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# Requirements of the AFCEN and ASME Codes in Processing and Welding of Metal Parts of Nuclear Reactor Containment

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**Abstract:** The article presents the contents and requirements of the AFCEN RCC-CW and ASME Section III codes as well as associated standard specifications concerning parent materials, welding consumables and manufacturing processes, including welding and heat treatment, used in the production of steel parts of nuclear reactor containments.

**Keywords:** nuclear power plant, containment vessel, steel, code, ASME, AFCEN, requirements, welding

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## Introduction

On the basis of the assumptions of the Polish Nuclear Energy Programme (PNEP) of 28 January 2014, the first nuclear power plant in Poland should come into existence approximately in 2024. Potential suppliers of nuclear technology include AREVA (EPRTM), GE Hitachi (ABWR) and Westinghouse (AP1000), although KEPCO (APR1400) and AECL (ACR-1000) also still remain in play.

Regardless of the nuclear technology supplier, some works connected with the construction of the nuclear power plant as well as the delivery of equipment and services (e.g. NDT) will certainly be subcontracted to Polish companies. There is a huge probability that such orders will include works connected with the construction and manufacture of the nuclear reactor containment or its individual parts and components. Therefore, there is no doubt that it would be recommendable to prepare and become familiar both with the scope of works

of possible orders and requirements of regulations which must be satisfied.

## Nuclear reactor containment

In contrast to conventional power plants, a nuclear power plant consists of two parts, i.e. nuclear and conventional, which in technical publications are often referred to as islands, i.e. a nuclear island and a turbine or conventional island. Presently, newly built nuclear power plants are usually provided with a Pressurized Water Reactor (PWR) or a Boiling Water Reactor (BWR). Irrespective of the reactor type, the reactor pressure vessel, as well as other primary equipment and nuclear systems (e.g. steam generator, pressure stabiliser, pumps, main pipelines, cooling water tanks etc.), are located in the building reactor, which undoubtedly is the most important object of a nuclear power plant, as one of its primary tasks is the protection of operating personnel and surroundings against radiation as well as the protection of the

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reactor and other important equipment against damage caused by external factors and against the release of radioactive substances. And as a result, the nuclear reactor containment is designed and calculated in a manner enabling the reactor to withstand seismic activity, terrorist attacks (e.g. an intended airplane crash), tsunami and many other factors or phenomena (e.g. tornado, hurricane, snowstorm etc.) as well as ensuring entire leak-tightness.

A nuclear reactor containment (building) in today's nuclear power plants is a complex structure, in most cases composed of a tight metal liner and a reinforced concrete structure of various configurations and designs, depending on the reactor type and the nuclear technology supplier.

A nuclear reactor containment should not only be appropriately designed, but also made in accordance with the requirements of related codes, standards and regulations as quality workmanship is decisive for the safe operation of a nuclear power plant for a minimum of 60-70 years.

## Primary regulations and technical standards

As mentioned before, presently, the most probable suppliers of nuclear technology for Poland's first nuclear power plant include companies from France, Japan, Canada, South Korea and the USA. Listing countries rather than potential companies-suppliers of nuclear technology is more appropriate as regards the technical regulations applied when making a nuclear reactor as well as other primary equipment and structures as their design and manufacture require the application of codes, standards and regulations valid in the supplier's country of origin.

Due to its lack of nuclear power plants, Poland does not have its own regulations applying to the construction and operation of such plants. A draft regulation by the Minister of Economy concerning the technical conditions of the technical supervision of technical

equipment or equipment subject to technical inspection of a nuclear power plant states that the design and construction of the mechanical equipment and the construction of nuclear power plant containments rated among safety classes assumes the use of the following recognised codes or their respective sections as well as the standards of the following countries:

- AFCEN (France),
- JSME (Japan),
- CSA (Canada),
- KEPIC (South Korea),
- KTA (Germany),
- ASME (USA).

Worldwide, the widest application of regulations is that of the appropriate sections of the ASME B & PVC code (American Society of Mechanical Engineers Boiler and Pressure Vessel Code), among which the most important is ASME Section III [1]. This section, along with other sections it refers to, is used in the construction of nuclear power plants not only in the USA but also in many other countries all over the world. Nuclear codes of Japan, South Korea and Canada are based on ASME B & PVC; some existing differences or extensions result from local conditions or are connected, as is the case in Canada, with a specific design of some units of a CANDU reactor.

