COUPLING OF AST-500 HEATING REACTORS WITH DESALINATION FACILITIES

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Abstract

The general issues regarding NHR and desalination facility joint operation for potable water production are briefly considered. AST-500 reactor plant and DOU GTPA-type evaporating desalination facilities, both relying on proven technology and solid experience of construction and operation, are taken as a basis for the design of a large-output nuclear desalination complex. Its main design characteristics are given. Similarity of NHR operation for a heating grid and a desalination facility in respect of reactor plant operating conditions and power regulation principles is pointed out. The issues of nuclear desalination complexes composition are discussed briefly as well.

1. Introduction

A low-grade nuclear heating reactor is capable to be used effectively as a part of water desalination complexes, taking into account their distinctive features such as:
- high reliability of the heat generation;
- extended refuelling interval (2 years);
- identity of NHR operating conditions both for the heating grid and for a desalination facility;
- enhanced radiological safety, which allows:
    * to construct the nuclear power plant close to a sea shore or any other sources of salted water used for a desalination process;
    * to create an integrated complex incorporating both desalination facilities with desalted water stocks and a nuclear power plant;
    * to deploy such complexes close to fresh water consumers, e.g. industrial-residential centers [1].

2. Desalination Complex Composition

The AST-reactor is designed to produce low parameter heat, which defines the type of an appropriate desalination facility. Direct usage of the low-parameter heat is most effective in evaporating facilities. Long operation experience is available in Russia for the desalination facilities with horizontal film evaporators, in particular more than 20-year experience of plant operation in the industrial nuclear desalination complex with the BN-350 fast reactor (also developed by OKBM) on the Caspian sea shore.

Desalination plants of such type are characterized by the good quality of distilled water produced, low power consumption, long-term (more than 25 years) service life of the basic equipment.

Rate of expansion of the desalination facilities with the horizontal-tube film evaporators for the last 10 years was the highest, according to the IAEA data, compared with the desalination plants of other types, which is explained by their mass production mastering, better economics: relatively low (in comparison with the reverse osmosis facilities) operational cost and lower price of desalinated water, as well as higher quality of potable water (data of IDE Technology LTD., Israel).

