АЕЦ КОЗЛОДУЙ ЕАД

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KNPP achievements towards mitigation of severe accidents

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IAEA IEM-7 on SAM in the Light of the Accident at the Fukushima Daichi NPP, Vienna, 17-20 March 2014

Introduction

Kozloduy NPP is situated on the South bank of the Danube river

It is the main electricity producer in Bulgaria

The NPP is a major driver of the regional development

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Introduction

Units 1 and 2-WWER-440/230-water-moderated power reactors, standard Russian design of first generation

Commissioned in 1974 and 1975, respectively.
Unit 1: 23 fuel campaigns, generated 66 675 GWh
Unit 2: 24 fuel campaigns, generated 68 905 GWh

Shutdown for decommissioning on 31st December 2002

Handed over to SE RAW

Introduction

Units 3 and 4 - WWER-440/230 - upgraded Russian design

Unit 3: 22 fuel campaigns, generated 68 703 GWh

Unit 4: 21 fuel campaigns, generated 66 712 GWh

Shutdown for decommissioning on 31st December 2006

Handed over to SE RAW

Introduction

Units 5 and 6 - WWER-1000/320-water-moderated power reactors,
standard second generation Russian design

Commissioned in 1988 and 1993, respectively.

License for operation of nuclear reactors:
Unit 5 - by November 2017
Unit 6 - by October 2019

Generation since the units' commissioning up to 30 June 2013
Unit 5: 134 912 GWh
Unit 6: 125 660 GWh
- 32,6 % of the national electricity production

KNPP SAM – Conception

- Severe Accident (SA) phenomena
  - Investigation of units 5&6
  - Develop guidance for Severe Accident Management (SAM)
- Appropriate provisions were provided to support the SAMG (Severe Accident Management Guidance)

SA Phenomena Investigation for Units 5&6

- Investigation of the core behavior during the SA conditions:
  - In-Vessel Phase
  - Ex-Vessel Phase
- Investigation the containment behavior during the SA conditions to:
  - Define the vulnerability of the containment
  - Determine the <u>actions for response</u> to the SA

SA - Analyses

- The analysis needed to determine and understand the behavior of the RPV in units 5&6 during SA situations include:
  - Thermal behavior of corium in the lower head of KNPP units 5&6
- The accident scenario include the following IEs as limited to SA conditions:
  - Station Blackout, without containment bypass
  - LLOCA with Station Blackout, without & with containment bypass
  - SLOCA (Dn 50), without containment bypass
- Radiological consequences of different SA sequences in KNPP units 5&6

Supporting Analyses with Possible Operational Actions

- SBO with PORV actuation when the core temperature reaches 850 °C
- LLOCA and Station Blackout with containment bypass

- SLOCA, HPP(TQ3) start at 8000s
- SLOCA, SS(TQ1) start at 10000s
- SLOCA, FVS(XC) operation 25000s

Most Important Threat Identified from Analyses, Concerned with VVER 1000 Design

The phenomena, that could threaten containment failure and provoke fission products (FP) release to the environment involve:

- vessel failure
- containment bypass inducing FP releases
- hydrogen detonation
- containment over pressure
- basemat melt-through

Development of the SAMG – Procedures

1. The strategies for SAM were determined in the base of analyses
2. Measurement channels that might be used for the SA condition monitoring were defined
3. The identification of unit-specific equipment, which might be used for mitigation of the SA conditions, was made

Strategies for SAM - List

- Primary circuit depressurization
- Injection into primary circuit
- SG depressurization
- SG feeding
- Containment Conditions Management

These typical strategies are included in SAM procedures.

They should be used simultaneously, when technical conditions for their starting by the operators occur.

Strategies for SAM

The following steps are defined for each of the already mentioned strategies:

1. Appropriate systems and equipment are required for the application of the respective strategy
2. Specific instrumentation channels are required through which conditions both in the Core and the Containment can be monitored
3. Evaluation of the positive&negative consequences is required for every strategy applied with SAM

SAM – Procedures

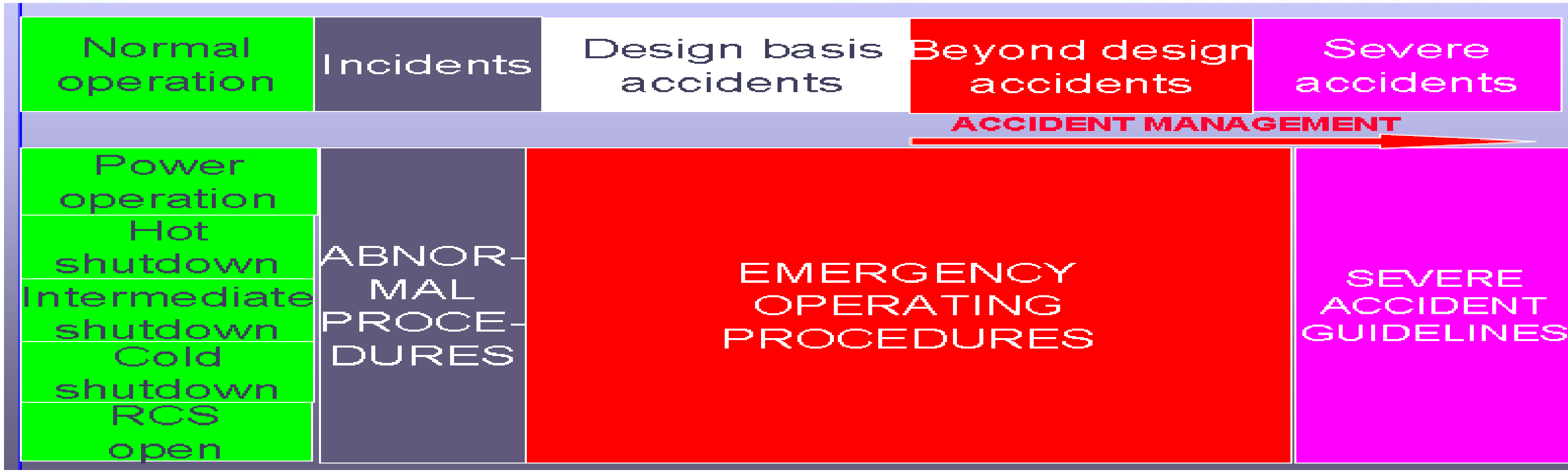
ЗАБЕЛЕЖКА

АКО температурата на изход от АкЗ е под 980°С, **ТО** е допустимо да се подава борен разтвор към АкЗ по всички възможни начини.

