IMPLEMENTATION OF ALARA AT THE DESIGN STAGE OF NUCLEAR POWER PLANTS

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INTRODUCTION

In the 1970s, Electricité de France (EdF) had limited knowledge and experience of pressurized water reactors (PWRs). Electricity generation by nuclear units was oriented towards gas-graphite reactors, even though EdF had a share in the PWR unit of CHOOZ A-1 (250 MWe, later upgraded to 320 MWe). Some facts about the origin of doses in that kind of reactor were known to the research and development (R&D) support staff of EdF, which mainly comprises the French Atomic Commission (CEA), but only a few of EdF's engineers were aware of these facts. One has to bear in mind that CHOOZ A-1 only went critical in April 1967 and was officially connected to the grid in May 1970 after some important problems had been solved. Meanwhile, the nuclear program was launched at full speed, beginning with the order for FESSENHEIM 1 in 1970, FESSENHEIM 2 and BUGEY 2 and 3 in 1971. TIHANGE 1, in which EdF had a share, went on-line in September 1975.

Also, supposing that EdF had had such knowledge and experience, it is quite evident that it would have been very difficult to modify the lay-out inside the reactor building.

Thus, in 1977, looking at results from the United States, an annual dose, D, of some 6 Sv was estimated for operating and maintaining a 900 MWe standard PWR unit.

The first signs of EdF worrying about the main source of exposure in a PWR, e.g., corrosion products (CP), can be traced back to 1975: technical studies were carried out using the CEA software "PACTOLE" to try and predict the influence of such parameters as cobalt and nickel input, primary water chemistry, on the deposition of activated corrosion products. These studies were finalized in the early 1980s, with the following conclusions:[1]

- with the available design, the cobalt input was dominated by (in decreasing order of priority) (a) the cobalt content of the steam generator's alloy, (b) the cobalt content of in-vessel materials, particularly alloy 718 of the fuel grids, (c) the cobalt content of CVCS parts downstream filters and ion exchangers, and (d) hard-facing materials with high cobalt (stellite™) during normal wear and corrosion (and, on the contrary, a possible high impact on Co^{60} build-up in abnormal situations)[1]

- pHt (300°C) should be strictly controlled and be kept at a constant value of 7.0* (as much as possible, given the specified limits for Li concentration) and cold shutdown operations should be carefully managed to prevent CP redeposition, and a too high a residual activity in the water; this was applied as early as mid-1981[2]

- it was interesting to study the impact of load follow operation mode, the effect of "efficient" purification processes (high temperature, high flowrate), the effect of passivation, surface roughness, and decontamination (soft and hard chemicals, both singly or combined with ultra-sonic devices)

*In Reference 2, a pH of 6.9 is quoted: this is because the use of dissociation coefficients for water different from international practice.

From this, it is clear that the underlying assumption was "...a reduction of sources will lead to a reduction of dose rates and thus to a reduction of doses."

The aim of this presentation is to show that even though we did obtain, and still have some control on sources and dose rates, it has not been sufficient to satisfactorily control the doses. We will try and explain why, and what countermeasures are being applied to the existing plants.

Although it is not yet decided whether to build nuclear units with a new design ("PWR 2000"), we will describe how we think ALARA should be applied at the design stage.

CONTROL OF SOURCES AND DOSE RATES

Control of Sources

EdF has applied a methodology to control sources which includes the traditional three steps of the ALARA approach: prediction of parameter values, measurement of actual values, and analysis of actual discrepancies versus measured values. This has been described in Reference 3 and is only briefly summarized here:

- ***prediction*** of the active deposition of corrosion products (mainly GBq.m^2 of Co^{58} and Co^{60}) with the "PACTOLE" software:[1] although this software is not, and was not believed to be perfect, it has a phenomenological basis, thus introducing some logic in the results. Several of the results are "tied" together (e.g., production of isotopes is tied by the release of the base materials, a value that is calculated) and it is not possible to adjust one given value to the actual measurement (say, Co^{58} activity) without introducing a discrepancy in another (say, Co^{60}, Mn^{54}, or Fe^{59}).

