NON-ELECTRICITY APPLICATION OF NUCLEAR ENERGY: SOME *GENERAL ISSUES AND PROSPECTS*

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Non-electricity application of nuclear energy may serve to:

- improve efficiency and cost-effectiveness of nuclear facilities
- expand the area of nuclear energy application;
- replace fossil fuel in the new areas and further reduce the greenhouse effect.

CO-GENERATION
of electricity and heat for district heating or for water desalination

- real way of enhancing thermal and economic efficiency of nuclear power plants;
- most promising for non-electricity use of nuclear power;

DISTRICT HEATING in Russia

- largest and growing power sector (>50% of power capacity; 40% of electricity production, 85% of heat production);
- 30 mln Gkal/year to produce by NPP in 2020;
- Program of activities on "Application of Nuclear Power Facilities for CHP";
- co-generation as the most efficient way of power saving, fossil fuel economy and reducing CO_2 emissions (Kioto Protocol).

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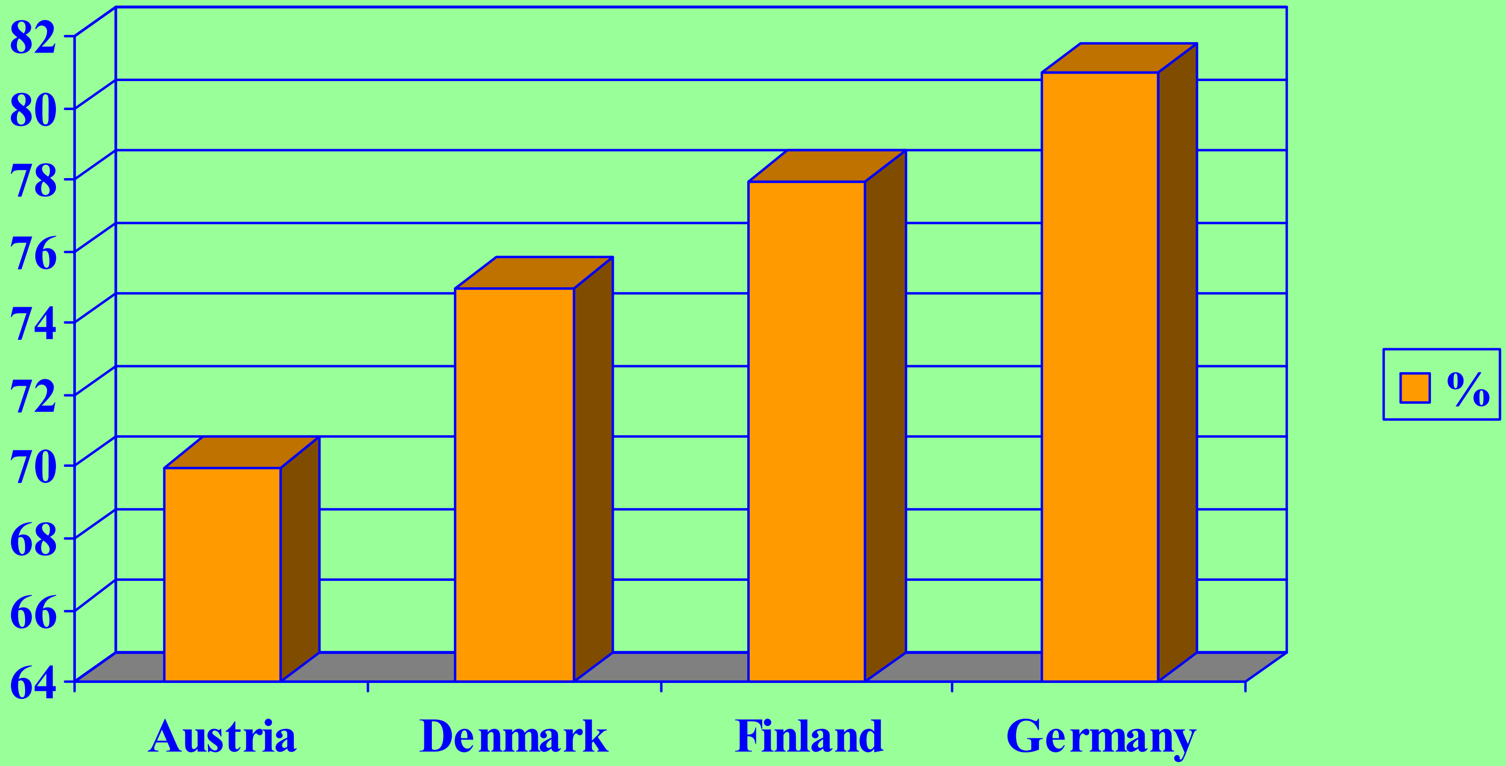
CHP share in DH production



Average share

67%

Specific requirements to nuclear power units for CHP

- ***MEDIUM UNIT CAPACITY 200 – 300 MWe***
  - district heating reliability requirements.
- ***VERY HIGH SAFETY (up to deterministic);***
- ***SMALL CONTROL AREA (5 km);***
- ***ENHANCED RELIABILITY (district heating) ;***
- ***COMPETITIVNESS WITH FOSSIL-FUEL CHP AND WITH NPP.***

