RUSSIAN MARITIME REGISTER OF SHIPPING

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RULES

FOR THE CLASSIFICATION AND CONSTRUCTION OF NUCLEAR SHIPS AND NUCLEAR SUPPORT VESSELS

PART III

HULL

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RULES FOR THE CLASSIFICATION AND CONSTRUCTION OF NUCLEAR SHIPS AND NUCLEAR SUPPORT VESSELS

Rules for the Classification and Construction of Nuclear Ships and Nuclear Support Vessels developed by Russian Maritime Register of Shipping (RS, the Register) have been approved in accordance with the established approval procedure and come into force on 1 October 2022.

The present edition is based on the 2022 edition of the Rules for the Classification and Construction of Nuclear Ships and Floating Facilities and on the 2017 edition of the Rules for the Classification and Construction of Nuclear Support Vessels, taking into account Circular Letters No. 110-312-1-1695c dated 04.02.2022 and No. 110-312-1-1702c dated 14.02.2022, amendments and additions developed immediately before publication.

The Rules set down specific requirements for the nuclear ships, nuclear support vessels and supplement the Rules for the Classification and Construction of Sea-Going Ships and the Rules for the Equipment of Sea-Going Ships of Russian Maritime Register of Shipping.

The Rules are published in the following parts:

Part I "Classification";
Part II "Safety Standards";
Part III "Hull";
Part IV "Stability. Subdivision";
Part V "Fire Protection";
Part VI "Nuclear Steam Supply Systems";
Part VII "Special Systems";
Part VIII "Electrical and Automation Equipment";
Part IX "Radiation Safety";
Part X "Physical Security".

REVISION HISTORY

(purely editorial amendments are not included in the Revision History)

For this version, there are no amendments to be included in the Revision History.

1 GENERAL

1.1 This Part of the Rules for the Classification and Construction of Nuclear Ships and Nuclear Support Vessels[1] supplements Part II "Hull" of the Rules for the Classification and Construction of Sea-Going Ships[2] and sets down requirements for special structures of nuclear ships and nuclear support vessels[3].

1.2 Definitions and explanations relating to adopted abbreviations and terms are given in Part I "Classification".

[1] Hereinafter referred to as "these Rules".
[2] Hereinafter referred to as "the Rules for the Classification".
[3] Hereinafter referred to as "the NS vessels".

2 DESIGN PRINCIPLES

2.1 The hull structure of controlled area spaces, including foundations, shall prevent stagnation areas on the couse of decontamination.

2.2 The bulkhead members shall be fitted on the side of the spaces with less probability of contamination.

2.3 Materials to be used for manufacturing structural system components and containment shall be of category D (for thicknesses below 12,5 mm) and category E (for thicknesses above 12,5 mm).

2.4 When determining the scantlings of framing members, consideration shall be given to the following cases:

.1 when longitudinal girders are broken due to design collision;

.2 grounding and stranding.

2.5 There shall be a smooth transition between the structural protection area (refer to 3.1) and the reminder of the hull. This transition shall ensure continuous girders contributing to the total strength of the ship. The transition area shall be designed so as to forces induced in way of the reactor compartment and structural protection are transferred to the other parts of the ship hull.

2.6 When selecting design thickness of fillet welds of collision, grounding and stranding protection structures accoding to Part II "Hull" of the Rules for the Classification, weld efficiency factor shall be taken to be 0,45.

2.7 Components of protection structures jointed with the shell plating shall be of full penetration type.

2.8 100 % of welded joints of containment structure shall be subject to non-destructive testing during the ship construction.

2.9 20 % of welded joints of hull structures in way of the reactor compartment and structural protection shall be subject to non-destructive testing during the ship construction.

2.10 No intermittent welds are allowed in the controlled area.

3 REQUIREMENTS FOR SPECIAL STRUCTURES OF NUCLEAR SHIPS AND NS VESSELS

3.1 STRUCTURAL PROTECTION

3.1.1 Structural protection for absorbing power released due to collisions, grounding and stranding shall be provided in way of the reactor compartment. Tightness of shielding barrier shall be maintained in case of collisions, grounding and stranding.