1.	Понижете налягането в АкЗ	
1.А.	Проверете налягането в АкЗ **- НАД 20kgf/cm²**	а1. Включете всяка раполагаема помпа TQ2 към I контур а2. **АКО** успеете да включите помпа TQ2 към I контур, **ТО ПРЕМИНЕТЕ КЪМ** ст.3. а3. Включете всяка раполагаема помпа помпа TQ3 към I контур а4. **АКО** успеете да включите помпа TQ3 към I контур, **ТО ПРЕМИНЕТЕ КЪМ** ст.2.
1.Б.	Отворете YP21S01 чрез отваряне на YP21S08 **И** YP21S09 **– ОТВОРЕНИ**	б. Отворете всички разполагаеми арматури: • YR61S01 •YR62S01 •YR63S01 • YR51S01 •YR52S01 •YR53S01 • YR01S01 •YR02S01 •YR03S01
1.В.	Контролирайте налягането в АкЗ **– НАМАЛЯВА**	в. Отворете всички разполагаеми арматури: • YR61S01 •YR62S01 •YR63S01 • YR51S01 •YR52S01 •YR53S01 • YR01S01 •YR02S01 •YR03S01
1.Г.	Проверете температура на изход от касети **– НАМАЛЯВА**	г. **АКО** температурата на изход от АкЗ нарасне до 980°С, **ТО ПРЕМИНЕТЕ КЪМ** РУТА-0.2 „Дълговременни действия при тежка авария”.

- SAM – procedures for MCR
  - RUTA – 00 „Loss of 6kV emergency power (Full blackout)”
  - RUTA – 01 „Immediate actions”
  - RUTA – 02 „Long-term actions”
- SAM – procedures for MCR (Definition)
  - Sep-by-step procedures that should be used by the operators in MCR in case of SA (follow EOP design)
  - The operators start using these procedures after core damage indication occurs.
  - These procedures describe specific operator actions (main and alternative actions) through which SAM strategies are applied
- Supporting procedures and attachments

SAM – Procedures, Implementation into the Plant Emergency Documentation

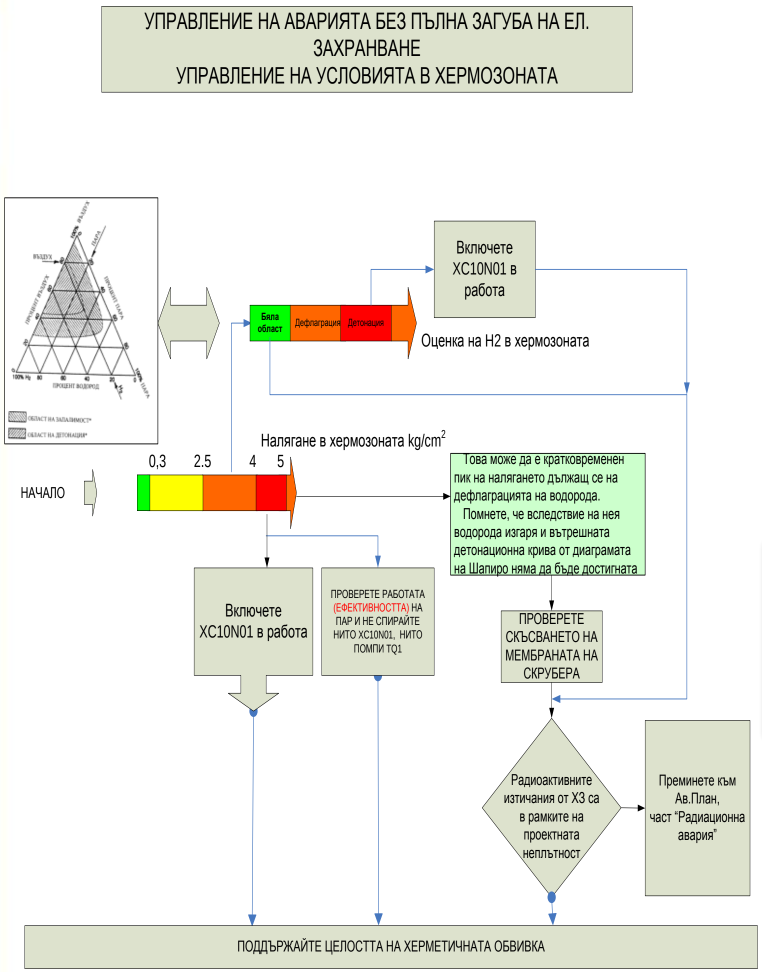


Transitions to SAM procedures must occur when CSF violated and can not be restored. The following EOP transitions were defined:

<u>To RUTA – 01 ,, Immediate actions”</u>

1. From “*VFZ -1.1. Core overheating*” **:** “Temperatures at FA exits are greater than **650** °C **<u>AND</u>** is rising.”
2. RV level indicator has been equivalent to 0 (**ZERO**) for about 30 min. (cold leg)

SAM – Procedures of Emergency Center



Format:

– logical schemes + graphs & attachments

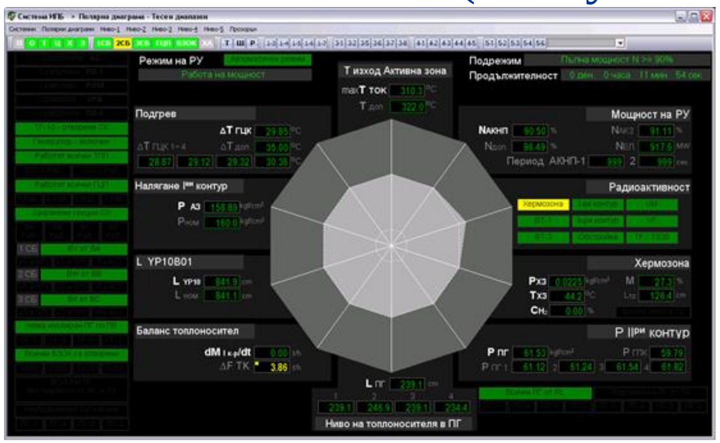
Structure:

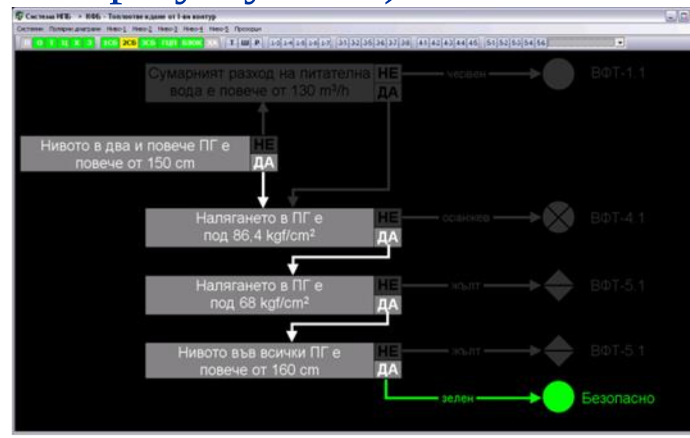
– same strategies as in MCR + much more analytical support

