# *Development of Components for Recovery Annealing of VVER-1000 Reactor Vessel Welds*

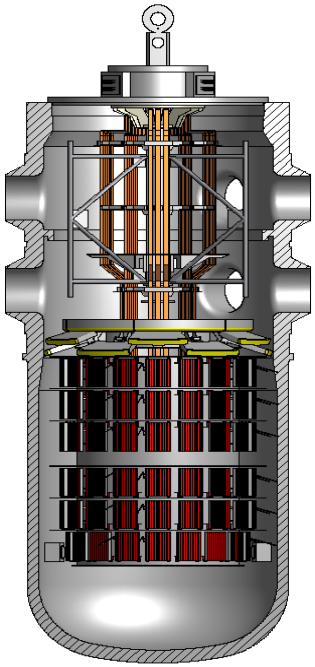
*Выполненные работы*

## 2010

Development of technical task

Development of technical proposal

Development of draft project of heating device



## 2011

Development of design, manufacturing and testing of pilot sensors for monitoring and registration of thermal mode.

Development of system РКД for automatic control, monitoring and registration of thermal mode.

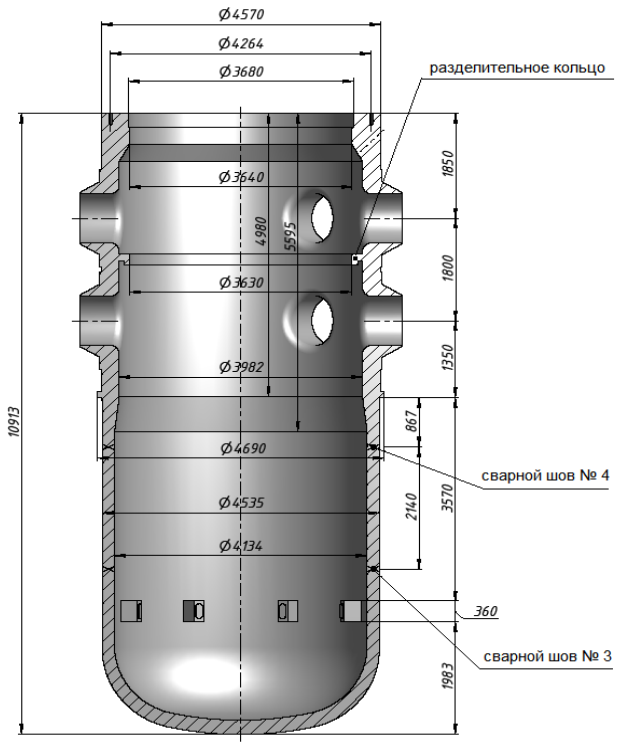
Preparation of production, manufacturing and testing of pilot heating panels.

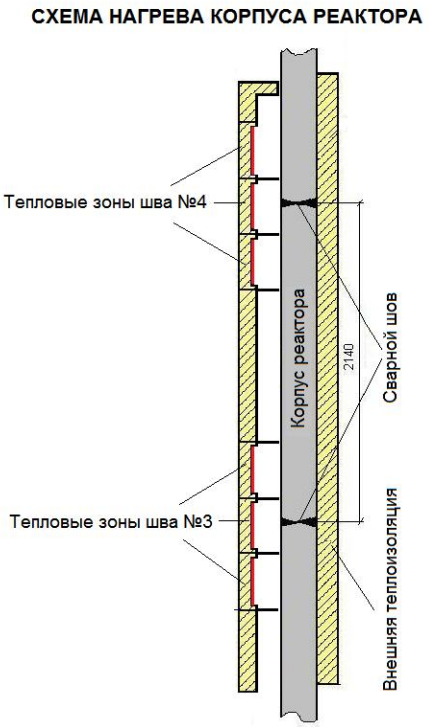
Manufacturing of heating device mock-up and performing experiments with this mock-up.

Development of RKD for heating device

# *Technical Task on Installation and Main Technical Decisions*

- *Heating of reactor vessel welds №3,4 at a rate of 20°C /hour maximum from the ambient temperature to 570°C;*
- *Exposure at temperature 570°C , duration 120-150 hours;*
- *Cooling from 570°C to 100°C at an average rate 7°C /hour*
- *Maldistribution of temperature in weld volume ± 15°C maximum*



***The scheme of double-side heating (heating of internal and external surface of vessel)***

***The scheme of one-side heating of internal vessel side with well-done heat insulation of external surface (heating of internal and external surface of vessel)***

***Installation of thermal insulation in hard- to- access places  is a difficult task but a real one.***

***Weld № 4 is located close to the reactor support, there is no practical possibility to install external insulation in this place that additionally increases heat flow and creates a risk of support concrete heating higher than permissible temperature.***

***Due to complicated reactor vessel configuration significant heat losses must be compensated with a very limited height of thermal area.***

