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Material Selection According to ALARA during Design Stages of EPR™

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Introduction

The EPR™ Nuclear Power Plant

- **Pressurized Water Reactor of generation III+**
  - **Four units are currently under construction**

OLKILUOTO, FINLAND

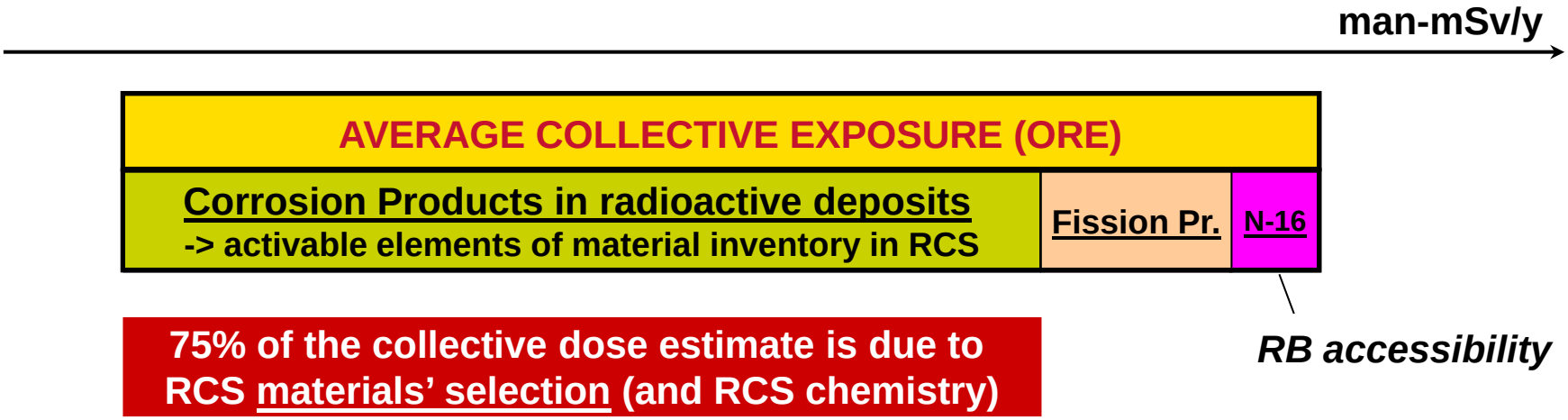
Radiation Protection at the Design Stages

- **ALARA approach at the design stage of new plants mandatory as of beginning of EPR™ Basic Design in 1995**
  - **Based on ICRP publication 60**
  - **National regulations**
    - European level (Directive 96/29)
    - Member countries of reference plants (France, Germany)
  - **European Utility Requirements (EUR)**
    - Material selection with low release rates
    - Justification of activable species (focus on Cobalt, Nickel)
- **Adaptation to other regulatory frameworks**
  - **European countries (UK, …)**
  - **Outside Europe (China, USA, …)**
- **Second principle of "optimization" = ALARA design**

SOME « EVOLUTIONS » WERE SMALL REVOLUTIONS IN DESIGN METHODOLOGY

Several Radiation Sources: Where the Effort Should be Made?

