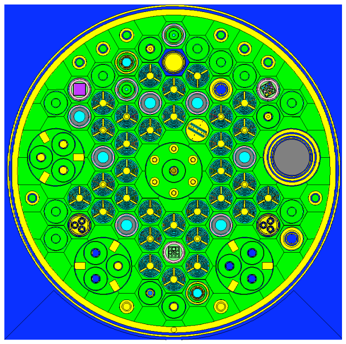
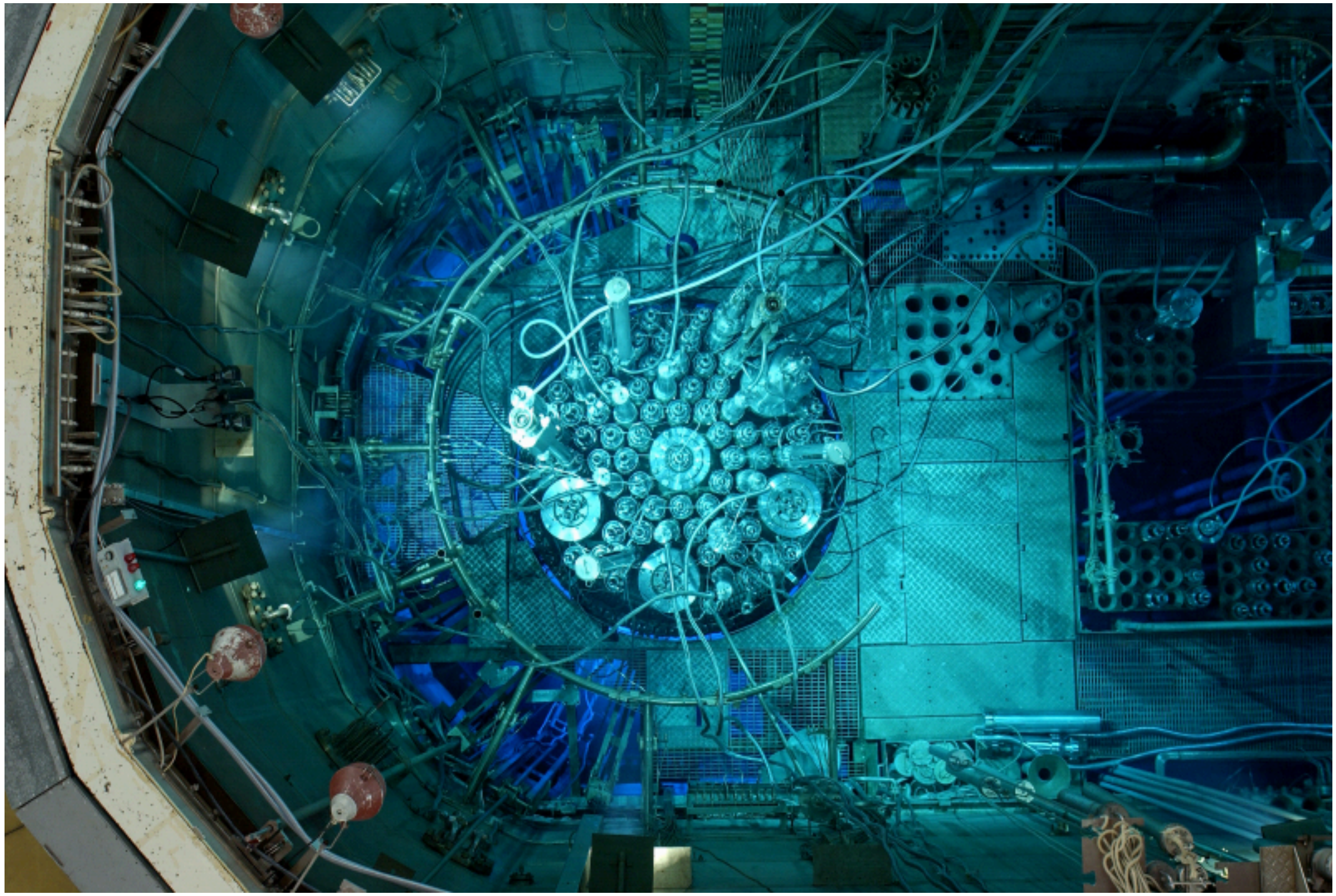
EVITA nuclear measurement program