***Heating with process gap 380 (it was 250)***

***To reduce mutual influence of thermal area there are flexible metal thermal screens to be installed.***

# *Calculated Validation of Adopted Technical Decisions*

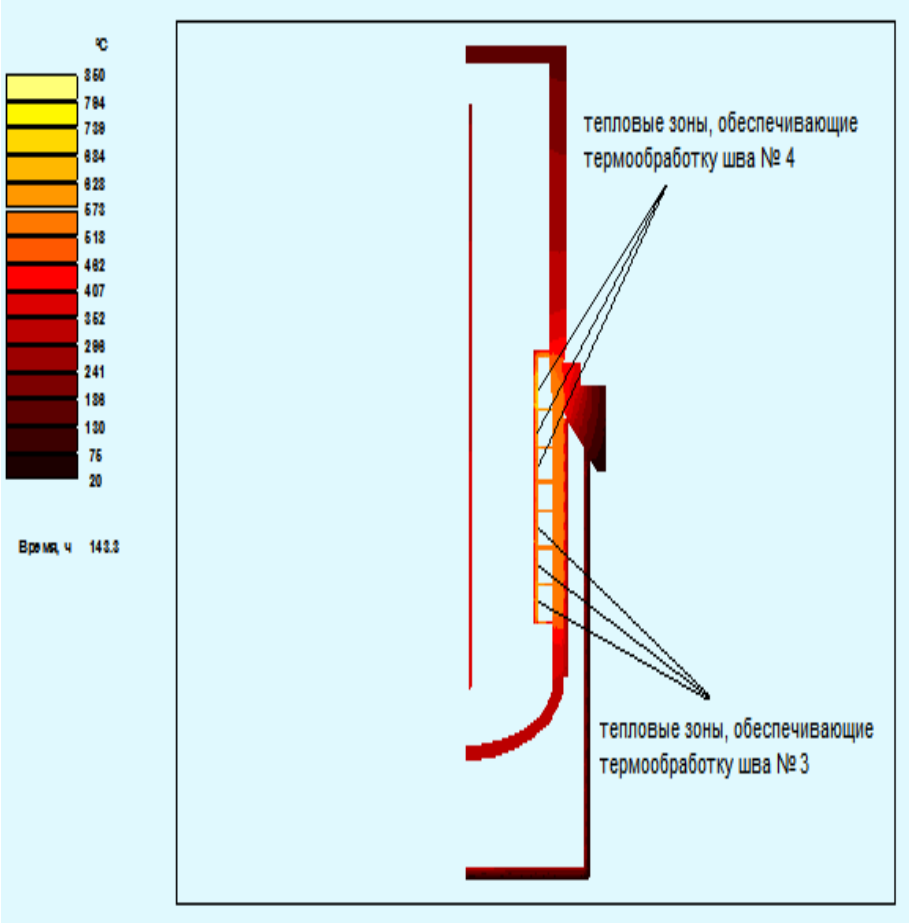
- *mathematical model of multi-link system of thermal-technically massive and thin bodies considering heat exchange with irradiation, heat conductivity and convection between them*

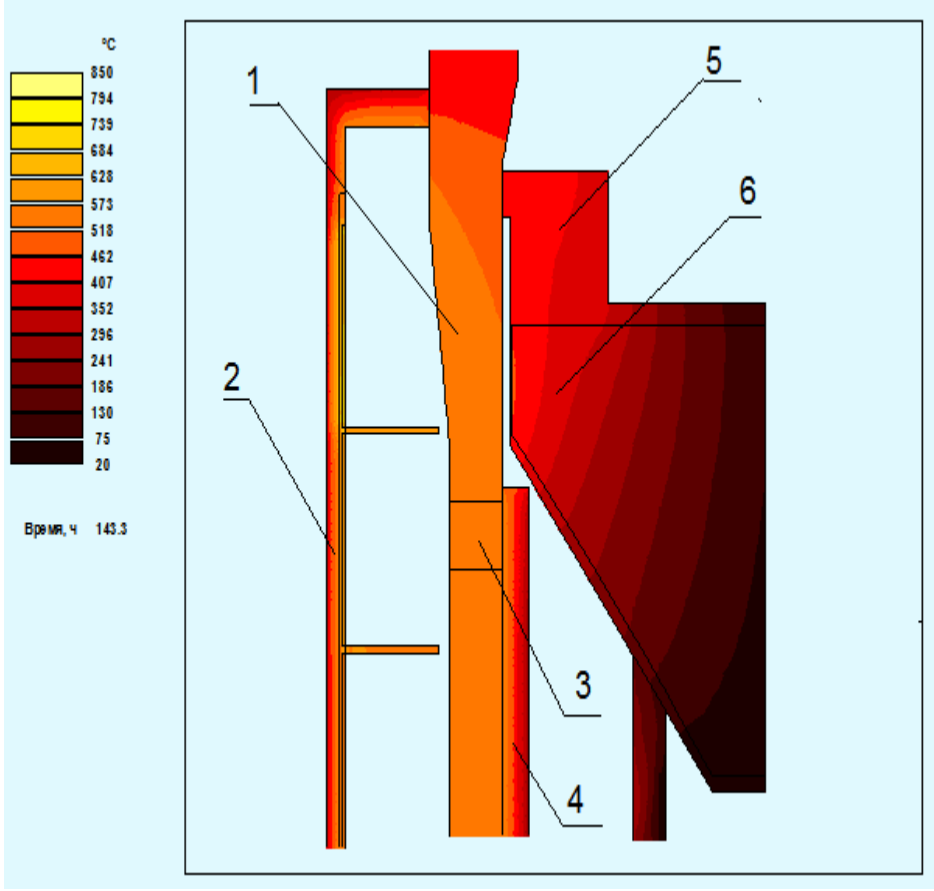
- *set of programs (2-D and 3-D) providing for simulation of stationary and non-stationary thermal processes during recovery annealing of VVER-1000 reactor vessel considering specific features of reactor vessel design, reactor pit and heating device*

