NEW TYPE OF VVER440 FUEL LICENSED FOR DUKOVANY NPP

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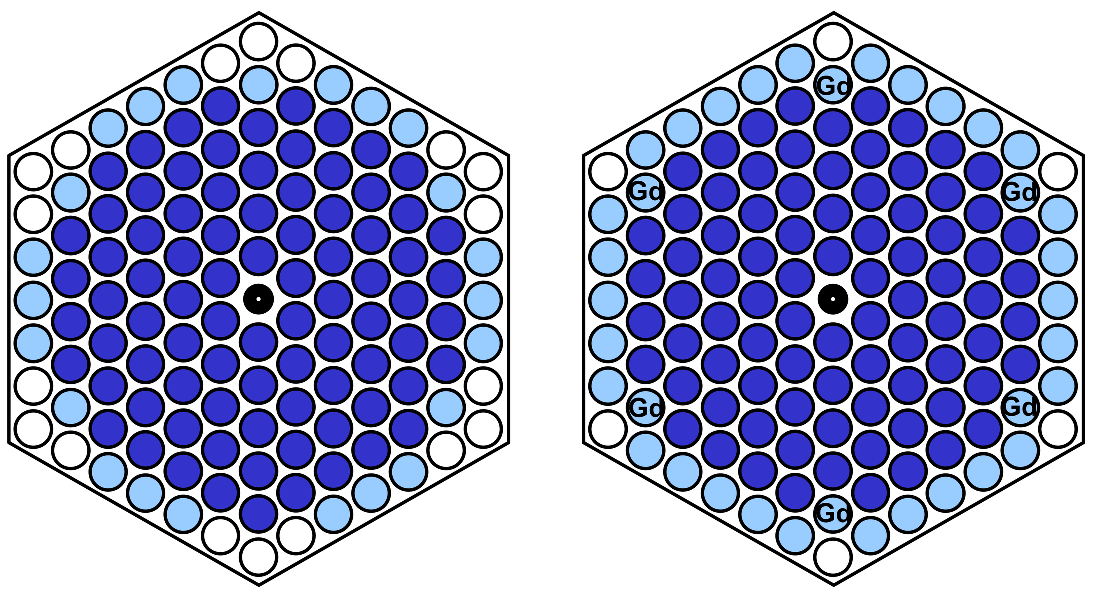
Nuclear energy in the Czech Republic is produced by 4 (four) VVER440 reactors (supplied with Russian fuel) and 2 VVER1000 reactors (supplied with Westinghouse fuel).
Two major innovations in Dukovany NPP are under realisation at present **:** the extensive upgrade of I&C systems and the fuel + fuel cycle improvements.
The new VVER440 fuel designed for 5x1 year cycle with mean burnup over 50 MWd/kgU (local burnup up to 65 MWd/kgU) will be loaded into Dukovany reactors 2 and 1 in May and July 2003 respectively.

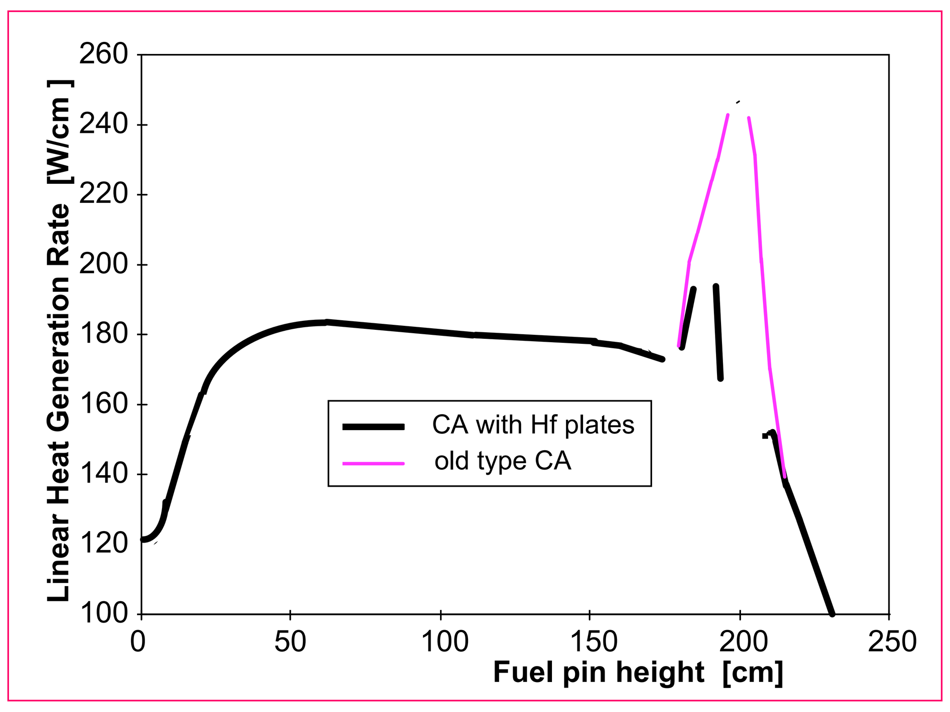
Figures below:
Two types of radial profiling of enrichment in fuel assembly (FA). The profiling reflects better neutron moderation in water layer between assemblies in the core. Local power flattening could be characterised by intra-assembly relative radial power peaking factor <1,1.

