EPR^{TM} Reactor Activity Management: Design Performance and Chemistry Program

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ENGINEERING & PROJECTS ORGANIZATION

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CONTENT

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Introduction

EPR^{TM} Nuclear Power Plant

- **Third generation four loops PWR: 4 units under construction: OL3, FA3 & TSN 1/2**

Flamanville 3 - April, 2012

RCS Activity Management

- **Application of the ALARA approach at the design stage, in order to:**
  - **Minimize the radioactive source term**
  - **Minimize the transport of radioactive source term material in RCS and Auxiliary systems, and thus minimize the release to the environment, the ORE and the outage duration**

- **Field impacting the radio-activity management (source term)**
  - **Choice of material, Manufacturing Process**
  - **Primary Coolant Purification**
  - **Primary Coolant Chemistry during the commissioning phase and normal operating condition**

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Reactor Coolant System Source Term Identification

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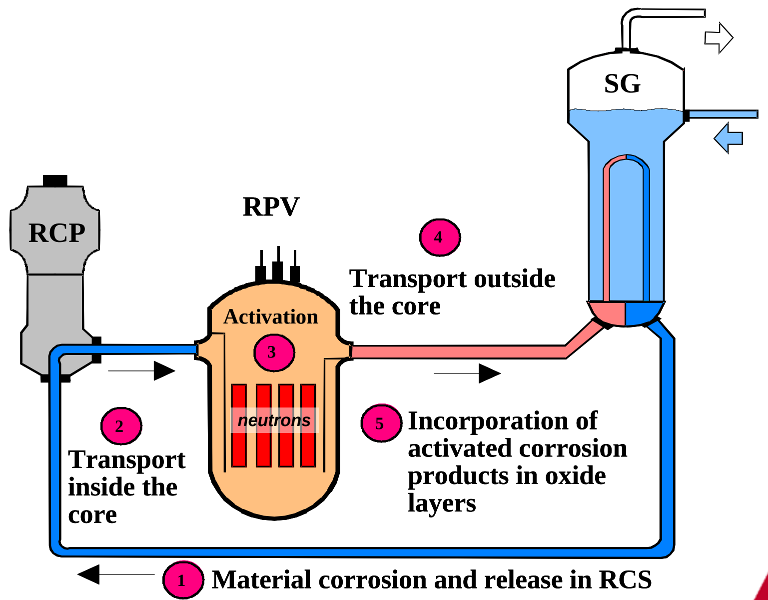
5. ***Conclusion***

Reactor Coolant System Source Term Identification

- **Radioactivity in RCS is typically from 4 sources**
  - **Fission products (noble gas, iodine and caesium) and Radioactive Actinides: mainly retained inside the fuel rod (except for tramp uranium contamination outside fuel rod)**
  - **Activation products: Tritium, Carbon-14, Nitrogen-16, Argon-41**
  - **Corrosion products: mainly Cobalt-58 and cobalt-60 (Iron, Manganese, Chromium)**

Focus on the key radionuclides for ORE

- **Dose mainly accumulated during maintenance and outage activities,**
- **Cobalt-58 and Cobalt-60 are the dominant contributors at the vicinity of contaminated piping and components (formed by neutron capture of respectively Nickel-58 and Cobalt-59)**



Impact of Design

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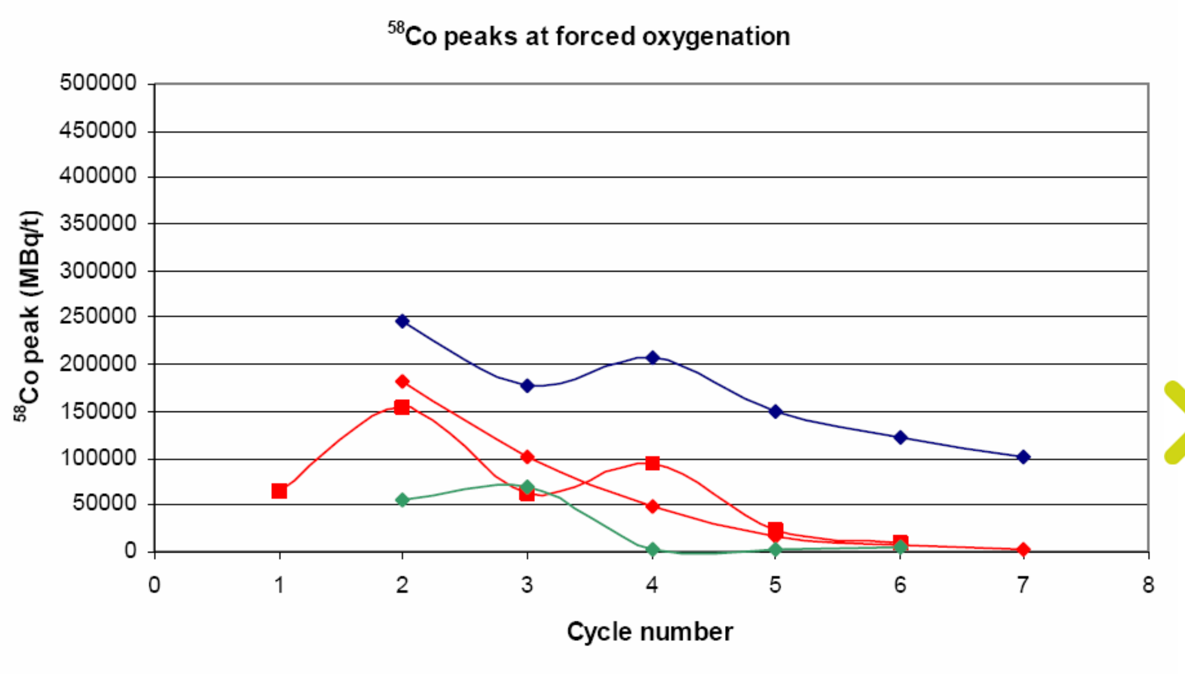
Materials & Manufacturing Process