- *non-stationary calculations with 2-D model of heating device proved correctness of heating device scheme selected and demonstrated that design decisions provide for the following requirements of the technical task:*

•reactor vessel heating with the rate of 20 $^{O}$C/hour up to 570 $^{O}$C;
• exposure during 100 and more hours at this temperature;
• temperature variation along reactor vessel during exposure period close to welds being thermally processes (± 100 mm by height from middle weld line) is within 19 $^{O}$C.

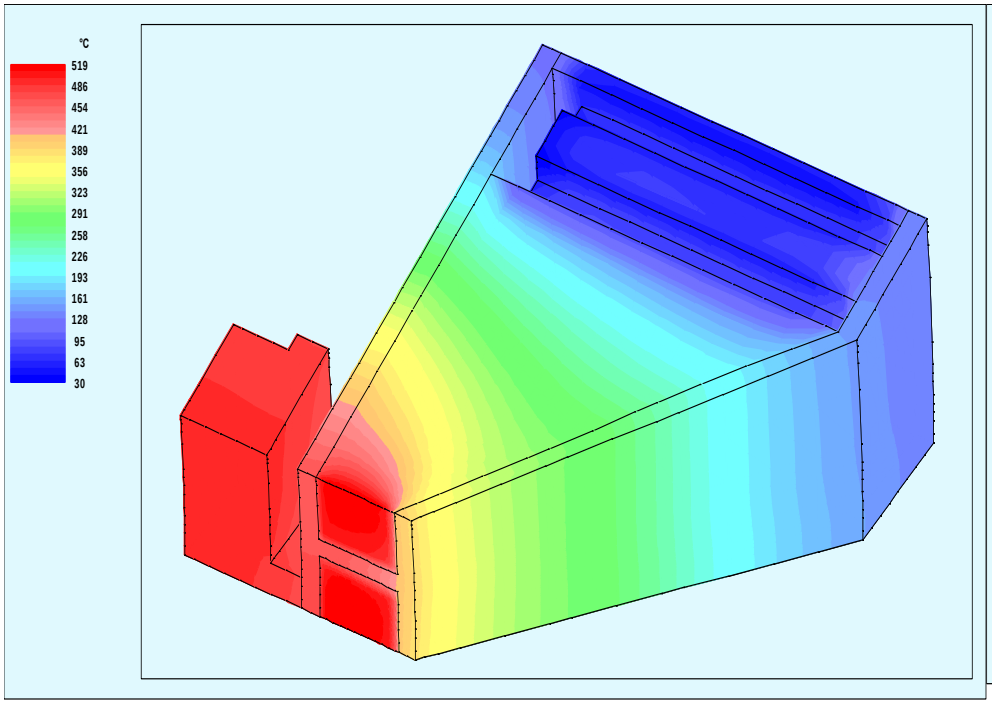
# The Area of Weld №4 being Thermally Processes

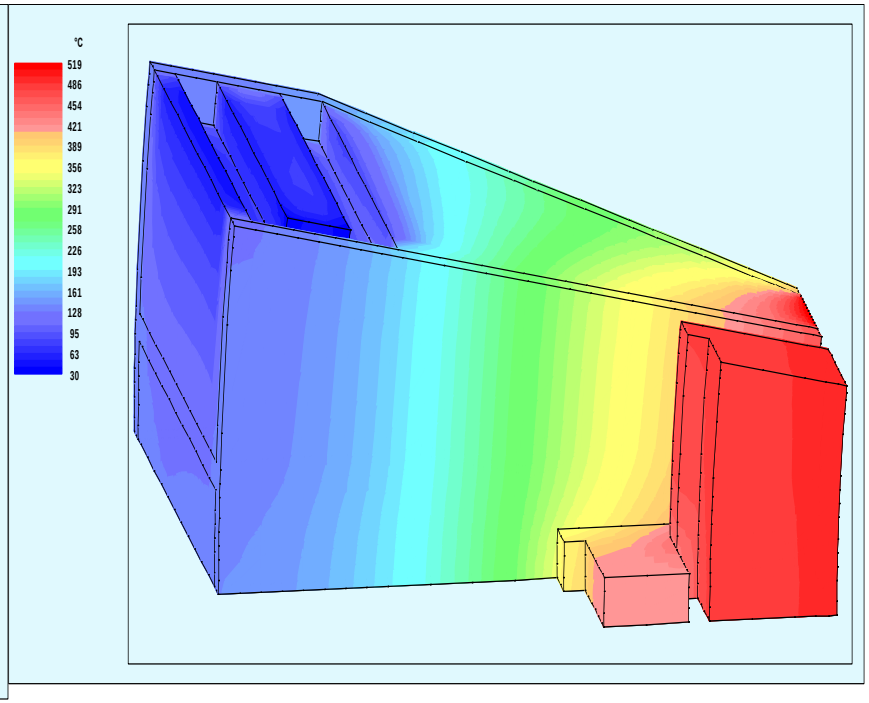



Temperature fields of the vessel during annealing

- Reactor vessel; 2- heating device; 3- weld № 4; 4- external heat insulation; 5- supporting ring; 6- supporting frame