- **Contributions to ORE in EPR™ configuration**



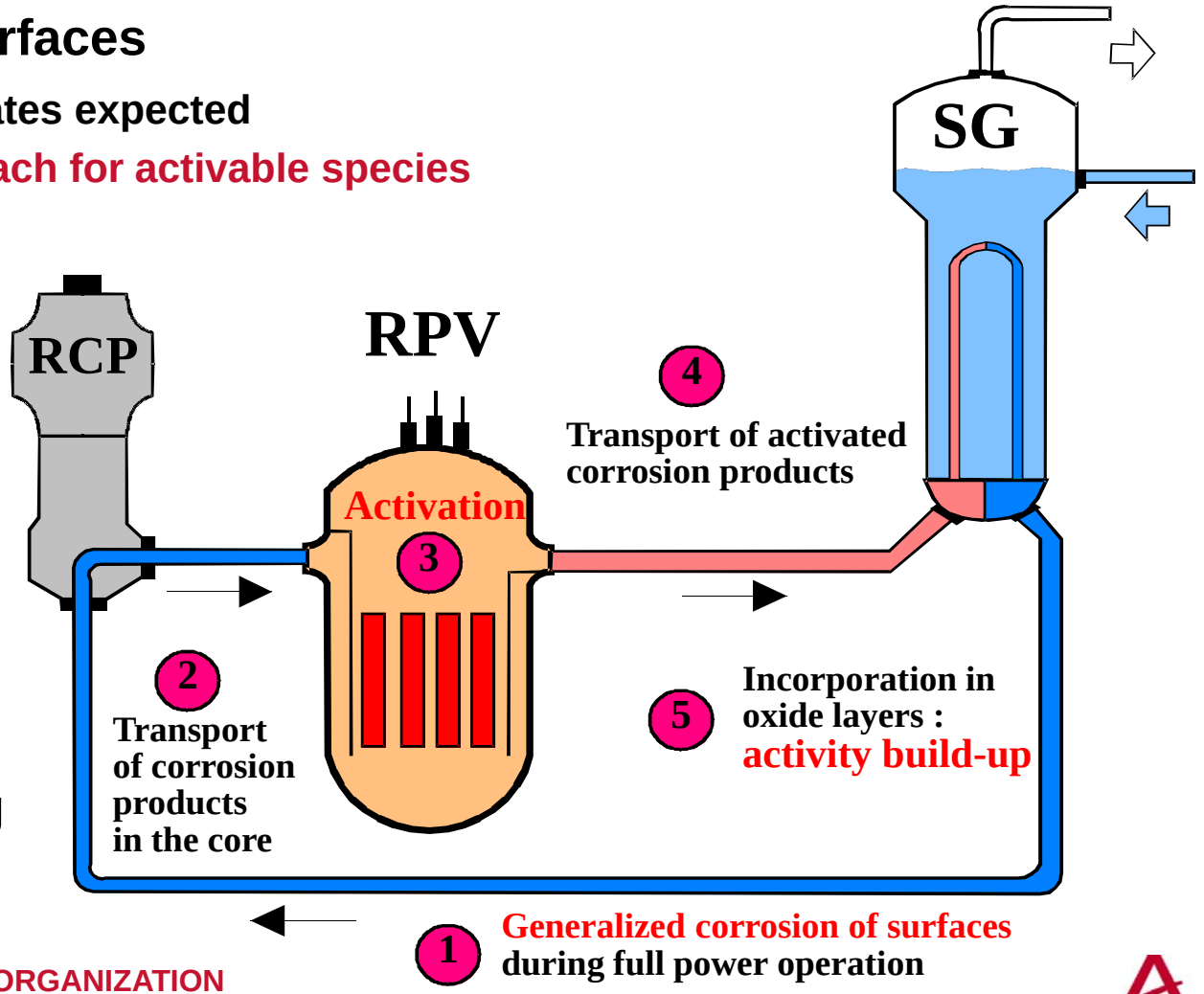
75% of the collective dose estimate is due to RCS materials' selection (and RCS chemistry)

THE SELECTION OR EXCLUSION OF CERTAIN MATERIALS (INCLUDING IMPURITIES) IS ONE ESSENTIAL ASPECT OF RADIATION PROTECTION AT THE DESIGN STAGE