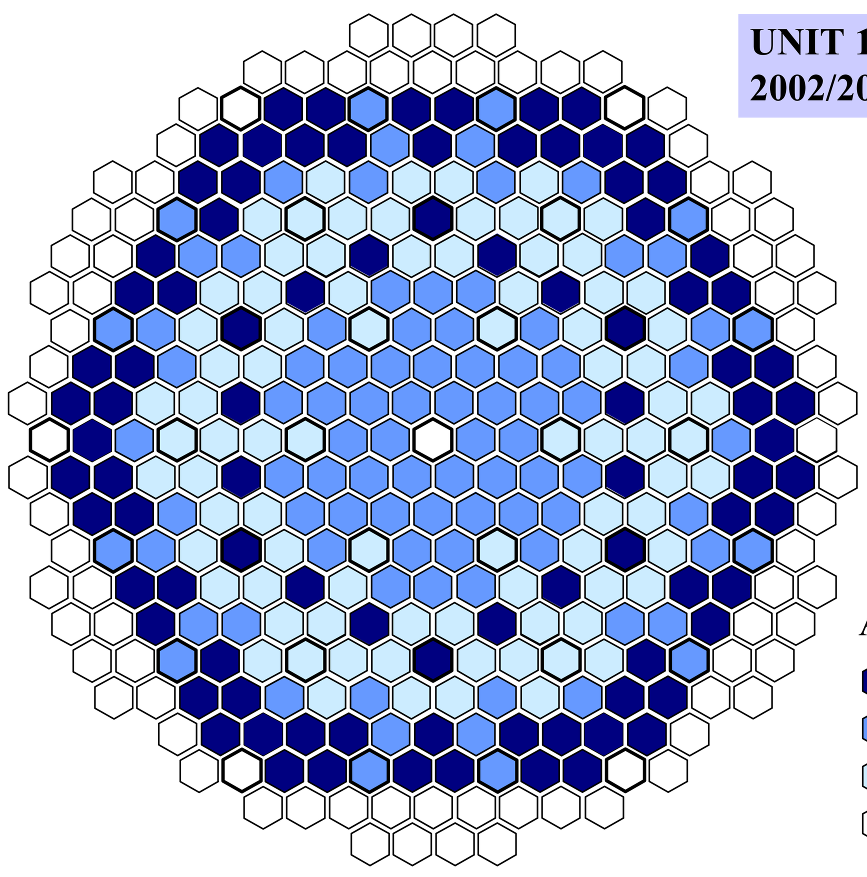
Three types of FAs were licensed: the first one with mean enrichment below 4 wt% U^{235} (for control assemblies, without any burnable absorbers) and two types of FAs with mean enrichment over 4 wt% U^{235} (regular assemblies with burnable absorbers).



- fuel pins with enrichment above 4 wt%U^{235}
- fuel pins with enrichment below 4 wt% U^{235}
- fuel pins with burnable absorber Gd_2O_3
- fuel pins with very low enrichment
- central tube (Zr-Nb alloy)

Figure right:
Improvement of control assembly (CA) design. Hafnium elements (plates) in the top nozzle of CA follower depress the neutron flux in adjacent fuel pins.
A "neutron sphere" in this core region was under critics as an in-adequate feature of the VVER440 reactor design.
Figure right shows power distribution (LHGR) in a fuel pin which is adjacent to control assembly. A suppression of power peak in vicinity of connecting part between absorber and follower of CA is evident.
(Results of the code MOBYDICK, calculation by V.Krýsl, SKODA Pilsen)





UNIT 1, CYCLE 18 2002/2003

Assemblies:
- fresh
- 2-nd year
- 3-rd year
- 4-th year

Figure left:
L3P reload scheme for 4x1 year cycle by using only ***one*** type of fuel assembly with enrichment below 4 w/o U^{235} (the same type of fuel bundle was designed for regular fuel assemblies as well as for control assemblies respectively). No burnable absorbers were introduced into the fuel bundle.

