>X (BW)</td><td rowspan="2">X</td><td rowspan="2">X</td></tr>
<tr><td colspan="2">X (corner-welded)</td></tr>
<tr><td>NP-105-18 Tables N2 & N3</td><td colspan="2">X</td><td>X (BW d≥100mm, t>5,5mm)</td><td>X (radiographic thickness ≤100mm)</td><td>X</td><td>X</td></tr>
</table>

		Ferritic steels				Austenitic steels	
RCC-M class 2		surface		volumetric		surface	volumetric
NP categories IIa, IIv		PT	MT	UT	RT	PT	RT
BW plates	RCC-M Table S 7720.1 & S 7720.2	X (MT if t>50mm. PT or MT in other cases)		X (t≥50mm)	X	X	X
	NP-105-18 t. N2 & N3 cat. IIa	X		X (t>5,5mm)	X	X	X
	NP-105-18 t. N2 & N3 cat. IIv	50%		X (t>5,5mm)	X (t≤5,5mm) / 50% (t>5mm)	X	X
Piping, nozzles, pipe branches, flanges	RCC-M Table S 7720.2	X		X (d≥114mm, main scanning surface t≥50mm)	X	X	X
	NP-105-18 t. N2 & N3 cat. IIa	X		X (BW, d≥100mm, t>5,5mm)	X (t≤5,5mm & t>5,5mm d>325mm) / 50% (t>5,5mm, d≤325mm)	X	X
	NP-105-18 t. N2 & N3 cat. IIv	50%		X (BW, d≥100mm, t>5,5mm)	X (t≤5,5mm, d>325mm) / 50% (t≤5,5mm, d≤325mm & t>5,5mm, d>325mm) / 25% (t>5,5mm, d≤325mm)	X	X (d>325mm) / 50% (d≤325mm)

		Ferritic steels				Austenitic steels	
RCC-M class 3		surface		**volumetric**		surface	volumetric
NP categories IIIa, IIIv		PT	MT	UT	RT	PT	RT
BW plates	RCC-M Table S 7731 & S 7732	X		10% of length of each lot (UT applicable for t≥8mm)		X	X
	NP-105-18 t. N2 & N3 cat. IIIa	-		X (t>5,5mm)	50%	X	50%
	NP-105-18 t. N2 & N3 cat. IIIv	-		25% (t>5,5mm)	50% (t≤5,5mm) / 25% (t>5mm)	X	50%
Piping, nozzles, pipe branches, flanges	RCC-M Table S 7731 & S 7732	X		1 weld out of 10 of each lot (UT applicable for t≥8mm)		X	X
	NP-105-18 t. N2 & N3 cat. IIIa	-		X (BW, d≥100mm, t≥2,0mm)	50% (d>325mm) / 25% (d≤325mm)	X	50% (d>325mm) / 25% (d≤325mm)
	NP-105-18 t. N2 & N3 cat. IIIv	-		50% (BW, d≥100mm 2,0≤t≤5,5mm) 25% (BW, d≥100mm, t>5,5mm)	50% (t≤5,5mm, d>325mm) / 25% (t≤5,5mm, d≤325mm & t>5,5mm)	X	50% (d>325mm) / 25% (d≤325mm)

Note: scope of testing required by NP-105-18 is somewhat more conservative than that required by PNAE G-7-010-89 concerning UT of 2-5mm category III piping weld

Applicable code / standard	NP-105-18; GOST R 50.05.08-2018	RCC-M	SFS-EN ISO 5817
Examination conditions	General illumination ≥500lx local illumination ≥1250lx Viewing distance 250-350mm (200-600mm if not accessible) Magnification ≤7x (GOST R 50.05.08-2018, Subchapter 7.1)	Illumination ≥500lx Viewing distance ≤600mm Viewing angle ≥30° Magnification ≤6x (RCC-M 2015, paras. MC 7143, MC 7131)	Illumination ≥300lx (≥500lx preferred) Viewing distance ≤600mm Viewing angle ≥30° Magnification ≤5x (SFS-EN ISO 5817 2014, Chapter 4)
Acceptance criteria	Not permitted: Cracks (100), burn-through (510), worm-holes (2016), overlap (506), shrinkage cavities (202), undercut (501), lack of fusion or penetration (400), clustered porosity (2013), clustered inclusions (3013), spatter (602) Acceptance criteria for single inclusions and pores (2017) (Comprehensive acceptance criteria is given in Table N 4.1): Examples for 6, 12, 90 & 200mm for categories I / II / III: allowable single defect in mm (number of inclusions or pores allowed per 100mm). t=6mm: 0,5 (2) / 0.6 (3) / 0,8 (4) t=12mm: 1,0 (3) / 1,2 (4) / 1,5 (5) t=90mm: 1,5 (5) / 2,0 (6) / 2,5 (7) t=200mm: 1,5 (6) / 2,0 (7) / 2,5 (8)	Weld classes 1 & 2 Not permitted: Cracks (100), overlap (506), shrinkage cavities (202), undercut (501), lack of fusion or penetration (400), surface pores (2017) , clustered porosity (2013), clustered inclusions (3013), spatter (602), incompletely filled groove (511) except for joints welded in overhead position. Weld thickness: 1/10 of bead width + 1mm (max. 5mm) Excessive penetration (with backing run): 1/10 of bead width + 1mm Excessive penetration (without backing run): 1/20 of bead width + 0,5mm (max. 1,5mm). (RCC-M 2015, Chapter MC 7100)	Quality level B Not permitted: t>3mm: Cracks (100), lack of fusion or penetration (400), surface pores (2017), crater pipes (2025), overlap (506), root porosity (516), insufficient throat thickness (5214), stray arc (601). Additionally for t≤3: Root concavity (515), sagging (509), incompletely filled groove (511), undercut (501) Undercut (501) t>3: h ≤ 0,05 t, but max. 0,5 mm Root concavity (515)