Activity Build-Up on Primary Component Surfaces

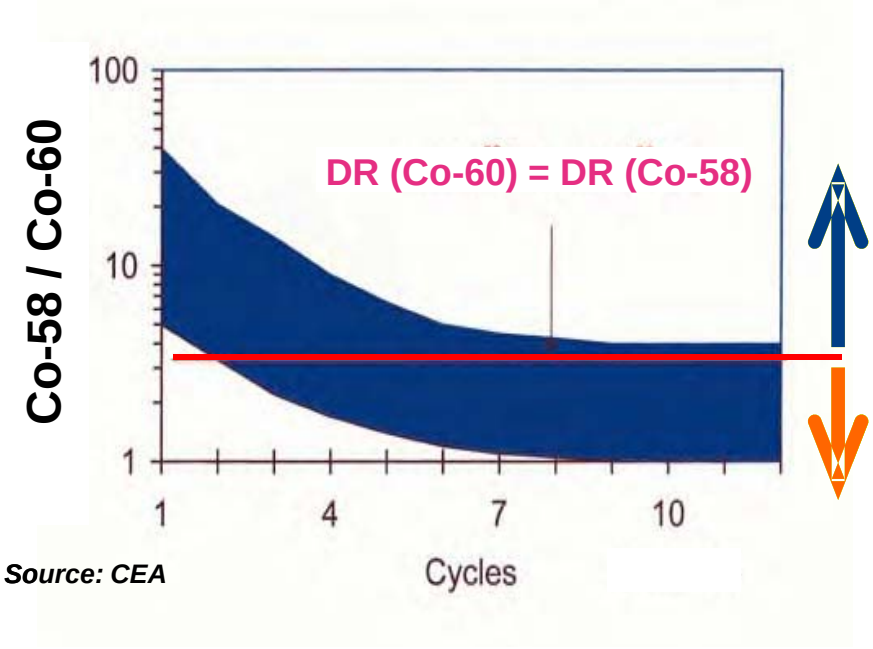
Activity Build-Up of Corrosion Products

- **RCS Wetted surfaces**
  - Low release rates expected
  - ALARA approach for activable species
- **Primary water chemistry minimizes corrosion**
  - pH value
  - Hydrogen concentration
- **Surface conditioning during commissioning**
  - Protective oxide layer



Corrosion Product Contribution to RCS Dose Rates (DR) *vs* Time

- **<u>Deposits of Co-60 and Co-58</u> are the dominant contributors to dose rates measured at the vicinity of empty contaminated piping and components**



Source: CEA

Major contribution of Cobalt-58 to the DR **Source: Nickel**

Major contribution of Cobalt-60 to the DR **Source: Cobalt**

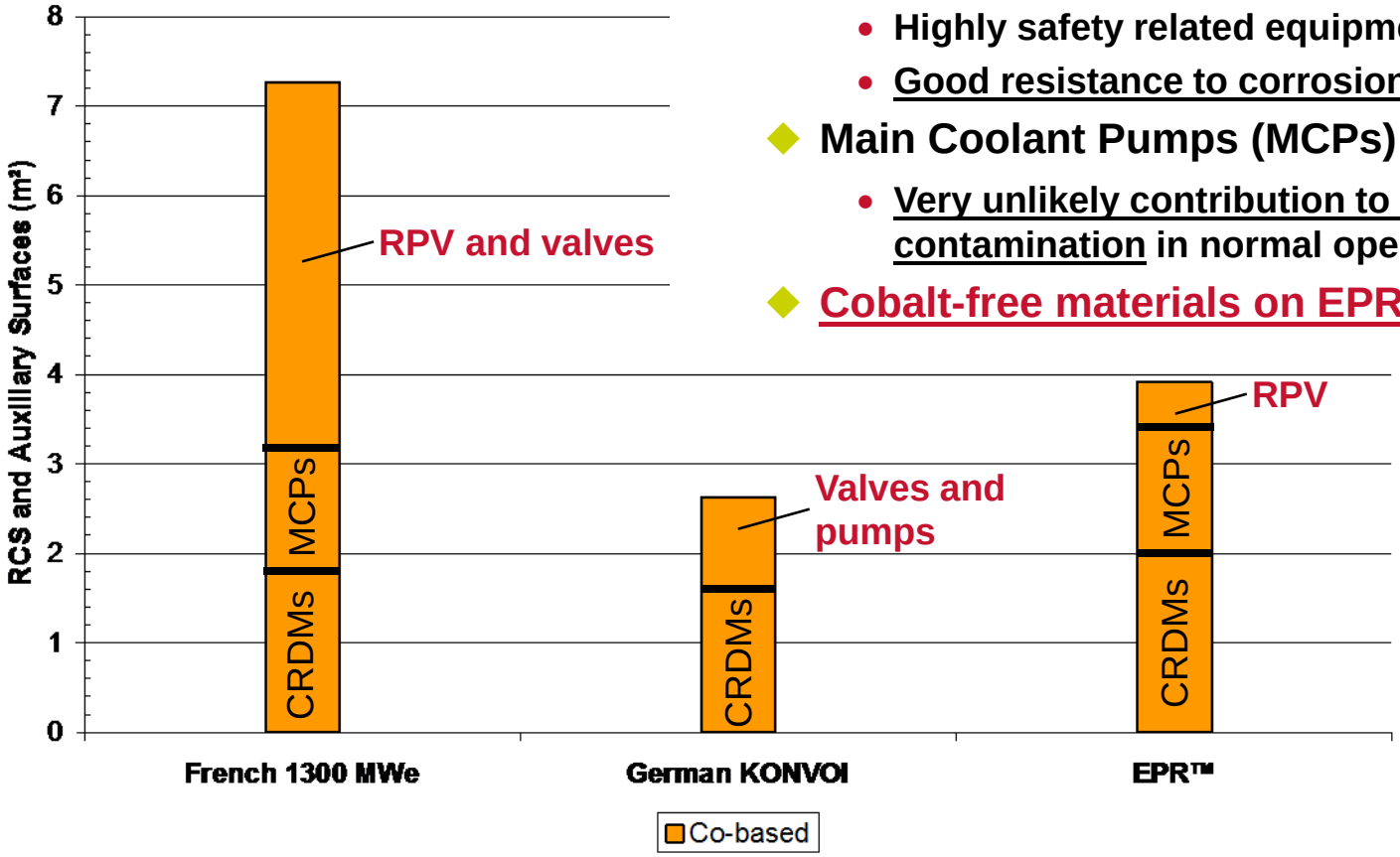
- **Stellite™ hardfacing parts**
  - **Corrosion and wear**
- **Cobalt residual content**
  - **General corrosion**