A ship designed for reception and storage of new fuel assemblies and irradiated fuel assemblies and/or radioactive waste shall have collision, grounding or stranding protection for absorbing power released due to collisions, grounding and stranding in way of the storage facilities.

When the ship is fitted with a helicopter/helideck, structural protection against helicopter crash shall be provided in way of the reactor compartment and facilities for storing cores and fuel assemblies.

3.1.2 The length of structural protection forward and aft of traverse bulkheads of reactor compartment and used fuel storage compartment shall be chosen with regard to 2.5 and the length shall be at least 0,2 of compartment length.

3.1.3 Double bottom and foundations in the reactor compartment shall be designed as to provide protection of the reactor, its safety systems and core storage facilities against damages due to grounding and stranding.

The bottom of the ship shall be B/15 or 2 m (whichever is greater) apart from the lower part of the shielding barrier.

3.1.4 Double-skin structure shall be provided in way of the spaces intended for storage of new fuel assemblies, irradiated fuel assemblies and radioactive waste. Longitudinal bulkheads shall be positioned at a distance equal to at least 1/5 of the ship breadth from the ship's side, except the cases when collision protection prevents the damage that deep.

3.1.5 The height of the double bottom in the vicinity of the engine room shall be sufficient to withstand the damage with dimensions specified in 3.1, Part IV "Stability. Subdivision".

3.2 CONTAINMENT

3.2.1 The containment shall be designed as to reduce release of radioactive materials into environment for any states of the plant (SC1 — SC4). For permissible leakage values, refer to 3.2.10.

3.2.2 Containment may be designed as a reinforced leaktight structure if the ship hull or as independent reinforced leaktight containment which is no integral with the hull.

When the ship is fitted with several SSS, there plants shall be enclosed in a separate containment.

3.2.3 Containment shall be designed and manufactured to meet requirements of safety class 2 structures (refer to Section 5, Part II "Safety Standards"),

3.2.4 Containment shall withstand the inner pressure due to emergency release of coolant caused by rupture of the primary circuit (refer to 9.9, Part II "Safety Standards").

Safety valves to release gas-vapor mixture at SC4 are not permitted on the containment.

If there is an approved system for reducing pressure in case of emergency release, the maximum pressure, which may occur in the containment with regard to such a system, shall be taken as a design pressure.

3.2.5 The containment shall be designed as to withstand the design pressure specified in 3.2.4 with regard to inertial forces at sea states.

Thermal stresses in the structure in case of emergency shall be considered.

3.2.6 Containment shall be operational due to action of external pressure and in case of flooding (refer to 4.5, Part VI "Nuclear Steam Supply Systems").

3.2.7 All means of closure, doors, stop valves/shut-off valves, cable passages sealing arrangements and other components included into tight circuit of the containment shall be designed, manufactured and tested on benches (prior to mounting onto containment) under supervision of the Register and according to the approved procedures.

Tightness standards for tight circuit components shall be determined as per method (refer to Appendix) and included into design documents. These standards shall be specified in the delivery specifications.

3.2.8 The constructed containment along with its means of closure shall be subject to hydraulic test at 1,1 times the design pressure (refer to 3.2.4). Test pressure P_{test} shall be calculated by the formula

$$P_{test} = (1{,}1\ \sigma_T/\sigma_t)P_{design} \qquad (3.2.8)$$

where σ_T = yield strength of containment material at test temperature;
σ_t = yield strength of containment material at design temperature (maximum temperature in case of the maximum design-basis accident);
P_{design} = pressure in containment in case of the maximum design-basis accident.

3.2.9 If hydrostatic pressure in the course of containment test exceeds the test pressure and results in the risk of damage of structure, equipment or their foundations, hydraulic tests may be replaced with air pressure tests. The containment shall be subject to air pressure test when tight circuit of the containment is completely installed. Test pressure P_{test} shall be determined by formula as shown in Formula (3.2.8).