	Root concavity (515) for pipe joints (comprehensive acceptance criteria is given in Table N 4.3): Examples are given for t=2mm / t= 6mm / t=12mm rotating workpiece: 0,4 / 0,8 / 1,2mm fixed workpiece: 0,6 / 1,0 / 0,15t (max 1,6mm) Excess penetration (504) for pipe joints: Ø≤25: 1,5mm 25<Ø≤150: 2,0mm Ø>150: 2,5mm Tolerances for weld geometry such as weld reinforcement, width, and weld toe are given separately in technical documentation. (NP-105-18 2018, appendix 4, items 1-8; Tables N4.1, N4.2, N4.3, N4.4, N4.5)		t>3: (short imperfections only) h ≤ 0,05 t, but max. 0,5 mm Excess penetration (504) t≤3: h ≤ 1 mm + 0,1 x width of root t>3: h ≤ 1 mm + 0,2 x width of root, (max. 3 mm). (SFS-EN ISO 5817 2014, Table 1)

Note: acceptance criteria defined by NP-105-18 is negligibly more conservative for 6-8mm category I welds than those required by PNAE G-7-010-89

Applicable code / standard	NP-105-18; GOST R 50.05.09-2018	RCC-M (ISO 3452-1, ISO 3452-2)	ASME BPVC III; ASME BPVC V article 6 & standard practice SE-165
Testing technique and products	Visible/colored or fluorescent. Recommended brands of products are specified appendix 1 of standard (all sensitivity level II products are colored). It is not recommended to mix products from different product families. (GOST R 50.05.09-2018, i. 6.1.1)	Visible/colored (Type II) or fluorescent (Type I) or dual purpose (Type III) the penetrant and excess penetrant remover shall be from a single manufacturer. Only approved product families shall be used. Products shall be type and batch tested. (SFS-EN ISO 3452-1. 2013, Subchapters 6.1, 6.2; Table 1)	Visible/colored (Type II) or fluorescent (Type I) Any liquid penetrant, remover and developer listed in QPL-25135/QPLAMS2644 can be used, regardless of the manufacturer. Intermixing of penetrants and emulsifiers from different manufacturers is prohibited. (ASME BPVC V 2015, Article 6, i. T-651)
Sensitivity level	Unless stated otherwise in design documentation, sensitivity class II is required. Sensitivity is verified on GOST-specific reference specimen which for sensitivity class II includes cracks with width of 1µm…10µm. (GOST R 50.05.09-2018, items 5.8, 5.9; Table 1; appendix B)	Colored products: sensitivity level at least 2 (ISO 3452-2, ISO 3452-3) Fluorescent products: 100% of 20µm discontinuities found, > 75% of 10µm discontinuities found. Sensitivity is verified on ISO reference specimens (ISO 3452-3) depending on examination technique (type of products). (RCC-M 2015, Chapter MC 4200)	Not specified in ASME BPVC. A reference to industry standard AMS 2644 is made but required sensitivity level is not specified. AMS 2644 does not include colored products.
Surface conditions	Surface shall be machined to R_a3,2. R_a6,3 is allowed if does not cause background that would hinder inspection. (GOST R 50.05.09-2018, items 8.1.4, 8.1.5)	Contaminants such as scale, rust, oil, grease or paint shall be removed. Ground and machined surfaces: R_a6,3 Weld surfaces at final or intermediate stage may be left as-welded. (RCC-M 2015, Chapter MC 4200; SFS-EN ISO 3452-1. 2013, para. 8.2.1)	No requirements for surface roughness. Surfaces may be as-welded. Surfaces shall be dry and free of all dirt, grease, lint, scale, welding flux, weld spatter, paint, oil, and other extraneous matter. (ASME BPVC V 2015, Article 6, i. T-642)

