SUMMARY

In the framework of a radiation exposure management program entitled «ALARA», EDF aims at decreasing the mass dosimetry of nuclear power plants workers. So, the annual dose per unit, which has improved from 2.44 mSv in 1991 to 1.08 in 2000 (figure 1), should target 0.8 mSv in the year 2005 term in order to meet the results of the best nuclear operators.

One of the guidelines for irradiation source term reduction is the optimization of operation parameters, including reactor coolant system (RCS) chemistry in operation, RCS shutdown chemistry and RCS cleanup improvement.

This paper presents the EDF strategy for the shutdown and start up RCS chemistry optimization. All the shutdown modes have been reviewed and for each of them, the chemical specifications will be fine tuned. A survey of some US PWRs shutdown practices has been conducted for an acid and reducing shutdown chemistry implementation test at one EDF unit. This survey shows that deviating from the EPRI recommended practice for acid and reducing shutdown chemistry is possible and that critical path impact can be minimized. The paper also presents some investigations about soluble and insoluble species behavior and characterization; the study focuses here on Ag110⁰, Sb122, Sb124 and iodine contamination.

Concerning RCS cleanup improvement, the paper presents two studies. The first one highlights some limited design modifications that are either underway or planned, for an increased flow rate during the most critical periods of the shutdown. The second one focuses on the strategy EDF envisions for filters and resins selection criteria. Matching the study on contaminants behavior with the study of filters and resins selection criteria should allow improving the cleanup efficiency.
1. THE 2004-2005 TARGET FOR EDF PWRs FLEET MASS DOSIMETRY REDUCTION

In order to decrease the dosimetry of the PWRs workers involved in the maintenance activities, the EDF "ALARA" project has selected three programs to hit the designed target:

- optimization of design factors such as the selection of the materials surface condition, core design, RCS cleanup design and sizing;
- optimization of operating parameters such as RCS chemistry in operation especially as concerns the use of high burn up fuels and as concerns the redox potential driven by hydrogen concentration and oxidants ingress, RCS shutdown chemistry, types of filters and resins for RCS cleanup either in operation or at shutdown;
- incidental pollutions mitigation (characterization, prevention, monitoring, solving).

These programs for improvement are intended for making even more progress in the arena of workers dosimetry to meet the performance of the best worldwide nuclear operators, who also are getting better performances (see figure 1 for EDF PWRs).

Strengthened by all these possibilities for improving the situation, which require launching quite a number of research and engineering programs, EDF targets for 2004-2005 term an annual mass dosimetry of 0.8 mSv/year/unit.

2. SHUTDOWN CHEMISTRY OPTIMIZATION

The contact between liquid and materials generates corrosion products (or cruds) generation, either in solution or as suspended solids (mainly Ni, Co, Ag, Sb, Cr, Fe), which circulate in the RCS. When the reactor is operating, the cruds are partially activated by the neutron flux, the level of activation depending on the core residential time. These radioactive cruds can subsequently precipitate at various locations in the RCS or auxiliary systems, according to local physical, chemical or hydraulic conditions.

Besides this, fuel clad failures may release fission products in the RCS, some being volatile under certain shutdown circumstances and very contaminating for human being (iodine isotopes). So, for EDF PWRs:

- 80% of plant personnel dosimetry stems from outage period;
- over 90% of plant personnel dosimetry stems from activated cruds contaminating the surfaces in contact with the primary water;
- less than 10% of plant personnel dosimetry originates from fission products, especially those that can absorb and desorb from metallic surfaces in contact with the primary water (iodine compounds types).

<table>
<thead>
<tr>
<th>Radio-isotope</th>
<th>Standard contribution (900 &amp; 1300 MW PWRs)</th>
<th>Incidental contribution in excess of total dosimetry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co60</td>
<td>50 %</td>
<td>20 to 30 % (hots spots)</td>
</tr>
<tr>
<td>Co58</td>
<td>30 %</td>
<td>20 % (poor forced oxygenation)</td>
</tr>
<tr>
<td>Ag110+</td>
<td>3 to 5 %</td>
<td>15 % (control rod clad failures)</td>
</tr>
<tr>
<td>Sb124</td>
<td>3 to 5 %</td>
<td>20 % (auxiliary systems pumps bearings)</td>
</tr>
<tr>
<td>Cr51</td>
<td>3 to 5 %</td>
<td>10 to 20 % (oxygen ingress)</td>
</tr>
</tbody>
</table>

Table 1 : activated cruds contribution to the mass dosimetry - 900 & 1300 MW EDF PWRs fleet.