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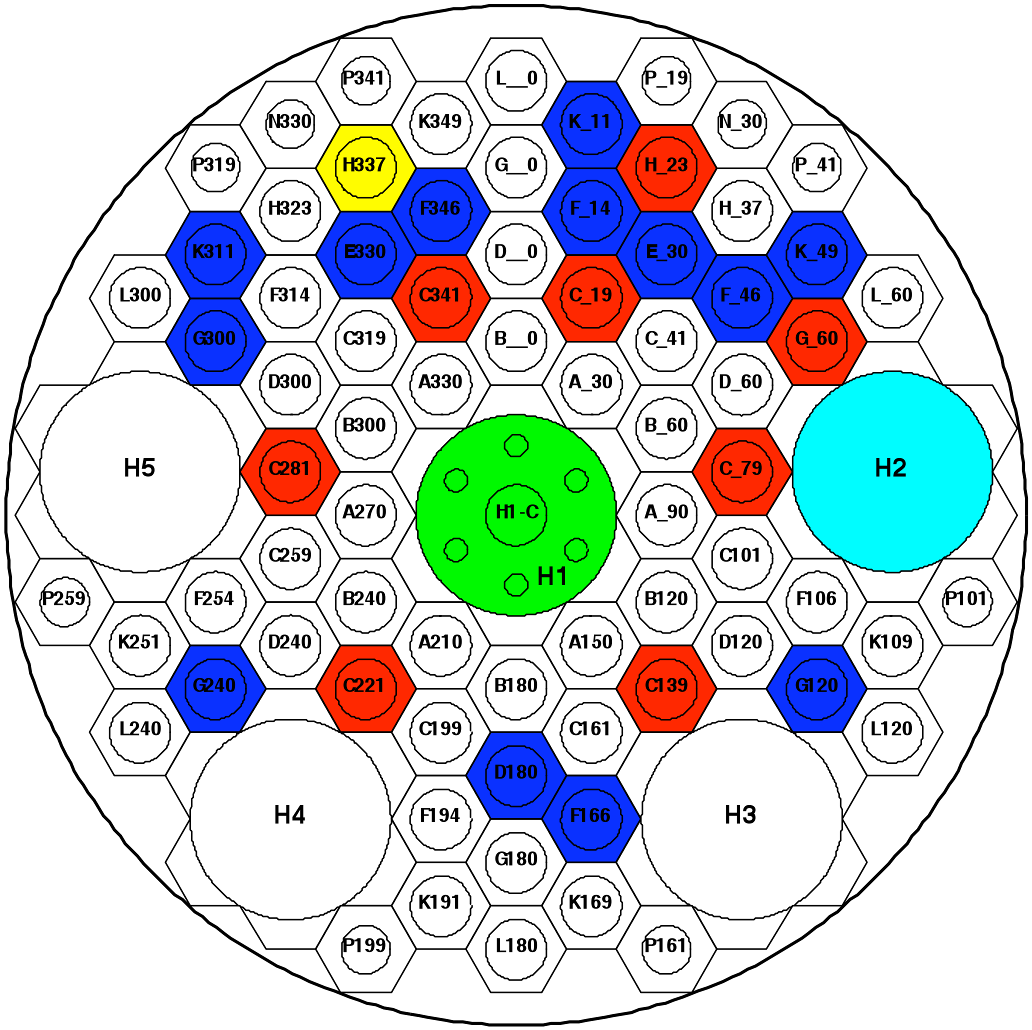
13th IGORR Conference

September 19-23, 2010, ORNL,TN,USA

BR2 core configuration



- compact core arrangement in the twisted Be matrix
  -> high power densities
- large number of irradiation positions, including a 200 mm central flux trap
- variable core configuration & operation mode
  -> flexibility of utilization & tailored irradiation conditions