Temperature limits	-40°C…+40°C According to manufacturer recommendations. (GOST R 50.05.09-2018, i. 5.5)	+10°C...+50°C Special requirements for products and procedures apply for testing outside the specified temperature range. (RCC-M 2015, Chapter MC 4200; SFS-EN ISO 3452-1. 2013, Subchapter 8.3)	+5°C..+52°C Techniques for outside this temperature range require qualification. (ASME BPVC V 2015, Article 6, i. T-652)
Illumination	Color contrast techniques: Candelecsent lamps: general illumination ≥500lx, illumination on inspection area ≥2000lx Luminescence lamps General illumination ≥750lx, illumination on inspection area ≥2500lx Fluorescent techniques: UV-A ≥1 000 µW/cm2, visible light <20lx (GOST R 50.05.09-2018, Tables 2, 3)	Color contrast techniques: ≥500lx Fluorescent techniques: UV-A >1 000 µW/cm2, visible light <20lx (SFS-EN ISO 3452-1. 2013, paras. 8.7.1.2, 8.7.1.3)	Color contrast techniques: ≥1000lx Fluorescent techniques: UV-A >1 000 µW/cm2 (ASME BPVC V 2015, Article 6, items T-676.3, T-676.4)
Method of penetrant application	Brushing, rolling or spraying. (GOST R 50.05.09-2018, Subchapter 8.2.1)	Spraying, brushing, flooding, dipping or immersion. (SFS-EN ISO 3452-1. 2013, para. 8.4.1)	Dipping, brushing, flooding or spraying. (ASME BPVC V 2015, Article 6, i. T-671)
Penetrant dwell time	Minimum 5 minutes but not less than the manufacturer's recommended time. (GOST R 50.05.09-2018, i. 8.2.1.1)	5...60 min and shall not be less than the manufacturer's recommended time for the required sensitivity. (SFS-EN ISO 3452-1. 2013, para. 8.4.2)	Minimum 5 minutes. For temperatures +4...+10C minimum 20minutes is recommended. Penetrant shall not be allowed to dry. (ASME BPVC V 2015, Article 6, i. T-671; Table T-672)
Developing time	Dwell time is specified by testing product manufacturer. (GOST R 50.05.09-2018, i. 8.3.1)	10...30 min in normal temperature range (SFS-EN ISO 3452-1. 2013, para. 8.6.7)	Dwell time as recommended by manufacturer but minimum 10 minutes. (ASME BPVC V 2015, Article 6, i. T-675.3)

Acceptance criteria	Linear indications are not permitted Indications <0,6mm are not evaluated. Only single indications are allowed (distance betweem indications more than twice the longer dimension of smaller indication) Acceptance level for rounded indications are defined as three times the values for VT for dimensions and equal to values for VT for number of allowed inclusions per 100mm. Examples for 6, 12, 90 & 200mm categories I / II / III max. allowable indication in mm (number of indications allowed per 100mm) t=6mm: 1,5 (2) / 1,8 (3) / 2,4 (4) t=12mm: 3,0 (3) / 3,6 (4) / 4,5 (5) t=90mm: 4,5 (5) / 6,0 (6) / 7,5 (7) t=200mm: 4,5 (6) / 6,0 (7) / 7,5 (8) (NP-105-18 2018, appendix 4, items 15-20; Table N4.1)	(Corresponds to ISO 23277 acceptance level 1 for single indications.) Linear indications are not permitted Recording level: 2mm Acceptance level for rounded indications Classes 1, 2, 3: single indication 4mm; 3 indications less than 3mm apart Class 1: 5 or more indications in a rectangular area of 100cm^2 (major dimension of this area max. 20 cm with the area taken in the most unfavorable location relative to the indications being evaluated) Class 2: 8 or more indications in a rectangular area of 100cm^2 Class 3: 12 or more indications in a rectangular area of 100cm^2 Indications with distance between them less than twice the longer dimension of smaller indication are considered single indication. (RCC-M 2015, clauses S 7714.1, S7724.1, S7724.3)	Linear indications are not permitted. Only indications over 1,5mm shall be considered relevant. Acceptance criteria for rounded indications: Class 1 components single indication: 5 mm; 4 indications in a line separated by 1.5 mm or less; ten or more rounded indications in any 40 cm2 of surface (with the major dimension of this area max. 15 cm with the area taken in the most unfavorable location relative to the indications being evaluated). (ASME BPVC III 2015, i. NB-5350)

Note: acceptance criteria defined by NP-105-18 is negligibly more conservative for 6-8mm category I welds than those required by PNAE G-7-010-89.