3.2.10 Containment shall be subject to leak test at pressure equal to the design pressure. In case of air pressure tests, the leak tests may be combined with the pressure tests, provided that the test pressure P_{test} is brought to design pressure P_{design}.

Procedures for testing and calculating relative leakage rate as well as the Calibration Certificate for the measurement procedure shall be approved by the Register.

In case of hydraulic tests, the air test pressure in the containment in the course of leak test may be reduced provided that relative leakage rate shall be measured three times at test pressures of 0,07 MPa, 0,05 MPa and 0,03 MPa. Test procedures, Calibration Certificate for the measurement procedure and extrapolation of test results at decreased pressures to the design pressure shall be approved by the Register. Permissible relative leakage rate at design pressure shall be justified by the Designer with regard to radiation safety conditions as per applicable Radiation Safety Standards for the Personnel and People. It should be noted that decrease in permissible relative leakage rate down to 1 % per day and less as compared to the design maximum permissible value results in decrease in potential radiation hazard for the personnel and population in case of maximum design-basis accident. Therefore, it shall be established with possibility of reaching and measuring this value.

3.2.11 When the core is loaded into reactor and installation works are complete, the containment shall be subject to leak tests (outside and inside) at excessive air pressure of 0,05 MPa.

3.2.12 When the containment is subject to leak test, compressed air parameters within the containment shall be recorded (pressure, temperature) at least every hour until the validation criterion is met at $a \geq 0{,}95$ to be calculated with regard to inequalities

$$\begin{cases} L_M + \zeta_L \leq L_p \\ \zeta_L \leq 0{,}3 L_p \end{cases} \quad (3.2.12)$$

where L_M = measured relative leakage rate based on directly measured pressure P, temperature T, time $\tilde{\tau}$ obtained in tests, %/days (refer to Appendix 4 of the Guidelines on Technical Supervision of Nuclear Ships, Nuclear Floating Facilities and Nuclear Support Vessels under Construction[1]),
ζ_L = design measurement error of relative leakage rate, %/day;
L_p = permissible relative leakage rate specified in design of the nuclear ship, %/day;
a = confidential probability.

3.2.13 The containment shall be subject to leak tests during ship operation (in the course of periodical surveys and after reactor core reloading). In such a case, test pressure shall be 0,05 MPa, permissible relative leakage rate shall be equal to measured relative leakage rate at initial test pressure of 0,05 MPa.

The test results assessment criterion shall be the condition when the inequality holds true

$$L_D^{EX} \leq 1{,}15(L_M + \zeta_L) \quad (3.2.13)$$

where L_D^{EX} = permissible relative leakage rate at excessive pressure of 0,05 MPa to be controlled during ship operation, %/day;
L_M = measured relative leakage rate at excessive pressure of 0,05 MPa obtained during ship construction, %/day;
ζ_L = design measurement error at excessive pressure of 0,05 MPa obtained during ship construction, %/day;
1,15 = factor, which accounts for operating life of the ship.

The measured relative leakage rate at initial excessive test pressure of 0,05 MPa shall comply with inequalities (3.2.12).

[1] Available in Russian only.

3.3 SHIELDING BARRIER

3.3.1 The containment and significant radioactive sources related to SSS shall be surrounded by shielding barrier. Boundaries of the containment and shielding barrier shall not be combined.

3.3.2 All bulkheads, decks and other structures forming the shielding barrier shall be steel and watertight as required by the Rules for the Classification for similar structures.

3.3.3 Boundary bulkheads of the reactor compartment and other compartments of the ship may be used as forward and aft traverse bulkheads of shielding barrier.

3.3.4 Longitudinal bulkheads forming side walls of shielding barrier shall be $B/5$ or 11,5 m (whichever is less) apart from the ship's side unless the other penetration height is specified for collision protection.

3.3.5 Shielding barrier shall be subject to watertight test as per hull watertight test set-up.

3.3.6 Upon completion of all mounting operations, shielding barrier shall be subject to leak test. The test procedures and standards shall comply with the requirements to the ship spaces.