The EVITA irradiation program

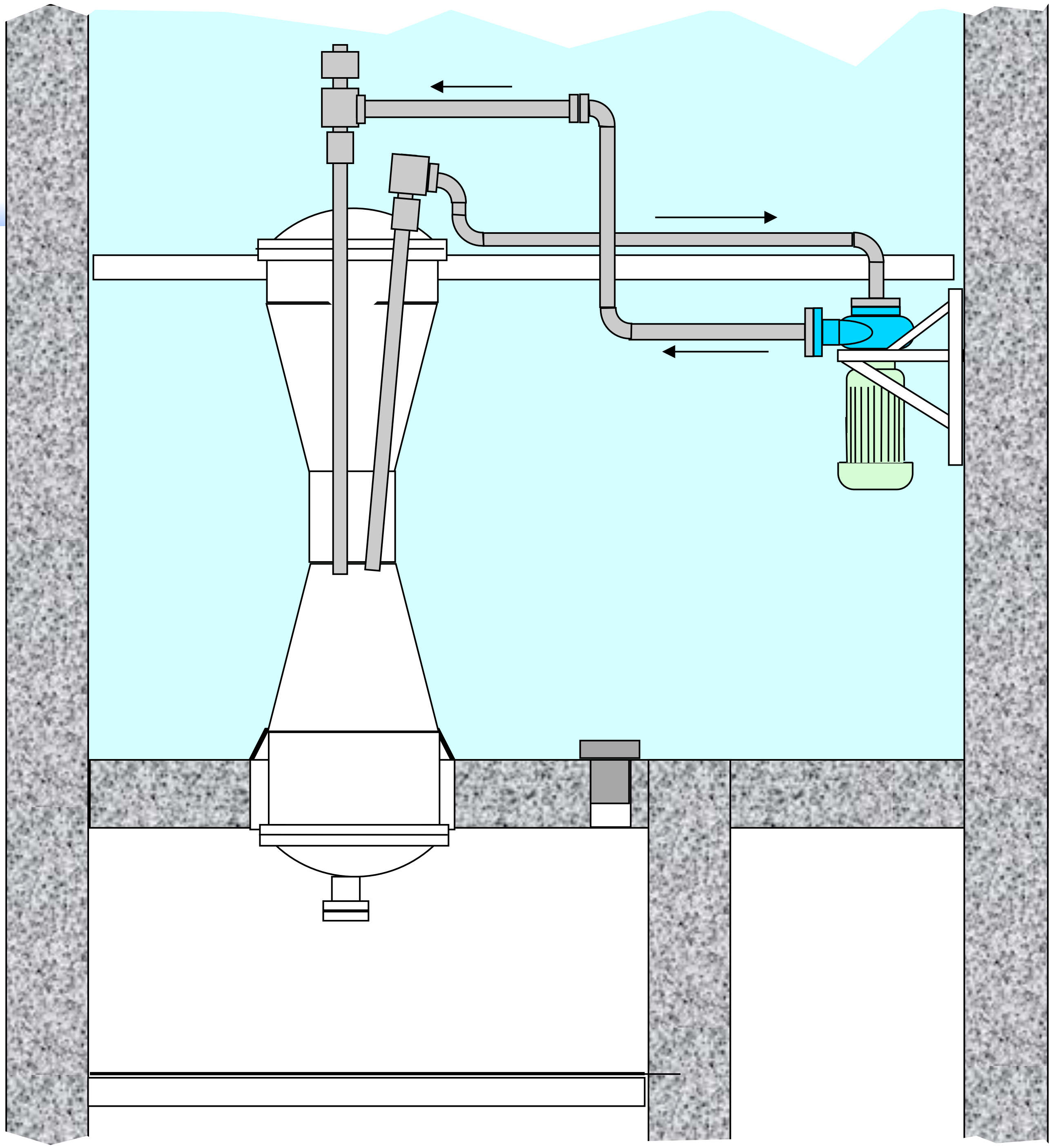
- An experimental program launched by CEA to qualify the JHR start-up fuel (dispersed U_3Si_2, 4.8 gUtot/cm^3, 720 gU5 per element **) under conditions representative of the future JHR operation.
- This qualification program is carried in the BR2 reactor where a specific loop EVITA has been designed for the irradiation of full-size JHR lead test fuel elements
- CEA wants to investigate the thermo-mechanical behaviour of the full-size element. The outer diameter is ~ 95 mm (standard BR2 channel: 84 mm) => a 200 mm channel is required
- Usually in the central 200 mm flux-trap H1:

  200 mm Be-plug with a central 84 mm hole for BR2 driver fuel or Be-plug, and 6 peripheral 33 mm holes for high thermal flux irradiations (RI, vessel surveillance samples)

EVITA - loop

Simulation of RJH thermo-hydraulics

Semi-open water speed booster loop – water taken from 2 peripheral channels and pumped through the IPS loaded inside the central 200 mm channel equipped with a dedicated plug (Al/H2O or Be)