Applicable code / standard	NP-105-18; GOST R 50.05.06-2018	RCC-M	ASME BPVC III; ASME BPVC V article 7
Magnetizing method and equipment	Circular (e.g wire etc), longitudinal (e.g yoke) or combined. (GOST R 50.05.06-2018, Subchapter 6.1)	Electric current flow apparatus (e.g prods); magnetic flow apparatus (e.g yoke), or fixed MT units AC or DC (RCC-M 2015, i. MC 5130)	Prods, longitudinal magnetization, circular magnetization, yoke, or multidirectional magnetization. (ASME BPVC III 2015, article 7, i. T-751)
Detection media	Fluorescent or visible, dry or wet. (GOST R 50.05.06-2018, Subchapter 6.2)	Fluorescent or visible dry powder or ink. (RCC-M 2015, i. MC 5135)	Fluorescent or visible dry powder or ink. (ASME BPVC III 2015, article 7, i. T-731)
Illumination	≥1000lx for visible media ≥2000µW/cm2 (=20W/m2) for fluorescent media (GOST R 50.05.06-2018, i. 7.1.8)	≥500lx for visible media UV light intensity ≥10W/m2 for fluorescent media in darkened room (no maximum value given) (RCC-M 2015, i. MC 5148)	≥1000lx for visible media ≥1000 µW/cm2 (=10W/m2) for fluorescent media in darkened room (no maximum value given) (ASME BPVC III 2015, article 7, items T-777.1, T-777.2)
Acceptance criteria	Linear indications are not permitted Only single indications are allowed (distance between indications more than twice the longer dimension of smaller indication) Acceptance level for rounded indications are defined as same as the values for VT. Examples for 6, 12, 90 & 200mm categories I / II / III max. allowable indication in mm (number of indications allowed per 100mm)	Linear indications are not permitted Recording level: 2mm Acceptance level for rounded indications: Classes 1, 2, 3 single indication 4mm; 3 or more aligned indications less than 3mm apart or extending for more than 20mm if 3…6mm apart (RCC-M 2015, items S7714.2, S7724.2, S7724.3)	Linear indications are not permitted. Only indications over 1,5mm are considered relevant. Acceptance criteria for rounded indications: Class 1 components single indication: 5 mm; 4 indications in a line separated by 1.5 mm or less; 10 or more rounded indications in any 40 cm2 of surface (with the major dimension of this area max. 15 cm with the area taken in the most unfavorable location relative to the indications being evaluated). (ASME BPVC III 2015, i. NB-5340)

	t=6mm: 0,5 (2) / 0.6 (3) / 0,8 (4) t=12mm: 1,0 (3) / 1,2 (4) / 1,5 (5) t=90mm: 1,5 (5) / 2,0 (6) / 2,5 (7) t=200mm: 1,5 (6) / 2,0 (7) / 2,5 (8) (NP-105-18 2018, appendix 4, Table N4.1)		

Note: acceptance criteria defined by NP-105-18 is negligibly more conservative for 6-8mm category I welds than those required by PNAE G-7-010-89.

Applicable code / standard	**NP-105-18; GOST R 50.05.07-2018**	**RCC-M**	**ASME BPVC III; ASME BPVC V article 2**	**SFS-EN ISO 17636-1; SFS-EN ISO 10675-1**
Radiation source and energy	X-ray: w≤100mm Se 75: 5≤w≤30mm Ir 192: 5≤w≤100mm Co 60: 30≤w≤150mm Accelerator: w≥80mm (GOST R 50.05.07-2018, appendix B, Table b.1)	X-ray ≤400kV: w<70mm Se 75: w<40mm Ir 192: w<100mm Co 60: w≥70mm Accelerator 1…3 MeV: w≥70mm Accelerator 4…6 MeV: w≥80mm Accelerator 8…12 MeV: w≥90mm (RCC-M 2015, Table MC 3142)	Not limited if IQI and density require-ments are met	X-ray ≤1000kV: w is limited by maximum tube voltage Se 75: 14≤w≤40mm Ir 192: 20≤w≤90mm Co 60: 60≤w≤150mm 1…4 MeV X-ray: 80≤w≤150mm 4…12 MeV X-ray: w≥80mm >10MeV X-ray: w≥100mm (SFS-EN ISO 17636-1 2013, Table 2)
Film systems clas-ses (acc. ISO 11699-1)	X-ray, w≤20: C4 X-ray, w>20: C5 Se 75, Ir 192, w≤30: C4 Ir 192 w>30: C5 Co 60 30…80mm: C4 Co 60 80…150mm: C5 Particle accelerator, 80<w≤150mm: C3 Particle accelerator, w>150mm: C4 (GOST R 50.05.07-2018, appendix B, Table b.1)	X-ray: up to C4 Se 75: C1 to C3 (outside class 1 and t > 16mm C4 is allowed) Ir 192: C1 and C2 Co60 t ≤ 300: C1 & C2 Co60 t > 300: up to C5 (RCC-M 2015, i. MC 3312.4)	Not specified.	X-ray ≤150kV: C3 X-ray 150kV…500kV, w≤50mm & X-ray 500kV…1000kV, w≤75mm: C4 X-ray 250kV…500kV, w>50mm & X-ray 500kV…1000kV, w>75mm: C5 Se 75, IR 192, Co 60 w≤100mm: C4 Co 60 w>100mm: C5 X-ray energy 1MeV…4MeV, w≤100mm: C3 X-ray energy 1MeV…4MeV, w>100mm: C5 X-ray energy 4MeV…12MeV, w≤300mm: C4 (SFS-EN ISO 17636-1 2013, Table 3)