3.3.7 In the course of the ship operation, the shielding barrier spaces are not required to be leak tested, provided that the design pressure in these spaces is maintained to be below the atmospheric pressure.

3.4 REACTOR FOUNDATIONS. FASTENERS OF CONTAINMENT AND BIOLOGICAL SHIELDING

3.4.1 Reactor foundations and fasteners of containment shall provide effective support under external conditions as specified in Section 8, Part II "Safety Standards".

The foundations shall be capable of keeping the reactor and primary systems as well as containment at place in case of inclinations of the ship up to and including capsizing.

3.4.2 The foundations shall be capable of withstanding thermal stresses.

3.4.3 The foundation structures shall be accessible for inspection as far as possible.

3.4.4 Provision shall be made for reliable securing of the biological shielding designed with regard to the inertia forces acting on it as specified for equipment of safety classes 2 and 3 and to deformation of ship's hull and exposure to excessive pressure in the containment.

APPENDIX

NSSS CONTAINMENT LEAK TIGHT CIRCUIT COMPONENTS. PROCEDURE FOR CALCULATING LEAK TIGHTNESS STANDARD VALUES

1 SCOPE

1.1 This Procedure covers the containment leak-tight circuit components for NSSS of ships. The Document shall be used for design and establishes procedure for calculating leak-tightness standard values.

2 DESIGNATIONS

L_{PERM} = permissible relative leakage rate, %/day;
P_a = atmospheric pressure, Pa;
$P_{MAX\ DESIGN-BASIS}$ = absolute air pressure equal to emergency fluid pressure in case of the maximum design-basis accident, Pa;
P_1 = absolute air pressure within containment in 24 test hours, Pa;
ΔP_{PERM} = permissible pressure variation for given L_{PERM}, Pa;
P_{TEST} = absolute test pressure, Pa;
τ = time within which pressure changes by value of ΔP_{PERM}, s;
Q_{PERM} = permissible total air flow through miniature defects of containment leak tight circuit at pressure $P_{MAX\ DESIGN-BASIS}$, W (m^{3}Pa/s);
Q_i = air flow through one component of leak-tight circuit at P_{TEST}, W;
V = containment volume, m ^{3};
B_Σ = total leakage value (leak tightness standard) for the whole containment leak-tight circuit, W;
B_i = leak tightness standard value for the component of leak-tight circuit, W;
B_{wj} = leak tightness standard value for welded joint of leak-tight circuit, W;
B_{dji} = leak tightness standard value for components of detachable joint-tight circuit, W;
B_{dji} = leak tightness standard value for components of flange joint-tight circuit, W;
$В_i^{sf}$ = leak tightness standard value for the component of leak-tight circuit with regard to the safety factor, k, W;
l_i = joint length on the leak-tight circuit component, m;
n_i = number of leak-tight circuit components;
l_{wj} = length of welded joints, m;
l_{dj} = length of detachable joints, m;
l_{fj} = length of flanged joints, m;
n_{sf} = number of stop valves communicating with air pressure under test (stop valves are included into leak-tight circuit);
n_{ns} = number of sealings for cable/conductor penetrations;
n_{cs} = number of cable sections.

3 TERMS AND DEFINITIONS

3.1 Relative leakage rate is a ratio of leakage rate (by weight/volume) to air mass/volume in the controlled volume at given initial parameters (pressure, temperature) expressed as a percentage per unit time (%/day).

At that a leakage rate is understood as an air mass/volume escaped from the controlled volume per unit time in kg/h (m^3/h) or kg/day (m^3/day) at given initial parameters (pressure, temperature).

3.2 Air flow is an air consumption where air quantity is expressed as a product of volume and initial pressure drop, m^3Pa/s (W).

3.3 Ratio of leak tightness standard value to air flow is an atmospheric air flow discharged into vacuum under normal conditions: t = 20 °C and P_a = 101333 Pa (760 mm Hg), m^3Pa/s (W).