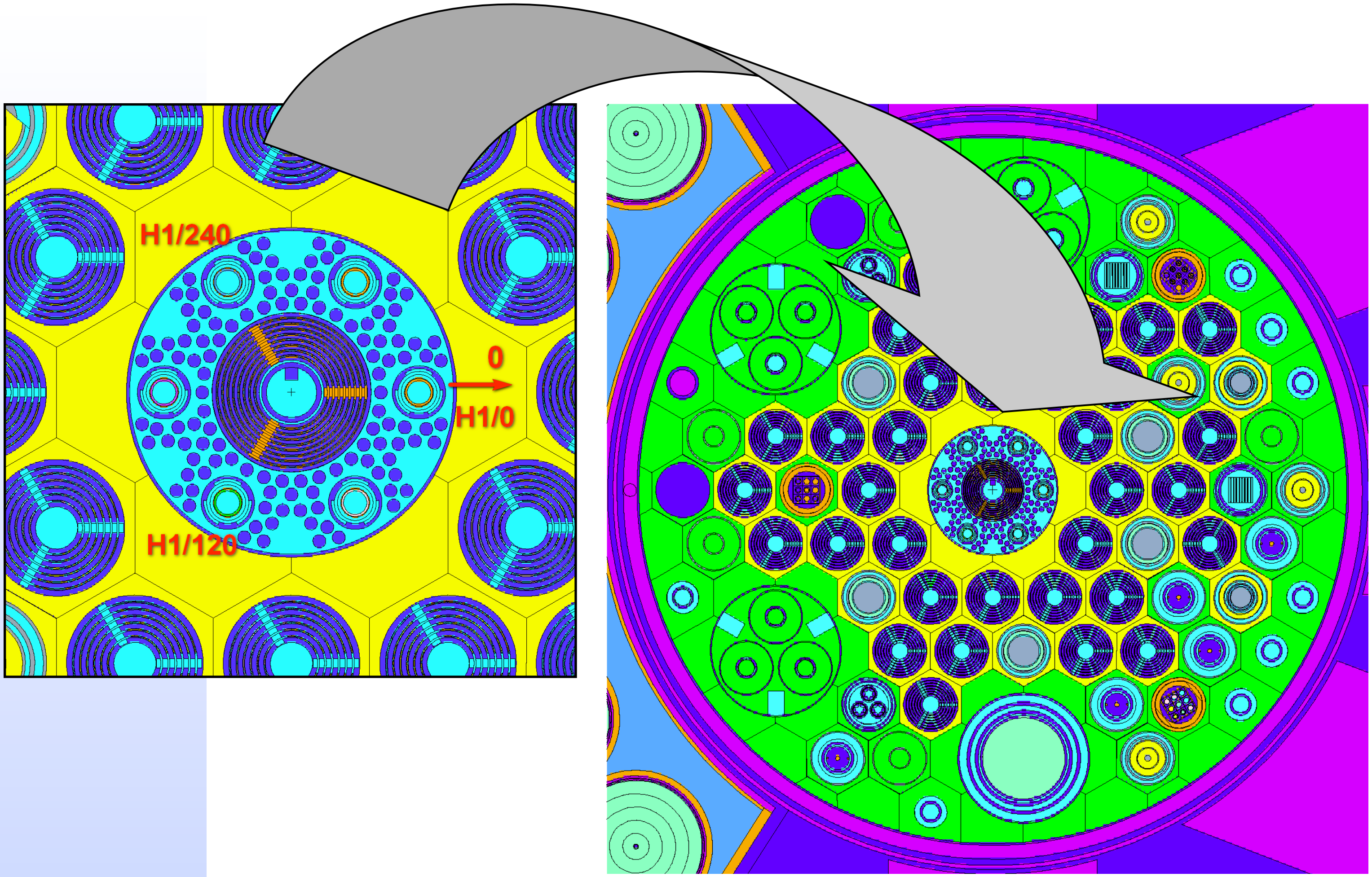
Feasibility in BR2

- The EVITA irradiation program requires to operate the BR2 reactor with a fresh JHR fuel element in its centre, at a required power level, while still being able to offer the requested irradiation conditions for other users
- The initial feasibility calculations showed that the reactivity effects and their variation with burn-up were huge
- The necessity to adapt the environment of the central 200 mm channel became apparent.
- Various solutions have been investigated:
  - H1 central plug in a material with adapted absorbing capacities
  - absorbing screen round the JHR fuel element
  - removing or varying the burn-up of the BR2 driver fuel elements in the first crown
  - changing the position of control rods

Conclusions of neutronic evaluation 1/2

- New central 200 mm with a larger central hole needed. Be being to reactive, an Al plug was studied
- Spectrum and power in the JHR fuel element can be adapted by changing the water fraction in this central Al plug. Water can be introduced by designing:
  - Al plug with water channels
  - Al grid in the cooling water
- The optimum plug for the central 200 mm channel H1 is an annular cylinder made of Al with water filled channels (volumetric fractions 70% / 30%)
- With this Al/H2O plug, the requested power and the maximum heat flux in the JHR fuel element at BOC of the 1st irradiation cycle obtained at an acceptable BR2 operating power level and an acceptable cycle length