Besides implementing an acid and reducing shutdown chemistry, which can be considered as a mild out of core RCS surfaces decontamination, thus being worthwhile, the RCS shutdown chemistry optimization requires the characterization of the chemical conditions of the metals of the structures in contact with the primary media, in which the soluble species contents are modified.

So, among the RCS shutdown chemistry specifications, three parameters impact the generation either of soluble or insoluble contaminating radioactive species:

- the boron content, knowing that this parameter is, in first place, driven by core neutronic considerations and not by chemistry;
- the lithium concentration (impact on pH);
- the hydrogen or oxygen content, depending on the moment of the shutdown: before or after forced oxygenation (impact on redox potential).
Studies focusing on lithium, hydrogen and oxygen contents are in progress, geared to the behavior of the structures metals and iodine, and to the boron content as long as chemistry considerations have the hand on it. The target of these studies being drawing up technical specifications fine tuned to the reactor operating modes, the most relevant way of tackling the studies consists in heading them, when starting them up, towards the paramount following questions:

What is the final mode to be reached?

And

Are we willing to add an extra intermediate steady step before reaching this final mode?

Then, for each of the answers brought up to these questions, the chemical specifications issues for every mode encountered in the shutdown process must be studied, until final mode is reached. Therefore, the following situations will have to be studied:

- cold shutdown oxygenated hold;
- hot shutdown hold;
- biphasic standby under RHR conditions (180 to 160°C);
- biphasic standby under RHR conditions (160 to 120°C);
- cold shutdown, RCS not oxygenated (90 to 10°C);
- cold shutdown with forced oxygenation, followed by heating and by a biphasic standby under RHR conditions (180 to 160°C).

3. ASSESSMENT OF THE ACID-REDUCING SHUTDOWN CHEMISTRY FOR IMPLEMENTATION AT ONE EDF UNIT

Most of the US PWRs include an acid-reducing phase in their shutdown procedure. This means that some amount of hydrogen is kept in the RCS up to rather low temperatures as compared to French practice. The boration necessary for neutronic compliance, along with lithium removal, cause the RCS pH to turn acidic, thus inducing acid and reducing conditions. According to EPRI guidelines [2], the acid and reducing conditions during shutdown enhance the nickel ferrite decomposition, thus improving the RCS decontamination. The basic process for this decontamination is at first (1), and at second (2):

\[
\text{Ni}_x\text{Fe}_{3-x}\text{O}_4(s) + 4 \frac{x}{3} \text{H}_2 \Rightarrow x\text{Ni}(s) + (1 - \frac{x}{3})\text{Fe}_3\text{O}_4(s) + 4 \frac{x}{3} \text{H}_2\text{O} \quad (1)
\]

\[
\text{Ni}_x\text{Fe}_{3-x}\text{O}_4(s) + 2x\text{H}^+ + \frac{x}{3} \text{H}_2 \Rightarrow x\text{Ni}^{2+} + (1 - \frac{x}{3})\text{Fe}_3\text{O}_4(s) + 4 \frac{x}{3} \text{H}_2\text{O} \quad (2)
\]

Again, according to EPRI guidelines [2], the best conditions for nickel ferrite decomposition are: acidic pH, [hydrogen] > 10 cc/kg and 150°C > temperature > 120°C; these conditions should be maintained at least for 16 hours.

As EDF may perform on one of its units a shutdown test including an acid and reducing phase, the French Utility was interested in gathering some information on US PWRs shutdown practices, especially geared to the realisation of this acid and reducing phase. Accordingly, EDF launched a survey and visited some plants. The main conclusions of this effort are drawn hereafter.

The general conclusion is that not a single unit among the 15 visited strictly follows the EPRI guidelines. As refers to EPRI recommendations, some deviations were noted concerning hydrogen concentration, temperature hold and holding time.

**RCS hydrogen concentration.**

The RCS hydrogen content at shutdown may be higher or lower than the EPRI recommended value (15 cc/kg). Typically, the hydrogen content at shutdown ranges from 10 to 45 cc/kg.

**RCS temperature.**

3
The tendency for the plants is to widen the holding temperature range for nickel ferrite decomposition. The EPRI recommended range is 150 to 1200°C and the actual field range may be much wider: 200 to 1000°C.