3.4 Ratio of leak tightness standard value to air flow is determined by the formulae:

$$B_i = Q_i \frac{P_a^2}{P_{TEST}^2 - P_a^2} \quad (3.4\text{-}1)$$

or

$$Q_i = B_i \frac{P_{TEST}^2 - P_a^2}{P_a^2}. \quad (3.4\text{-}2)$$

4 CALCULATION PROCEDURE

4.1 The permissible air pressure variation ΔP_{PERM} at design values of L_{PERM} and $P_{MAX\ DESIGN-BASIS}$ and assumption that $T_0 = T_1$ and $P_a = \text{const}(P_a = 1{,}0 \times 10^5\ \text{Pa})$ is determined by the formula

$$\Delta P_{PERM} = L_{PERM} P_{MAX\ DESIGN-BASIS}/100. \quad (4.1)$$

4.2 The total permissible air flow Q_{PERM} through miniature defects of the containment leak-tight circuit shall be calculated as follows:

$$Q_{PERM} = \Delta P_{PERM} V/\tau. \quad (4.2)$$

4.3 Leak tightness standard value B_Σ of the containment leak tight circuit shall be calculated as follows:

$$B_\Sigma = Q_{PERM}\ P_a^2/(P_{MAX\ DESIGN-BASIS}^2 - P_a^2). \quad (4.3)$$

4.4 For normalized ratio in leak tightness standard value B_Σ, refer to Table 4.4.

Table 4.4

Leak tightness standard value

Type of joint for the leak tight circuit component					
Welded joints	Detachable joints	Flanged joints	Stop valves	Sealings for cable/conductor penetrations	Cable section
0,05B_Σ	0,32B_Σ	0,18B_Σ	0,19B_Σ	0,21B_Σ	0,05B_Σ

4.5 Based on the data in Table 4.4 leak tightness standard values are estimated as follows:

.1 for welded joints of leak-tight circuit:

$$B_{wj} = 0{,}05B_{\Sigma}/l_{wj};\qquad (4.5.1)$$

.2 for components of leak-tight circuit with detachable joint:

$$B_{dji} = \frac{0{,}32B_{\Sigma}}{l_{dj}}l_{dji};\qquad (4.5.2)$$

.3 for components of leak-tight circuit with flanged joint:

$$B_{dji} = \frac{0{,}19B_{\Sigma}}{l_{dj}}l_{dji};\qquad (4.5.3)$$

.4 for stop valves of the leak-tight circuit component:

$$B_{sfi} = 0{,}18B_{\Sigma}/n_{sf};\qquad (4.5.4)$$

.5 for sealings of cable/conductor penetrations of the component of the leak-tight circuit:

$$B_{sfi} = 0{,}21B_{\Sigma}/n_{sf};\qquad (4.5.5)$$

.6 for cable sections per cable:

$$B_{csi} = 0{,}05B_{\Sigma}/n_{sf}.\qquad (4.5.6)$$

4.6 Safety factor of 0,1 (k = 0,1) shall be taken into account to test calculated values more exactly. Then leak tightness standard value with regard to safety factor shall be as follows:

$$B_i^{sf} = kB_i.\qquad (4.6)$$

5 EXAMPLE

5.1 Supposing that design parameters have the following values:

L_{PERM} = 1 %/day; $P_{MAX\ DESIGN-BASIS}$ = 5,0 × 10^5 Pa; V = 680 m^3; l_{wj} = 600 m; l_{dj} = 34,5 m; l_{fj} = 6 m; n_{sf} = 32 items; n_s = 6 items; n_{cs} = 800 items.

5.2 Permissible air pressure variation ΔP_{PERM} is determined by Formula (4.1)

$$\Delta P_{PERM} = L_p P_{MAX\ DESIGN-BASIS}/100 = 1 \times 5 \times 10^5/100 = 5000 \text{ Pa}.$$

5.3 Total permissible air flow Q_{PERM} is determined by Formula (4.2)

$$Q_{PERM} = \Delta P_{PERM}V/f = 5000 \times 680/24 \times 3600 = 40 \text{ W (m}^3\text{Pa/s)}.$$