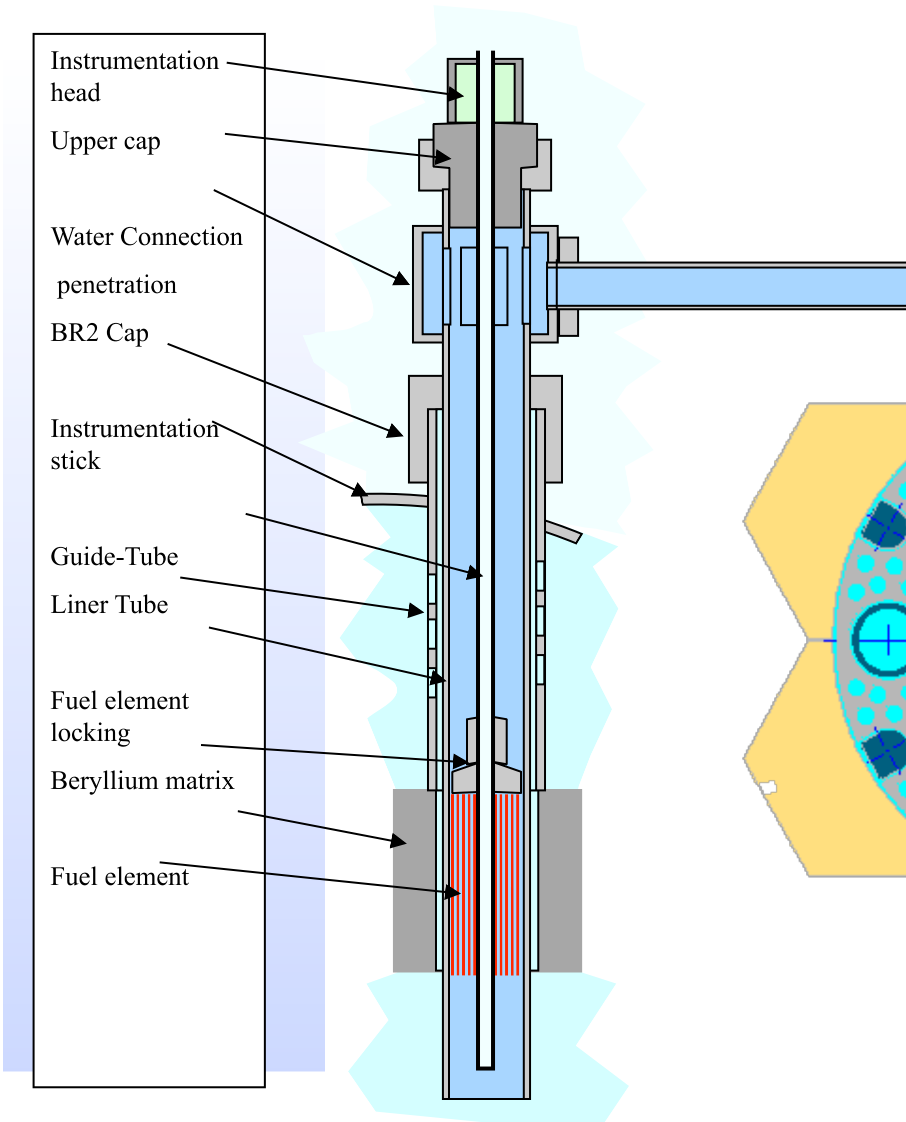
EVITA Nuclear Design:
a specific Al/H2O H1-plug was designed to compensate JHR FA excess reactivity

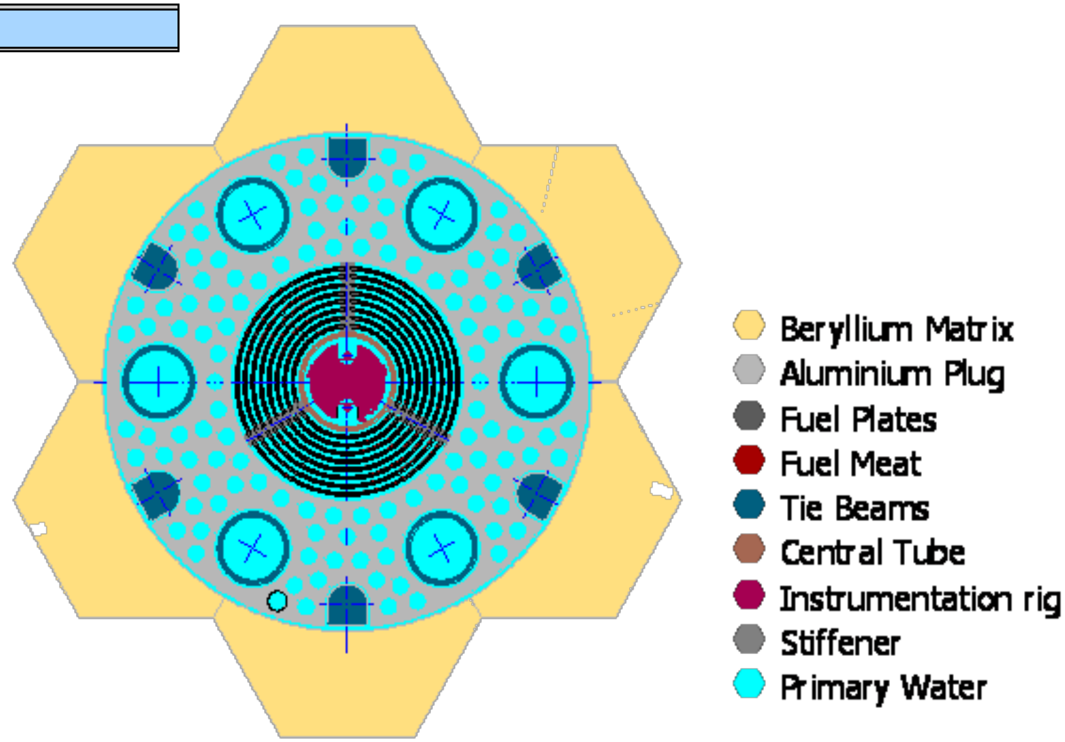


Conclusions of neutronic evaluation 2/2

- The 200 mm “Al-H2O plug” is optimized for the irradiation of a fresh or partially burned JHR fuel element (for 2/3 cycles)
- The targeted mean fuel burn-up after 4 cycles of irradiation in the H1 channel is ~ 55%
- The necessity to dispose of a second plug with different absorbing capacity became apparent to compensate the large reactivity variations resulting from the burn-up of the EVITA fuel element which holds no burnable absorbers
- A new 200 mm Be plug with a larger central hole (~ 100 mm) to accomodate the JHR element was found adequate to compensate the huge reactivity change
- Peripheral holes for the loading of absorbing targets are foreseen in this new Be plug to allow for a smooth change of plug (Al -> Be) by ajusting the absorbing load in this holes.