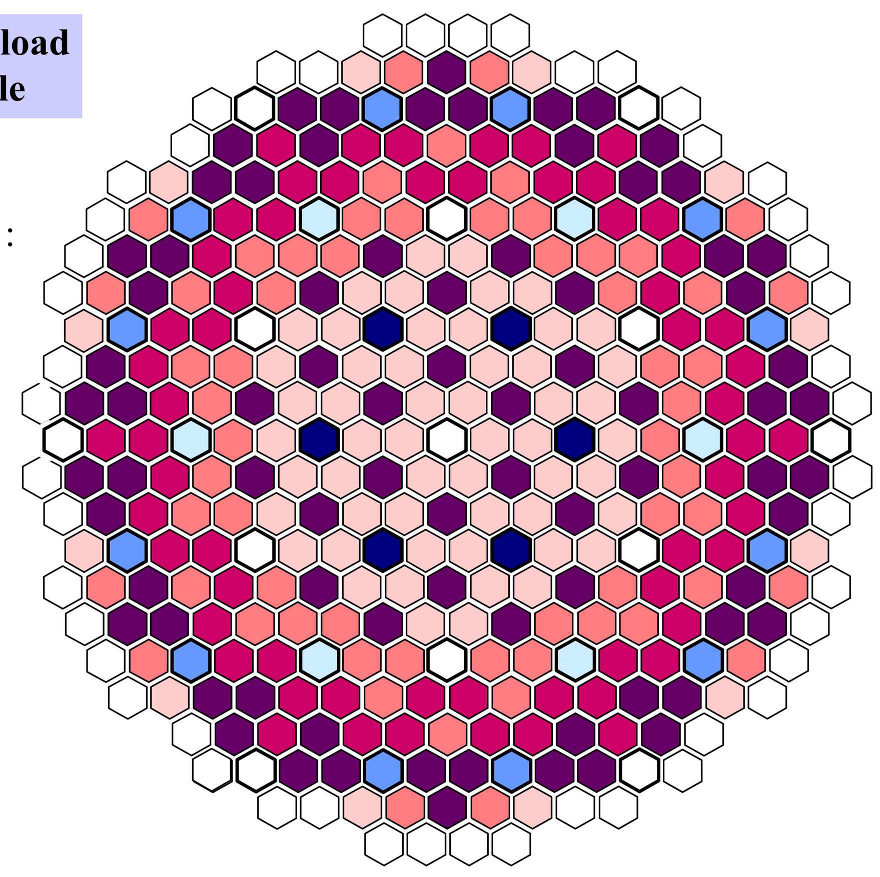
Figure right:
L3P reload scheme with ***two*** types of fuel assemblies.
Regular assemblies in 5x1 year cycle with enrichment > 4 w/o U^{235}, burnable absorbers.
Control assemblies in 4x1 year cycle with enrichment below 4 w/o U^{235} and without burnable absorbers.

Figures left and right:
Core design with power peaking limits F_{dH}<1.55, F_Q<2.1
(Core designer J.Bajgl, computer codes OPTIMAL and MOBYDICK).

Equilibrium reload in 5x1 year cycle

Regular fuel assemblies :
- fresh
- 2-nd year
- 3-rd year
- 4-th year
- 5-th year

Control assemblies :
- fresh
- 2-nd year
- 3-rd year
- 4-th year



LICENSING

The general conservative methodology applied
in safety analysis is based on standard international recommendations :
- **IAEA Safety Reports Series No. 23 (2002)**
- **US NRC NUREG-800 (rev.2, 1981)**
- Contents of safety analyses according to **US NRC RG 1.70**

Acceptance criteria
are close to those stated in **Guidelines IAEA-EBP-WWER-01 (1995)** and among them the most important are the following:
- **no crisis boiling** at hottest fuel rod (subchannel)
- **no fuel melting**; limiting fuel temperature **2570 °C**
- **pressure** in reactor and main steam systems **below 110 %** of design value
- **fuel pellet enthalpy below 963 J/g**, (radially averaged)
- **fuel cladding temperature below 1200 °C**.

Analysis in parallel ....
Safety analyses were performed concurrently by fuel supplier and by domestic organisations:

Fuel has to be licensed in country of origin and therefore consistent documentation starting from the fuel design up to safety analyses has to be available

Safety analyses have to be consistently complemented, enlarged, explained, etc., on request of the SONS and this could be satisfied effectively through domestic analyses. All strongly site-related analyses including their radiological consequences were performed by domestic organisations only.

Main Software Tools
at participating domestic organisations :

RELAP5/MOD3.2.1 for transients and accidents,
DYN3D/M2 for 3D dependent events,
WIMS8, HELIOS, MOBYDICK, STAMOD for neutronic and thermal-hydraulical analysis.

at fuel supplier technical support organisations :

DINAMIKA-97 for non LOCA events,
TECH-M-97 for LOCA accidents
ATHLET/BIPR8KN for 3D dependent events,
KASSETA, BIPR7, PERMAK for neutronic analysis
STAR for thermal-hydraulical analysis.

