International RCP purification practices during shutdown Based on ISOE Network

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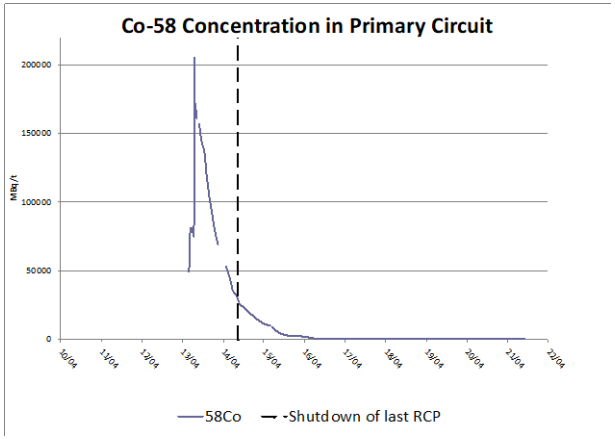
Content

- Context
- Questionnaire structure
- EDF practices
- International practices
- Conclusion

Context

- Shortening RCP operation during purification may help to save time on the critical path according to EDF practices



- RCP shutdown strategies can in theory have an impact on radiological conditions of the plants and by consequence on the integrated dose during outages.

- EDF would like to compare its practices with international shutdown strategies.

⇒ International ISOE request of information concerning the RCPs shutdown strategies and their radiological impacts.

Questionnaire structure

- General information on the unit(s)
- Specific information on RCP operation practices during shutdown:
  - Shutdown strategies
  - Clean-up criterion to stop the last RCP
  - Rationale for the criteria
  - Purification time
- A dedicated questionnaire sent through ISOE Network: 10 answers received from 7 countries in addition to EDF:
  - 4 European countries: UK, Spain, Sweden, Slovenia
  - China
  - South Africa
  - USA (4 plants)

EDF practices

- Forced oxidation with RCPs running: all RCPs during at least 3 hours after forced oxidation then RCPs stopped one after the other
- Criteria to stop the last RCP: Co-58 concentration in primary circuit below 50 GBq.t-1 (EPR: 30 GBq.t-1). Value at Co-58 concentration peak often below this value.
- A basic good practice regarding RP: purification extended after reaching clean-up criterion.
- Criteria defined to have a dose rate below 50 µSv/h at the floor above the reactor cavity (EPR: 25 µSv/h). Value defined to reduce dose rates in the plant to improve RP results during an outage.

EDF practices

- Duration between peroxide addition and shutdown criterion (mean duration planned in outage schedule) :
  - 900 MW_E: 15h,
  - 1300, 1450 MW_E: 20h,
  - 4 cycles post SGR 900 MW_E: extended duration (+1: 25h, +2: 25h, +3: 21h, +4: 15h). More release of corrosion products from material of new SG until passivation of material.

- The real purification time may vary depending on actual characteristics of primary circuit

- Purification maintained with a reduce flow after shutdown of last RCP.

RCP shutdown strategies

- Three strategies most commonly used:
  1. Forced oxidation with one or several RCPs running (EDF)
  2. Forced oxidation with all RCPs secured and full RCS volume
  3. Forced oxidation with all RCPs secured and reduced RCS volume

	Strategy 1	**Strategy 2**	**Strategy 3**
Byron	x		
Farley	x		
Krško	x		
Sizewell B	x		
Almaraz	x		
EDF	x		
Paloverde	x		
LingAo, Daya Bay	x	x	
Koeberg	x		
Calvert Cliffs		x	

Cleanup criterion (1/2)

- Radionuclides concentration in primary circuit:

Site	Concentration in the primary circuit (GBq/t)					
	Gamma	Cobalt total	Co-58	Xe-133	I-131	Ag-110m
EDF (hors EPR)	< 100		< 50	< 1,5	< 0,1	
Byron			< 25,9			
Sizewell B		< 10				
Paloverde			< 1,85			
Daya Bay & Ling Ao	< 50		< 25	< 1,5	< 0,1	< 40
Koeberg	< 100		< 50	< 1,5	< 0,1	
Krško			< 1,85	< 18,5	< 0,37	

- Shutdown of last RCP based on outage schedule:
  - Byron, Daya Bay and Ling Ao
  - Farley stops last RCP 1 hour after peroxide injection
  - Almaraz stops 2 to 4 h after Co-58 concentration peak
  - Krško: reactor subcritical for at least 100 h before refuelling operation

Cleanup criterion (2/2)

- Primary circuit temperature
  - Koeberg: below 80°C
  - Ringhals: below 60°C
  - Calvert Cliffs: part of a specific procedure, peroxide injection coolant temperature below 180 F (82°C).

- Proportion of solubilized Co-58: Koeberg considers this criterion. Value defined by chemistry department.

- Other: Ringhals considers criterion of concentrations in primary circuit for the opening of the reactor vessel that implies a duration of operation of RCPs to reach these criteria.

Justification of shutdown criteria

- A similar objective: reduce dose rates and save doses:
  - Byron, Paloverde and Almaraz with no precise dose rates value
  - Sizewell B: objective is to have a total cobalt concentration in the reactor pool below 2 GBq/t in order to have dose rates on the level of the floor above the reactor cavity below 50 µSv/h.
  - Krško with a target dose rate of 25 µSv/h.

- Daya Bay, Ling Ao and Koeberg: criteria easy to reached and quantified and linked to dose rates.

Purification times (1/2)

Site	Duration between peroxide addition and shutdown criterion	Duration between peroxide addition and shutdown of last RCP
Site performing purification with at least 1 RCP in operation		
EDF	900 MWe: 15h 1300, 1450 MWe : 20h 4 cycles post-SGR 900 MWe: extended duration	
Byron	21h (most recent outage)	4 to 24h
Sizewell	5h	5h
PaloVerde	30-50h	
Daya Bay LingAo		12-27h
Almaraz	10h	10h
Koeberg	14h	14h
Ringhals (2017)	Unit 2 : 12h Unit 3 : 24h Unit 4 : 32h	
Farley	24 to 36h	
Krško	60-80h	almost 30h
Site performing purification with secured RCPs		
Calvert Cliffs	20h	18h

Purification times (2/2)

- EDF, Paloverde, Daya Bay, Ling Ao, Almaraz, Ringhals and Koeberg: extension of purification time after reaching the shutdown criterion.
- Ringhals and Krško: no impact on outage critical path, purification during the 100 hours between shutdown of the reactor and beginning of fuel unloading.
- Sizewell: purification adds 5 hours to outage critical path. Few cobalt releases in primary circuit so purification not necessary to reach cleanup criterion.
- Krško: peroxide addition is performed 40 hours after shutdown of the reactor when primary circuit temperature is below 80°C.
- Calvert Cliffs, RCPs are stopped before peroxide addition and purification is maintained during the whole outage except during:
  - Draining of primary circuit
  - Unloading when SDC is not in service

Concluding remarks

- Most of the sites that answered are using the following shutdown strategy: peroxide addition and purification with at least one RCP in operation.
- Most of the sites use as a criterion radionuclides concentration in primary circuit for the shutdown of the last RCP
- The principal objective for the sites behind the definition of the shutdown criteria is to decrease dose rates at the level of the floor above the reactor cavity or nearby primary circuit to reduce the outage dosimetry.
- Purification times with RCPs in operation vary considerably from one site to another (between 4 and 80 h).

Concluding remarks

- It is necessary to find an equilibrium between purification time and impact on critical path.
- There are other factors that can be considered during definition of criteria for shutdown of last RCP: design, materials used, etc

Thank you for your attention