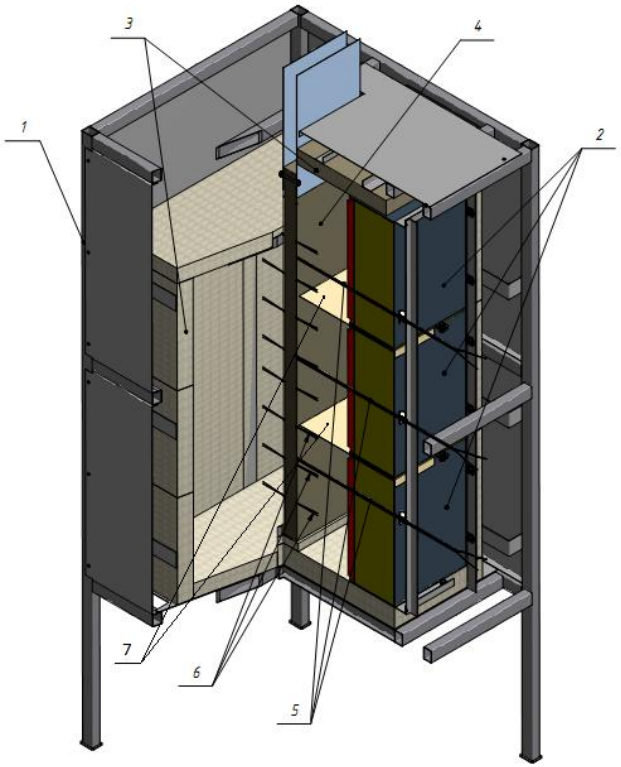



# *Temperature field of supporting frame*

*The temperature of adjacent to the reactor elements of supporting frame (about 140mm thickness) can reach 500-430 °C (regulated temperature - 430 °C) under conditions adopted for 3D model calculations*

# *Experimental Support to Validate Technical Decisions*




## Bench for Thermal Testing

1- body;
2- heating panels;
3- heating insulation;
4- reactor vessel imitator;
5- regulating thermo couples;
6- control thermocouples;
7- thermal screens

Heating panels

# Installation of heating panels during installation of bench

# Hoist model in initial and lifted position

*1. Experimental stability checking of automatic temperature control system and determination of mutual influence rate for thermal areas*

**Provides for stable system operation, mutual influence of thermal areas does not impact on control quality, dynamic settings of temperature PID regulators are determined**

*2. Comparative testing of two variants for heating panel design*

**A panel with zigzag heater made of resistance alloy 550x400 size is the most reliable**

***3.*** *Checking of compliance between contact type thermal couple indications and real temperatures of reactor vessel surface*

**Thermal couples provided for compliance of indications and actual temperature of the surface being measured with error maximum $2^{O}C$**

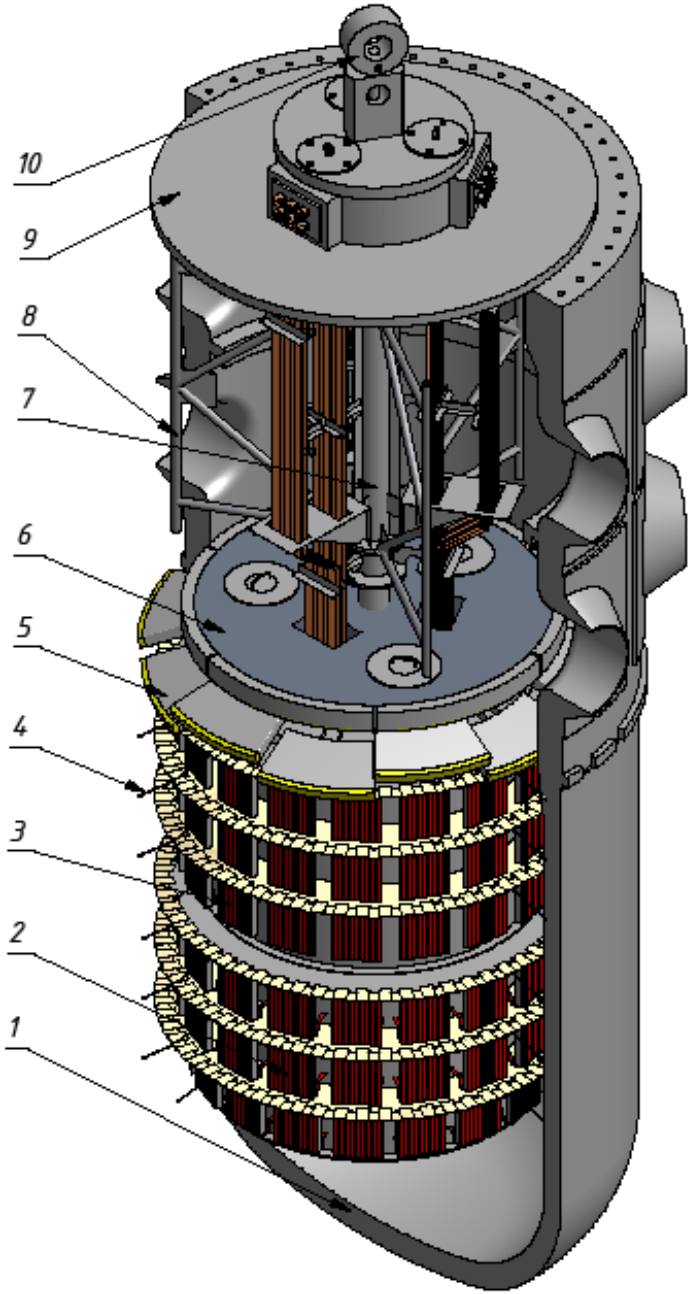
***4.*** *Checking availability of the main device for installation of external heat insulation of reactor vessel (scaled 1:3)*