- ***direct measurement*** of the values of sources through the walls of circuits and components using an *in situ* quantitative gamma spectrometry device (EMECC, described many times, and lately in Reference 4). This kind of technique, which is frequently applied by various utilities or companies, has the advantage on dose rate measurement to get at the origin (dose rate can be a misleading parameter because it integrates sources, lay-out, and the components' characteristics), and to bypass the numerous problems related to build-up factors.

- ***analysis*** of the differences between actual and predicted values is carried out using various softwares, including EdF's "TIGRE-RP" data base.[4] "PACTOLE" also is very useful because it allows sensibility studies in which tentative hypotheses to explain discrepancies can be tested.

Figures 1 and 2 show the contamination by Co^{60} of primary loops and steam generator (SG) tubes (which is nearly equal to the total out-of-vessel activity) for a few units versus cycle #. The predicted maximum values, referred to in EdF in 1983 as the source term for corrosion products, are indicated. The margins between the envelope and the actual evolution for given plants are explained (not all...) in terms of:

- lower input of cobalt: content of SG tubes (see Figure 3, impact of SG tubes with ~130 ppm Co^{59} at DAMPIERRE 1 instead of 450 ppm), introduction of zircaloy fuel grids,

- higher input of cobalt: abnormal wear of stellites™, high cobalt content of nickel plating of inconel grids,

- effect of surface roughness of SG tubes affecting the distribution of deposits (between SG and loops and channel heads areas),

- effect of primary chemistry (principally for a few units that had their first cycle in 1981 and 1982).

In fact, in most cases, the observed margin has, for its origin, a combination of the above causes (see EPRI seminars on radiation field control and BNES conferences).

Control of Dose Rates

Dose rates (DRs) are measured on all plants, at all EOC, within the frame of the "Standard Radiation Monitoring Program," which is quite similar to that of the EPRI. From these measurements, a dose rate index (DRI) is calculated. There is a good correlation between a function of Co^{58} and Co^{60} deposited activity on the loops and DRI.[3]

Figures 4 and 5 show the evolution of DRI versus cycle number and unit type.

The DRI and average DR (per unit) at the center point of the SG channel head is presented in Figure 6.

The figure shows that the average values of DRIs are moderately high for the oldest 900 MW units, and lower for the more recent 900 MW units. The DRIs for 1300 MW units are quite low. A rapid stabilization of DRIs is seen, that can be explained (at least in part) by the coordinated chemistry applied to the primary water.

EVOLUTION OF DOSES

Presentation of Results

On the basis of the standard indicator of collective dose/year/unit, Figure 7 shows that the French results compared favorably with those of other countries (with a nuclear capacity of more than 10 GWe) until 1988 with 1.77 man.Sv. Afterwards, and up to 1991 (2.44 man.Sv), the trend was an increase, whereas for other countries a decrease was observed. The increasing trend in the French results has been reversed lately with 2.36 and 2.04 man.Sv in 1992 and 1993, respectively.

Explanation of the Observed Dose Trends in France

DRI is representative of the primary circuit. The studies currently carried out in EdF do not reveal a very strong link between the activity and dose rates of primary and auxiliary systems. There are several (tentative) explanations for that, such as a higher possibility of contamination during the cooling down operation for auxiliary circuits than for primary circuit, or preferential deposition of Ag^{110M} (when present) on the cold parts of auxiliary systems.

However, as a first step, one can assume that low DRIs correspond to low DRs on auxiliary systems. The collective dose for maintenance (~85% of the annual dose) can roughly be broken in two equal parts for primary and auxiliary circuits. One should expect some kind of correlation between DRIs and doses. It can be seen from Figure 8 that the ratio of doses to DRIs largely increases with years in France. Because the DRIs are mainly stable (see section on Control of Dose Rates), the increasing parameter is the volume of work. It is mainly explained by:

- the extended visits that are mandatory at the end of cycle 1, 5, 10 etc. on a 900 MW. Experience shows that these visits require 50 to 100% more dose than for a standard visit,

- EdF's unit have suffered from the "Inconel 600 syndrome," the latest (last?) episode being cracks in the penetrations of the head of the vessel,

- units are operated presently with a cycle duration of approximately one year (which usually is recognized as penalizing for the annual dose indicator value) and the move to long cycles will take many years,

- a perfectible organization of maintenance jobs.