EVITA loop loaded in the Al/H2O plug in the central 200 mm flux-trap channel of BR2





EVITA Nuclear Measurement Program (NMP)

- Due to the initial unavailability of a partially burned JHR fuel element the measurement program had to be executed in two phases:
  - the 1st before the first cycle with only fresh JHR elements
  - the 2nd later with partially burned elements available
- The first phase of Nuclear Measurement Programme was executed during a 'zero power‘ operation period preceding the first full power operation cycle of BR2 with the EVITA loop
- The main objective was to verify the theoretical predictions and to evaluate the impact of the presence of the EVITA loop loaded with a fresh JHR element on the reactivity balance of BR2, for safety and operational reasons

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Execution of the NMP phase 1

- The measurement campaigns were executed under full compliance with the safety criteria, following a cautious step-by-step evolution, from a standard BR2 configuration to the new EVITA configuration
- Which reactor loads were measured in the first campaign ?
  - Standard BR2 fuel element in the BR2-Be-H1-plug
  - Standard Be Ø 84 mm plug in the BR2-Be-H1-plug
  - Standard BR2 fuel element + Al adapter in the EVITA-Al/H2O H1 plug
  - A fresh JHR element in the EVITA-Al/H2O H1 plug
  - Additional Ir targets in the peripheral holes of the EVITA-Al/H2O H1 plug
- The neutronic characteristics of each load were measured and compared with the predictions by MCNP

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MCNP-models of the core loads for the EVITA NMP phase 1

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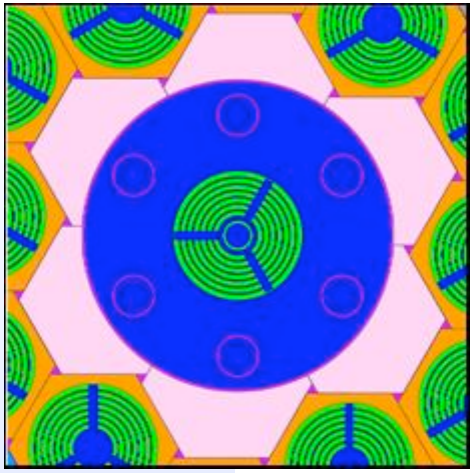

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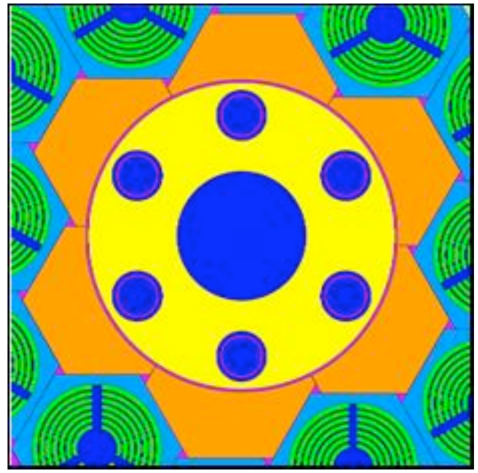

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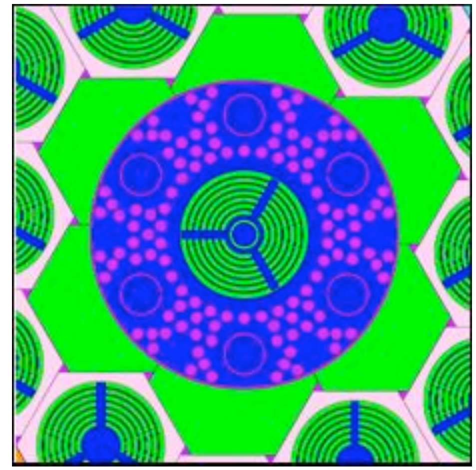

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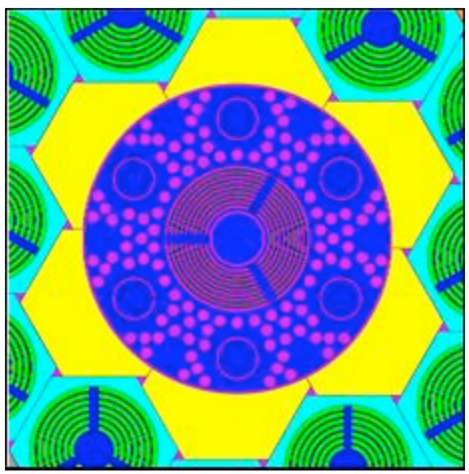