This is the appropriate design for people who take decisions & manage accidents

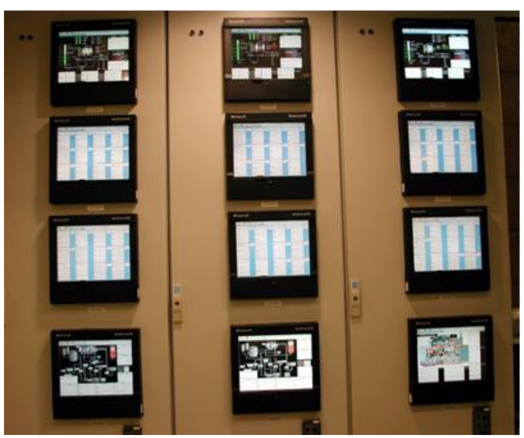
Monitoring systems for emergency support to operators

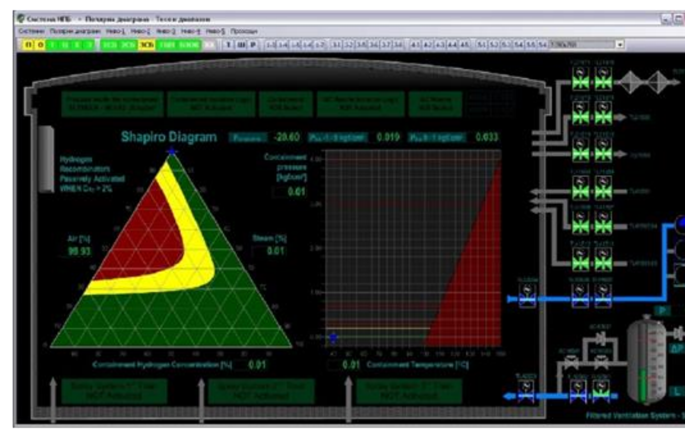
SPDS (Safety Parameters Display System)





PAMS (Post accident monitoring system)

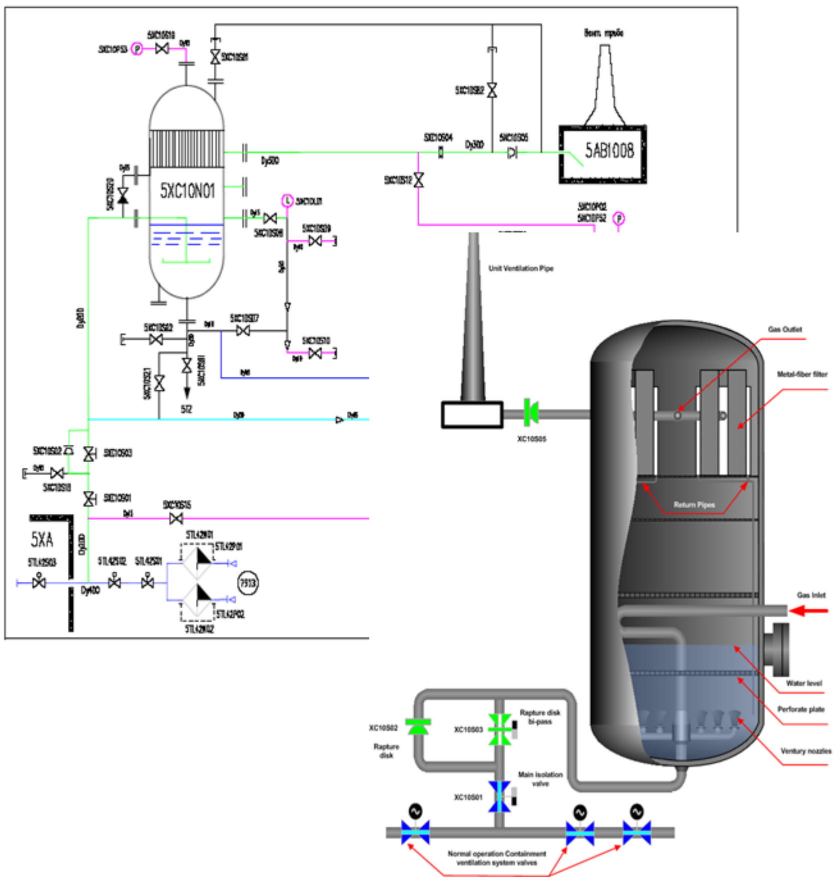




SPDS not available during total blackout;
SPDS is used for EOPs
PAMS is used for SAMGs

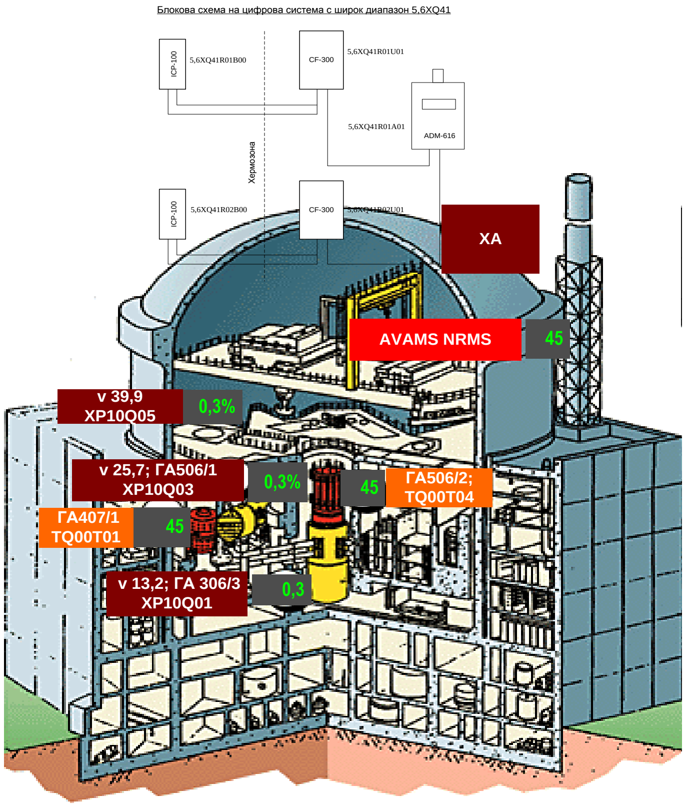
Important SAM Equipment

Containment Filtered Pressure Relief System



- Protect containment from overpressure
- Equipment valves could operate outside from containment
- Equipped with membrane which is destroyed when containment pressure rise with 5 kgf/cm^2

Important SAM Equipment



Hydrogen Reduction System)

- enable the recombination of hydrogen and oxygen into steam at the needed capacity and is entirely passive
- self-starting recombination in the range of 50°C - 150°C and 0.8 – 5.0 bar, at low hydrogen concentrations (< 2 Vol. %)

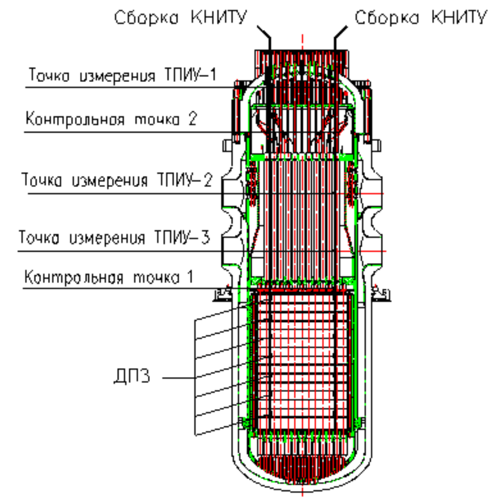
Monitoring Systems (MS):