FOCUS ON COBALT INVENTORY AT THE DESIGN STAGE SINCE COBALT-60 IS A LONG-TERM CONTRIBUTOR TO COLLECTIVE DOSES

Impact of Current EPR™ Material Inventory on Primary Circuit Contamination

Potential Cobalt-60 Sources from Stellite™ Hardfacing Parts

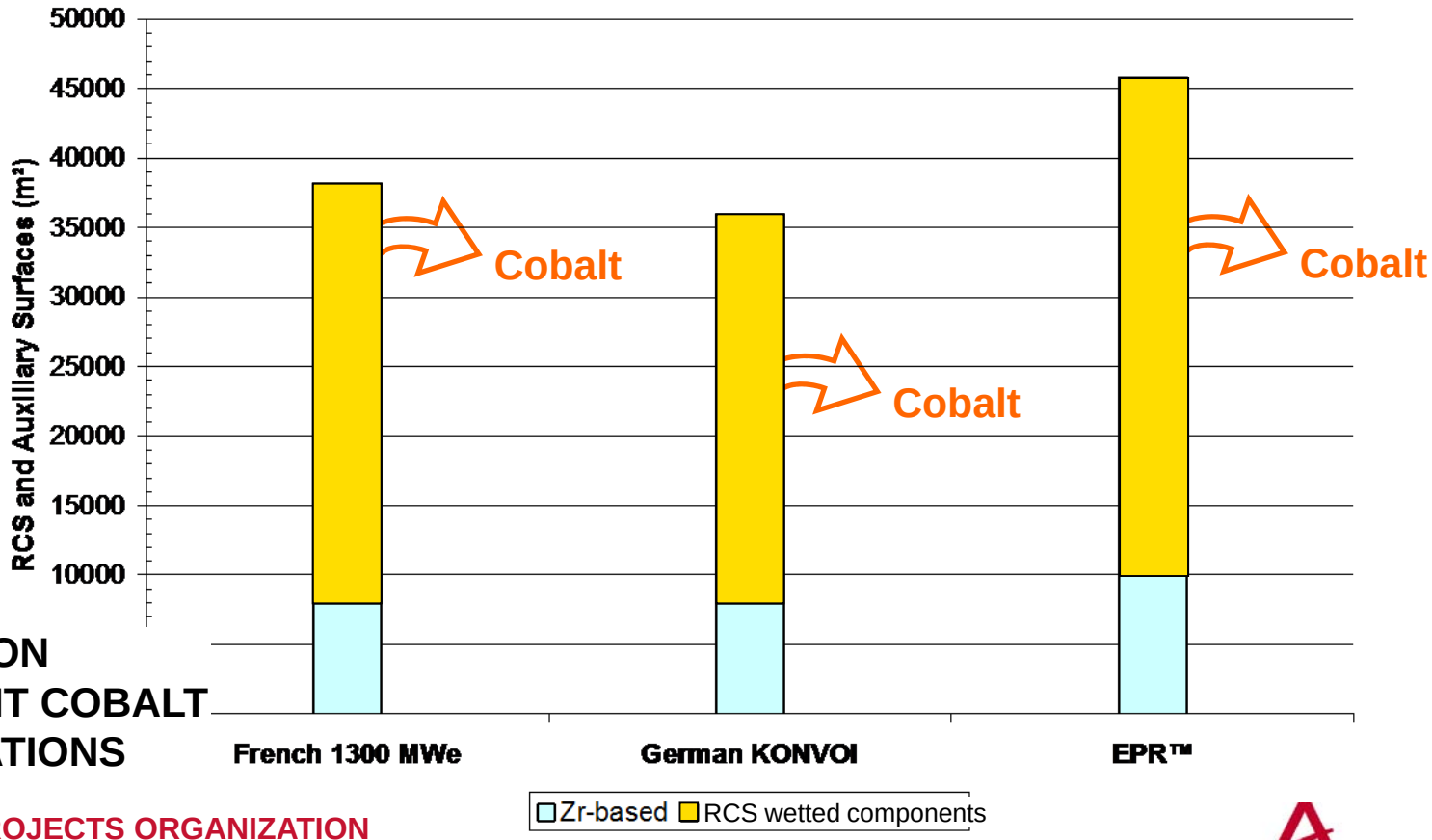
- **Comparative Stellite™ surfaces between EPR™ and reference plants**
  - **Control Rod Drive Mechanisms (CRDMs)**
    - **Highly safety related equipment**
    - **Good resistance to corrosion and wear**
  - **Main Coolant Pumps (MCPs)**
    - **Very unlikely contribution to cobalt contamination in normal operation**
  - **Cobalt-free materials on EPR™ RCS valves**