Flow chart of the licensing process *(SONS = the State Office for Nuclear Safety of the Czech Republic)*

frame extent of the licensing documentation agreed with fuel supplier and domestic participants
- Fuel supplier (Russia) :
  - nuclear-physical analysis
  - thermal-mechanical analysis
  - thermal-hydraulical analysis
  - fuel technical specifications
  - safety analysis
- Domestic organisations :
  - operational experience
  - nuclear-physical analysis
  - thermal-hydraulic analysis
  - safety analysis

→ **preparatory activities**
- methodology covering:
  - acceptance criteria
  - conservatism
  - SONS requirements
- verification and validation of computer codes by SONS procedure
- NPP database for analyses revised and completed

→ **contents and complexity of safety documentation presented by Applicant**
- extent of SAR Amendment:
  - nuclear fuel
  - nuclear and thermal-hydraulical design
  - spectrum of analysed events proposed
  - methodology, criteria
  - participating organisations
- requirements of the SONS fulfilled

→ **finalization of settings (inputs, content, extent of safety analyses)**
- final version of the input database, unification of main initial and boundary conditions
- spectrum of analysed events and corresponding acceptance criteria defined
- rules for necessary modifications of assumptions and inputs clarified

→ **fulfillment of analyses by fuel supplier and by domestic organisations**
- results and input data applied in analyses reviewed by experts
- analyses fulfilled, final reports elaborated

→ **compilation of the SAR Amendment (SARA)**
- typical extent of SARA.:
  - fuel design
  - safety analyses (including radiological consequences)
  - specific aspects (subcriticality of the spent fuel racks, reactor vessel irradiation, etc).
- assembling of the safety documentation according to the Czech "Atomic Law"

→ **review of safety documentation by the SONS experts: Requests on Additional Information**
- application to the SONS for loading of new fuel type (SAR amendment enclosed)
- Additional Information agreed by the SONS
- **Approval given by the SONS**

MARGINS FOR THE MOST LIMITING EVENTS (CONSERVATIVE ANALYSIS)

DNBR margins for the most limiting events

(margin = DNBR/DNBR limit)

Event - specification (variant)	Margin from analyses:	
	domestic	fuel supplier
Increase in Heat Removal by the Secondary System		
- the full opening of the steam generator (SG) safety valve	1.076	-
- the full opening of the SG steam dump to atmosphere	1.076	-
- the full opening of the steam dump to condenser (2 legs)	1.059	-
- the full opening of all steam dump to condenser (4 legs)	**1.019**÷1.889[1)]	1.969
- the main steam header (MSH) rupture (full power)	1.061÷1.068[1)]	1.939
- the MSH rupture (zero power)	2.189	-
- the steamline break (SLB) outside containment	1.028	1.743÷2.300[2)]
- the SLB inside containment	1.079	**1.562**
Decrease in Heat Removal by the Secondary System		
- the simultaneous closure of the both turbine stop valves	1.040	1.829
- the closure of one main steam isolation valve (MSIV)	1.031	1.640
- the closure of three MSIVs	**1.013**	-
- the closure of all MSIVs	1.040	-
- the complete loss of feedwater (FW)	1.076	**1.452**
Decrease in Reactor Coolant System Flow Rate		
- the trip of 3 main coolant pumps (MCP) from 6	**1.004**	**1.013**
- the trip of 6 MCPs from 6	1.031	-
- the seizure/break of a single MCP rotor	1.004	1.217÷1.633[3)]
Reactivity and Power Distribution Anomalies		
- the control bank withdrawal (zero power)	**1.000**[4)]	5.094
- the control bank withdrawal (full power)	1.001[4)]	**2.096**

Fuel enthalpy margins for the most limiting events

(margin = fuel enthalpy limit - maximum fuel enthalpy, [J/g])

Event - specification (variant)	Margin from analyses:	
	domestic	fuel supplier
Decrease in Reactor Coolant System Flow Rate		
- the seizure/break of a single MCP rotor	-	426
Reactivity and Power Distribution Anomalies		
- the start-up of a loop at 5-loop operation at incorrect tem-re	432	496
- the start-up of a loop at 5-loop operation at zero boron	-	437
- the ejection of 1 control assembly (full power)	**294**	**421**

Fuel temperature margins for the most limiting events

(margin = fuel temperature limit - maximum fuel temperature, [°C])