Geometric unsharp-ness (Ug)	GOST R sets minimum source-to-object distance in relation to radiographic thickness of object, focal spot size and IQI requirement. (GOST R 50.05.07-2018, appendix G)		X-ray ≥ 400kV, Se 75, Ir 192: 0,30mm Co 60: 0,60mm Accelerator: 1,0mm (RCC-M 2015, Table MC 3143)	t ≤ 50: 0.51mm 50< t ≤75: 0.76mm 75< t ≤100: 1.02mm t>100: 1.78mm (ASME BPVC V 2015, article 2, i. T-274.2)	ISO standard sets minimum source-to-object distance in relation to object-to-film distance and focal spot size. (SFS-EN ISO 17636-1 2013, Subchapter 7.6)
IQI	Category I: 1,0 < t ≤ 4,5: 0,10mm 4,5 < t ≤ 12: 0,20mm 12 < t ≤ 21: 0,30mm 21 < t ≤ 30: 0,40mm 30 < t ≤ 40: 0,50mm 40 < t ≤ 55: 0,60mm 55 < t ≤ 75: 0,75mm 75 < t ≤ 100: 1,00mm 100 < t ≤ 125: 1,25mm 125 < t ≤ 150: 1,50mm 150 < t ≤ 200: 2,00mm 200 < t ≤ 250: 2,50mm 250 < t ≤ 300: 3,00mm 300 < t ≤ 350: 3,50mm	Category II: 1,0 < t ≤ 3,5: 0,10mm 3,5 < t ≤ 10: 0,20mm 10 < t ≤ 18: 0,30mm 18 < t ≤ 24: 0,40mm 24 < t ≤ 32: 0,50mm 32 < t ≤ 44: 0,60mm 44 < t ≤ 60: 0,75mm 60 < t ≤ 80: 1,00mm 80 < t ≤ 100: 1,25mm 100 < t ≤ 120: 1,50mm 120 < t ≤ 140: 1,75mm 140 < t ≤ 160: 2,00mm 160 < t ≤ 200: 2,50mm 200 < t ≤ 240: 3,00mm 240 < t ≤ 280: 3,50mm t > 280: 4,0mm	Wire IQI, source side: t ≤ 3: 0,10mm 3 < t ≤ 6: 0,125mm 6 < t ≤ 10: 0,16mm 10 < t ≤ 16: 0,20mm 16 < t ≤ 25: 0,25mm 15 < t ≤ 32: 0,32mm 32 < t ≤ 40: 0,40mm 40 < t ≤ 80: 0,50mm 80 < t ≤ 125: 0,60mm 125 < t ≤ 160: 0,80mm 160 < t ≤ 200: 1,00mm 200 < t ≤ 250: 1,60mm 250 < t ≤ 320: 2,00mm 320 < t ≤ 400: 2,50mm (RCC-M 2015, i. MC 3160; Table MC 3162.1)	Wire IQI, source side: t ≤ 10: 0.15mm 10 < t ≤ 13: 0.25mm 13< t ≤16: 0.33mm 16< t ≤25: 0.41mm 25< t ≤32 0.51mm 32< t ≤38: 0.64mm 38< t ≤50: 0.81mm 50< t ≤75: 1.02mm 75< t ≤100: 1.27mm 100< t ≤150: 1.60mm 150< t ≤200: 2.54mm 200< t ≤250: 3.20mm 250< t ≤300): 4.06mm 300< t ≤400: 6.35mm 400< t ≤ 500: 8.13mm (ASME BPVC III 2015, Table NB-5111-1)	Image quality class B Wire IQI, source side: t < 1,5 W19 (0,05mm) 1,5 ≤ t < 2,5 W18 (0,063mm) 2,5 ≤ t < 4 W17 (0,08mm) 4 ≤ t < 6 W16 (0,10mm) 6 ≤ t < 8 W15 (0,125mm) 8 ≤ t < 12 W14 (0,16mm) 12 ≤ t < 20 W13 (0,20mm) 20 ≤ t < 30 W12 (0,25mm) 30 ≤ t < 35 W11 (0,32mm) 35 ≤ t < 45 W10 (0,40mm) 45 ≤ t < 65 W9 (0,50mm) 65 ≤ t < 120 W8 (0,63mm) 120 ≤ t < 200 W7 (0,8mm) 200 ≤ t < 350 W6 (1,0mm) 350 < t W5 (1,25mm) (SFS-EN ISO 17636-1 2013, Subchapter 6.7; Annex B, Table B.3)