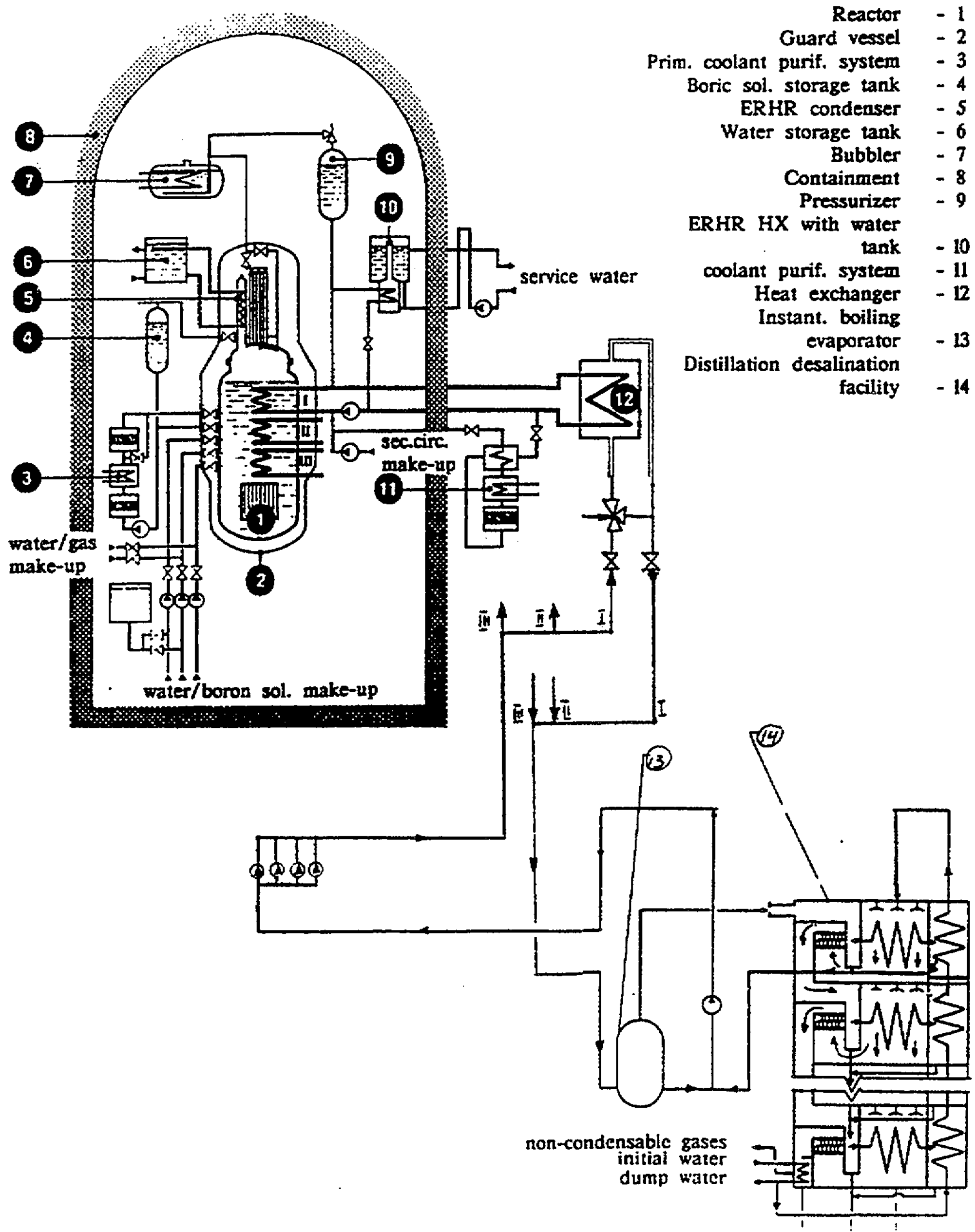

Fig. 1 AST-500 NHR-based Desalination Facility Principal Flow Diagram

Creation of desalination complexes incorporating the AST-500 power units of some 200,000 m^3 per day output and even more in one unit (see Fig.) presumes availability of large consumers of desalinated water in the region, as well as of developed system for water supplying and distribution (pipelines, pump stations, etc.), and of developed power systems. Under these conditions there are grounds to energize the desalination complex from the external power system, while the reactor is operated only for heat supply to desalination facilities. This simplifies the complex operation, and improves the efficiency of the generated heat usage.

However, for regions with weak-developed power grids and high tariffs for electricity, there is a possibility to realize on the basis of AST-500 reactor a desalination complex powered from the own auxiliary turbogenerator. A turbine building, related electrical equipment, etc. should,be additionally included in the plant: in this case the desalination complex output is decreased by appr. 20% due to redistribution of thermal power generated by the reactor between a turbine plant and a desalination facility.

The number of power units in the desalination complex is to be determined by the specified output of desalinated water with account of its maximum consumption and load variation over seasons, and by the availability of other sources of fresh water in the given region. The water output should not be less than a constant portion of the year load curve determined by the residential and industrial water consumption with account of planned outage of one power unit for refuelling. The reactor refuelling should be carried out in the period of minimum load in water consumption, if this factor takes place (e.g. regions with irrigated agriculture).

3. Plant Operation Control Concept

Considering a nuclear desalination plant control principles, its similarity with the NHR operation for the heating grid (load variation over seasons) and for the hot water supply (daytime load variation) should be noted. But in the given case there is wider possibility to flatten the influence of load variations onto the nuclear reactor because of the flexibility to accumulate or consume desalinated water in water tanks following a daytime reduction or rising in water consumption respectively. Besides, there is also a possibility to divide the peaks of industrial and agricultural loads (e.g. fields irrigation during night hours, if possible).

Thanks to the availability of desalinated water stocks, the continuous supply of fresh water to consumers can be secured also in a case of short-term unplanned outage of the desalination unit. Taking account of a heating rate limit specified for the AST-500 reactor start-up mode, the minimum period of interruption in desalinated water production process for this unit amounts to appr. 24 hours.

In general, the choice of the method for heat output regulation to the base-load or load-following principle (or their combination) is dictated by specific conditions and requirements of the User. The actual and prospective loads of industrial, household and agricultural consumers of water are taken into account as well as their variation curves, availability of other sources of fresh water and heat, the range of heating water temperature variation at the desalination facility inlet, etc. The AST-500 reactor ensures the reliable operation of the complex both in base-load and load-following operation modes at the reactor power variation rate limit of 25% N_{nom} per hour.