Event - specification (variant)	Margin from analyses:	
	domestic	fuel supplier
Increase in Heat Removal by the Secondary System		
- the full opening of all steam dump to condenser (4 legs)	**509**	1002
- the steamline break (SLB) outside containment	688	**979**
Decrease in Heat Removal by the Secondary System		
- the complete loss of feedwater (FW)	861	1058
Decrease in Reactor Coolant System Flow Rate		
- the trip of 3 main coolant pumps (MCP) from 6	958	1048
Reactivity and Power Distribution Anomalies		
- the control bank withdrawal (low to full power)	**74**	856
- the start-up of a loop at 5-loop operation at incorrect tem-re	226	395
- the start-up of a loop at 5-loop operation at zero boron	-	**247**

← *Legend to the left*

1) In dependence on control systems functioning or off site power availability
2) In dependence on break size
3) In dependence on scenarios
4) Hypothetical limiting case

Cladding temperature margins for the most limiting events

(margin = cladding temperature limit - maximum cladding temperature, [°C])

Event - specification (variant)	Margin from analyses:	
	domestic	fuel supplier
Loss-of-Coolant Accidents (LOCA) resulting from the spectrum of postulated piping breaks within the reactor coolant pressure boundary		
- the break of the cold leg with equivalent diameter 50 mm	245	784
- the break of the cold leg with equivalent diameter 90 mm	319	856
- the break of the line connecting reactor shaft and accumulator (equivalent diameter 233 mm)	334	512
- the break of the cold leg 2 ×496 mm	**104**	**343**

Reactor coolant pressure margins for the most limiting events

(margin = reactor coolant pressure limit - maximum reactor coolant pressure, [MPa])

Event - specification (variant)	Margin from analyses:	
	domestic	fuel supplier
Increase in Heat Removal by the Secondary System		
- the full opening of all steam dump to condenser (4 legs)	0.16	**0.15**
- the main steam header (MSH) rupture (full power)	**0.10**	0.35
Decrease in Heat Removal by the Secondary System		
- the closure of three main steam isolation valves (MSIV)	0.06	-
- the complete loss of feedwater (FW)	**0.01**÷0.31[1)]	0.12
- the loss of external electrical load	-	**0.03**
Decrease in Reactor Coolant System Flow Rate		
- the trip of 3 main coolant pumps (MCP) from 6	**0.03**	**0.47**
- the inadvertent closure of one primary loop isolation valve	0.06	-
Reactivity and Power Distribution Anomalies		
- the control bank withdrawal (at full power)	-	**0.40**
Increase in Reactor Coolant Inventory		
- the initiation of 1 or 3 high pressure injection pump (HPIP)	**0.0** (3 HPIP)	**0.2** (1 HPIP)

1) In dependence on turbine power decreasing assumptions

Main steam system pressure margins for the most limiting events

(margin = steam system pressure limit - maximum steam pressure, [MPa])

Event - specification (variant)	Margin from analyses:	
	domestic	fuel supplier
Decrease in Heat Removal by the Secondary System		
- the simultaneous closure of the both turbine stop valves	0.21	0.27
- the closure of one main steam isolation valve (MSIV)	**0.08**	0.06
- the feedline break between steam line check valve and steam generator	-	0.09
	-	
- the loss of external electrical load	-	**0.03**
Decrease in Reactor Coolant System Flow Rate		
- the trip of 3 main coolant pumps (MCP) from 6	1.15	0.34
- the seizure/break of a single MCP rotor	**0.24**	**0.25**

LARGE BREAK LOCA AT COLD LEG 2 x 496 mm

Acceptance criteria

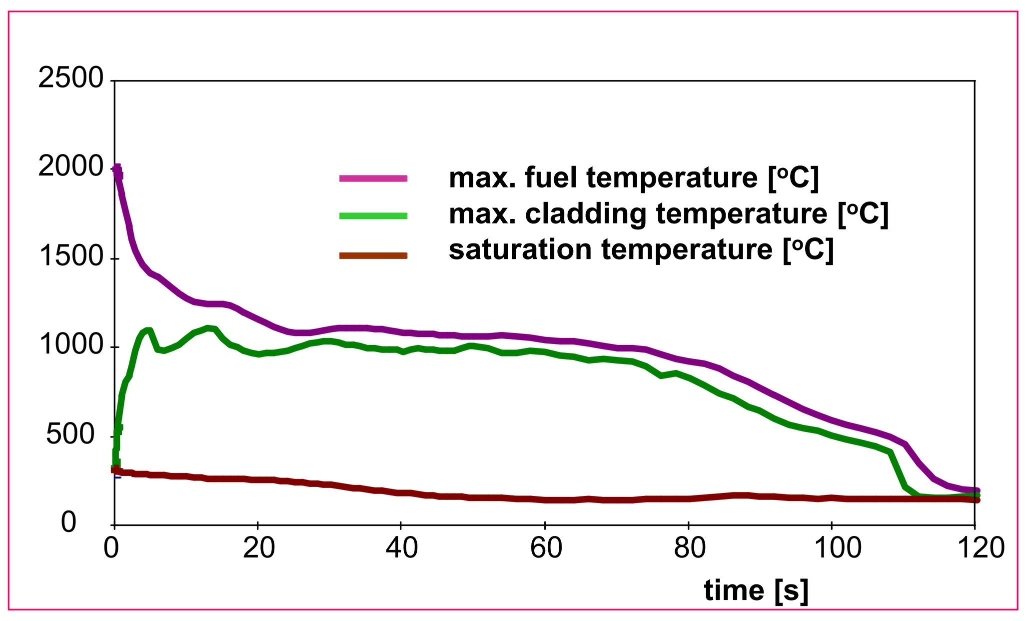
- cladding temperature < 1200 °C
- cladding oxidation up to 18%, Hydrogen from reaction of1% of cladding volume
- secondary pressure below 6.15 MPa (110% of design value)
- fuel melting temperature not met (2570 °C)