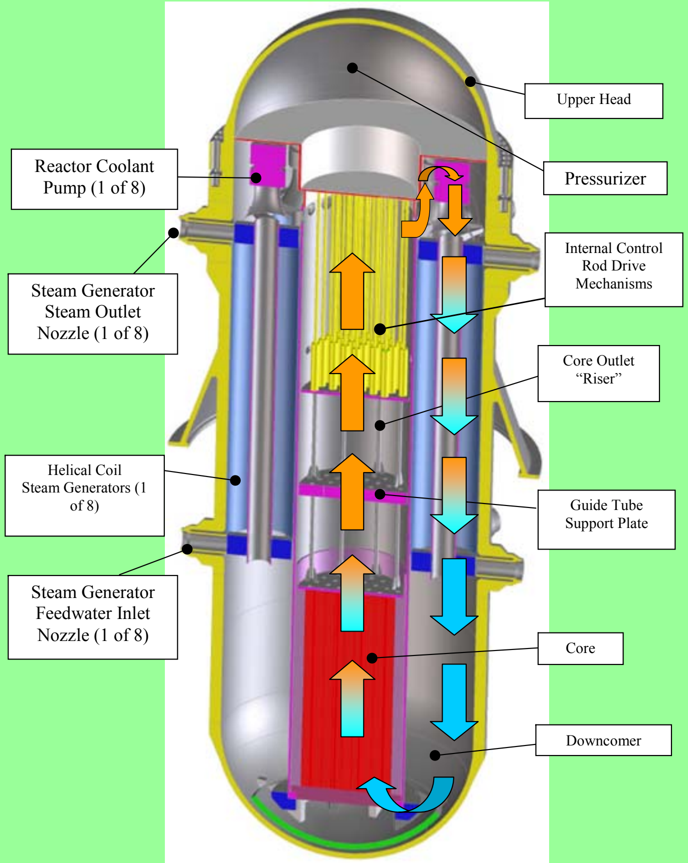
INNOVATIONS
to satisfy to the requirements

- PWR
- ❖ Integral arrangement of the reactor facility
- ❖ IRIS Project
- BWR
- ❖ Ultimate simplicity
- ❖ Ultimate passivity
- ❖ SBWR, VK-300

IRIS Design Objectives

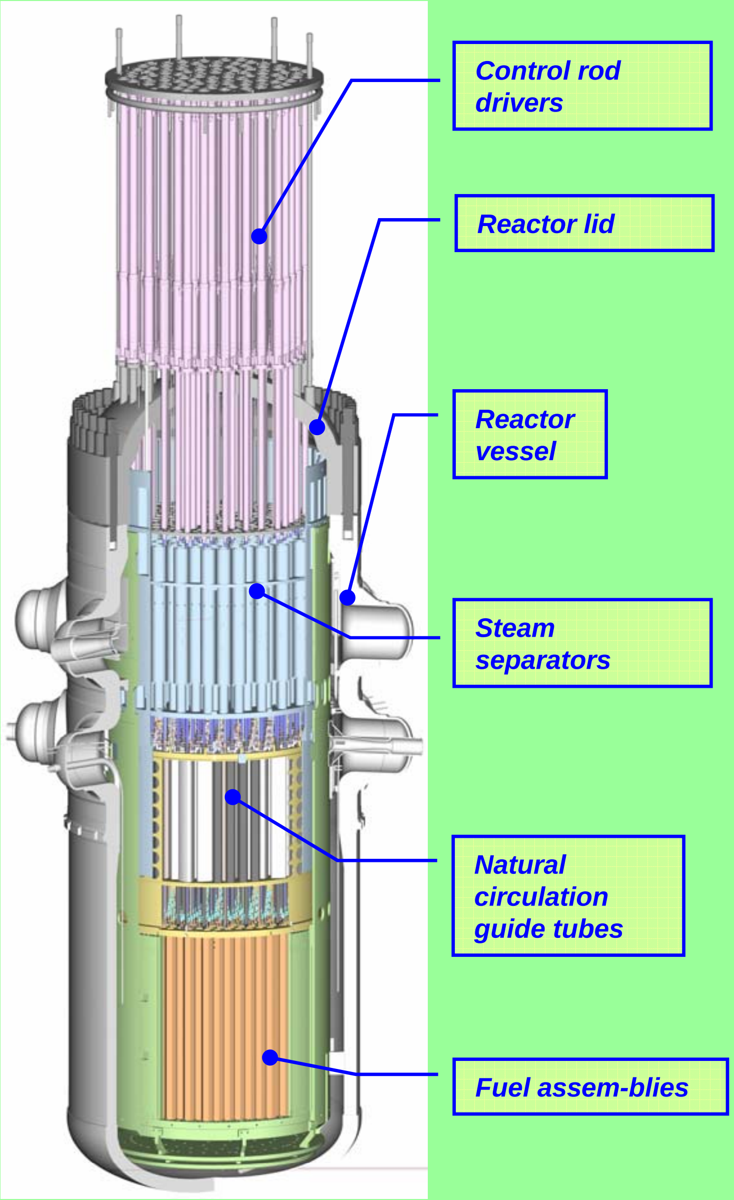
IRIS - International Reactor Innovative and Secure

- International Cooperation (more than 20 members from ten countries, led by Westinghouse)
- Safety-by-Design™ philosophy
- Based on Proven Technology
- 1000 MWt Modules
- Integral Layout (RPV* contains internal RCP*, CRDM*, SG*, Pressurizer, etc.)
- Simplified Design
- Competitive Economics