Presently, the only supplier of welding technology in Western Europe is AREVA from France. As a result, in this part of the world, most of the nuclear power plants have been built on the basis of requirements specified in the French AFCEN codes (Association Française pour les Règles de Conception, de Construction et de Surveillance en Exploitation des Matériels des Chaudières Electro Nucléaires, or in English - French Association for the Rules Governing the Design, Construction and Operating Supervision of the Equipment Items for Electro Nuclear Boilers). For approximately 40 years, the AFCEN codes have been developed in France independent of the ASME code, which has led to their considerably different structure, and in

some cases, also contents. However, this does not change the fact that the contents of the appropriate sections of both codes (AFCEN and ASME) is substantially very similar. The foregoing has inspired the analysis and presentation of requirements concerning the manufacture of steel structures of a nuclear reactor containment, specified in appropriate sections of both codes, i.e. the French AFCEN and the US ASME, as well as in related standards and regulations.

### Regulations and standards concerning steel elements of a nuclear reactor containment

Requirements concerning the manufacture of a nuclear reactor containment refer to both reinforced concrete structures and steel elements. In the case of steel elements, depending on the nuclear technology supplier, and thus of a nuclear reactor containment structure, requirements are contained in the following standards and sections of the AFCEN and ASME codes:

- AFCEN RCC-CW “Design and construction rules for civil works in PWR nuclear islands” [2],
- ASME Section III, Division 1 – Subsection NE “Class MC Components” [3],
- ASME Section III, Division 2 “Code for Concrete Containments” [4],
- ANSI/AISC N690 “Specification for Safety-Related Steel Structures for Nuclear Facilities” [5].

As can be seen, requirements according to ASME are in various sections, as this code is the basis for the design and manufacture of both pressurised water reactors (PWR) and boiling water reactors (BWR). The first group includes an AP1000 reactor manufactured by Westinghouse, whereas the second groups includes an ABWR reactor manufactured by GE Hitachi. The reactors differ not only technologically, but also as regards the design of the nuclear reactor containment. As a result, requirements concerning individual nuclear reactor containments are described in different sections, i.e. ASME Section III: Division 1 – Subsection NE or Division 2.

### Requirements according to AFCEN RCC-CW

The EPR nuclear reactor containment manufactured by AREVA is a building structure composed of a 6 mm thick internal tight metal liner and two ring-shaped structures made of reinforced concrete (Fig. 1). Requirements concerning both of these elements are presented in the code RCC-CW, which in March 2015 replaced the previously used code ETC-C 2012. The code RCC-CW specifies requirements regarding the design, manufacture and examination of elements and structures made of reinforced concrete as well as those made of metal. The structure of the code RCC-CW is the following:

- Part G General,
- Part D Design + Appendices,
- Part C Construction + Appendices,
- Part M Maintenance and Monitoring + Appendices.

Requirements concerning construction works and the manufacture of individual nuclear reactor building elements made of reinforced concrete and those made of metal are contained in respective sections of Part C:

- CGEOT Earthworks and Soil Treatment,
- CCONC Concrete,
- CFNSH Surface Finish and Formwork,
- CREIN Reinforcement for Reinforced Concrete,
- CPTSS Post Tensioning System,
- CPREF Prefabricated Concrete Elements and Reinforcement Cages,
- CCLIN Leak-tight Metal Parts on Containments,
- CPLIN Pools and Tanks,
- CSTLW Structural Steelwork,
- CANCH Metal Elements Embedded into the Concrete,
- CBURP Reinforced Concrete Pipelines,
- CJOIN Joint Sealing,
- CTOLR Survey Networks, Tolerances and Monitoring Systems.

As can be seen above, requirements concerning the manufacture of the leak tight metal liner



of a nuclear reactor containment and of steel structures are described in two sections – CCLIN and CSTLW.

**a) leak-tight metal parts of the containment (CCLIN)**

Section CCLIN of the RCC-cw code presents requirements concerned with the manufacture and structure of a leak-tight metal containment composed of the following elements:

- liner, including liner metal sheets, connectors, anchor plates for the fastening of devices and the anchor system for all the elements enumerated above;
- penetrations:
  - sleeves with connecting rings:
    - ▶ for liquid media (standard piping, steam, water)
    - ▶ for ventilating penetrations
    - ▶ for electric penetrations
    - ▶ penetrations for relocating and shifting pipes
    - ▶ man-locks for personnel
    - ▶ spare sleeves
  - fastened part of a lock for technological equipment
  - cylindrical liner during construction;
- moving part of a lock for technological equipment;
- all anchor systems directly welded to leak-tight elements except for anchor plates for fastening the supports of a radial crane.