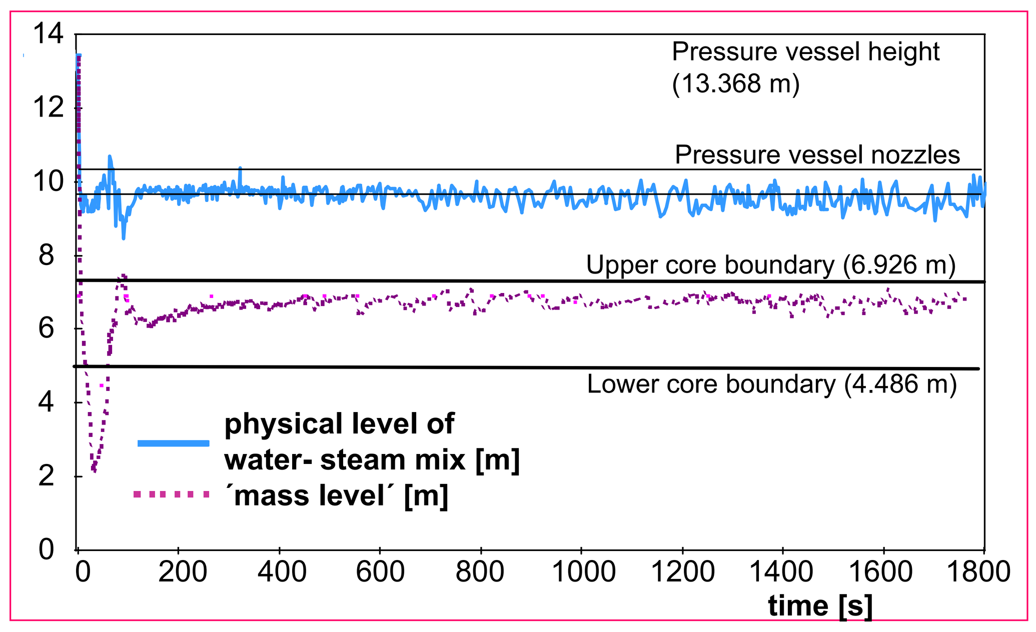
Conservative initial conditions (selection)

- reactor power 104% of nominal value, minimum primary coolant flow
- conservative reactor parameters, thermal conductivity
- conservative neutron kinetic parameters and reactivity coefficients
- scram with rod stuck, 1s signal delay taken into account

Computer Code RELAP 5/MOD3.2.1 (alternatively **TECH-M-97**)