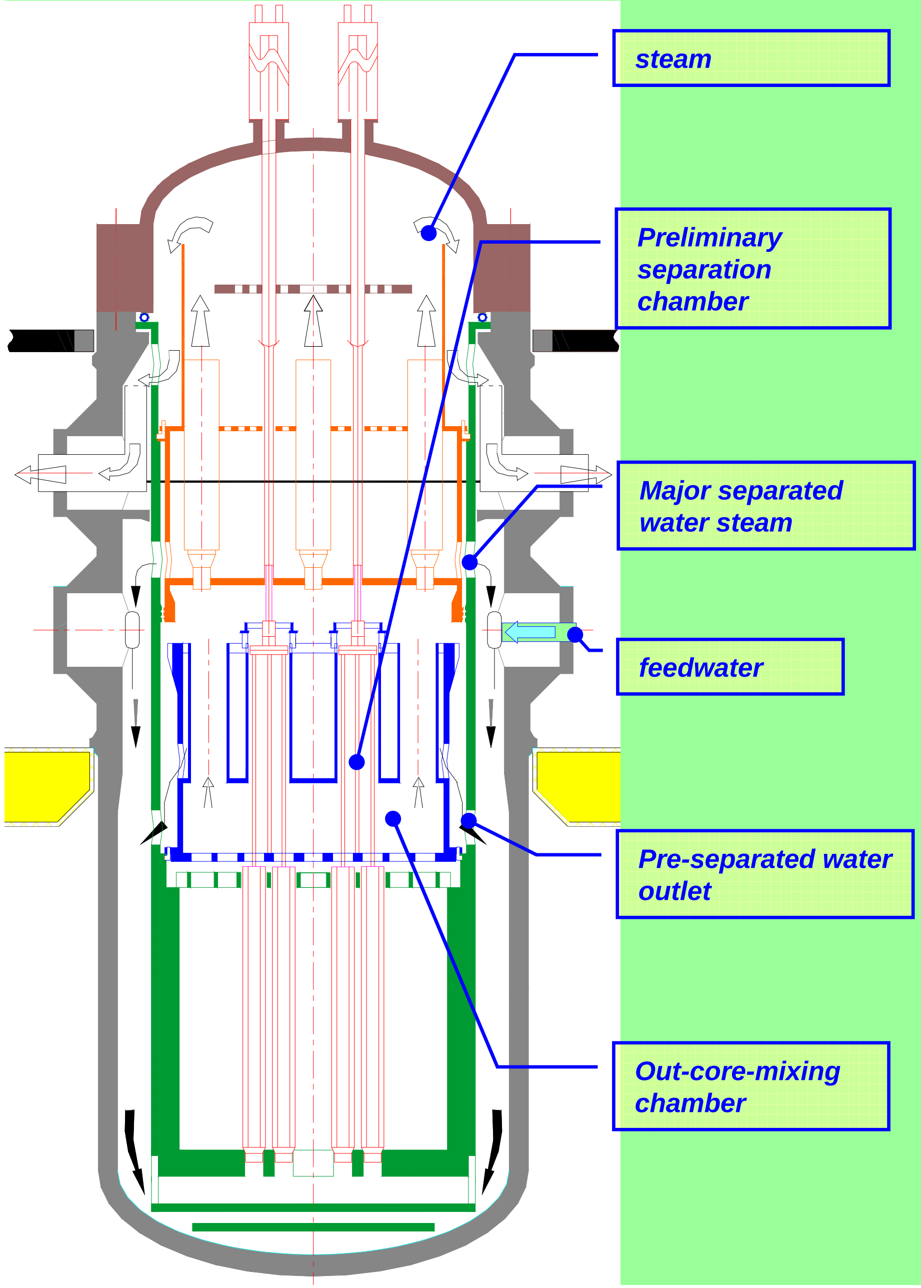
* RPV - Reactor Pressure Vessel; RCP - Reactor Coolant Pump; CRDM - Control Rod Drive Mechanism; SG - Steam Generator.

VK-300



- ***RUSSIAN SBWR***
- ***MEDIUM POWER***
  - Oriented to combined electricity and district heating power units
- ***ULTIMATE SIMPLICITY***
  - Single circuit system;
  - Integral lay-out;
  - Natural circulation in all operating modes;
  - Simple and passive safety systems.
- ***ULTIMATE PASSIVITY***
  - Natural circulation of coolant;
  - Passive safety system.
- ***BASING ON WWER EQUIPMENT***
  - Pressure vessel;
  - Fuel elements;
  - Cyclone separators.
- ***BASING ON DESIGN AND OPERSTION EXPERIENCE OF VK-50, BWR, SBWR, SWR-1000***

VK-300



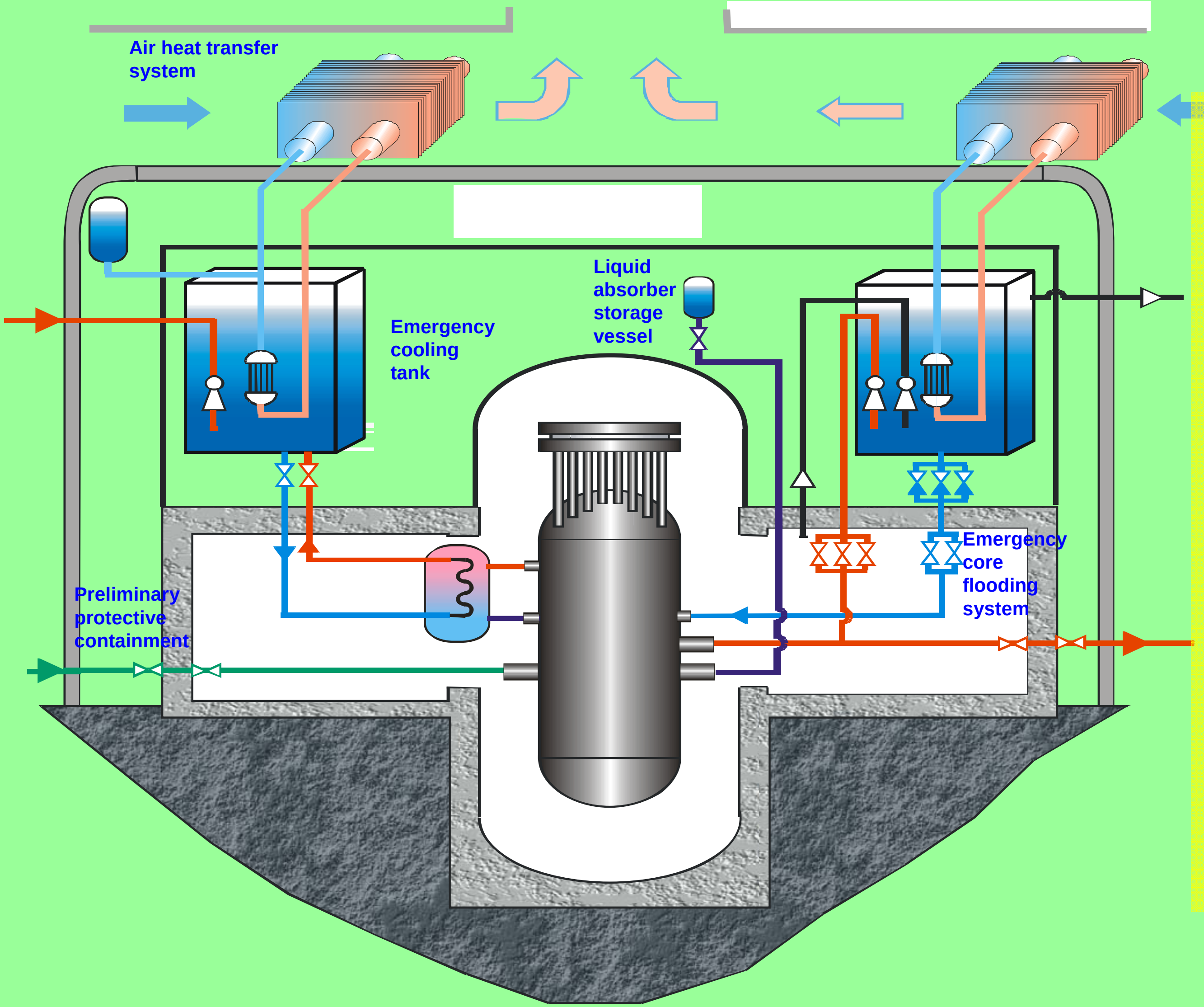
➢ ***UPPER CPS DRIVERS***
- ❖Decrease in reactor vessel height; (small vessel bottom volume);
- ❖Small compartment under reactor vessel (decrease in primary containment volume);
- ❖Control rod insertion by gravity.