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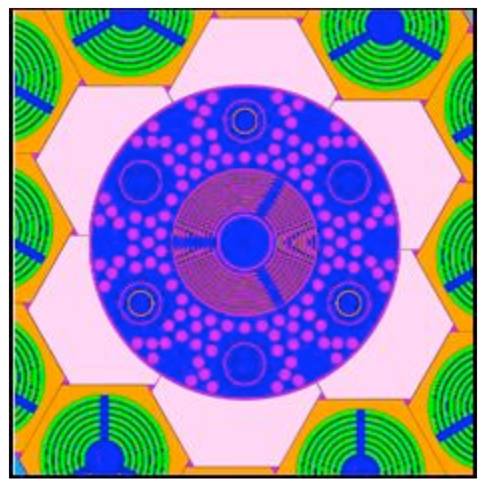


Execution of the NMP phase 1

- The following parameters were measured for the different core loads:
  - critical height of the control rod bank
  - reactivity characteristics of the different control rods
  - axial reactivity evolution vs control rod position
  - and determination of the reactivity effect of the central channel H1 for each configuration
- The reactivity of the individual rods was determined by positive period and rod drop measurements
- Some ‘transition’ loads proved to be subcritical (as predicted by the MCNPX calculations); for these loads an additional quantification of the level of sub-criticality took place (subcritical countings)
- An improved methodology, including the contribution of the delayed neutrons from the beryllium matrix, was applied for the determination of the control rod worth, derived from rod-drop and period measurements.

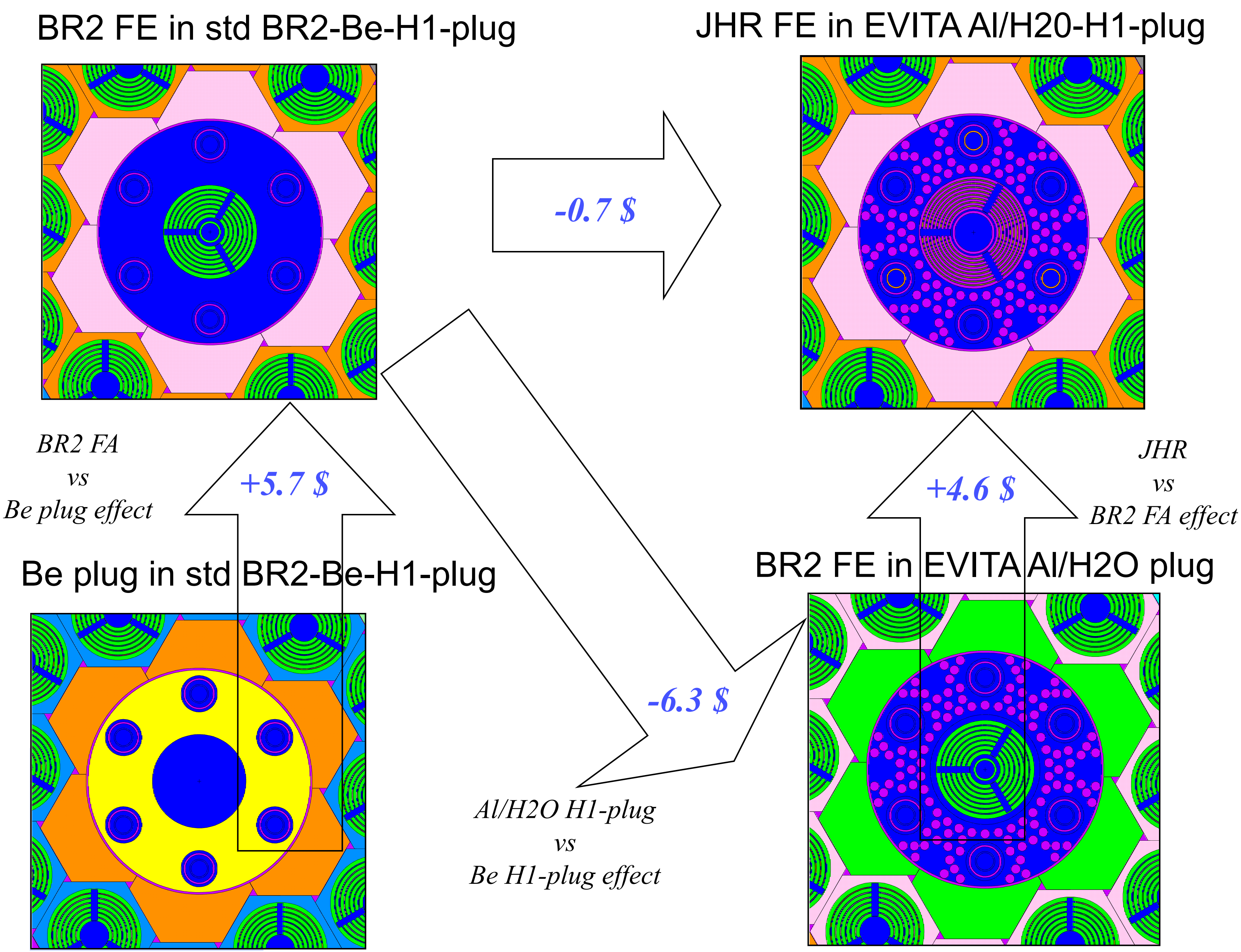
Results of the NMP phase 1

- The measured values of the NMP EVITA (the critical heights, the subcritical countings, the control rod worths, derived from the rod-drop and period measurements) have been found in good agreement with the values predicted by MCNPX for the various configurations measured
- The value of the control rod worth decreased by approximately 1$ due to the presence of the JHR element in the central irradiation position
- In all measured loads, the difference between the measured and the predicted excess reactivity at criticality was less than 1$, as required by the SAR of the BR2 reactor