*Holding time.*

As the acid and reducing hold generally impacts the critical path, a common tendency is to shorten the minimum of 16 hours required by the EPRI guidelines. The figure 2 shows the holding time in acid and reducing conditions from reference [3]. The open bars represent the actual time elapsed between 200°C and the forced oxygenation, and the full bars represent the part of this time spent under EPRI recommended conditions for acid and reducing nickel ferrite decomposition.

![Figure 2: acid and reducing conditions holding time at some US PWRs [3].](image)

The efficiency of the acid and reducing phase can't be assessed from this survey, mainly because the reported units always have performed the same shutdown chemistry, including an acid and reducing hold. So the definite means for assessing the effectiveness of the acid and reducing shutdown chemistry on a French unit is to run a field test. This test is planned for 2003. The results from the US PWRs survey will help in determining the test conditions. For example, from the US units experience, we known that it is possible to implement an acid and reducing shutdown chemistry without having to strictly follow the EPRI recommendations and without major impact on the critical path.

4. THE Ag110\textsuperscript{m} CONTAMINATION

The RCS pollution, even by only a few dozens grams of activated silver, can increase the outage plant personnel dosimetry, thus jeopardizing the stringent plant dosimetry target. The Ag110\textsuperscript{m} isotope is a hard gamma emitter with a 250 days period (94 % γ emission at 658 keV, 73 % at 685 keV, 34 % at 937 keV and 24 % at 1384 keV for the major energy peaks) which stems from neutronic activation of Ag109.
In some instances, for 900 MW units evidencing an Ag\textsuperscript{110}\textsuperscript{m} pollution, the root cause for this silver pollution is the control rods neutronic absorbent, made of silver-indium-cadmium, when it gets in contact with the primary water in case of clad through wall wear.

The various measurements of silver activity in polluted units in operation, show a low Ag\textsuperscript{110}\textsuperscript{m} RCS volumetric activity (1 to 10 MBq/t). But, at cold shutdown, the activity is much higher with values peaking up to a range of 70 MBq/t to 62 GBq/t in year 2000.

The unusual silver behavior noted at cold shutdown raises quite a number of questions on its chemical form in the bulk RCS water. In fact, contrary to cobalt, silver is poorly removed by usual cleanup systems, and its high tendency to deposit on cold surfaces makes it the number one for some auxiliary systems pollution, thus generating locations with high doses rates which handicaps maintenance activities. Moreover, the silver solubilization after RCS forced oxygenation is highly variable with time, this behavior differing from all other RCS corrosion products.

The first information brought up by the studies conducted by EDF in relation with the silver behavior in the RCS, allows the following comments:

- depending on pH, redox, lithium and boron concentrations, temperature and pressure, silver can be found simultaneously under various chemical species as: metal Ag\textsuperscript{0}, ionic Ag\textsuperscript{+}, boron complex and colloid;
- for temperatures above 30°C, and in the operating pH range for PWRs, it would appear that from a thermo-dynamical standpoint, the prevalent species are Ag\textsuperscript{0} and Ag\textsuperscript{+}, which are very sensitive to the bulk water silver concentration and to the redox variations;
- in oxidizing conditions at 25°C, it would appear that Ag\textsuperscript{0} and Ag\textsuperscript{+} are prevalent, and so for a complex species Ag\textsubscript{3}B\textsubscript{2}(OH)\textsubscript{7} sensible to pH and to boron and lithium concentrations;
- field feedback also shows that in usual cleanup conditions, silver can be found as a so called colloidal state.

So, the silver contact with primary water is likely to generate a RCS pollution. According to the high level of doses rates it generates, tracking all sources of silver is compulsory (such as silver plated gaskets).

At last, it is necessary to improve the RCS cleanup performance in order to remove silver whatever its chemical forms in the RCS. Therefore, EDF has dedicated special resources for finding relevant field solutions by the way of an even more optimized chemistry (redox potential and pH) along with fine tuned cleanup systems.

5. THE Sb\textsubscript{122} - Sb\textsubscript{124} CONTAMINATION

RCS forced oxygenation often evidences various levels of antimony peaks Sb\textsubscript{122} and Sb\textsubscript{124}: if 1300 MW units encounter a rather low to medium pollution, 900 MW units pollution varies and is of a high level, as shown by table 2.