EPR Co-60 RADIATION FIELDS EXPECTED TO BE CLOSE TO KONVOI SERIES

Potential Cobalt-60 Sources from Cobalt Residual Content in Steels and SG Tubes

- **EPR™ RCS component surfaces**
  - **Larger surfaces on EPR™ than on reference French and German series**



EFFORTS ON EQUIPMENT COBALT SPECIFICATIONS

ALARA Approach for Primary Components (RPV, Internals and Main Coolant Loops)

- **Consideration of industrial capabilities according to ALARA**
  - **Optimization of margins between equipment specifications of existing French reference plants (RCC-M) and Cobalt content measurements**
  - **Costs from steel makers by additional selection of recycled materials**
  - **Different industrial contexts depending on location in the world**

Equipment/ Material	Cobalt residual content (%)	
	RCC-M requirement	EPR™
RPV internals (Stainless steel)	< 0.2 required, but < 0.1 expected	< 0.06
RPV and pressurizer stainless steel cladding	< 0.2	< 0.06
Main Coolant Lines and PZR surge line (Steel)	< 0.2 required, but < 0.1 expected	< 0.06
SG tubes (Alloy 690TT)	< 0.018	< 0.015

ALARA OPTIMIZATION WITH MORE RESTRICTIVE VALUES THAN REQUIRED

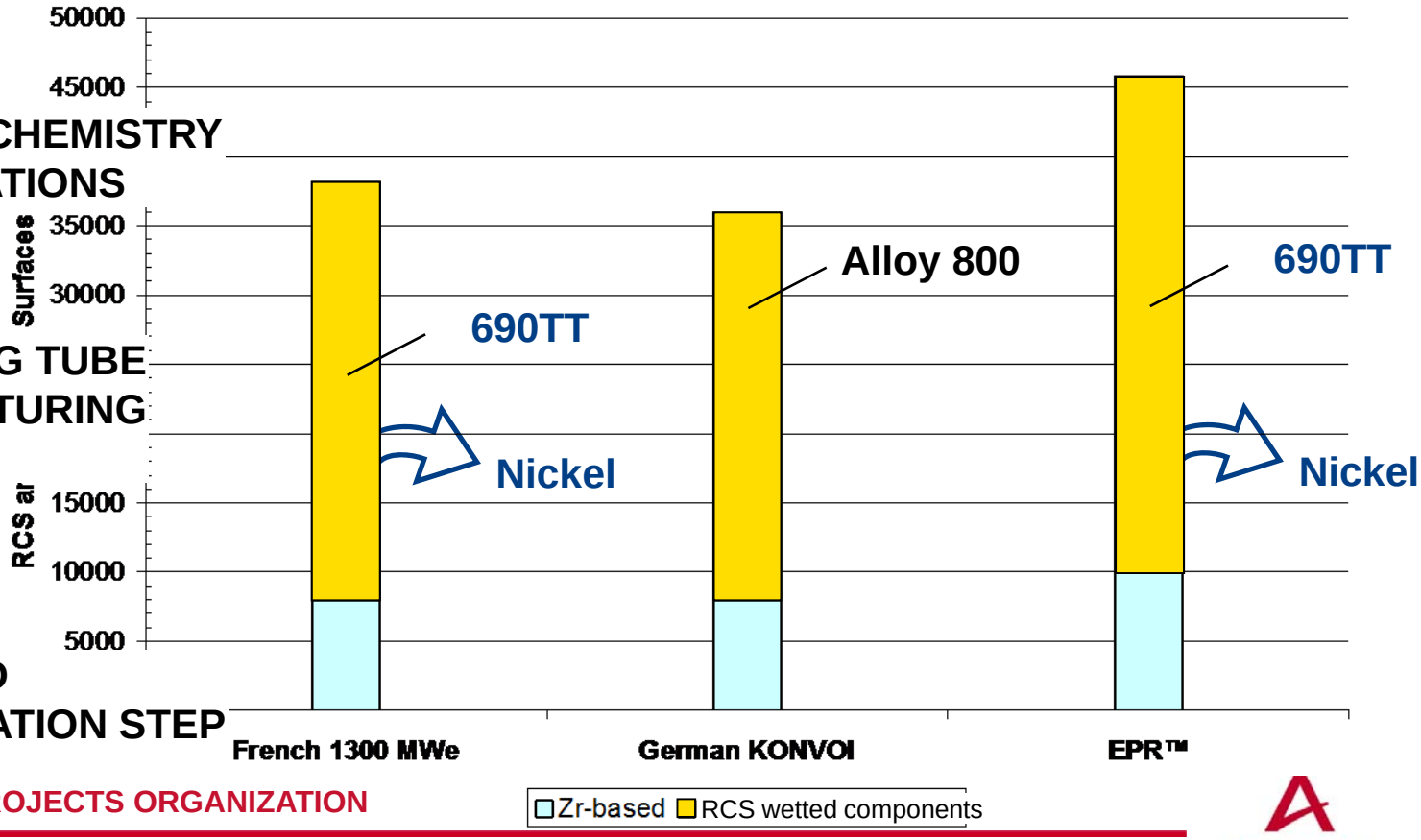
Potential Cobalt-58 Sources from Nickel in SG Tubes and Steel Surfaces

- **EPR™ RCS component surfaces**
  - **Different choice for SG tubes than on reference KONVOI series (integrated decision)**
- **Nickel potential release has to be mitigated by all ALARA means**

PRIMARY CHEMISTRY SPECIFICATIONS

RECENT SG TUBE MANUFACTURING PROCESS

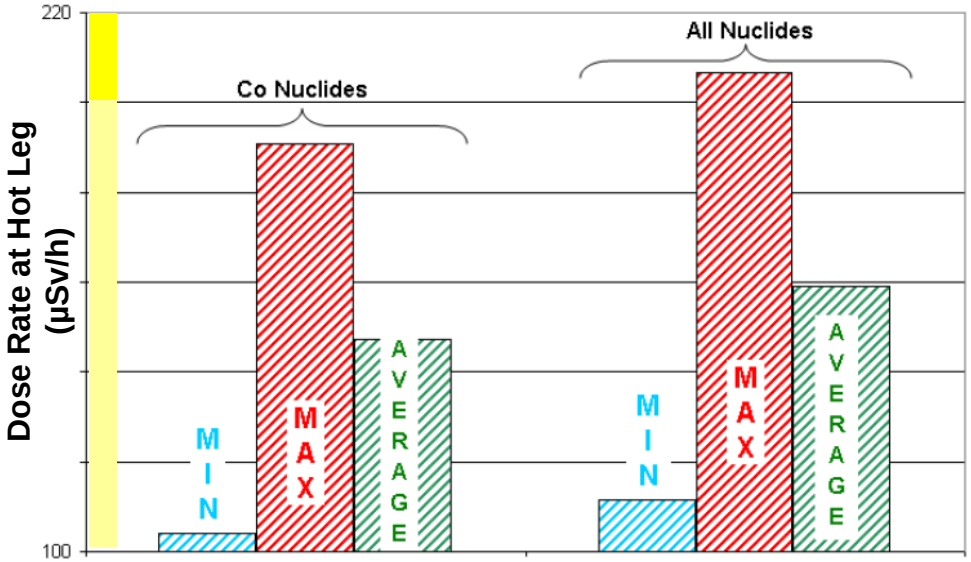
OPTIMIZED PRE-OXIDATION STEP



EPR™ Expected Deposit Dose Rates?