- Hydrogen - 8 channels
  - Measures a range rich to 10 Vol/%
- Radiation
  - Wide measuring range rich from:
    - 1E+9 Bq/m^3 to 1E+15 Bq/m^3
    - 10^{-2} to 10^6 Gy/h
- MS are independent from containment status
- MS withstand SA conditions
- These measures are implemented into PAMS (any operator could view them in the MCR)

Important SAM Equipment (Measurement)

Steam-gas mixture detector in the reactor pressure vessel (KNITU)

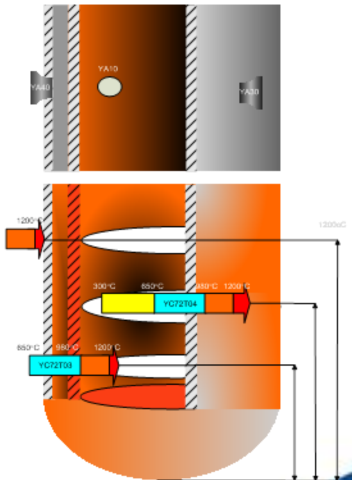
- measures of coolant temperature at the fuel assembly outlet; range rich to 1200 C^0 (10 min.)
- measures the coolant level in the RV



Vulnerability: In processes with fast decreasing of water level in RPV, TC are with slow reaction and can show T<400ºC, while real T_{clad} >1200 ºC (tested on full scope simulator; for this reason a new symptom in SAMGs was introduced (#2, see p.15)

3 wide range thermocouples, situated on the outer surface of RPV

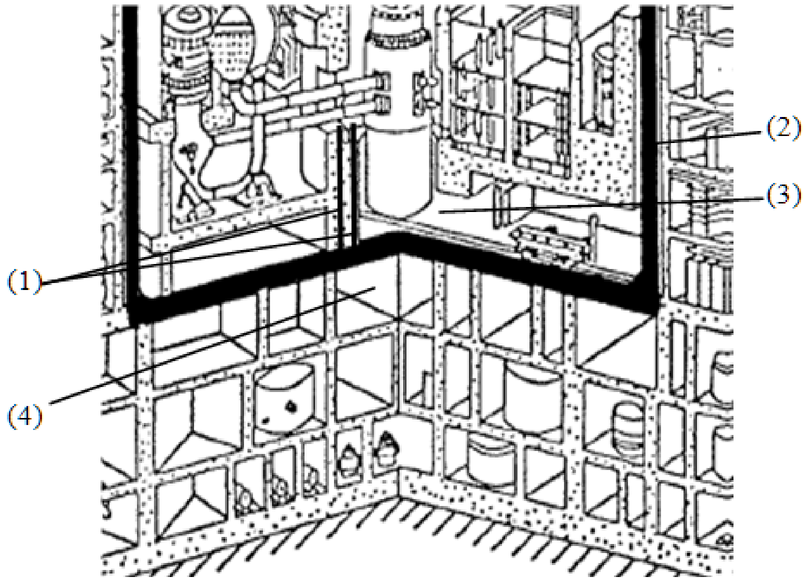
measure the temperature in the expected area for CHF (Critical heat flux), with range of 500 -1300 ºC



These measures are implemented into PAMS (any operator could view them in MCR)

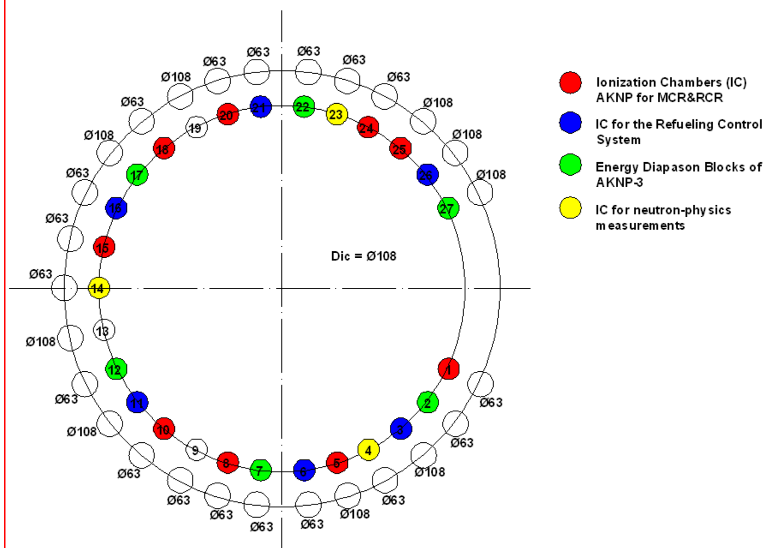
Important SAM Equipment

Prevention of early containment melt-through by ceramic plugs in Ionization Chamber channels



(1) Ionization chamber (IC) channel
(2) Containment wall
(3) Reactor pit
(4) Premise of the mechanisms for lifting IC

Layout of premises inside and outside the containment of VVER-1000 Design

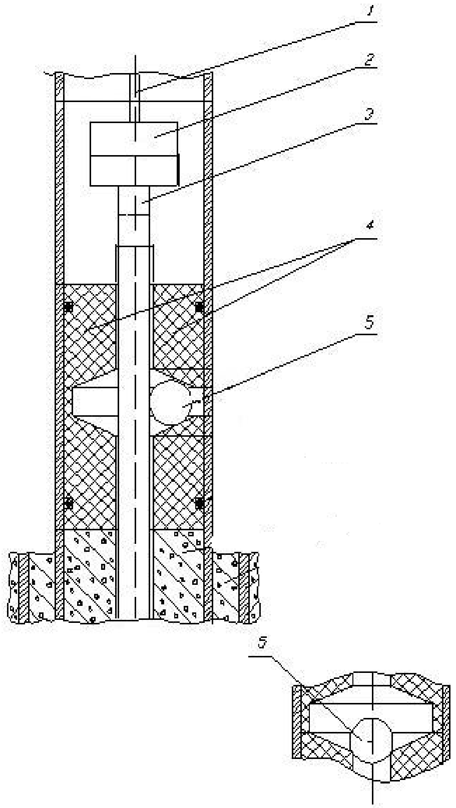


Layout of Ionization chamber (IC) channels in the concrete around the reactor pit

Vulnerability of VVER-1000 Design during ex-vessel phase of SA due to MCCI

Important SAM Equipment

Engineering solution for plugging IC channels



(1) Lifting cable for the Ionization chamber
(2) Ionization chamber
(3) Powering cable for IC
(4) Plug
(5) Plugging ball
(6) Outside steel tube

This vulnerability was overcame by installing ceramic plugs in the IC channels
(see my report on IEM-1)

The plug (4) is designed to be made of TiC:
$T_{m\ TiC} = 3170°C$
$\rho_{TiC} = 4930$ кg/m³
The ball (5) is designed to be made WC:
$T_{m\ WC} = 2870°C$
$\rho = 15800$ кg/m³

For comparison:
$T_{m\ UO_2} = 2837°C$
$\rho_{UO_2} = 8740$ кg/m³

Off- site Power Supply

The Power System(PS) of the Republic of Bulgaria(RB) is a part of the common European PS ENTSO, including the countries from Portugal to Ukraine and from Norway to Greece – extremely stable system with constant frequency 50.0Hz.