<table>
<thead>
<tr>
<th></th>
<th>Sb\textsubscript{122} (GBq/t)</th>
<th>Sb\textsubscript{124} (GBq/t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>900 MW PWRs</td>
<td>Minimum 2, Mean 21, maximum 200</td>
<td>Minimum 0,5, Mean 14, maximum 110</td>
</tr>
<tr>
<td>900 MW PWRs</td>
<td>Minimum 2, Mean 25, maximum 160</td>
<td>Minimum 0,5, Mean 18, maximum 140</td>
</tr>
<tr>
<td>1300 MW PWRs</td>
<td>Minimum 2, Mean 14, maximum 70</td>
<td>Minimum 2, Mean 11, maximum 55</td>
</tr>
</tbody>
</table>

Table 2: inventory of antimony volumetric activities at forced oxygenation for EDF PWRs.

Antimony 124 is the worse according to its period, 60 days (98 % γ emission at 603 keV and 48 % at 1691 keV), compared to antimony 122 which period is only 2.7 days (71 % γ emission at 564 keV).
Several studies have revealed potential or confirmed sources for RCS pollution with antimony:
  > secondary sources for initial neutron generation. In case of clad failure, antimony and beryllium can spread into RCS. However, these neutron sources have been withdrawn from 900 MW units;
  > the antimony saturated graphite to be found in bearings and thrust bearings for some kinds of pumps mounted with underwater rotors; several auxiliary systems are equipped with such pumps;
  > fuel cladding because zirconium contains less than 1% antimony. But this source is less likely taking into account that the evidence of having all the units equipped with the same fuel cladding zircaloy material doesn’t match with the wide variations of the units pollutions.

A study [4] shows that for normal operating conditions (300°C), the most likely stable species in the RCS is metallic antimony, with a very low solubility (figure 3).

![Figure 3: simplified Pourbaix diagram for antimony at 300°C (the species at oxidation state V are not plotted on this diagram). The dotted zone limits the RCS operating conditions.](image_url)

For shutdown conditions, RCS hydrogen free and oxygenated at 80°C, the stable species is $\text{SbO}_3^-$, more soluble species removed by CVCS resins (figure 4).
This antimony behavior difference, in hot and reducing conditions, compared to cold and oxidizing conditions, explains why it is impossible to foresee from the RCS antimony activity in operation, the level of RCS pollution at the next oxygenated cold shutdown.

6. THE IODINE ISSUE

For a cycle experiencing fuel failures, iodine released by a rod to the primary water is exposed to gamma irradiation and to hydrogen. Iodine is then found as a mixture of I\(^-\), IO\(_3\)\(^-\) and I\(_2\), according to the following equilibrium [5]:

\[
3 \text{I}^- + 3 \text{H}_2\text{O} \rightleftharpoons \text{I}_2 + 5 \text{IO}_3^- + 6 \text{H}^+ \\
\text{dismutation}
\]

However, the pH then ranging from 7 to 7.2 at 300°C and the redox conditions of the hydrogenated (thus reducing) RCS, strongly favor iodide formation. At low concentration, which is the RCS situation, these ions are soluble and are removed by the anionic resin of the lithiated mixed bed.

At the time of shutdown transient before forced oxygenation, the actual EDF practice for operating PWRs, in case of fuel failure, consists in cleaning up with a lithiated mixed bed in order to curtail any acidification: in these conditions, keeping a minimum lithium threshold favors the above equilibrium towards dismutation and so favors the generation of ionic iodine species which then can be removed by the anionic resin of the mixed bed.

Field experience shows that this cleaning up configuration is on the other hand, less favourable to Ag\(^{110m}\) removal for which acidic medium allows better removal. This acidification is brought up by lithium removal, using a mixed bed with an H\(^+\) form cation when the purification system design allows it, otherwise, using the cation bed in line with a lithiated mixed bed; both situations are called "acid purification".
One can note that there is some degree of inconsistency for CVCS cleanup configuration optimization when iodine and silver are both present.

However, laboratory cleaning up tests conducted with resins and run in conditions close to the CVCS ones, show that iodine removal performance, using a fresh mixed bed, saturated with lithium and equilibrated with boron, is not impacted by the lithium concentration of the deoxygenated water [4]: iodine removal is in excess of 99%, including when [Li] = 0 and [B] = 2000 ppm, media for which a more or less important iodine fraction, depending on the redox conditions, should exists as molecular. This can be explained by local alkaline conditions stemming from the anionic resins of the mixed bed, with a local pH close to 11 at 25°C, due to the strong base properties of anionic resins, which shift the above equilibrium towards dismutation. This laboratory experiment, which implies that the performance of iodine cleanup by anionic resin is unrelated with primary water pH, must however be duplicated in the field for strengthening this conclusion.