	Category III: 1 < t ≤ 3: 0,10mm 3 < t ≤ 8: 0,20mm 8 < t ≤ 12: 0,30mm 12 < t ≤ 18: 0,40mm 18 < t ≤ 24: 0,50mm 24 < t ≤ 35: 0,60mm 35 < t ≤ 50: 0,75mm 50 < t ≤ 70: 1,00mm 70 < t ≤ 85: 1,25mm 85 < t ≤ 100: 1,50mm 100 < t ≤ 130: 2,00mm 130 < t ≤ 165: 2,50mm 165 < t ≤ 200: 3,00mm 200 < t ≤ 225: 3,50mm t > 225: 4,0mm (NP-105-18 2018, appendix 4, Table N 4.8)			
Minimum density	Weld category I: 2,0…3,5 Weld categories II, III: 1,5…3,5 (GOST R 50.05.07-2018, i. 6.5.5)	single film technique: 2,0…4,5 (RCC-M 2015, i. MC 3161)	single film technique: X-ray source: min. 1,8 Gamma source: min. 2,0 (ASME BPVC V 2015, article 2, i. T-282.1)	Class B, single film technique: ≥2,3 Class A: ≥2,0 Maximum value not given but shall be reported. (SFS-EN ISO 17636-1 2013, Subchapter 7.8)
	Cracks, lack of fusion, lack of penetration are not permitted.. Comprehensive acceptance criteria is given in Table N 4,8.	Cracks, lack of fusion, lack of pene-tration, undercut are not permitted. Class 1: Acceptance criteria for gas cavities (largest dimension):	Cracks, lack of fusion, lack of pene-tration are not permitted. Class 1 components: Elongated indications: t ≤ 19: 6mm	Acceptance level 1 Cracks, lack of fusion, lack of penetration, crater pipes, shrinkage cavities, copper inclusions are not permitted.

Acceptance criteria	Examples for 6, 12, 90 & 200mm Category I Maximum permitted inclusions (metallic, slag, flux, oxide) t=6 / 12 / 90 / 200mm: single: 0,8 / 1,5 / 4,0 / 5,0mm cluster: 1,2 / 2,5 / 6,0 / 8,0mm number per 100mm: 11 / 12 / 24 / 23 cumulative area per 100mm: 2,5 / 7,5 / 72 / 150mm^2 Elongated inclusions, dimensions (number per 100mm of weld): 3,0x0,8 (1pcs) / 3,5x1,5 (1pcs) / 10,0x4,0 (2pcs) / 11x5,0 mm (2pcs). Category II Maximum permitted inclusions (metallic, slag, flux, oxide) t=6 / 12 / 90 / 200mm: single: 1,0 / 1,5 / 4,0 / 6,0mm cluster: 1,5 / 2,5 / 6,0 / 9,0mm number per 100mm: 12 / 13 / 25 / 24 cumulative area per 100mm: 4,5 / 10,0 / 81,0 / 160,0 mm^2 Elongated inclusions, dimensions (number per 100mm of weld): 4,0x1,0 (2pcs) / 5,0x1,0 (2pcs) / 12,0x4,0 (3pcs) / 14x6,0 mm (3pcs).	t ≤ 4,5: t/3mm 4,5 < t ≤ 6: 1,5mm 6 < t ≤ 10: 2mm 10 < t ≤ 25: 2,5mm 25 < t ≤ 50: 3mm 50 < t: 4mm Acceptance criteria for inclusions (largest dimension): t ≤ 6: 1,5mm 6 < t ≤ 10: 3mm 10 < t ≤ 60: t/3mm 60 < t: 20mm Two defects are considered as single defect is distance between them is less than 6 times length of longer one. Class 2 Acceptance criteria for gas cavities (largest dimension):: single cavity: 6mm or e/3 cluster: t over length of 12t or 150. Acceptance criteria for inclusion (largest dimension): t ≤ 18: 6mm 18 < t ≤ 60: t/3mm 60 < t: 20mm cluster: t over length of 12t	19 < t ≤ 57: t/3mm t > 57:19mm group of aligned indications (distance between indications less than 6 times the length of largest indications): cumulative length greater than t in a weld length of 12t is not allowed. Rounded indications: t ≤ 50: 1/3t or 6mm (isolated indication) / 1/4t or 4mm (non-isolated indication) t > 50: 10mm (isolated indication) / 4mm (non-isolated indication) cumulative diameter greater than t in a weld length of 12t is not allowed. Cluster length: 2t or 25mm Cumulative length of clusters: 25mm in 150mm length of weld. (ASME BPVC III 2015, i. NB-5320; appendix VI)	Acceptance criteria for gas cavities (porosity) Individual porosity d ≤ 0,2s, max. 3 mm Clustered porosity: d less than half the width of weld, max. 15mm Linear porosity: l≤ s, max. 25 mm d ≤ 0,2s, max. 2 mm Inclusions (slag, flux, oxide): h < 0,2s, max. 2 mm Σl ≤ s, max. 25 mm per 100mm of weld Metallic inclusions: l ≤ 0,2s, max. 2 mm Acceptance level 2 Cracks, lack of fusion, lack of penetration, crater pipes, shrinkage cavities, copper inclusions are not permitted. Acceptance criteria for gas cavities (porosity) Individual porosity d ≤ 0,3s, max. 4 mm Clustered porosity: d less than width of weld, max. 20mm Linear porosity: l ≤ s, max. 50 mm