The defence-in-depth in the electrical part of Kozloduy NPP starts as early as at the level of PS. For that purpose there is a Plan for restoration of the PS following severe accidents which is developed.

In severe accidents in the PS of RB, the plant **Open Switchgear (OSG)** is supplied with priority according to the approved corridors (electrical power lines 400 kV and 220 kV) from the PS of the neighbouring countries or from Chaira Pump Storage HPP / HPP of the RB.

Off- site Power Supply – cont’d

Through the Open Switchgear(OSG) KNPP is connected with the PS.

- 8 el. power lines at **400kV.** A fundamental significance for the defense in depth are the connections with :

- PS of Romania – directly, by 2 power lines
- PS of Serbia – 2 power lines via substations Sofia -West
- Pump Accumulator Station “Chaira” – via sub stations from the “big ring of CPS" - Vetren, Chervena mogila, Sofia –West.

- 3 power lines on **220kV**

The high number of (11) power lines increase the reliability of the external power supply of NPP from rings 400kV and 220kV. Procedures are developed for restoration of PS after severe accident and station blackout of KNPP.

Procedures have a goal immediately to supply voltage to OSG of KNPP aimed to supply house load of Units 5 and 6 and Bank Pumping Station.

Off- site Power Supply – cont'd

- The procedures cover all actions of operational staff, in electric power stations (with possibility for zero start), operational personnel of the system sub stations, On-Duty Dispatchers in the Regional Dispatching Centre and Central Dispatching Centre as well the operational personnel of KNPP.

- This gives the opportunity to the KNPP to receive via SG 400kV and 220kV in emergency mode of external power supply both system and intersystem:

- from PS of Romania – **up to 15 min** after station blackout;
- from PS of Serbia – **up to 30 min** after station blackout;
- Pump Storage HPP "Chaira"– **up to 1 h 30 min** after station blackout.

Important SAM Equipment

Auxiliary Diesel Generator (DG), module type, stationary.
P = 5.4MW, 6kV

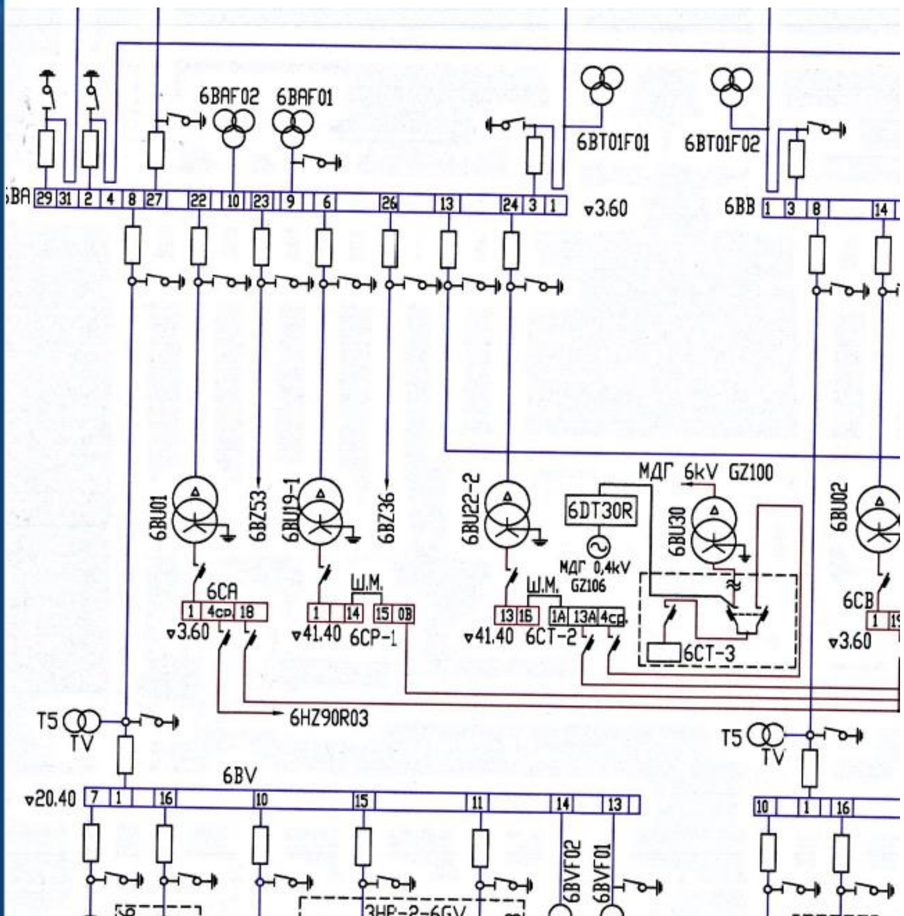
Mobile Diesel Generator (MDG)
P=1.1MW, 6kV

Important SAM Equipment

Two Mobile Diesel Generator (MDG) for each of Units 5&6

- voltage – 400/230V
- Nominal power – 389,3kW
- Maximal power – 448,3kW
- cold start at -20°C without preliminary warming

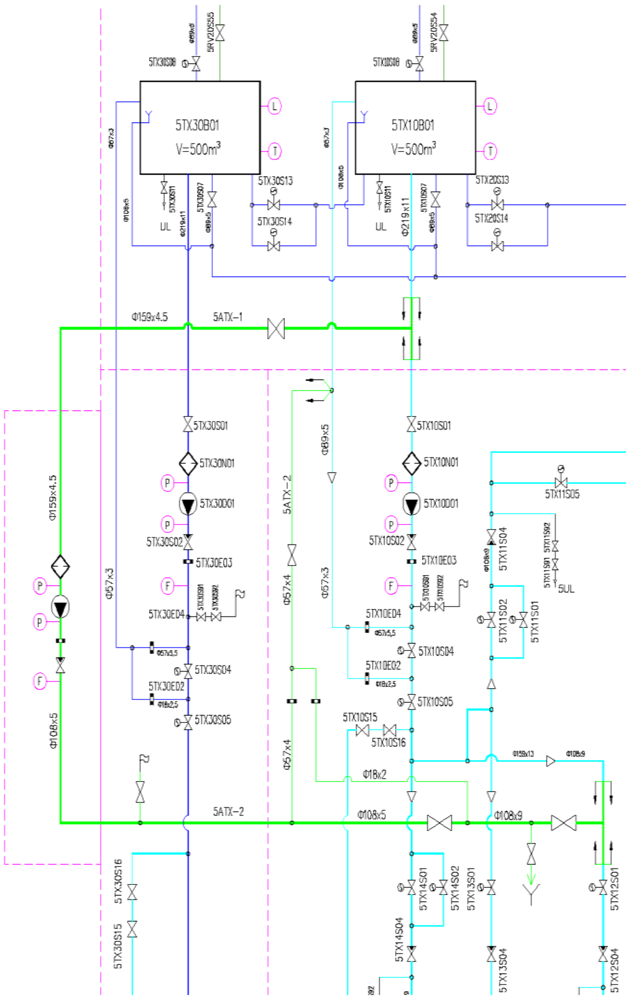
CT-3 bus 0.4 kV



MDG can supply:

