Requirements and recommendations for
cold shutdowns of nuclear power plants

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Within the framework of the optimisation of the shutdown of units, a procedure for moving to cold shutdown aimed at reconciling the length of shutdowns with dosimetry and the control and limitation of the production of waste is being extended to all 54 PWR reactors being operated by EDF. This procedure, which has been in place since 1984, has developed in the light of the feedback of experience gained.

1 - Aims of the shutdown procedure

The modification of the physical and chemical characteristics of the primary coolant during cold shutdown for refuelling (drop in temperature and pH, going from a reducing to an oxidising environment) leads to a considerable increase in the activity concentration of the primary coolant in terms of corrosion products (see Table 1).

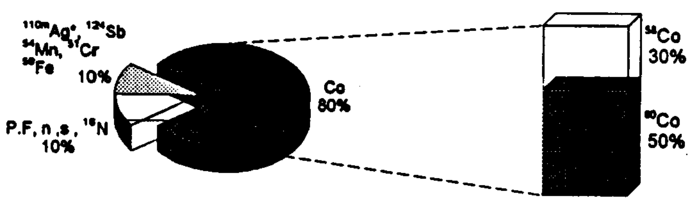
^{58}Co	^{60}Co	^{124}Sb	^{110m}Ag
150	4	10	2

Table 1: Activity values (GBq/t) at the oxygenation peak

In addition, the de-pressurisation of the primary cooling system may result in fission products (xenon, iodine, etc...) passing into the primary coolant and this may pose problems for the protection of workers when the primary cooling system is opened up.

The main objectives of the cold shutdown procedure are as follows:

- to reduce the activity of the primary coolant as quickly as possible and to avoid the contamination of out of flux areas through the deposition of active corrosion products on items of equipment. This is a very important point, since the active corrosion products (^{60}Co and ^{58}Co) are responsible for approximately 90% of integrated doses during maintenance operations (see Figure 1).
- to limit the risk of contamination of the atmosphere in the reactor building during the opening of the primary cooling system (volatile fission products),
- to limit the production of waste and to comply with stack release criteria,
- to facilitate fuel handling operations by ensuring the transparency of the water and by reducing the dose rate at the surface of the reactor cavity.



* impact of ^{110m}Ag varies greatly from unit to unit
n = neutrons, s = active structures

Figure 1: Contribution of corrosion products to collective shutdown dosimetry

2 - Oxygenation of the primary coolant

Since the oxygenation of the primary coolant during cold shutdown for refuelling is inevitable, it was decided to control this operation by provoking it deliberately. The activity is released quickly which enable the primary coolant to be purified efficiently.

This operation has evolved as follows:

- from the start up of unit up until 1994: aeration through scavenging the air of the CVCS tank from a temperature of 120°C
- since 1994: aeration through the injection of hydrogen peroxide at a temperature of 80°C.

In both cases, the temperature is reduced to the oxygenation temperature as quickly as possible (in accordance with technical operating specifications) and continues during the oxygenation phase.

A qualification program has been carried out before the use of hydrogen peroxide in PWR plants, in order to ensure that this reagent did not affect the materials used (Stellites in particular) and that the primary cooling system was not contaminated.

The use of hydrogen peroxide has the following main advantages:

- saving in time: the oxygenation phase last 0.5 hours instead from between 5 hours (lack of fuel cladding defects) and 10 hours (presence of fuel cladding defects).
  Where oxygenation is carried out in the air, the scavenging rate (and therefore the speed of oxygenation) is limited by compliance with stack activity limits (in order to remain below the pre-alarm threshold of $4.10^5 Bq/m^3$)
- improved control over oxygenation, particularly in the presence of fuel cladding defects and therefore improved control over the risk of contamination of out-of-flux equipment by active corrosion products.

3 - Radiochemical specifications adopted and justification

In order to achieve the objectives set out above, thresholds were established for the various steps of the cold shutdown of the reactor.
These limits are set out in Table 2 and the justification for their application is as follows:

- **Hydrogen**
  The objective is to remove hydrogen from the primary cooling circuit in order to prevent dangerous hydrogen-oxygen mixtures.

- **Xenon and Iodine**
  The limits concern ^{133}Xe and ^{131}I and are intended to limit:
  - gas releases,
  - the risk of contamination of the reactor building when the primary cooling circuit is opened.

- **^{58}Co and γ_{total} activity**
  The objective is to ensure adequate purification of the primary coolant and to limit the risk of contamination of out-of-flux equipment by active corrosion products.
  These limits concern ^{58}Co, which is the most abundant radionuclide and γ_{total} activity which enables the presence of other radionuclides, such as antimony and silver, to be taken into account.

TRANSIENT STAGE	SHUTDOWN With RCS aeration With reactor cavity filling	SHUTDOWN With RCS aeration With RCS opening and without reactor cavity filling	SHUTDOWN With RCS aeration Without RCS opening	SHUTDOWN Without RCS aeration
Load reduction	H2 : 5 ml/kg TPN Xe133 < 8 GBq/t I131 < 2 GBq/t			
Borication				H2 : Chemical spec. 2ppm<LiOH<2,2ppm B mini fixed by STE
Aeration	H2<3 ml/kg TPN et H2<2% gas phase of closed vessels Xe133 < 4 GBq/t I131 < 4 GBq/t			
RCS pumps shutdown	Co58 < 80 GBq/t Co58 < 50 GBq/t γt < 160 GBq/t γt < 100 GBq/t			
RCS opening	Xe133 < 1 GBq/t I131 < 0,05 GBq/t			
Reactor cavity filling	Co58 < 2 GBq/t γt < 4 GBq/t			
Temperature increase		H2 fixed by chemical specifications Co58 < 7GBq/t γt < 14 GBq/t		

All measurements are performed in liquid phase of primary circuit

γt values before RCS pumps shutdown and reactor cavity filling are depending on γt activity in reactor cavity tank

X (shaded)	*Limit*
X	*Guideline*

Tableau 2 : Radiochemical limits for cold shutdown of PWR plants