	Category III Maximum permitted inclusions (metallic, slag, flux, oxide) t=6 / 12 / 90 / 200mm: single: 1,2 / 2,0 / 5,0 / 6,0mm cluster: 2,0 / 3,0 / 7,0 / 9,0mm number per 100mm: 13 / 14 / 26 / 25 cumulative area per 100mm: 6,0 / 12,0 / 92,0 / 160,0 mm^2 Elongated inclusions, dimensions (number per 100mm of weld): 5,0x1,2 (3pcs) / 6,0x2,0 (3pcs) / 14,0x5,0 (4pcs) / 15x6,0 mm (4pcs). (NP-105-18 2018, appendix 4, Table N 4.8)	Two defects are considered as single defect if distance between them is less than 6 times length of longer one. Class 3 Acceptance criteria for gas cavities (largest dimension):: single cavity: 6mm or e/3 cluster: t over length of 12t or 150. Acceptance criteria for inclusion (largest dimension): t ≤ 9: 6mm 9 < t ≤ 30: 2t/3mm 30 < t: 20mm cluster: t over length of 12t Two defects are considered as single defect is distance between them is less than 6 times length of longer one. (RCC-M 2015, items S 7714.3, S 7724.3, S 7734.3)		d ≤ 0,3s, max. 3 mm Inclusions (slag, flux, oxide): h < 0,3s, max. 3 mm Σl ≤ s, max. 50 mm Metallic inclusions: l ≤ 0,3s, max. 3 mm Two defects are considered as single defect is distance between them is less than diameter of smaller imperfection. Dimensions of imperfections are summed in case distance between them is more than diameter of smaller imperfection. Cumulative dimension is used for assessing conformity in each testing length 100mm. (SFS-EN ISO 10675-1:2016, Table 2)

Note: acceptance criteria defined by NP-105-18 are identical to those required by PNAE G-7-010-89.

Applicable code / standard	GOST R 50.05.02-2018 NP-105-18	RCC-M	ASME BPVC III; ASME BPVC V article 4	SFS-EN ISO 17640; SFS-EN ISO 11666
Frequencies and angles	t= 2…5,5mm: 5..12MHz, 70..77° t=5,5…12mm 4,0…6,0MHz, 65°/70° (half- and full skip) t=12…60mm: 1,8…6,0MHz, 65°/70° (half skip) & 45° (full skip) t>60mm:1,0…2,5MHz, 45°& 60° (half skip) (GOST R 50.05.02-2018, Subchapter 6.2)	1...6MHz 35-70°, chosen according to weld thickness and geometry When 2 angles are used, difference shall be at least 15° (RCC-M 2015, i. MC 2634)	1..5MHz 45°, 60° and 70° Beam angles other than 45° and 60° are permitted provided the measured difference between angles is at least 10 deg. (ASME BPVC V 2015, article 4 i. T-432; appendix I)	2…5MHz 35°-70° (SFS-EN ISO 17640. 2011, Subchapter 6.3; Table A.1)
Evaluation technique and reference reflectors	NP-105-18 Tables N 4.12, N 4.13 t=2…5,5mm: DAC notch 1,0x0,4…1,2x1,1mm (further specified in Table N 4.12) t>5,5mm: DGS CO-3 or V1 r=100mm (NP-105-18 2018, appendix 4, Tables N 4.12, N 4.13)	DAC ∅2mm SDH (RCC-M 2015, i. MC 2635)	DAC Diameter of SDH varies over weld thickness. t≤25mm: 2,5mm 25<t≤50mm: 3mm 50<t≤100mm: 5mm 19<t≤57mm: 5mm +1,5mm per each t 50mm over 100mm (ASME BPVC V 2015, article 4 i. T-434.2)	DAC or DGS DAC ∅3mm SDH or alternatively for t<15mm: 1mm notch DGS 1,5MHz…2,5MHz 15≤t<40mm: DSR ∅2,5mm 3,0MHz…5,0MHz 15≤t<40mm: DSR ∅2,0mm t>40mm: ∅3,0mm (SFS-EN ISO 17640. 2011, Subchapter 10.2; Table 3; SFS-EN ISO 11666. 2011, Table A.2)
Surface requirements	Ra 6,3 temperature 5…40C (GOST R 50.05.02-2018, i. 6.8.9)	Ra 6,3 (RCC-M 2015, i. MC 2633)	Shall not interfere inspection but not further specified.	Waviness of the test surface shall not result in a gap between the probe and test surfaces greater than 0,5 mm. (SFS-EN ISO 17640. 2011, Chapter 8)