- Emergency water pump for SG
- TB10D03 pump – to feed the reactor with borated water (still interconnection pipelines are needed)
- TB30D04 pump – to feed SFP with borated water

Important to SAM Equipment



Alternative Feed Water System for SG

- New pomp used existing EFW – line
- MDG power supply

ULTIMATE HEAT SINK (UHS)

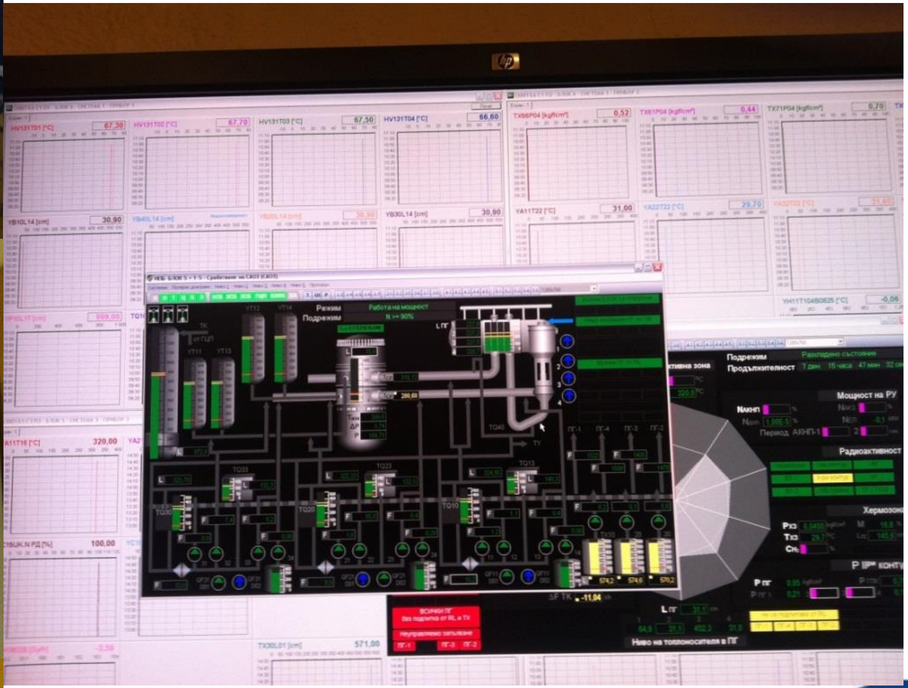
Main UHS is the river Danube by Cold&Warm Channels

Core & Safety systems UHS – Atmosphere by Spay Pools

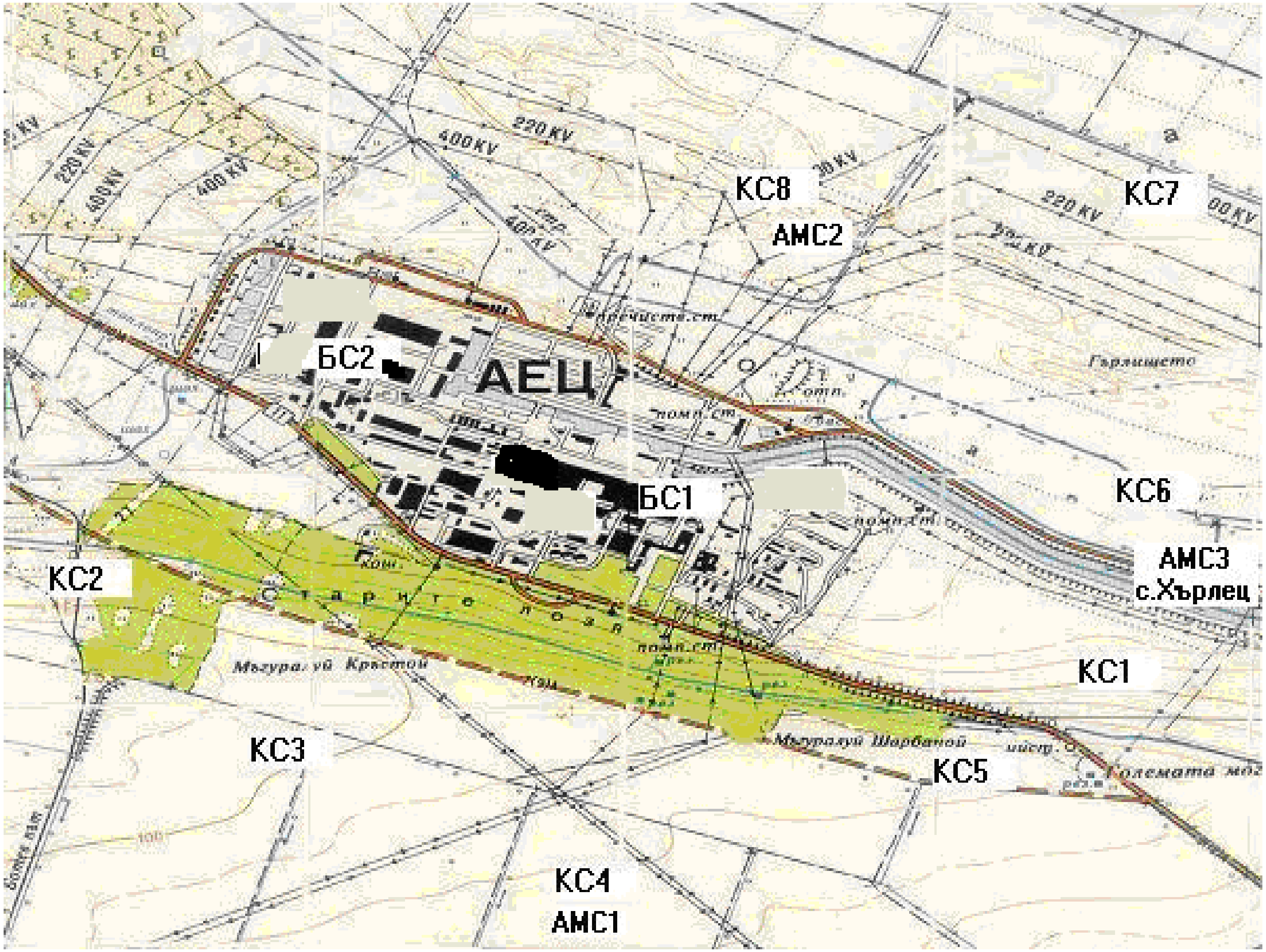
THE EMERGENCY CENTRE (TSC)