At 80°C, RCS oxygenated, the amphoterization reaction rate is high: iodides present in the RCS are then oxidized to molecular iodine which is mainly adsorbed on RCS materials surfaces, especially on steam generator tubes and fuel rods. Taking this into account, cleanup with resins is no more efficient as concerns iodine removal. A major iodine quantity may then desorb, especially from steam generator tubes, as a consequence of RCS aeration and draining. So, for maintenance personnel protection against contamination, EDF preventive strategy consists in implementing specials equipments implying dynamic venting for high risky works (pressure reduction devices and iodine traps connected to containment building venting system), as soon as primary water I131 equivalent activity exceeds 50 MBq/t before RCS breaking.

7. RCS CLEANUP OPTIMIZATION

RCS cleanup is achieved by CVCS, by the way of filters and resins. The combination of both of these processes allows soluble and insoluble species, and even so colloids, to be removed. RCS cleanup optimization has to come out from filters and resin beds arrangement, taking into account operational sequences and pollution origins. This means for the plant, the possibility of being able of quickly tuning the cleanup system to the various operation sequences, which implies the possibility of multiple choices for filters and resin beds selection. The RCS cleanup optimization can be achieved by the way of:

- the system design, which can be modified to make operation more flexible;
- the operation parameters, with procedures and products complying with stringent requirements;
- the knowledge of the behavior of the pollutants to be removed, according to the various RCS physical and chemical conditions.

7.1 SYSTEM DESIGN MODIFICATIONS

The RCS cleanup performance mainly depends on the reaction time when faced with a sudden change in operation conditions. A quick modification of the cleanup system arrangement allows minimizing any loss of cleanup availability and to adapt to new situations. The figure 5 presents a sketch of the majority of the EDF PWRs CVCS cleanup designs.
Figure 5: CVCS cleanup designs at most of EDF PWRs (UF: upstream filter, DF: downstream filter, Li MB: lithium saturated mixed bed, Cationic Bed: cationic bed for lithium removal, Anionic Bed: anionic bed for end of cycle boron removal).

Cleanup process description

The primary water, after cooling and pressure reduction, is first filtered for insoluble removal, then chemically cleaned up with ions exchangers when flowing through one of the two lithiated mixed beds. If lithium removal is needed at the beginning of the cycle, the flow can go through the cationic bed. At the end of the cycle, as soon as RCS boron content is as low as 150 to 50 ppm, depending on the series of reactors, or in stretch out, the primary water can be lined to one of the two anionic beds for boron removal. The water then flows back to RCS through the downstream filter.

This design is acceptable when the reactor is at power, but operation shifts are reluctant using anionic beds due to high induced costs.

But this cleanup configuration is not fine tuned to cold shutdown with forced oxygenation, because cold shutdown and oxygenation bring large quantities of cruds to CVCS which promptly plug the upstream filter. Moreover, the compulsory use of one of the two lithiated mixed beds leaves little room for the kind of treatment to be picked up.

Current design modifications for cold shutdown

- **Upstream filter redundancy**: the possibility of switching filters prevents any filtering function unavailability due to pressure loss or to high activity while cleaning up. Moreover, the filters size mesh can be optimised for finer and finer mesh implementation planning.
- **Standardization of boron removal anionic beds**: the possibility of by-passing the two lithiated mixed beds leaves room for easier operation during plant cold shutdown. In these conditions, the beds initially dedicated to boron removal can be filled with various resins, each being tuned to the different shutdown phases. For example, one of these beds may be filled with a non lithiated (H+ form) mixed bed, which would extend the life of the very costly lithiated mixed beds resins. So, when a specific pollution has to be mitigated, it could be possible to apply a specific cleanup process by lining on one of these beds filled with a type of resin accorded to this specific pollution.

Figure 6 presents the CVCS design modifications, that are planning to be implemented at most of EDF PWRs.

![Figure 6: CVCS design modifications](image)

> Figure 6: 1 = upstream filter redundancy; 2 = installation of a mixed bed bypass for straightforward flow access to the standardized beds; 3 = boron removal anionic beds standardization, allowing tuning the type of resins to the various needs.