- Given the current material inventory on EPR™, RCS dose rates due to corrosion product deposits are assumed to be driven
  - By Cobalt-58, approximately 50%
  - By Cobalt-60, approximately 40%, due to decrease in Cobalt inventory
- Remaining 10% are due to radioactive Iron and Manganese
  - Silver and Antimony in bearings and gaskets are suppressed or avoided
- RCS expected dose rates?
  - < 200 µSv/h
  - Ageing covered
  - Valid for several reactor states

AS LOW AS ON BEST EXISTING UNITS



Are Further Improvements in Material Inventory ALARA?

Continuous Improvement

- **Several design iterations have been performed during 15 years**
  - **Already integrated optimization of current EPR™ material choices**

BUT

- **Further design changes have to be considered anyway**
  - **ALARA approach should be continuously questioned by designers**
  - **Requests from Customers towards lower potential radiation sources**
  - **Different regulatory or Safety documentation can impose local rules**
- **Development of a calculation "decision-making" tool for Cobalt-60 potential sources**
  - **Wetted surfaces and material release rates/ wear**
  - **Component location (under/ outer neutron flux – RCS/ auxiliary system)**
  - **Benchmark of the tool with in-situ Cobalt-60 activity measurements on reference plants**

Design Changes Involving Cobalt Inventory

- **Impact on ORE expected in a range between negligible and some percents**
  - **Less or no Stellite™ in RPV internals: minus 2-3% on the total ORE**
  - **No Stellite™ in CRDMs: minus 3-5% on the total ORE**
  - **No Stellite™ in MCPs: negligible**
  - **Lower Cobalt residual content in RCS steels : minus 5-6% on the total ORE**
- **Industrial/ operational risks or sacrifices in comparison?**
  - **Costs (e.g. generalized low cobalt content, less than 0.05% in steels, …)**
  - **Absence of qualified Cobalt-free materials for some applications involving high design mechanical loads or severe transients**
  - **Increased outage duration and personnel doses in case of early replacements**
  - **Safety issue in case of safety equipment mechanical degradation**

A CASE BY CASE ANALYSIS IS NECESSARY BEFORE IMPLEMENTING

Conclusion

Conclusion

- **The current EPR™ design follows the ALARA approach with regard to material selection**
  - **Cobalt-free materials in all RCS valves**
  - **Minimum Stellite™ surfaces in RPV internals**
  - **No corrosion and wear expected for remaining parts with Stellite™ hardfacing**
  - **Limitation of Cobalt residual content in primary components**
  - **Avoidance of other potential corrosion product sources (Silver, Antimony)**
- **Complementary means are implemented to decrease doses ALARA**
  - **Primary chemistry specification**
  - **Latest SG manufacturing process ensuring low release rates of Nickel**
  - **Optimized pre-oxidation step during commissioning**
- **EPR will have low dose rates and ORE values close to best existing plants**
- **Other dose reduction measures have to be analyzed case by case**

SOME CHANGES MIGHT BECOME MORE “REASONABLE” IN THE FUTURE

Thank you for your attention…

Questions ?

Design Changes Involving Nickel Inventory

- **Change of the SG tube material from Alloy 690TT to Alloy 800?**
  - **EPR™ already has low ORE values between 0.35 and 0.5 man-Sv/y on average over 60 years**
  - **On one hand, plants of existing fleets with Alloy 690TT as SG tube material already exhibit a good behavior regarding Nickel release and fulfill the above EPR™ values of ORE**
    - Primary chemistry
    - SG tube manufacturing process of recent plants follows the “state-of-the-art”
  - **On the other hand, occupational doses in the same range as for KONVOI units may be achievable with this design change**
- **Industrial/ operational risks or sacrifices in comparison?**
  - **International word-wide experience is in favor of Alloy 690TT regarding the number of Nuclear Power Plants in operation**
  - **Suspicion of corrosion issues on Alloy 800 in certain chemical environments in the secondary side *[international corrosion expert opinion]***
  - **Cost of early SG repairs or replacement (outage duration, additional dose)**