The further part of section CCLIN presents detailed requirements based on requirements specified in EN 1090-2+A1 [7] in relation to the manufacture of structures in at least class ExC3, supplemented and modified taking into consideration specific nuclear requirements, e.g. tolerances and the type and scope of non-destructive tests (NDT).

The analysis of the contents of CCLIN reveals that the manufacture of a liner should be performed using sheets intended for pressure vessels in accordance with EN 10028-2 (e.g. P265GH),

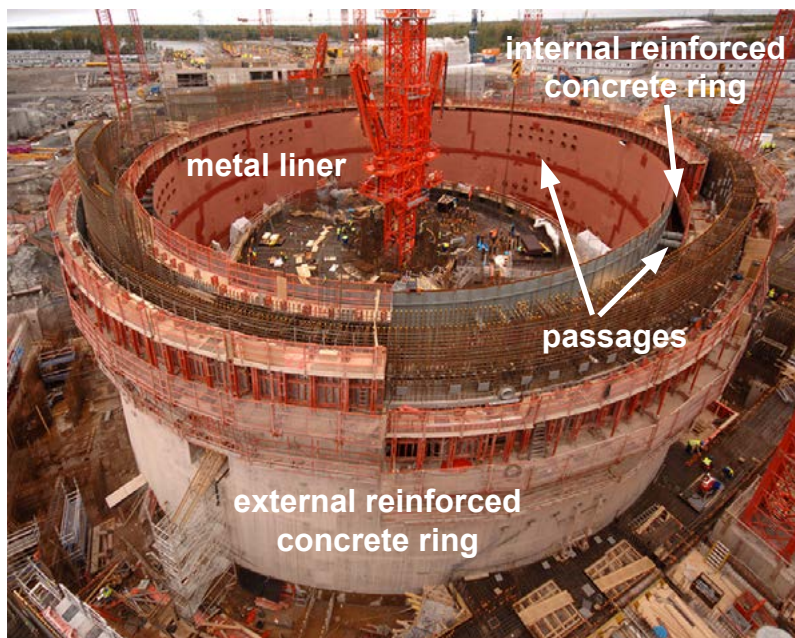


Fig. 1. Construction of nuclear power station Olkiluoto 3 with an EPR manufactured by AREVA [6]

whereas pipes in accordance with standard EN 10216-2 and EN 10217-1/A1. The primary inspection document is Quality Certificate 3.1 in accordance with EN 10204, although some sheets, pipes, shapes, pins or filler metals can be delivered if accompanied by Conformity Certificate 2.2. In some cases, particularly as regards filler metals, in addition to the inspection documents mentioned above, it may also be necessary to submit entire test reports, including additional test reports. Great attention is paid to the identifiability of each minute part of a product or structure during the whole process, from the delivery of base materials and filler metals to the assembly and fastening of a finished element at its intended place of operation. The vast majority of confinement liner welded joints should be in 100 % subjected to visual tests (VT), penetrant (PT) or magnetic particle tests (MT) and radiographic (RT) or ultrasonic tests (UT). Slight deviations from the aforesaid principle depend on the specified level of weld quality, i.e. Level A, B or C according to Table DCLIN 4500-2.

**b) manufacture of steel structures (CSTLW)**

Section CSTLW of the RCC-cw code includes requirements concerning all other steel structures (i.e. apart from the liner) as well as ponds

and tanks. Among other things, the section also presents requirements concerning the manufacture of radial crane supports. Similar to information contained in section CCLIN, these requirements are based on EN 1090-2+A1, supplemented and modified taking into consideration specific nuclear requirements. CSTLW describes requirements concerning deliveries of sheets (e.g. S235JR and S355 according to EN 10025-2), shapes and various types of pipe connectors and galvanised products as well as the processing of these products by cutting, welding or mechanical joining.

### Requirements according to ASME

As regards an AP1000 reactor, the confinement consists of an internal liner (Fig. 2) and external panel steel-concrete structure (first used in Japan when constructing a nuclear reactor building in 1996). The sheet thickness at the internal bottom cylindrical part of the AP1000 reactor confinement liner amounts to 1.875 inch (47.625 mm), whereas in the remaining part – 1.75 inch (44.45 mm). The thickness of sheets making up the containment vessel bottom and top heads amounts to 1.625 inches (41.275 mm). Appropriately formed liner elements, joined on the construction site, primarily using mechanised welding methods, are made of ASME SA-738 Grade B sheet.