4. Design Study for AST-500 Integration into Desalination Complex

The design study was carried out by the OKBM together with other design Institutions (SverdNI1ChimMash, NIAEP, Kurchatov Institute, etc.) aiming at the development of a desalination complex which is composed of several (more than two) autonomous units each comprising the AST-500

Table 1 Nuclear desalination plant main technical data

Nuclear reactor plant

1.	Reactor thermal power, MW	400
2.	Primary circuit pressure, MPa	2
3.	Primary circuit temperature, °C	208/141
4.	Secondary circuit pressure, MPa	1.2
5.	Secondary circuit temperature, °C	160/102
6.	Tertiary circuit pressure, MPa	2
7.	Tertiary circuit temperature, °C	130/98
8.	Auxiliary power (off-site power source), MW	appr. 7
9.	Auxiliary heat consumption, MW	appr. 15

Desalination facility		evaporating type on the basis of DOU GTPA-700 apparatus with horizontal tube- film evaporators
10.	Number of evaporation apparatus	
	total	16
	operating	13
	stand-by	3
11.	Auxiliary power (off-site power source), MW	appr. 12
12.	Nominal output, m^3/day	appr. 220,000 (16,800x 13)
13.	Sea water max. boiling temperature in the first stage of each apparatus, °C	<115
14.	Salt concentration in desalinated water, mg/1	<20

reactor plant and a desalination facility [2]. The number of desalination apparatus in the facility which are working in parallel is defined by taking account of the possibility to disconnect a part of them for preventive maintenance and repair, because the maintenance interval may not coincide with the reactor refuelling one. The level of the redundancy accounts also for the necessity of annual maintenance for desalination apparatus, this work duration (up to 20 days), as well as a probability of additional failure of one of them.

Main technical characteristics of the nuclear desalination unit based on the AST-500 reactor (without a turbogenerator plant) are given in Table 1.

The potential available for the advanced AST-500 M reactor uprating allows to raise additionally the desalination facility output by appr. 15%. The nuclear desalination complex principal flow diagram is given in Fig.1. A three-loop flow diagram being traditional for the AST-500 secondary and tertiary circuits is retained here along with a possibility for one loop disconnection from the consumer.

In the desalination complex, as well as in the AST-500, tertiary circuit loops are joined by "hot' and 'cold' headers. Circulating pumps similar to the grid ones in the AST-500 provide heat transport from the reactor plant to consumers - the desalination apparatus with water recirculation through a closed loop. Heating medium can be supplied to the first stage of desalination apparatus as water or steam produced from this water in an instantaneous boiling facility. Both methods are verified in the operating nuclear desalination complex with the BN-350 nuclear reactor.

At the plant operation under automatic control, the reactor power and parameters of the circuits are established and maintained by the reactor control rods and three-way valves in the loops of the tertiary (heating) circuit according to the control algorithm similar to that adopted for the AST-500. The reactor power variation range (10-100% N_{nom}) overlaps with a margin the range of stable operation of the desalination apparatus (30-100% G_{nom}, where G_{nom} - nominal flow of desalinated water).

When determining a volume of stand-by desalinated water storage tanks it is expedient to take account of the power variation rate admissible for the reactor at planned variations of desalinated water consumption. Transients associated with complete loss of load cause the reactor shutdown by emergency protection signals and its cooling down by the normal or emergency heat removal systems. The reactor operation with incomplete number of heat transport loops without time limitation is permitted in the range of 10-50% N_{nom}, if the design limits and safety conditions specified for the AST-500 are satisfied. The reactor transition to partial operation mode means proportional decrease in desalination facility output by disconnection of several desalination apparatus or by proportional decrease of each apparatus output.

5. Conclusion

The AST-500 NHR has become a reference reactor plant for the whole series of integral enhanced safety reactors which have been developed recently in OKBM. The basic principles and engineering decisions realized in the reactor plant allow to use it effectively as a heat source for an evaporating desalination facility on the basis of well proven apparatus of DOU GTPA-type with horizontal tube-film evaporators.

The rated output of this facility amounts to 220,000 m^3 /day of desalinated water, with the potential for 15% increase in the output. Modes of the AST-500 operation in combination with the desalination facility are similar to those for operation to heating grid.

High level of radiological safety intrinsic for the AST-500 reactor allows to site it close to water sources, to fresh water consumers and in the immediate proximity of desalination facility, thus forming an integrated power-desalination complex.

Russian positive practical experience of in creation and operation of sea water nuclear desalination system based on the BN-350 reactor and on the desalination apparatus of DOU GTPA-type, together with the proven technology of the AST-500 NHR allow to facilitate substantially licensing and creation of the AST-based desalination complexes. Their excellent safety and economic characteristics give grounds to consider them as a rather prospective for the deployment in many regions worldwide suffering from shortage of potable water.

REFERENCES

[1] IAEA draft report on nuclear heating reactors utilization for sea water desalination, 1990.

[2] Report on investigation for OKBM-designed reactor plants for desalination complexes, - OKBM, 1992, (in Russian).