➢ ***EFFECTIVE IN-VESSEL STEAM SEPARATION***
- ❖Stage 1 hydro-dynamic separation (annular – dispersed two – phase flow in chimneys);
- ❖Stage 2 gravity – inertial separation (plenum above chimneys);
- ❖Stage 3 inertial separation (cyclone separators).

RESULTS

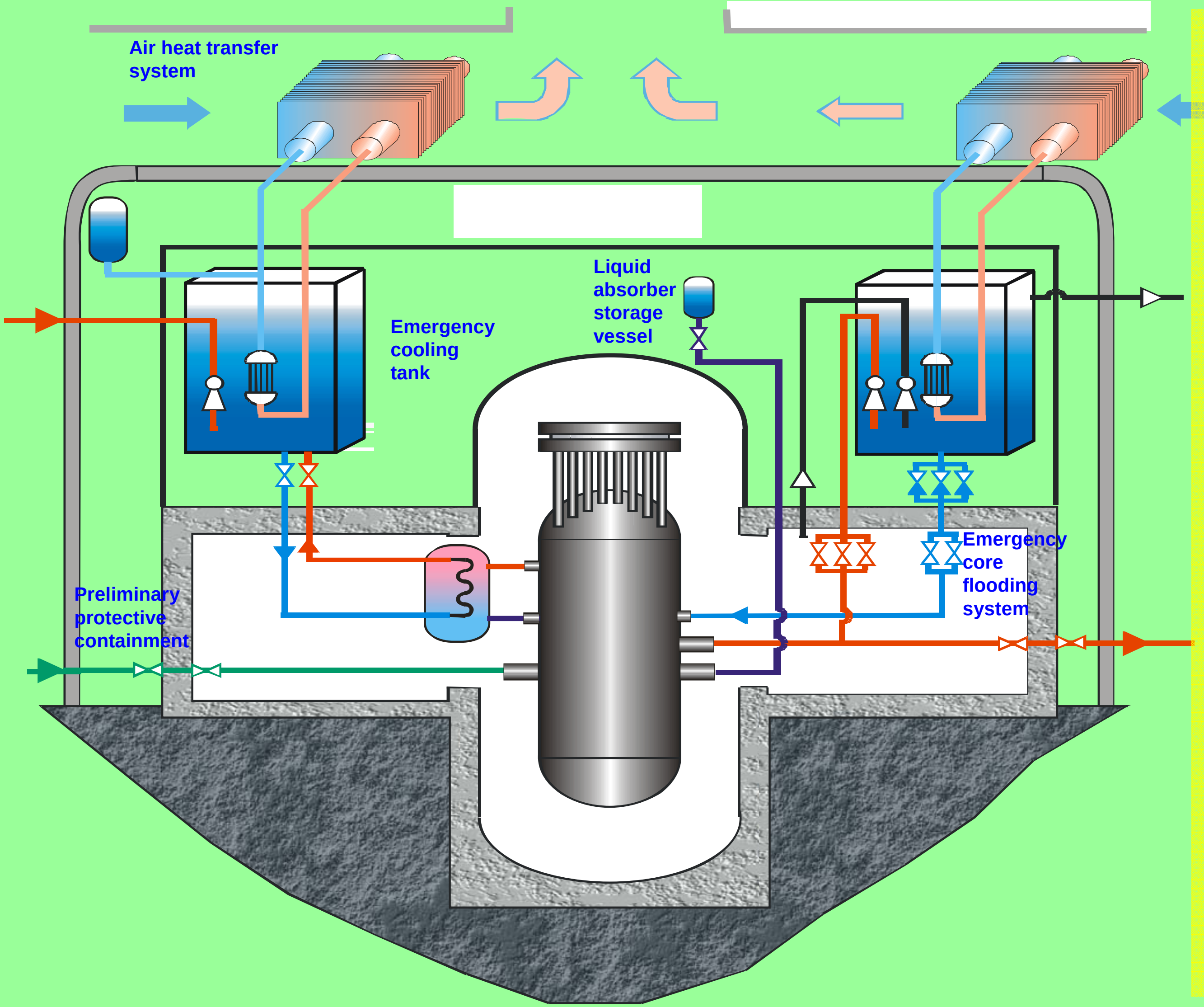
- 55 % wt. DRAINED AFTER STAGE 1 AND 2.
- 0.1 % STEAM QUALITY AFTER STAGE 3.
- 1.5 FACTOR OF IN – VESSEL POWER DENSITY AS COMPARED WITH SBWR

PASSIVE SAFETY SYSTEMS



- ***SELF-REGULATION AND SELF-LIMITATION OF POWER (NEGATIVE EFFECTS OF REACTIVITY)***
- ***TWO REACTIVITY CONTROL SYSTEMS***:
  - CONTROL RODS;
  - BORIC ACID INJECTION.
- ***PRIMARY CONTAINMENT VESSEL:***
  - SMALL IN VOLUME (~1500 cub.m);
  - SAFETY BARRIER.
- ***COOLING OF THE CORE IN ALL ACCIDENTS BY REACTOR COOLANT (NO ADDITIONAL COOLANT)***