Fig. 2. Liner of an AP1000 reactor manufactured by Westinghouse [8]

Similar to an EPR reactor, the confinement of an ABWR reactor consists of a reinforced concrete structure and an internal liner (Fig. 3). An ABWR reactor confinement liner is made of stainless and carbon steels. Stainless steel ASME SA-240 Type 304L is used for the bottom fragment of a liner as it is more exposed to corrosive factors than the top element, which in turn is made of carbon steel ASME SA-516 Gr. 70 (6.35 mm thick). Liner anchor plates (also referred to as liner anchors) are made of normalised high strength low-alloy ASTM A-633 Grade C steel sheets. Due to various designs of the steel part, AP1000 and ABWR reactor confinements are made following different ASME code sections. The manufacture of an AP1000 reactor liner is performed in accordance with requirements contained in ASME Section III, Division 1 – Subsection NE [3], whereas an ABWR reactor liner is made following requirements contained in ASME Section III, Division 2 [4]. However, placing an AP1000 reactor liner in a reinforced concrete base is possible only as a result of making a steel support structure, manufactured in accordance with requirements contained in ANSI/AISC N690 [5].

The section below contiguously presents the contents of the ASME code sections enumerated above and concerning the manufacture of AP1000 and ABWR reactor confinement liners.



Fig. 3. Cylindrical fragment of an ABWR reactor liner manufactured by GE Hitachi [9]



### **a) ASME Section III, Division 1 – Subsection NE**

Subsection NE contains rules and requirements concerning materials, design, manufacture, non-destructive tests, checks, acceptance tests and the preparation of reports in relation to a confinement liner. Manufacturing-related requirements are presented in the following subsections:

- NE-2000 Material,
- NE-4000 Fabrication and Installation,
- NE-5000 Examination,
- NE-6000 Testing.

The sections mentioned above describe requirements concerning steels and steel products, filler metals used when making a liner (NE-2000), entire manufacture process (NE-4000), non-destructive tests (NDT) (NE-5000) and acceptance tests (NE-6000). Section NE-8000 contains a statement that a containment liner should be provided with the symbol “N”, whereas its parts and accessories should be stamped with the letters “NPT”.

Requirements contained in the sections referred to above are very detailed, e.g. section NE-2000, concerning steels and filler metals, in addition to standard requirements (chemical, mechanical properties etc.), presents the scope of additional tests, their course, result assessment criteria, permissibility and course of repairs (NA-2500) as well as supplier’s quality assurance system (NE-2600).

As mentioned before, the support structure for placing an AP1000 reactor confinement liner should be made following requirements of standard ANSI/AISC N690 [5], specifying, among other things, requirements concerning structural materials, design of steel structures and their steel elements, manufacturing (including cutting and welding) (section NM), as well as the quality assurance system (section NN). As regards production, the standard states that the manufacture of welded structures should, as a rule, follow the requirements of AWS D1.1 [10] and AWS D1.6 [11].

### **b) ASME Section III, Division 2**

Section “Division 2” has been developed jointly by the American Concrete Institute (ACI) and ASME and contains, among other things, requirements in relation to materials, design, manufacture, construction, NDT, acceptance tests, labelling, reporting etc. when making a reinforced concrete nuclear reactor containment. Such a containment is composed of the following elements:

- pressure-resistant concrete shell and its elements,
- liner,
- penetrations in the liner passing through the concrete shell.

Requirement related to base materials and the manufacture of a containment liner are presented in the following sections:

- CC-2500 Material for Liners
  - CC-2510 Permitted Material Specifications
  - CC-2520 Fracture Toughness Requirements for Materials
  - CC-2530 Examination and Repair of Liner Material
  - CC-2540 Material Identification
- CC-2600 Welding Material
  - CC-2610 Welding Material Requirements
  - CC-2620 Stud Welding Material
  - CC-2630 Identification of Welding Material
- CC-2800 Material Manufacturer’s Quality System Programs
  - CC-2810 Documentation and Maintenance of Quality System Programs
- CC-4500 Fabrication of Liners
  - CC-4510 General Requirements
  - CC-4520 Forming, Fitting, and Aligning
  - CC-4530 Welding Qualification
  - CC-4540 Rules Governing Making, Examining, and Repairing Welds
  - CC-4550 Heat Treatment
  - CC-4560 Protection of Attachments
- CC-4600 Fabrication of Embedment Anchors
  - CC-4610 General Requirements
  - CC-4620 Forming, Fitting, and Aligning
  - CC-4630 Welding Qualification