**Testing of hoist model proved availability of design developed and allowed for correcting the choice of materials for specific details of the device модели**

# *Heating device*

*1) Heating device is designed for recovery of metal mechanical properties in welds №3 и №4 of VVER-1000 reactor vessel after multiple application at NPP ( must be decontaminated)*

Installed capacity, кВА.....max. 1000
Voltage, V, Hz..... 380/220, 50
Heater voltage, V ..... 36,6
Current at heaters, A..... 364
Number of heaters, pcs..... 108
Number of heating areas, pcs. .....18
Connection of heaters in the area serial
Size of heating unit, mm:
Diameter.....max 3830
Height .....10900
Weight, kg.....32000



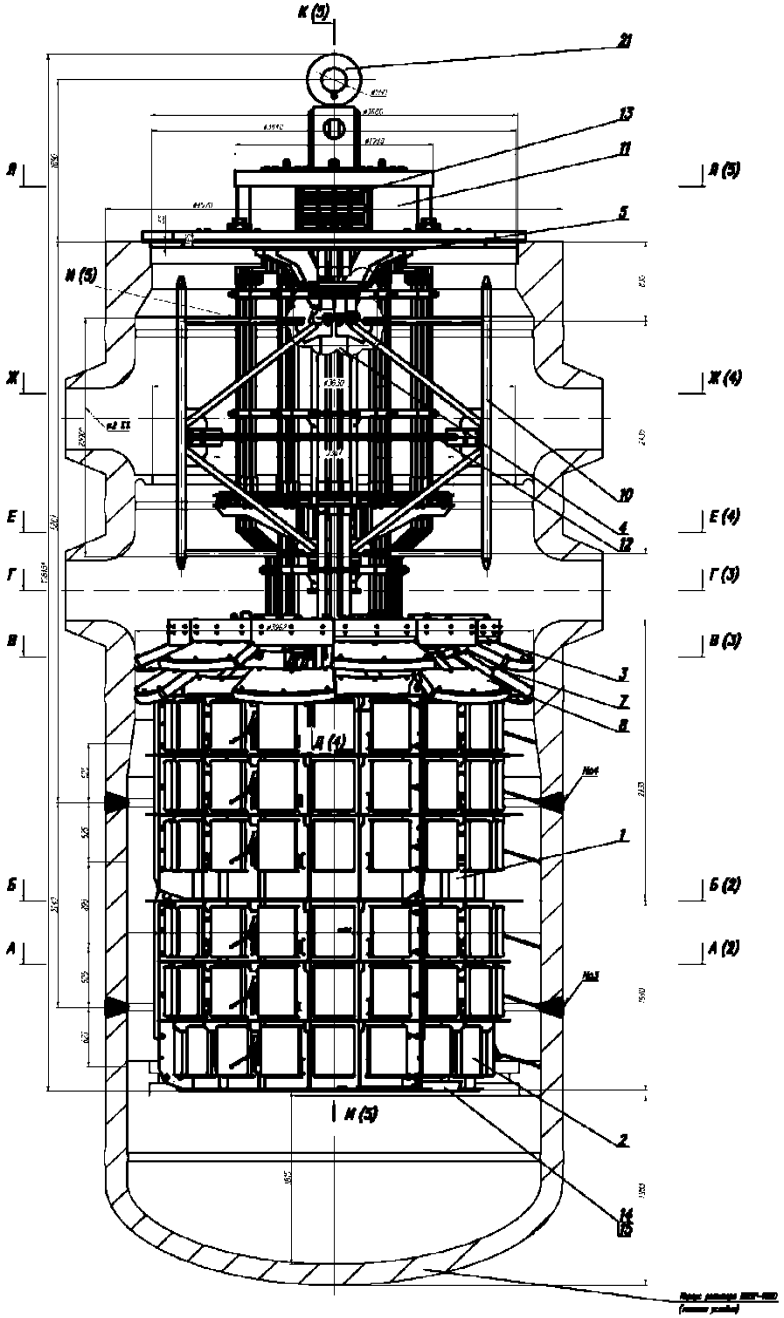

***2)*** *Heating device contains a lid of biological protection and two heater units connected with a bar with membrane installed on it linked with a curtain and a draw bar.*