Analysis with RELAP by Mrs J.Krhounková, Nuclear Research Institute Rez





EJECTION OF ONE CONTROL ASSEMBLY AT FULL POWER

Acceptance criteria

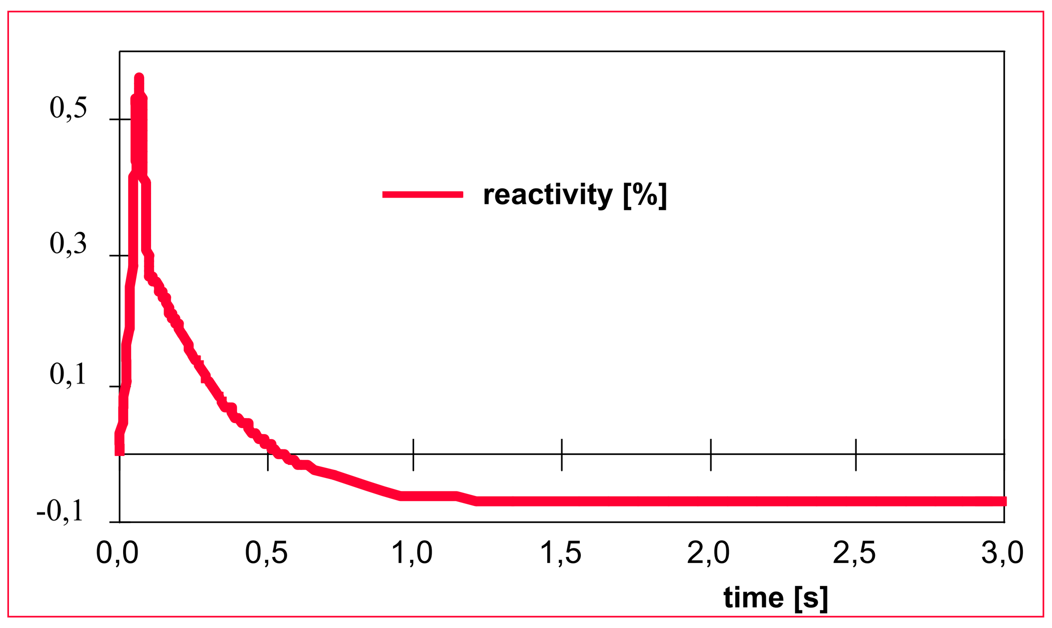
- fuel pin nodal radially averaged enthalpy < 230 cal/g (< 963 J/g),
- cladding temperature < 1480 °C
- fuel melting temperature not met (2570 °C)

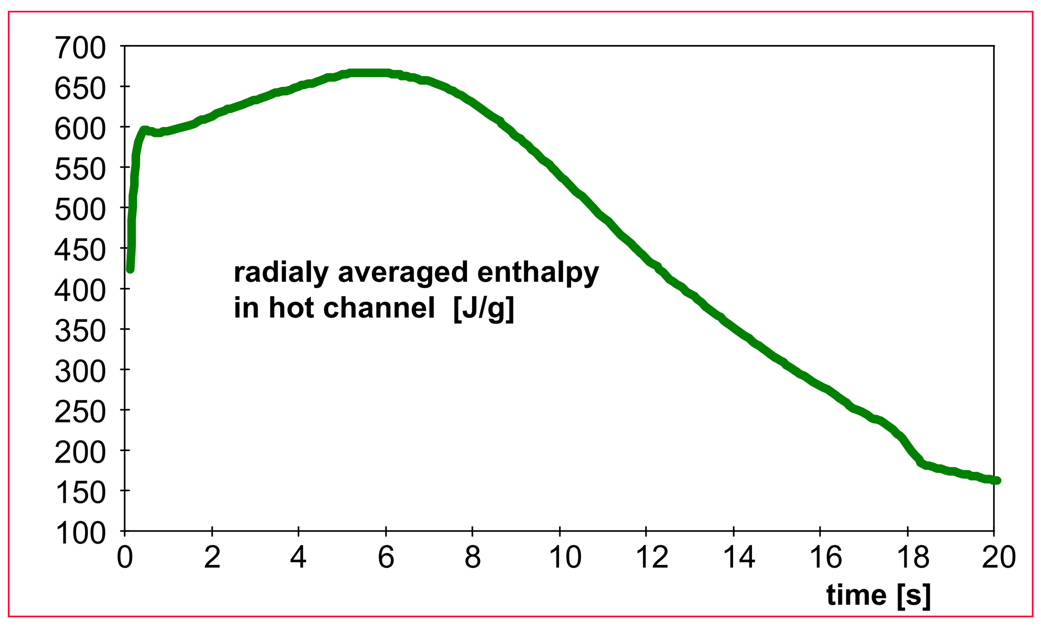
Conservative initial conditions (selection)

- full power, minimum primary coolant flow
- conservative hot channel methodology applied
- max.effectiveness of ejected control assembly, ejection from the lowest position
- conservative reactor parameters, thermal conductivity
- conservative neutron kinetic parameters and reactivity coefficients
- scram with one rod stuck, 1s signal delay taken into account

Computer Code DYN3D/M2 (alternatively **ATHLET/BIPR8KN**)