- CC-4640 Rules Governing Making, Examining, and Repairing Welds
- CC-4650 Heat Treatment
- CC-4660 Bolted Construction
- CC-5500 Examination of Welds
  - CC-5510 General
  - CC-5520 Required Examination of Welds
  - CC-5530 Examination Procedures
  - CC-5540 Acceptance Standards
- CC-6000 Structural Integrity Test of Concrete Containments.

The titles of sections and subsections presented above show that they describe all the stages related to the manufacture of a containment metal liner, from the recommended base materials, pins and filler metals along with accompanying inspection documents through processes of manufacture and heat treatment (including welding procedure specifications) to non-destructive tests of welded joints and acceptance tests of the entire containment structure. Not all requirements are completely described as some of them have already been formulated in another section or section of a code or standard. In such cases, the given text contains a reference to the related document or its part. Nevertheless, all important and additional requirements are specified in the sections mentioned above; the detail of these requirements is demonstrated by the contents of section CC-4530 concerning welding procedure qualifications:

### **CC-4530 Welding Qualifications**

- CC-4531 General Requirements
  - CC-4531.1 Types of Processes Permitted
    - ▶ CC-4531.1.1 Capacitor Discharge Welding
    - ▶ CC-4531.1.2 Low Energy Capacitor Discharge Welding
- CC-4532 Welding Qualifications, Records, and Identifying Stamp
  - CC-4532.1 Required Qualifications
  - CC-4532.2 Maintenance and Certification of Records
    - ▶ CC-4532.2.1 Identification of Joints by Welder or Welding Operator

- CC-4532.3 Welding Prior to Qualifications
- CC-4532.4 Transferring Qualifications
- CC-4533 General Requirements for Welding Procedure Qualification Tests
  - CC-4533.1 Conformance to Section IX Requirements
  - CC-4533.2 Base Material to Be Employed
  - CC-4533.3 Heat Treatment of Qualification Welds for Ferritic Materials
  - CC-4533.4 Preparation of Test Coupons and Specimens
    - ▶ CC-4533.4.1 Coupons Representing the Weld Deposits
    - ▶ CC-4533.4.2 Coupons Representing the Heat Affected Zone
  - CC-4533.5 Impact Test Requirements
    - ▶ CC-4533.5.1 Impact Tests of Weld Metal
    - ▶ CC-4533.5.2 Impact Tests of Heat Affected Zone
  - CC-4533.6 Qualification Requirements for Build-Up Weld Deposits
- CC-4534 Continuing Performance Test for Stud Welding.

The importance and detail of additional requirements are confirmed by the fact that the description related to impact tests (CC-4533.5 Impact Test Requirements) constitute nearly half of the contents of section CC-4530 consisting of several pages.

### **Summary**

The above analysis of the AFCEN and ASME codes concerning the manufacture of the structure and metal elements of a nuclear reactor confinement leads to the conclusion that, as regards the AFCEN RCC-CW code, the vast majority of requirements are convergent with the requirements of EN 1090-2+A1 in relation to the manufacture of structures in at least class EXC3, supplemented and modified taking into consideration specific nuclear requirements. As a result, nearly all of the component elements of the metal confinement manufacturing process, including base materials and filler metals, welding procedure qualifications, non-destructive tests

(NDT) and personnel qualification are based on requirements of European norms such as EN or EN ISO.

As regards the ASME code, when making a steel confinement and supporting structures, it is necessary to follow requirements contained in related sections of ASME Section III, Division 1 – Subsection NE or ASME Section III, Division 2 as well as in standards referred to in them such as ASTM, AWS, ANSI/AISC, ACI etc.

At the end it should be emphasized that, in most cases, regardless of the code applied, the manufacture of metal elements of a nuclear reactor containment, as well as pressure elements such as sheets, pipes, rods, pins and shapes, is performed using commonly known and widely used normalised carbon steels, the processing of which (cutting, bending, welding) should not pose any problem for Polish metal industry companies. It appears that the primary issue which needs solving is the possession of a certified quality assurance system taking into consideration specific nuclear requirements and demonstrating that a company has experience in making structures for nuclear objects or structures of similar responsibility and complexity.

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