PASSIVE SAFETY SYSTEMS



- ➢ *EMERGENCY HEAT SINKS OUTSIDE PCV (EMERGENCY TANKS & HEAT EXCHANGERS):*
  - ❖ACCUMULATING REACTOR ENERGY;
  - ❖CONDENCING STEAM;
  - ❖RETURN CONDENCED COOLANT TO REACTOR.
- ➢ *ULTIMATE HEAT SINK IS ATMOSPHERIC AIR*
- ➢ *NATURAL CIRCULATION OF COOLANT*
- ➢ *PASSIVE ACTIVATION OF SAFETY SYSTEMS*
- ➢ *SIMPLICITY IN DESIGN AND OPERATION*
- ➢ *SEVERE ACCIDENTS AND EXTERNAL IMPACTS MITIGATION BY SECONDARY CONTAINMENT*

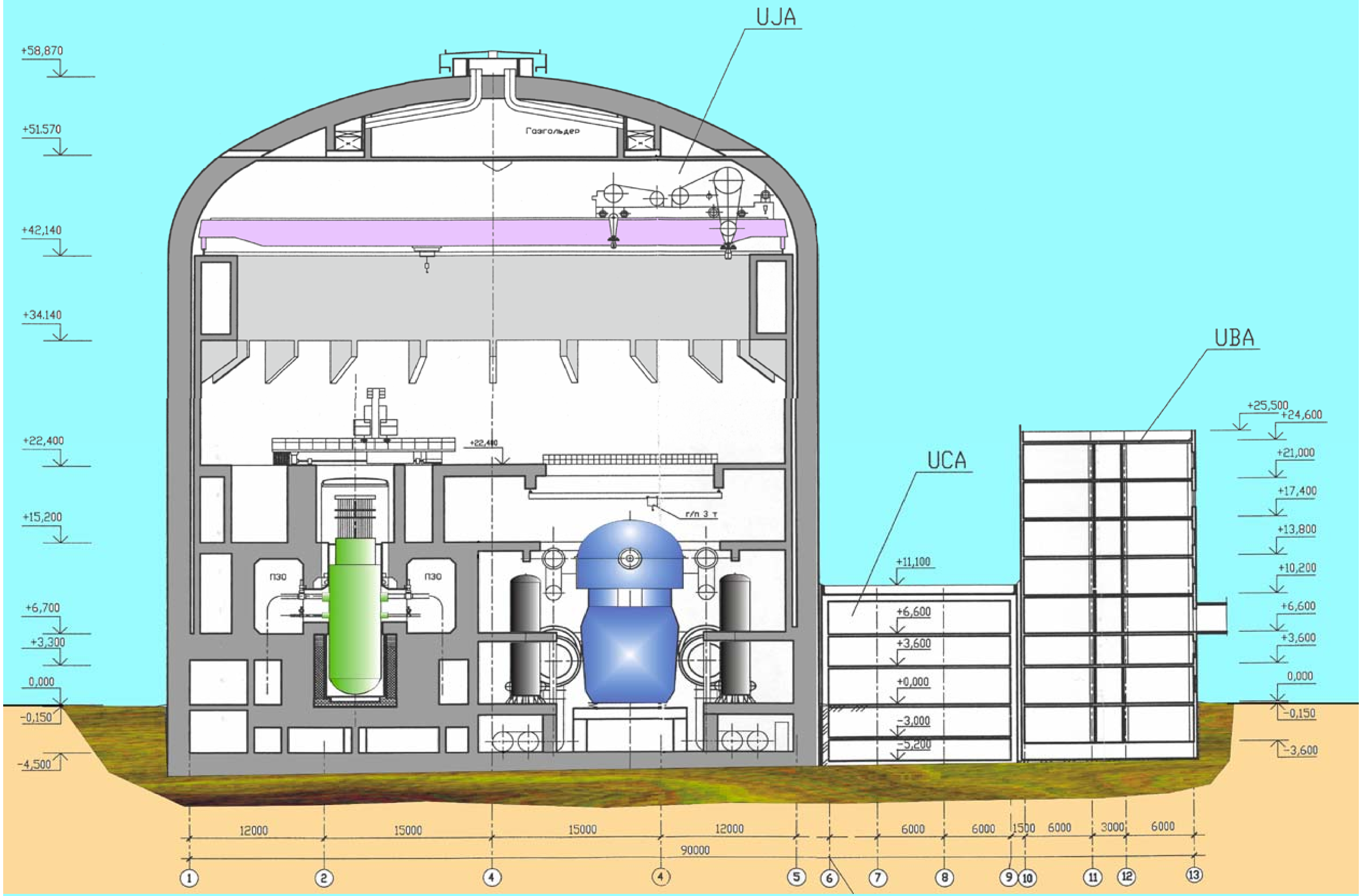
RESULTS

PROBABILITY OF SEVERE CORE DAMAGE <2.10^{-8}

Basic of the reactor

TITLE	SIGNIFICANCE
1. Power: • termal, MW, • electric (in the course of heat generation),MW, • (under condensation mode), MW,	 750 165 250
2. Heat generation, Gcal/h	400
3. Steam parameters at the reactor outlet • pressure, MPa • temperature, °C • output, t/h • moisture content, %	 7.0 285 1370 0.1
4. Fuel loading in terms of uranium, t	31.5
5. Uranium enrichment, %	4.0
6 . Average uranium burnup, MW·day/kg	43.5