- **Material Selection described at ISOE 2010 - P. Jolivet**
- **Improvement in the Alloy 690 SG tube manufacturing process lead to a low release rate of this material → Impact of the manufacturing process on ^{58}Co peaks – N4 series of reactors**
  [F. Carrette, International Conference on Water Chemistry of Nuclear Reactor – Jeju 2006]



1st manufacturing process
2nd manufacturing process
3rd manufacturing process
4rd manufacturing process

Improvement of the SG tube manufacturing process

Other design improvements

- Optimised design CVCS purification with a nominal purification rate of 72t/h during transient

- On line degasification system to remove dissolved gasses (72 t/h)

- All tanks, including the boron water make up tanks under nitrogen flushing leading to decrease the potential oxygen ingress in RCS.

Impact of Primary Coolant Chemistry

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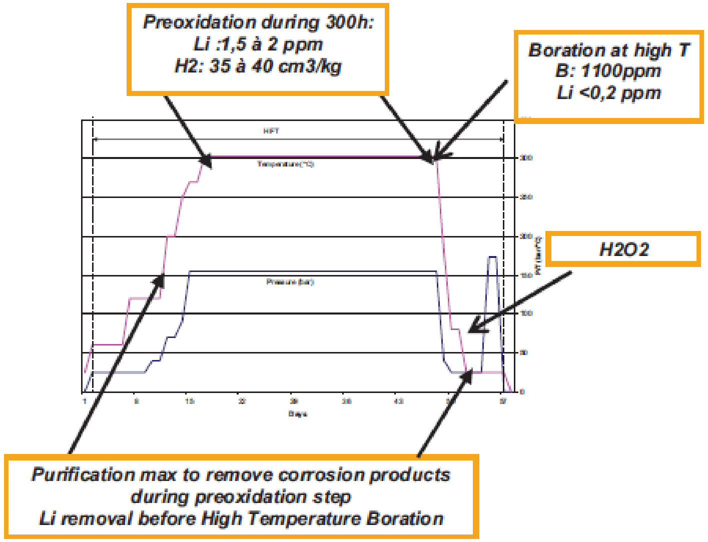
Commissioning Phase

▶ Hot Functional Test Optimized Pre-Oxidation Procedure

- **RCS subject to nominal condition (Temperature and Pressure) for the first time, leading to the formation of the internal oxide layer which must be as protective as possible in order to avoid future exchange with the primary medium (minimizing the corrosion release phenomena);**

- **Based on literature analysis and the recent test results, an optimized HFT procedure that minimizes further SG tube release is proposed :**
  - An alkaline step with high Hydrogen concentration (*300hours- Li ~1,5 à 2 mg/kg- H_2 ~ 35 à 40 cm3/kg)*
  - Boration at high temperature before cooling down (*B: ~ 1100mg/kg - Li <0,2 mg/kg)*
  - H_2O_2 injection at 80°C.
  - *Purification with max flowrate (72t/h) to remove corrosion products during pre-oxidation step*



Primary Coolant Chemistry: pH300°C management (1/2)

- pH300°C impacts the solubility and the stability of corrosion products and their re-deposition on system surfaces
- Choice of pH300°C value based on
  - theoretical calculations: scattered results depending on thermodynamic data, and chemical species considered. For iron (magnetite and nickel ferrite) minimum of solubility between 6.9-7.4; necessity to confirm those values with
  - lab measurements and,
  - OPEX (Operating Experience)
- Beneficial impact in term of primary coolant radioactivity of both:
  - the elevated $pH_{300°C}$
  - its constant value for the whole cycle.