Results of the NMP phase 1 2/2

- It was confirmed that the reactivity effect of the EVITA loop and the JHR fuel element are huge
- Replacing the standard Be plug by the Al-H2O plug had a negative reactivity effect of - 6.3 $
- Replacing a fresh BR2 fuel element by a fresh JHR fuel element had a positive reactivity effect of + 4.6 $
- The magnitude of both (compensating) effects confirmed the necessity to dispose of an Al-H2O plug for the irradiation of a fresh JHR fuel element
- The effect of adding Iridium targets in the peripheral channels of the Al-H2O plug was demonstrated

  (e.g. 90 g Ir gave a reactivity effect of - 1.4 $)


BR2 FE in std BR2-Be-H1-plug
JHR FE in EVITA Al/H20-H1-plug
-0.7 $
BR2 FA
vs
Be plug effect
+5.7 $
JHR
vs
BR2 FA effect
+4.6 $
Be plug in std BR2-Be-H1-plug
BR2 FE in EVITA Al/H2O plug
-6.3 $
Al/H2O H1-plug
vs
Be H1-plug effect

Nuclear Measurement Program phase 2

- A second nuclear measurement campaign has been executed when irradiated JHR fuel elements with significant burn-up became available

- Two special central plugs are available
  - geometrical identical
  - same functionality
  - different materials at the height of the reactor core
    - EVITA-Al-H1-plug: aluminium-water
    - EVITA-Be-H1-plug: beryllium

- The special Be plug can only be measured with a partially burned JHR element

Reactor loads for the EVITA NMP phase 2

Load	H1 (ϕ 200mm)	H1/central (ϕ 94mm)	H1/peripheral	Other channels	Remarks
03/2010.M1	EVITA-Be-H1-plug	JHR E4 (BU = 28.5%)	Stainless Steel	Identical for all loads As close as possible to reactor load for full power cycle	Extra absorbers in H1/ peripheral Safety margin first load EVITA-Be-H1-plug
03/2010.M2	EVITA-Be-H1-plug	JHR E4 (BU = 28.5%)	Stainless Steel		Load to evaluate the EVITA-Be-H1-plug in comparison with the EVITA-Al-H1-plug.
03/2010.M3	EVITA-Al-H1-plug	JHR E4 (BU = 28%)	Stainless Steel		Reference for EVITA-Be-H1-plug
03/2010.M4	EVITA-Al-H1-plug	JHR E3 (BU = 0%)	Stainless Steel		For comparison with load 03/2010.M3
03/2010.A	EVITA-Be-H1-plug	JHR E4 (BU = 28.5%)	Iridium	Load for cycle of 4 weeks	Load for cycle 03/2010

Execution EVITA NMP phase 2

Load	Load central flux-trap	Critical height calculated [mm]	Critical height measured [mm]	Reactivity rod bank [$]
03/2010.M1	EVITA-Be-H1-plug JHR (28.5% BU) 6×St.St.	510.0	512.0	–
03/2010.M2	EVITA-Be-H1-plug JHR (28.5% BU) 4×St.St.	460.0	466.6	14.30
03/2010.M3	EVITA-Al-H1-plug JHR (28.5% BU) 4×St.St.	750.0	774.0	16.31
03/2010.M4	EVITA-Al-H1-plug JHR (0% BU) 4×St.St.	610.0	625.0	13.41

Results of the NMP phase 2

- Again the initial predictions and the necessity to adapt the surrounding plug were confirmed
- load 03/2010.M2 vs load 03/2010.M3
  - **EVITA-Be-H1-plug** vs EVITA-Al-H1-plug
  - 6.6$ for load 03/2010.M2
  - 0.4$ for load 03/2010.M3
  - a difference of **6.2$**
- load 03/2010.M4 vs load 03/2010.M3
  - JHR (0% Bu) vs JHR (**28.5% Bu**) (both with Al/H2O plug)
  - 2.2$ for load 03/2010.M4
  - 0.4$ for load 03/2010.M3
  - a difference of **1.8$**

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Conclusions

- The results of the EVITA NMP and the predictions of the presently used calculation methods have been found in good agreement

- The huge reactivity differences between a fresh and a partially burnt JHR fuel element justify the availability of two special 200 mm plugs with a central hole of ~100 mm:
  - the EVITA-Al-H1-plug and
  - the EVITA-Be-H1-plug

- The EVITA irradiation program is well on its way.

  The 2nd element was irradiated up to mean burn-up 58%; both plugs were used with adapted RI target loads