Analysis with DYN3D/M2 by I.Tinka, Nuclear Research Institute Rez





CONTROL BANK WITHDRAWAL AT ZERO POWER

Acceptance criteria

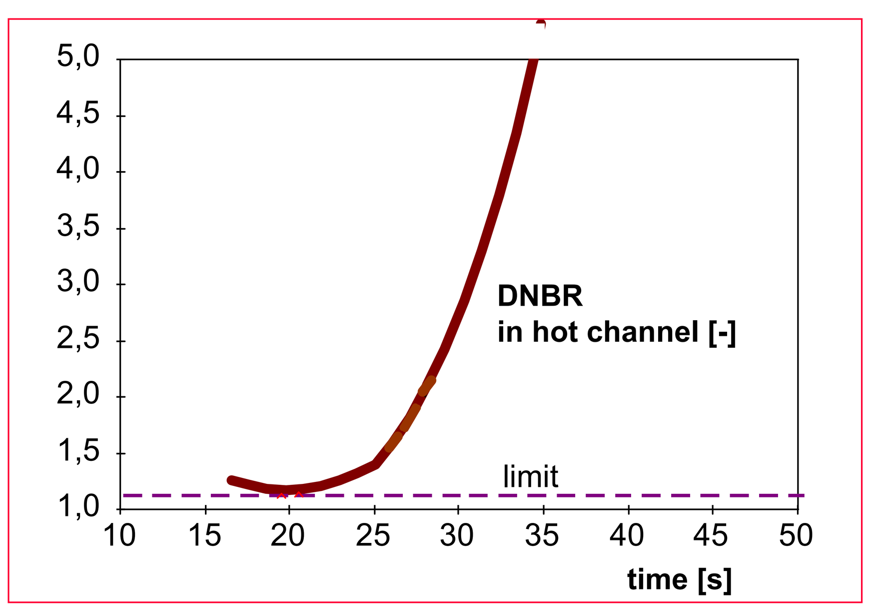
- DNBR > 1,125
- primary/secondary pressure below 15.1 / 6.15 MPa (110% of design value)
- fuel melting temperature not met (2570 °C)

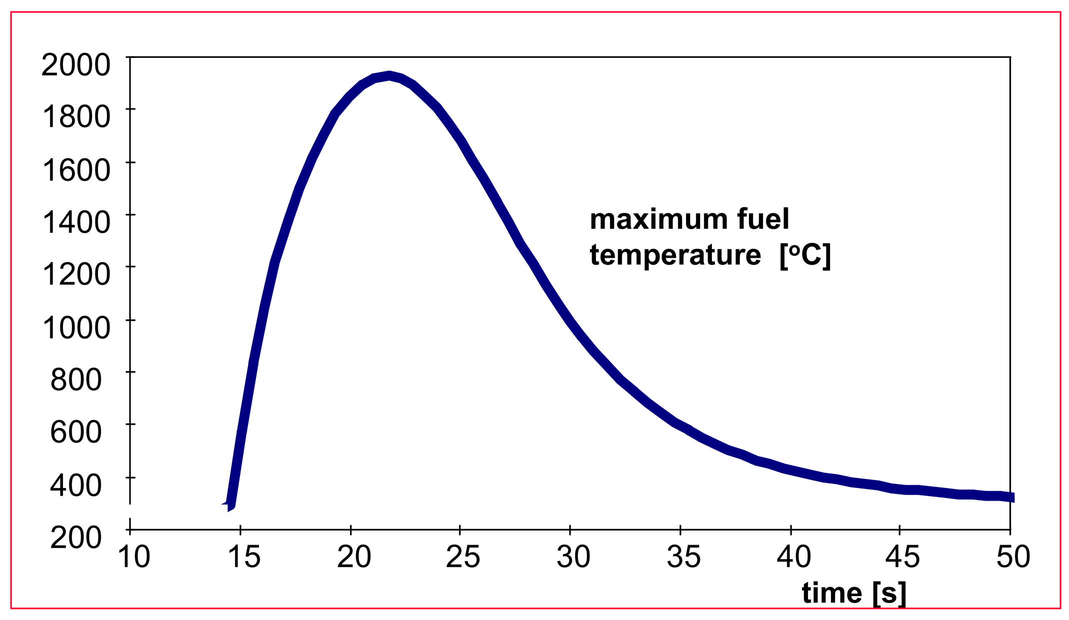
Conservative initial conditions (selection)

- zero power, minimum primary coolant flow
- conservative hot channel methodology applied
- conservative reactor parameters, thermal conductivity
- conservative neutron kinetic parameters and reactivity coefficients
- scram with one rod stuck, 1s signal delay taken into account

Computer Code REPA1D (alternatively **ATHLET/BIPR8KN**)

Analysis with REPA1D by I.Tinka, Nuclear Research Institute Rez





SIMULTANEOUS CLOSURE OF BOTH TURBINES STOP VALVES

Acceptance criteria

- DNBR > 1,125
- primary/secondary pressure below 15.1 / 6.15 MPa (110% of design value)
- fuel melting temperature not met (2570 °C)

Conservative initial conditions (selection)

- reactor power 104% of nominal value, minimum primary coolant flow
- steam dumped by SG safety valves only (other valves permanently closed)
- conservative reactor power distribution
- conservative reactor parameters, thermal conductivity
- conservative neutron kinetic parameters and reactivity coefficients
- scram with one rod stuck, first iniciation of scram signal not expired

Computer Code RELAP 5/MOD3.2.1

Analysis by J.Sommer, Nuclear Research Institute Rez