- Elevated <u>constant</u> $pH_{300°C}$ selected for EPR^{TM} reactor and $pH_{300°C} \geq 7.2$ maintained from the BOC to EOC.

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pH300°C management (2/2)

- Elevated constant $pH_{300°C}$ ≥ 7.2 maintained during the whole cycle is possible through:
  - Use of Boron-10 Enriched Boric Acid (EBA)
    - **To reduce the total boron concentration (necessary with new fuel cycle managements), with the same neutronic effect**
    - **Enrichment value depends on fuel managements**
    - **To allow to obtain the target $pH_{300°C}$ while respecting the limit value of Li concentration**
  - Lithium maximal concentration up to 4 mg/kg
    - **Allowed with M5® fuel cladding and**
    - **Primary system materials (austenitic stainless steel and Alloy 690TT**)

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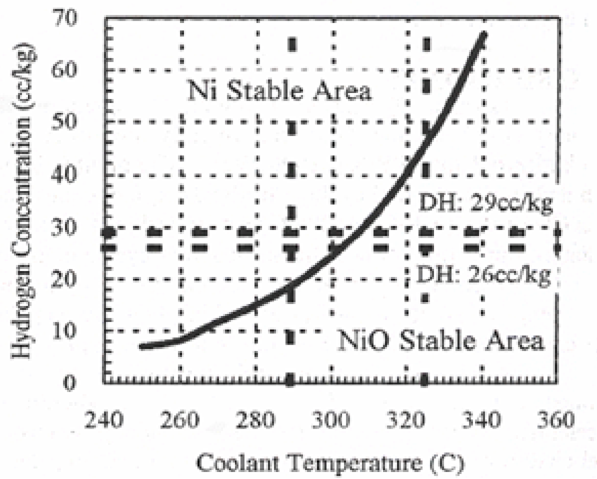
Primary Coolant Chemistry: Hydrogen management (1/2)

- Hydrogen is added in primary coolant water to maintain a reducing environment by limiting radiolytic decomposition of water. For EPR™ reactor hydrogen target concentration is optimized taking into account :
  - Water radiolysis : Minimum Hydrogen concentration required to avoid oxygen formation by radiolysis C_{H2} > 10 cm3 (STP)/kg
  - RCS material Corrosion risk (SS , alloy 690TT and fuel cladding)
  - Contamination
    - **Corrosion product solubility and stability :**

    By limiting the hydrogen concentration,
    Ni metal in the core is reduced and thus the production of Co-58 is limited.



Hydrogen management (2/2)

Contamination: OPEX

- Beznau 2: increase of DH from 34 to 45 cm^3(STP)/kg leads to an increase in the dissolved Co-58 by a factor more than 3 [H. VENZ, K. DINOV, Fukushima, Japan, 1998]
- Tsugura 2 : a decrease in the hydrogen concentration of 10 % lead to [K. HISAMUNE, JAIF 1998]:
  - **Decrease deposit in the core and a decrease of nickel enrichment in the deposit at the core inlet**
  - **Reduction of out-of-core deposit activity for Co-58 (20 to 40%) as well as dose rate (30%)**
- Ikata : CP measurement campaigns performed as a function of hydrogen concentration showed [N. ISHIHARA, Fukushima, Japan, 1998]:
  - **the Ni metal / total Ni ratio increases as the hydrogen concentration increases**
  - **the median size of Co-58 particles increases as the hydrogen concentration increases**

Hydrogen target concentration retained for EPR™ reactor: 17-28cm3 (STP)/kg

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Transient phases

- Optimizing procedures of Cold Shutdown and Start-up to optimize radioprotection

  - Cold shutdown
    - Use of the on line degasification system to remove fission products
    - Use of high flow rate CVCS purification removing efficiently the CP released in order:
      - To avoid RCS contamination by CP redeposit,
      - To reduce the primary water activity as soon as possible, in order to reach an acceptable specific activity for the reactor vessel opening.
      - Control the clarity of the pool in RB and the dose rate in the surrounded area

  - Start-up
    - Degassing operation by vacuum application and hydrazine injection, and use of on line degasification system
    - Purify at maximal flow rate when the solubility of corrosion products, in particular the nickel is high, before 100°C to avoid the deposit when the temperature increases,
    - Measure CP (Ni) during start up
    - Inject hydrogen and lithium at the end of temperature increase to purify efficiently during this phase

Conclusion

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Conclusion

- **The current EPR™ design follows the ALARA approach with regard to source term:**
  - **Choice of material, Manufacturing Process**
  - **Primary Coolant Purification**
  - **Primary Coolant Chemistry during the commissioning phase and normal operating condition**
- **Complementary means as Chemical and Radiochemical Specifications defining the control parameters are also essential for the activity management**
- **This lead for EPR™ to minimize dose rates and ORE values**

thank you for your attention…

OLKILUOTO 3, Finland - Nov. 2011