5.4 Leak tightness standard value of the whole leak-tight circuit is determined by Formula (4.3)

$$B_{\Sigma} = Q_{PERM}\ P_a^2/(P_{MAX\ DESIGN-BASIS}^2 - P_a^2) = 40\,\frac{(1{,}0\times10^5)^2}{(5{,}0\times10^5)^2(1{,}0\times10^5)^2} = 1{,}7 \text{ W}.$$

5.5 With regard to Table 4.4 and Formulae (4.3), (4.5.1) to (4.5.6), leak tightness standard value for welded joints of containment leak tight circuit is determined as follows:

$B_{wj} = 0{,}05 \times 1{,}7/l_{wj} = 1{,}4 \times 10^{-4}$;

$B_{wj}^{sf} = 0{,}1 \times 1{,}4 \times 10^{-4} = 1{,}4 \times 10^{-5}$ W;

.1 for the component of leak tight circuit with detachable joint (for example, main cover, $l_{mci} = 20$ m):

$B_{mci} = \frac{0{,}32 \times 1{,}7}{34{,}5} 20 = 0{,}3$ W;

$B_{mci}^{sf} = 0{,}1 \times 0{,}3 = 3{,}0 \times 10^{-2}$ W;

.2 for the component of leak-tight circuit with flanged joint (for example, fan-penetration joints $l_{fp} = 0{,}6$ m):

$B_{fpi} = \frac{0{,}18 \times 1{,}7}{6} 0{,}6 = 0{,}03$ W;

$B_{fpi}^{sf} = 0{,}1 \times 0{,}3 = 3{,}0 \times 10^{-3}$ W;

.3 for stop valves of the leak-tight circuit component:

$B_{svi} = \frac{0{,}18 \times 1{,}7}{32} = 9{,}6 \times 10^{-3} = 0{,}03$ W;

$B_{svi}^{sf} = 0{,}1 \times 9{,}6 \times 10^{-3} = 9{,}6 \times 10^{-4}$ W;

.4 for sealings of cable penetrations:

$B_{sci} = \frac{0{,}21 \times 1{,}7}{6} = 0{,}06$ W;

$B_{sci}^{sf} = 0{,}1 \times 0{,}6 \times 10^{-3} = 0{,}6 \times 10^{-3}$ W;

.5 for cable sections per cable:

$B_{csi} = \frac{0{,}18 \times 1{,}7}{6} = 1{,}4 \times 10^{-4}$ W;

$B_{csi}^{sf} = 0{,}1 \times 1{,}4 \times 10^{-4} = 1{,}4 \times 10^{-5}$ W.

5.6 Determination of standard values for bench tests of leak-tight circuit components.

Example: the bench of internal void volume equal to V_{void} = 2 m³ is made for main cover testing. Absolute air pressure at the beginning of the tests shall be taken to be $P_{TEST} = 2{,}0 \times 10^{5}$ Pa. Standard values for tests are determined by Formulae (3.4-1) and (4.2):

.1 permissible air flow:

$Q_{PERM} = B_{mci}^{sf} \frac{P_{test}^2 - P_a^2}{P_a^2} = 3{,}0 \times 10^{-2} \times 3 = 0{,}9 \times 10^{-3}$ W;

.2 permissible pressure drop for 1 test hour:

$\Delta P_{PERM} = Q_{PERM} f/V_c = 0{,}9 \times 10^{-3} \times 3600/2 = 1620$ Pa;

.3 test standard values:
Initial absolute pressure on the bench:

$P_{TEST} = 2{,}0 \times 10^5$ Pa;

test duration:

$\tau = 3600$ s (1 h);

Permissible pressure drop:

$\Delta P_{PERM} = 1620$ Pa.

6 APPLICATION NOTE

6.1 Leak tightness standard value for welded joints shall be given in the requirements of design documents on the containment hull structures.

6.2 Leak tightness standard value shall be given in the requirements of design documents on components of the containment leak-tight circuit with detachable and flanged joints.

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FAI "Russian Maritime Register of Shipping"
8, Dvortsovaya Naberezhnaya, 191186, St. Petersburg
www.rs-class.org/en/