***3)*** *There are 54 heaters in each unit, 108 in two. They create six heating rings by their height, 18 in each of the ring.*

***4)*** *Heating unit contains 18 independent thermal areas, 9 areas for each weld. Three annular heating areas with six heaters in each of the area*

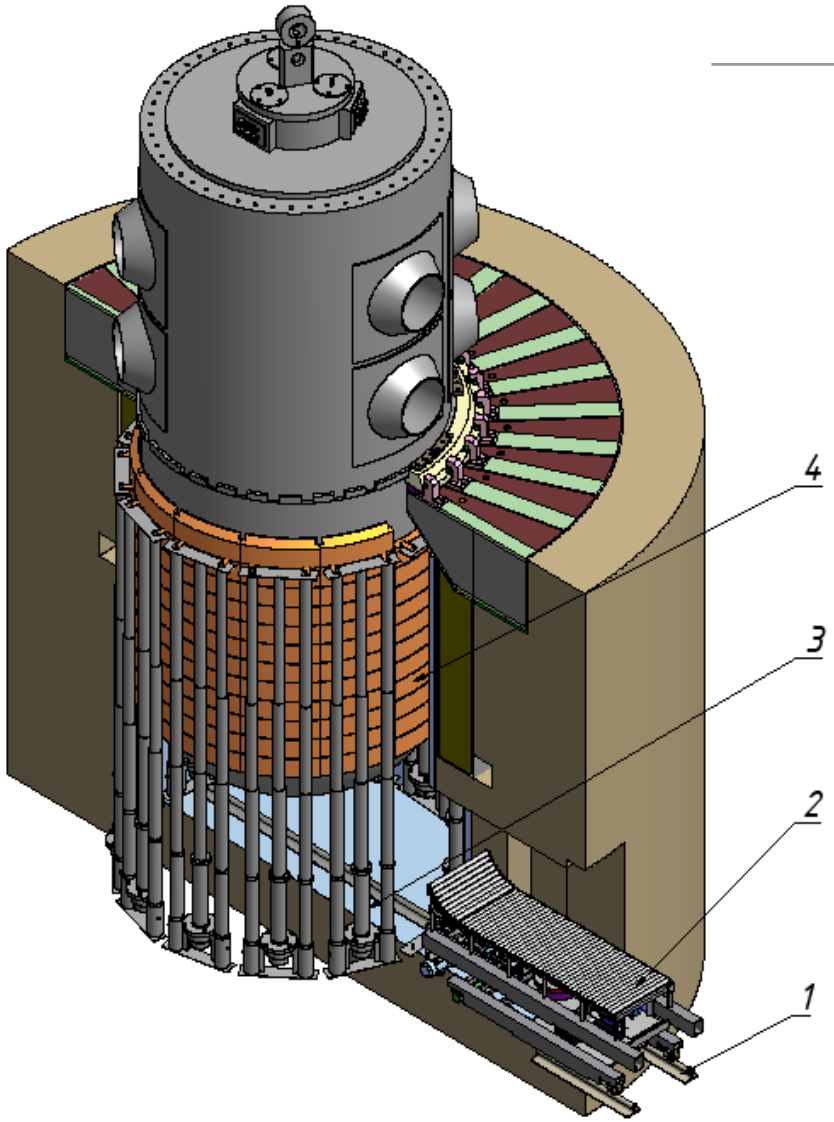
***5)*** *Heaters of each area are connected to the independent supply source with the help of supplies laid along the bar to the external surface of the lid.*

***6)*** *Each area is supplied with thermal couples in the form of double-arm lever*



Heating device in reactor vessel

# External Heat insulation, Tools for its Installation




The system of external heat insulation in working position

- 1- rails, 2- powered truck, 3- telescopic hoists,4- heat insulation.

*Thirteen vertical «straps» of heat insulation (metal box filled with heat insulation material).*

*Thirteen hoists in the form of telescopic four-way screw jack with two telescopic columns.*

*On upper surface – soft heat insulation filling the volume between the reactor vessel and concrete horn of reactor pit support part.*

*Powered truck with four grips (from tilting) and rotary frame.*

*Lifting tongs to move hoists, driving roller bed on which a strap of heat insulation is laid and a rotary drive with a gear.*

# *Electric Equipment and Tools for Automatic Control and Registration of Anneal Main Parameters*

Electric power supply to heating elements

Automatic control of thermal processing according to a temperature-time program set by an operator