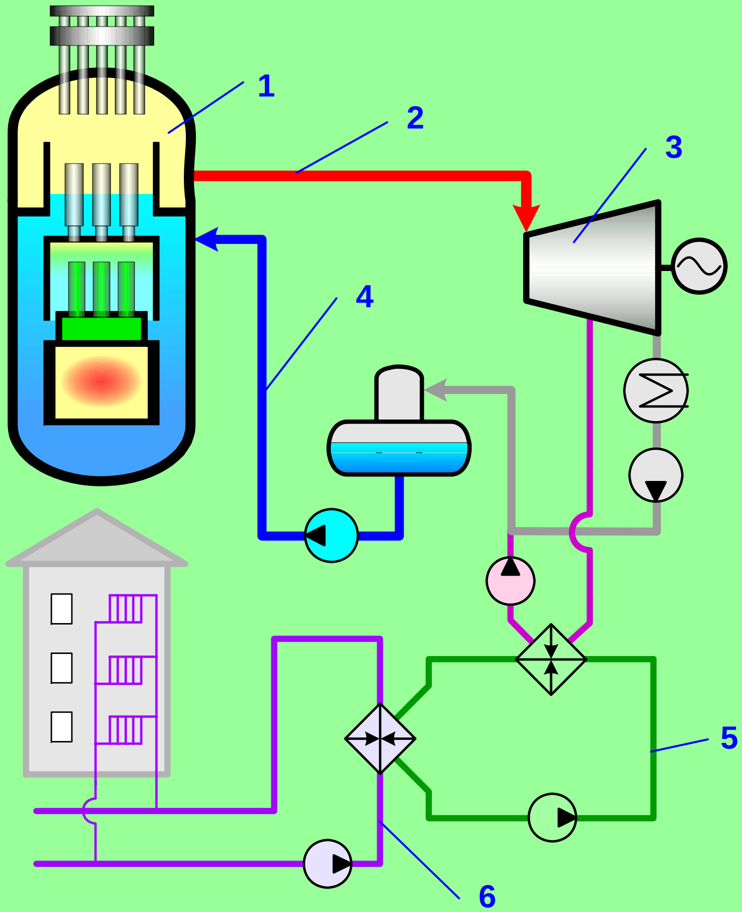
CNPP unit lay-out



POWER UNIT WITH THE VK-300 REACTOR FACILITY

Basic technical characteristics of the power unit

Description	Value
Installed power of the unit: • in condensation mode, MW • in heat supply mode: - electricity, MW - heat, Gcal/h	 250 150 400
Thermal power of the reactor facility, MW	750
Heat output of the heat supply plant, Gcal/h	400
Power unit arrangement	Direct cycle
Reactor type	VK-300, boiling water reactor
Turbine type	T-150/250-6,6/50



1 – VK-300 reactor
2 – steam supply to the turbine
3 – turbine plant
4 – feedwater supply to the reactor
5 – heat supply plant
6 – heat consumer

Basic of the Arkhangelsk CNPP

Description and dimensionality of characteristics	Value
Number of units	4
CGNP power on generator terminals, MW(e),	1000
CGNP heat generation, Gkal/h,	1600
Unit service life, years	60
Annual number of the CNPP operation hours	8000
Capacity factor of reactor facilities, %	91.3
Potential annual output: - power (from CNPP busbar), mln kWh/year - heat, thous. Gkal/year	 6003 7534

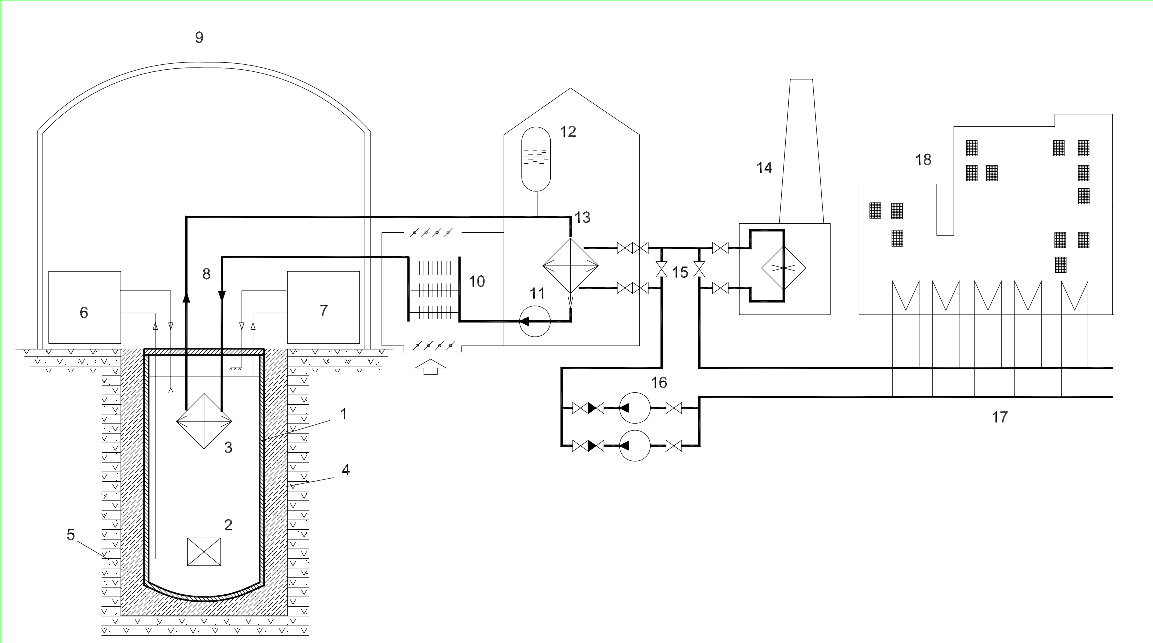
ECONOMICS

Description and dimensionality of characteristics	Value
Capital investments in the plant construction, mln $	880
Projected cost of supply: - power, cent/kWh - heat, $/Gkal	 ~1.0 ~3.3
Payback period (from the time of the Unit 1 startup), with no discount with discount at rate 8%	 5.75 7.6

CONCLUSIONS

The construction of the Arkhangelsk CGNP and its operation jointly with other power sources as part of the region's power supply system is a technically feasible and cost efficient project that will play an undoubtedly positive role in solving the Arkhangelsk Region problems.