7.2 OPERATIONAL PARAMETERS OPTIMIZATION

The primary water cleanup runs continuously all the cycle long, but it must be of a maximum efficiency at cold shutdown time, for minimizing the RCS recontamination by the cruds released during the transient stemming from RCS physical and chemical conditions changes. This high efficiency is therefore paramount for
ALARA considerations, in order to minimize structure doses rates during outage. For this, the operator must remove a large inventory of corrosion products, within roughly two days not to impact the critical path. Therefore, operation procedures need optimization and cleanup media must fit and be efficient.

High flow rate purification

Field experience shows that cruds activity dramatically increases as soon as temperature drops, at RHR connection (180°C), then at forced oxygenation (80°C) when the activity peak comes out; that peak has to be taken out for meeting RCPs securing criteria. Should these criteria not be met within the next 12 hours following forced oxygenation, then the reference critical path would be impacted. Tests and studies have shown that an increase in flow rate purification during peak cleanup, from 36 t/h / 158 gpm to 50 t/h / 220 gpm, was possible for 4 loops units, without any performance drop. The benefit from this procedure is real as it brings up an enhance cleanup rate when cruds concentration is maximum. So, with RCS being solid and pressurized, RCPs running, starting from 170°C, the high flow rate purification procedure is being implemented at all units.

Filters and resins selection criteria

The design and operation modifications may generate behavior issues for filters and resins, and jeopardize systems availability. An inventory of filters used for CVCS, BRS and RWS is going to be done for the whole EDF PWRs fleet, in conjunction with a field experience survey. The filters technical specifications will be updated in order to specify criteria for:

- burst resistance;
- hydraulic and heat withstanding;
- filters and supports chemical and radio-chemical withstanding.

Certified laboratories will qualify, according to their field of expertise and to specifications, the thus selected filters; a listing of qualified filters according to their halogen and sulphur contents, withstanding all these criteria, will be set. In summary, a procedure similar to the NPPs resins qualification one will be implemented.

As concerns usual NPPs qualified resins, the actual field experience survey will continue and new marketed products performance will be monitored. A check up for these resins performances will be set, accordingly to the modifications of the ways they are operated (i.e.: high flow rate cleanup).

7.3 BEHAVIOR OF THE POLLUTANTS WHEN FACING WITH VARIOUS CONDITIONS

RCS radioactive pollutants mitigation requires the perfect knowledge of their behavior taking into account the RCS specific physical and chemical conditions. Speciation studies of major and minor RCS species, including AgI\textsuperscript{110}, which is responsible for high dosimetry in 900 and 1450 MW units, are in progress. The results will drive the remedial actions, as concerns cold shutdown means but also strategy (modification of chemical conditions).

Means

Thanks to the knowledge of the pollutants physical and chemical conditions, targeted mitigating media (filters and resins) will be selected or even developed and tested; as for example, concerning colloid removal:

- Zeta potential driven filters will be tested;
- macro-cyclic resins, holding large steric voids, have undergone a special development; their performances have still to be assessed;
- internationally marketed resins, but so far now having been implemented for usual cleanup, have been selected to meet our specific needs. The qualification of these resins is underway, and performance tests are to be planned.

Thanks to pollutants speciation studies, the research can now focus on the most fitting products.

Cold shutdown strategy

Cold shutdown procedures are being reviewed. Taking into account safety regulations, we have to review and even modify some operation modes, procedures or transients to be able to lower plant personnel dosimetry. Therefore:

- the benefits for conducting acid and reducing shutdown and,
- the improvements of the shutdown chemistry specifications,

are being considered for implementation depending on the results of on-going tests and studies.
REFERENCES

[5]: Jean-Luc Bretelle EDF/GDL et als - Study of various chemical species behavior for contamination risks – This conference. SFEN – April 2002.

ACRONYMS (in order of appearance)

ALARA: As Low As Reasonably Achievable
EDF: Electricity of France
PWR: Pressurized Water Reactor
RCS: Reactor Cooling System
RHR: Reactor Heat Removal system
EPRI: Electric Power Research Institute
MBq/t: Mega Becquerel per metric ton = 0.027 10^3 μCurie/g
GBq/t: Giga Becquerel per metric ton = 0.027 μCurie/g
CVCS: Chemical and Volume Control System
RCP: Reactor (main) Coolant Pump
BRS: Boron Recovery System
RWS: Refuelling Water System (reactor cavity and spent fuel pool cooling and treatment system)
NPP: Nuclear Power Plant