Volume of inspection	Weld metal + 20mm base material adjacent to weld t<60mm: half skip / full skip L-scan, single surface, both directions t>60mm: half skip L-scan both surfaces, both directions. Scanning zone is additionally scanned with straight probe. (GOST R 50.05.02-2018, Subchapter 6.2)	S7712, S7722, MC 2634 Weld metal and adjacent base metal (t≤30: min. 5mm; t>30: min. 10mm). L-scan and T-scan both surfaces, both directions. (RCC-M 2015, items S7712, S7722, MC 2634)	Weld metal plus at least 1/2 in. (13 mm) adjacent base material. (ASME BPVC III 2015, i. NB-5140)	Weld metal and heat affected zone of base material. Testing level C: L-scan t<15: 1 angle, 1 surface, 2 directions (full-skip) t≥15: 2 angles 1 surface, 2 directions (full-skip) T-scan 2 angles, 1 surface, 2 directions (SFS-EN ISO 17640. 2011, Table A.2)
Acceptance criteria	Comprehensive recording and acceptance criteria is given in tables N 4.12 & N 4.13 t≤5,5mm: recording level: reference level -6dB acceptance level: reference level (applicable notch reflector) or 4..6 indications over recording level per 100mm. t>5mm over 30 levels are specified depending on thickness and weld category. Example (mm FBH): t=10..20mm: recording level: 2,0 / 2,5 / 3,5 acceptance level: 4,0 / 5,0 / 7,0 indications over recording level per 100mm: 5 / 6 / 8 t=80..100mm:	Linear indications are not permitted. Class 1, 2: Acceptance criteria for volumetric indications (2mm SDH): t<50mm over 150% (+6dB) DAC (2mm SDH) - not allowed 100%..150% (+6dB) DAC- 20mm 75% (-3dB)...100% DAC - 30mm 50% (-6dB) ... 75% (-3dB) DAC - 60mm t>50mm: Volumetric indications: 200% (+12dB) DAC - not allowed 150% (+6dB)...200% (+12dB) DAC- 20mm 100%...150% (+6dB) DAC - 30mm 50% (-6dB) ... 100% DAC - 60mm	Linear indications are not permitted. Acceptance level, volumetric indications (length of indication exceeding DAC). t≤19mm: 6mm 19<t≤57mm: 1/3t t>57mm: 19mm Evaluation/recording level: 20% (-14dB) DAC (ASME BPVC III 2015, i. NB-5331)	Linear indications are not permitted. Acceptance level for 8≤t<15mm acceptance level 2: l ≤ t: H0 – 4dB l>t: H0 - 10dB DGS: l ≤ t: H0 + 2dB l>t: H0 – 4dB Acceptance level for 15≤t<100mm acceptance level 2: DAC: l ≤ 0,5t: H0 0,5t<l≤t: H0 − 6dB: l>t: H0 - 10dB

	recording level: 5,0 / 7,5 / 10 acceptance level: 10,0 / 15,0 / 20,0 indications over recording level per 100mm: 7 / 9 / 11 t=200..300mm: recording level: 15,0 / 20,0 / 25,5 acceptance level: 20,0 / 40,0 / 50,0 indications over recording level per 100mm: 9 / 11 / 13 (NP-105-18 2018, appendix 4, Tables N 4.12, N 4.13)	Class 3: Same as acceptance level 2 acc. ISO11666 Recording level: 50% (-6dB) DAC (RCC-M 2015, Tables S7714.4, S7724.4, S7734.4)		DGS: l ≤ 0,5t: H0 + 6dB 0,5t<l≤t: H0 l>t: H0-4dB Recording level: 4dB below corresponding acceptance levels (SFS-EN ISO 11666. 2011, Table A.1)

Note: acceptance criteria defined by NP-105-18 are identical to those required by PNAE G-7-010-89, however, NP-105-18 includes acceptance criteria for 2-5mm thickness range.

	GOST	ISO
Tensile testing	GOST 6996-66. 2005. Welded joints. Methods of mechanical properties determination. Appendix 1 based on ISO 4136:1989.	SFS-EN ISO 4136. 2012. Destructive tests on welds in metallic materials. Transverse tensile test.
	GOST 1497-84. 2008. Metals. Methods of tension test. Based on ISO 6892-1:1984	SFS-EN ISO 6892-1:2019. Metallic materials. Tensile testing. Part 1: Method of test at room temperature.
	GOST 9651-84 Metals. Methods of tension tests at elevated temperatures Based on ISO 783:1989 superseded by ISO 6892-2	SFS-EN ISO 6892-2:2018. Metallic materials. Tensile testing. Part 2: Method of test at elevated temperature.
Impact testing	GOST 6996-66 Welded joints. Methods of mechanical properties determination. Chapter 5. GOST 9454-78. 2002. Metals. Method for testing the impact strength at the low, room and high temperature	SFS-EN ISO 148-1:2016. Metallic materials. Charpy pendulum impact test. Part 1: Test method
Bend testing	GOST 6996-66. 2005. Welded joints. Methods of mechanical properties determination. Appendices 2 & 3 based on ISO 5173:1981 and 5177:1981	SFS-EN ISO 5173 + A1. 2011. Destructive Tests On Welds In Metallic Materials. Bend Tests. Includes side bend tests merged from ISO 5177.
Hardness testing	GOST 6996-66 Welded joints. Methods of mechanical properties determination. Chapter 5.	SFS-EN ISO 9015-1. 2011. Destructive tests on welds in metallic materials. Hardness testing. Part 1: Hardness test on arc welded joints.