Collection of information on temperature state of reactor vessel and rea… room

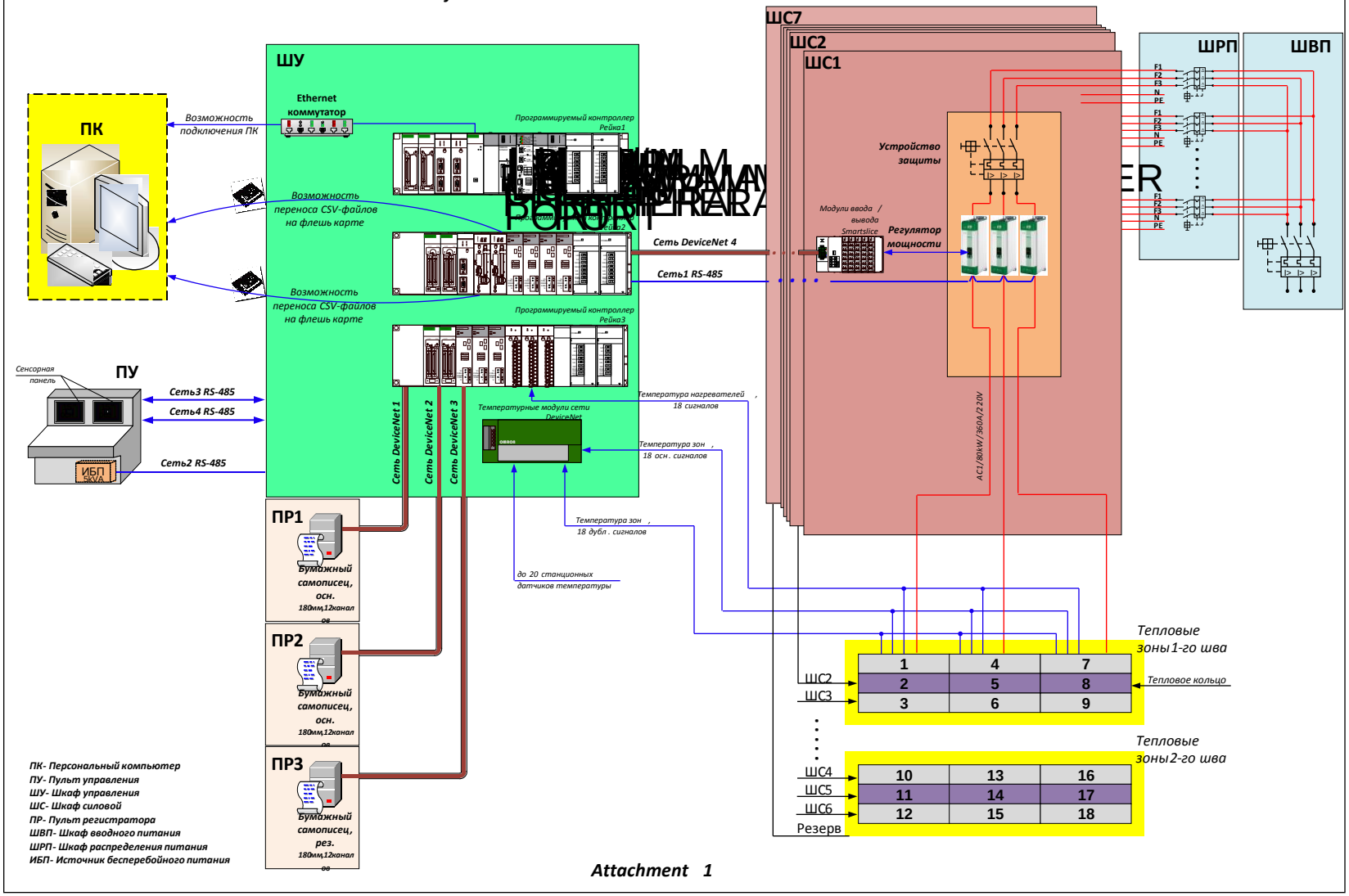
Visual presentation of thermal processing

Registration of process parameters in paper chart

Archiving and storage of process parameters

- ШУ – control cabinet; ШС1 ÷ ШС7 – power supply cabinets (ШС7 – back-up);
- ШРП – supply distribution cabinet; ШВП – supply input cabinet;
- ПУ – control board – main and back-up
- ПР1 ÷ ПР3 (ПР3 – back-up) – registration boards.

## *Functional scheme of control system for thermal processing of VVER-1000 reactor vessel welds -*




*ПК- Персональный компьютер*
*ПУ- Пульт управления*
*ШУ- Шкаф управления*
*ШС- Шкаф силовой*
*ПР- Пульт регистратора*
*ШВП- Шкаф вводного питания*
*ШРП- Шкаф распределения питания*
*ИБП- Источник бесперебойного питания*