INTERCONNECTION BETWEEN UNITS 5&6 - ERC

- SPDS and PAMS parameters are received in ERC by two ways: Cables and Wireless on the TSC PCs through serial interfaces



Automated system for external radiation control



Automated system for meteorological monitoring

СММ АЕЦ Козлодуй - ЦУА

Обобщени данни за района на АЕЦ Козлодуй на 21:03:2005 в 13:00 часа

Метеорологични параметри	Стойности
Температура на въздуха [deg C]	8.2
Относителна влажност [%]	66.5
Атмосферно налягане [hPa]	1015.6
Скорост на вятъра [m/s]	3.7
Посока на вятъра [deg]	306
Количество валеж [mm]	0.0
Интензивност на валежа [mm/h]	0.0

Минимум	Време	Максимум	Време
-3.4	06:20	8.2	12:59
66.5	12:59	77.8	06:19
1016	12:57	1019	07:20

Максималната скорост на вятъра е 8.1 м/с, измерена в 10:15 часа. Посока при регистриране на максималната скорост - 250 deg., Север - Североизток

Максималната интензивност на валежа е 0.0 мм/h., измерена в 00:00 часа.

Устойчивост на атмосферата по Pasquill: G - силно устойчива

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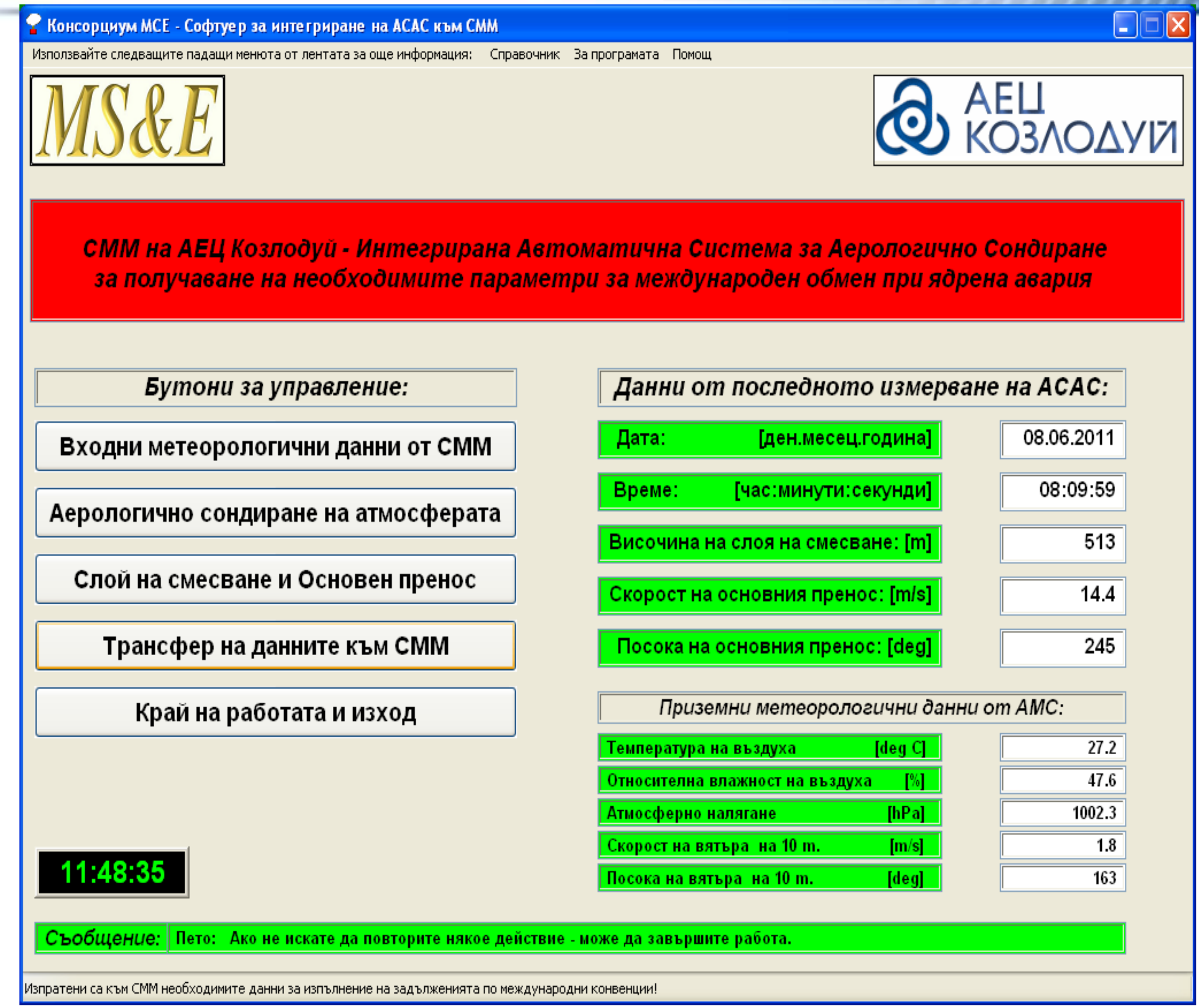
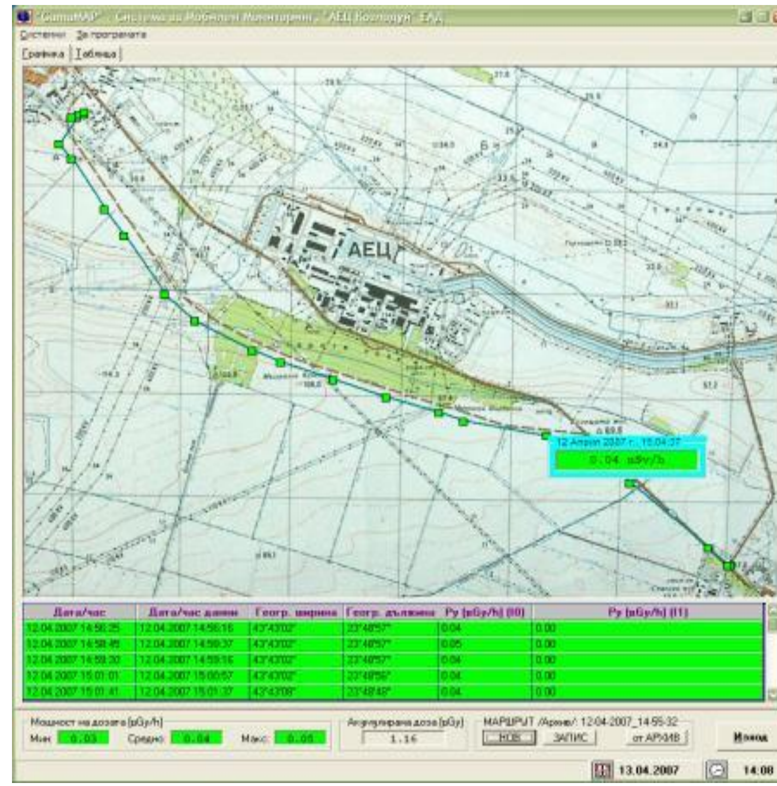
Automated system for aerologic sounding



Mobile radiation monitoring soil, air, water



EMERGENCY DRILLS

Planned Measures

Studying the possibilities for alternative options for Unit 5&6 decay heat removal using additional SG Emergency Makeup System (EMS) of closed Units 3&4. This system equipped with own DG & tank 1000m^3

•Installation of monitoring system for Steam & Oxygen(O_2) & Hydrogen (H_2) (and possibly CO_2 as well) into containment to provide necessary information for SAM (Severe Accident Management about the flammability of gases).