District Heating Plant with RUTA



- *pool-type reactor*
- *atmospheric water pressure and 100 ^{0}C temperature in the primary circuit*
- *good operating record of pool-type research reactor facilities*
- *self-regulating ability*
- *Inherent safety*
- *three circuit arrangement of heat transportation from reactor to consumer*

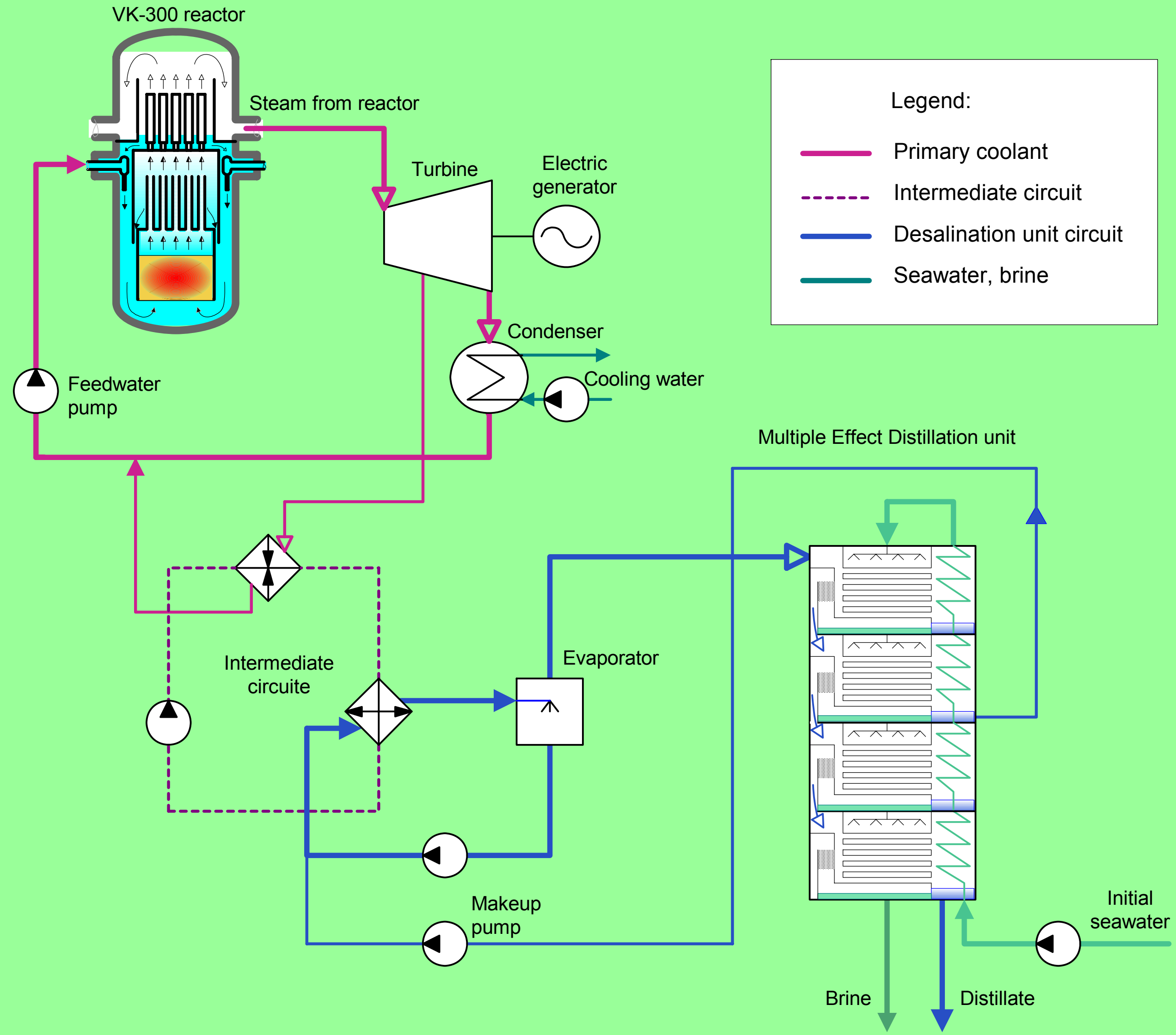
Cost indicators for RUTA-70

- **Capital costs, mln. EUR 26.7**
- **Heat production cost**

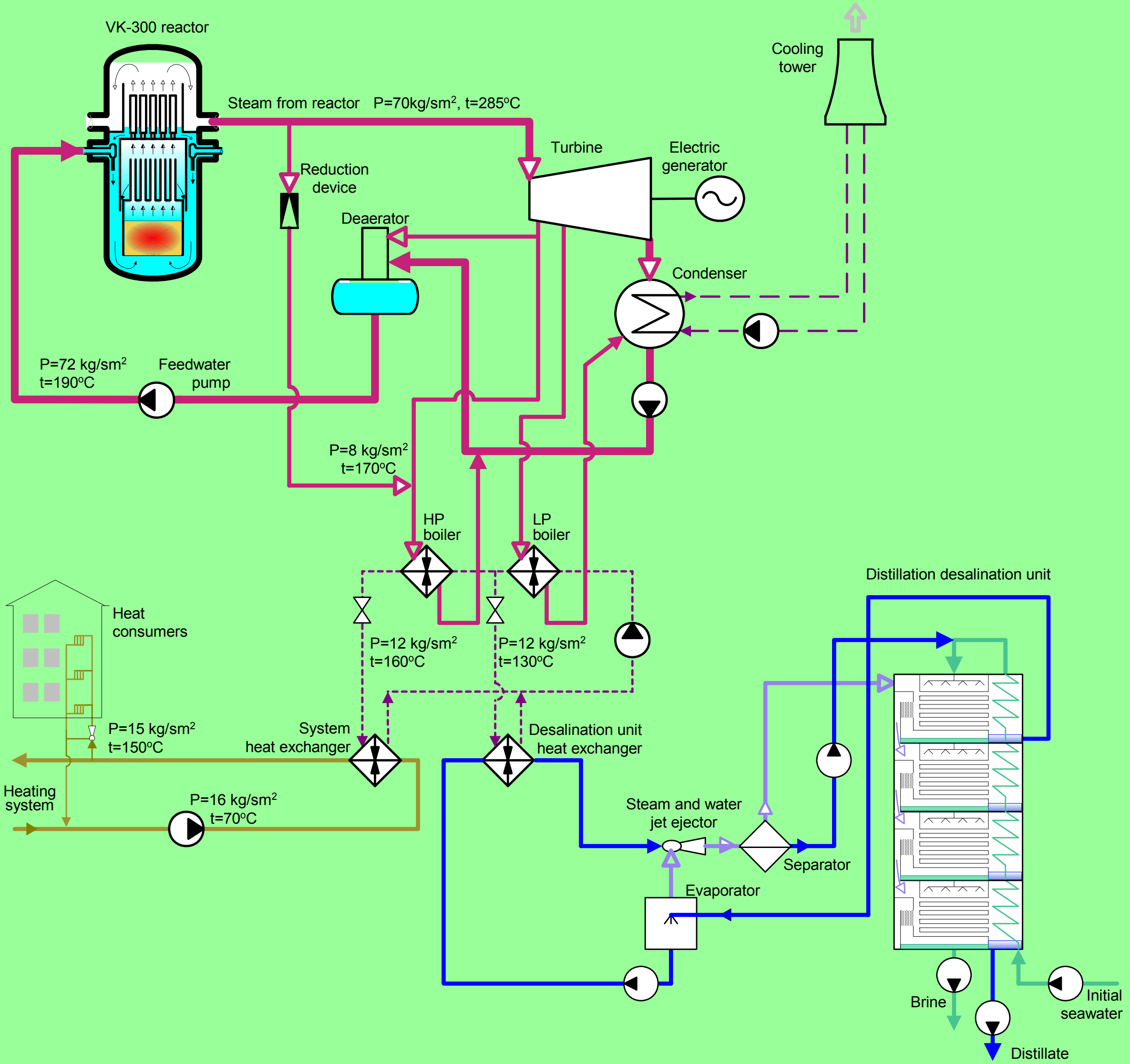
(with load factor 67%), EUR/Gcal 5.1

- **Return of investment time,years 11**

Coupling diagram of the VK-300 power unit and distillation unit with horizontal-tube film evaporators (MED technology)



Multi-purpose complex based on VK-300 reactor (electricity generation + domestic heating + desalination)



Technical and economic data of a VK-300 power and desalination complex:

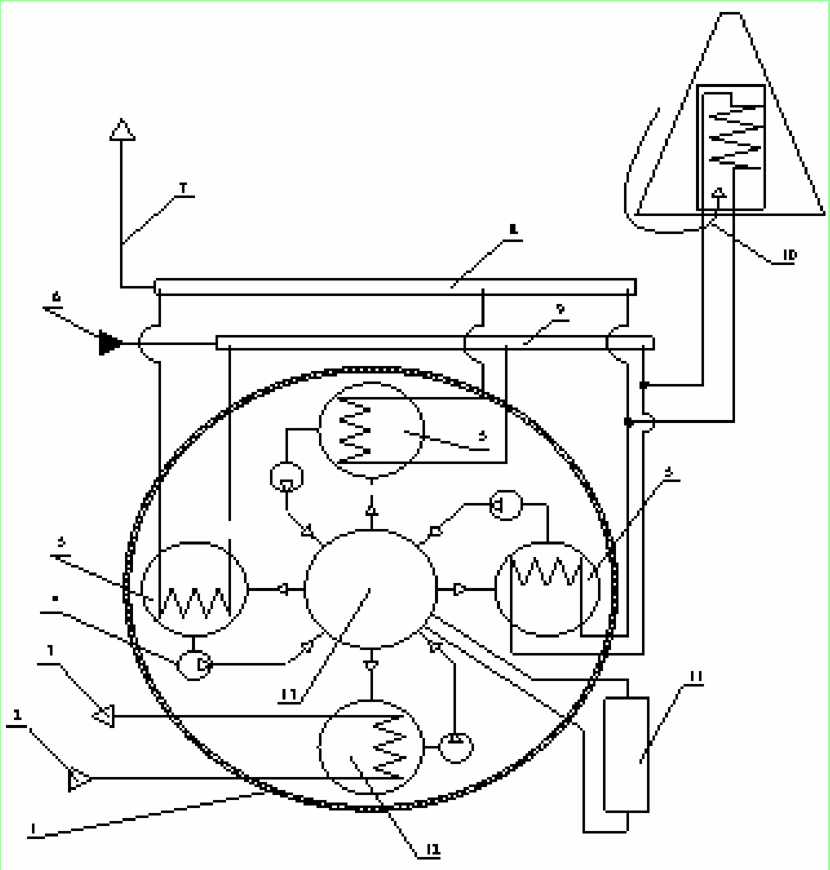
Description	Value		
Energy source	Two VK-300		
Nominal electric power MWe	(220 × 2)		
Construction cost, M$	515	470	515
Desalination technique	MED	RO	Hybrid MED+RO
Cost of desalination system, M$	326	260	296
Fresh water output, 10^3 m3/day	300	300	300,0 200+100
Distillate cost, dollars/m^3	0.59	0.51	0.53
Sale of excess electricity from two VK-300 to the grid, MWe	346	357	352

HTGR

Cogeneration of:

- electricity in a cycle with supercritical steam parameters (30-37 MPa, 650-700^{0}C, efficiency 55-60%);
- hydrogen in iodine-sulfur cycle;
- synthesis gas by coal gasification

$C + H_2O = CO + H_2$ – 119 kJ/mol (500^{0}C)



A power unit with high-temperature reactor
1- containment, 2- from HPC, 3 - to MPC, 4 - gas blower, 5 – steam generator, 6- from HPR, 7- to turbine, 8 – live steam header, 9 – feedwater header, 10- air entering passive heat removal system,
12 – intermediate reheater, 13 - reactor

CONCLUSION

- Non-electricity application is a very realistic way towards expanding the use of nuclear energy, raising the technical and economic efficiency of nuclear sources, and hence making them more attractive for investments.
- The non-electricity benefits of nuclear are most evident in case of heat and electricity cogeneration, of the quality required in different applications, such as district heating systems, heat desalination facilities, black and slate coal gasification, in hydrogen generation facilities.