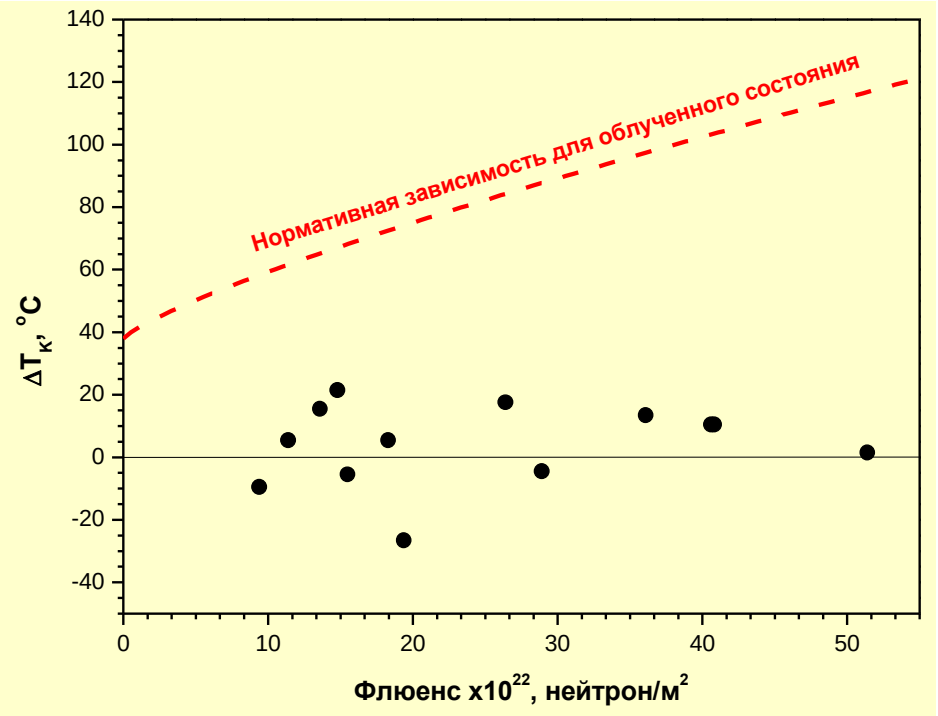
***Attachment 1***

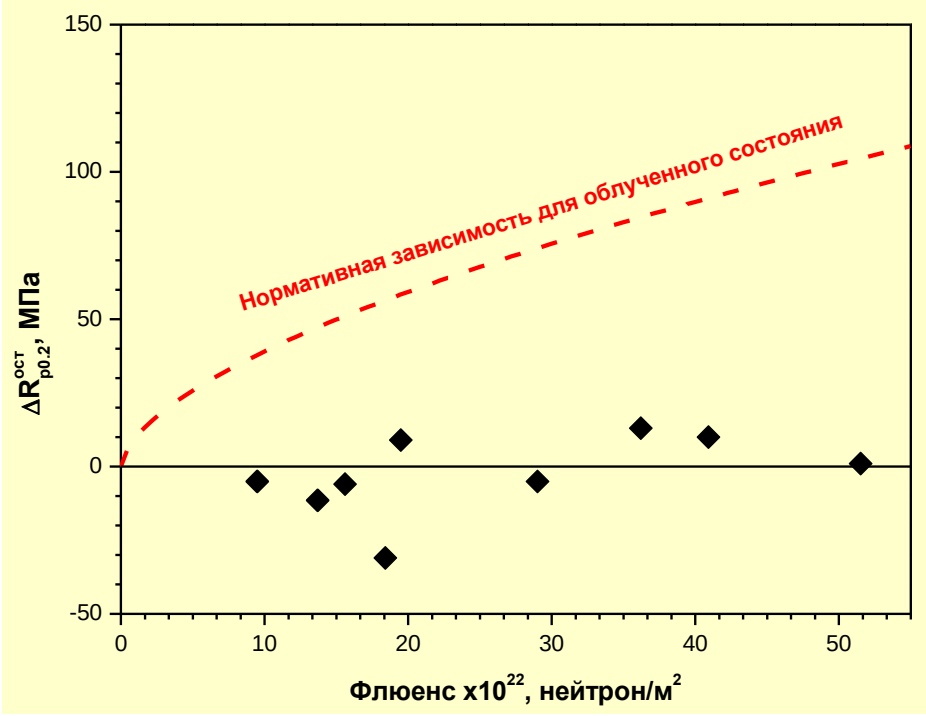
# *Conclusions and Results*

1. An annealing facility for №3 and 4 welds of VVER-1000 reactor vessel is designed.
2. Working design documents for heating device, control and heating mode registration systems providing for implementation of this annealing technology is developed.
3. Calculated and experimental validation of adopted technical decisions is made, heating device is being manufactured, auxiliary devices and facilities are being designed and tested.
4. The work is being done strictly according to the schedule providing for readiness of technology and components to first annealing in 2016-2017 (Balakovo NPP, unit №1).

**To refine equipment operation modes, specify real bordering conditions and temperature fields in reactor vessel and bearing structures it is necessary to perform full-scale experiments for «clean» reactor vessel not intended for further operation**

# Residual embrittlement of irradiated welds after recovery annealing 565±15°C /100 h




Possibility for almost total recovery of material structure and properties in VVER reactor vessel as a result of recovery annealing after irradiation within the range of neutron fluence corresponding to the design one as well as to prolonged up to 60 years operation period was proved experimentally. This demonstrates possibility of recovery annealing application to provide operation of reactor vessels up to 60 years and more.

# *Continuation of Work on Development of Equipment*

**Making control and power supply system**

**Making heating unit**

**Making external thermal insulation and tools for its installation**

**Designing and making a стапеля and rigging for installation of heating device before its loading to the reactor**

**Programming and debugging of control system**

**Hot testing, RKD correcting**

Experimental- calculated validation of reliability and sufficiency of proposed technology for recovering annealing of reactor vessel, safety of adopted concept for annealing of design elements of reactor, reactor pit and other NPP components.
Possible study of variants for cooling of support structures.
Development of operation documents, POR.
Creation and training of specialists for annealing