•Installation of additional Hydrogen Recombiners on each unit (taken from the closed Unit 3&4) based on results of hydrogen analyses during Severe Accident (SA), especially during MCCI– already installed on Unit 6, for Unit 5 planned to be completed up to the end of April 2014.

• Technical means to provide possibilities for direct water injection in the Core, SG, Spent Fuel Pool and to the Containment through mobile equipment.

Planned Measures

•Portable monitoring devices for MCR/ECR

• Redundant pipe line for Spent Fuel Pools injection from alternative water source (fire brigade mobile sources)

•Construction of a new external EMC with briefing rooms

•Thorough analyses of SA phenomena in SFP (undergoing)

•Writing SAMG for SFP (undergoing)

•Writing SAMG for Shutdown states

• Installation of SA analytical simulator

Next Steps

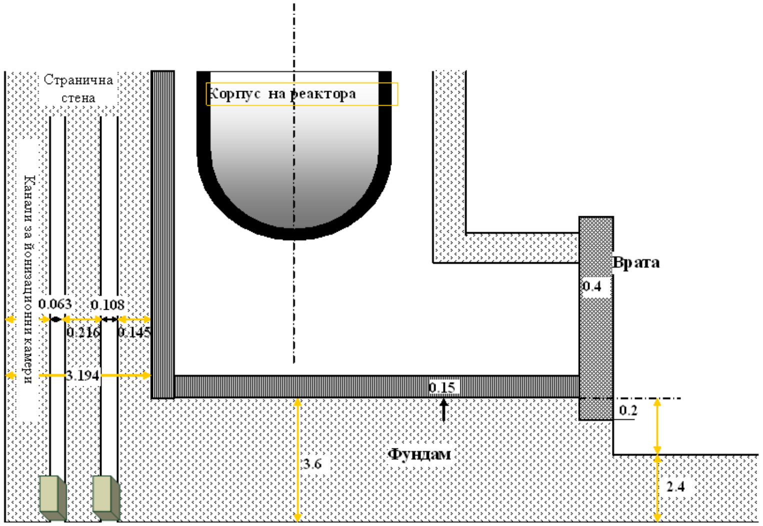
To resolve the goal of every SAM – long-term stabilization and cooling of molten corium and prevention of late basemat melt-through

Both concepts :

- IVR

- ExVR

are under development



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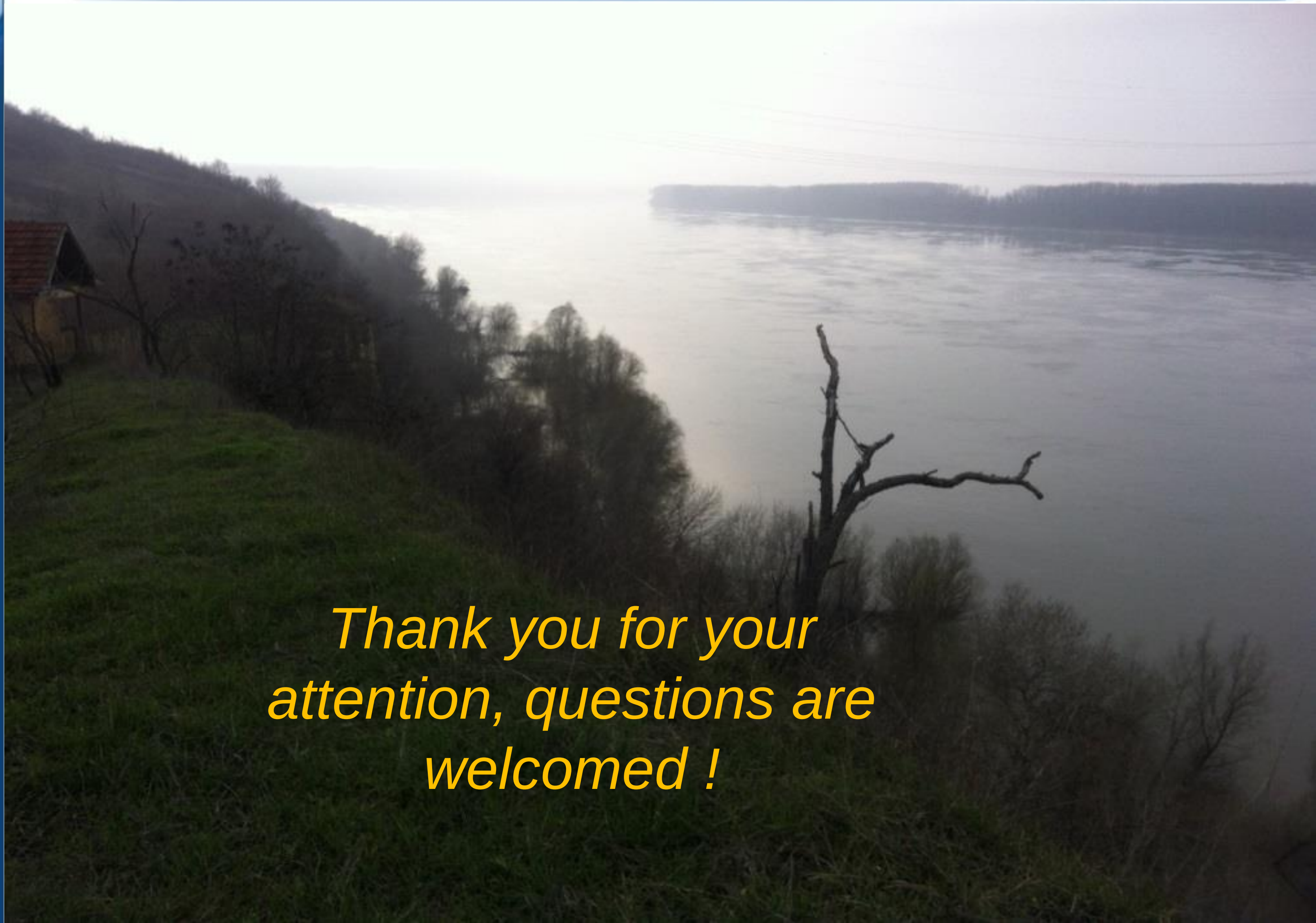

Thank you for your attention, questions are welcomed !