The decreasing trend observed these last two years is attributed to the ALARA policy that EdF decided to apply in 1990. Although one should not be too optimistic, it is noteworthy that this decrease is not an artifact of the indicator: the number of shutdowns for refueling and maintenance has been approximately the same (~45) through these years. Moreover, the dose for inspecting and repairing the vessel heads was 9% and 6% (in 1992 and 1993, respectively) of the total dose for maintenance.

A value of 1.6 man.Sv has been discussed as the goal for 1995.

INTEGRATING THE ALARA APPROACH TO NEW DESIGNS

Clearly, a new design should integrate more deeply than in the past the radiation protection *component* (rather than *constraint*). Should the radiation protection component not be taken into account in designing a nuclear power plant (NPP), one could ask in what kind of installation or circumstances it should be dealt with.

Many techniques to *minimize* the sources in PWRs (and other reactor types) are well established and agreed upon by the international community. Moreover, a proof that sources can be reduced to a very low level is given by the results of the German "konvoi" units for which an ALAP policy was applied. Indeed, the search for other or more efficient techniques is to be continued. Because these techniques are reviewed in many papers that are easily available, this paper will not add to the discussion. Rather, the aim of this paper is to emphasize that:

- analyzing EdF's operating units results in terms of doses, we learned that *keeping sources and dose rates at a moderate or low level was not sufficient to control doses,*

- by applying a complete ALARA methodology to the steam generator replacement (SGR) operation, we confirmed that *to control the dose* (including the associated costs), *it was necessary to cope with all the components of the dose.*

Lessons Learned from Replacing the Steam Generators

The steam generator replacement (SGR) operation at DAMPIERRE 1 in 1990 was, in EdF, the first maintenance operation carried out applying a ALARA methodology. Prediction of sources, dose rates (400 locations!), duration, and number of workers for any so-called "elementary task" was assessed, in which the whole operation was broken down. Several protection dispositions were compared for their impact on doses, costs, man.hours (shielding, decontamination, remote handling of tools, and automatization of tasks). Even though everything was not perfect, the results, in terms of dose, were sufficiently encouraging (2.13 man-Sv) to promote the extension of this approach to other SGRs: BUGEY 5 (BGY5) operation was performed in 1993 with a dose of 1.54 man.Sv, and GRAVELINES 1 (GRA1) was terminated in mid-April 1994 with a dose of 1.36 man-Sv (although the DRs were higher by 35% at GRA1 than at BGY5, and less protection was used; 50t instead of 70t at BGY5).

Dose for SGR (man.Sv):

U.S exp.	OBRIGHEIM	RINGHALS 2	DAMP. 1	DOEL 3	BUGEY 5	GRAV. 1
≥ 4.0 *	~ 7.0 *	2.9	2.13	1.96	1.54	1.36 **

*With reference to N.E.I. April, 1993 issue; 2.4 at NORTH ANNA 1 from another reference.
**Recent information to be confirmed.

A schematic representation of the formation of doses in a PWR is given in Figure 9. It is used inside EdF to keep in mind *the multiparameter aspect of the dose*. One cannot expect to keep doses ALARA by acting upon a single parameter, even though some might be more influential than others.

Moreover, the dose is described as having a three-layered constitution, D1 + D2 + D3, where:

- D1 is quite impossible to reduce considering a given state of the design and knowledge,

- D2 can be reduced (with increasing efforts when D2 + D1 tends to equal D1)

- D3 that can be avoided rather than reduced.

These parameters can be combined with the dose reduction vs. cost graph of CEPN (Figure 10). Although ALARA methodology can be applied to reduce any of the components D1, D2, and D3, the knowledge and tools required generally will not be identical.

Roughly speaking, pragmatism, common sense, adherence of all involved to the goals, basic knowledge, and adequate organization will be necessary in any case, but probably sufficient for avoiding D3. By contrast, an increasing level of sophistication in the knowledge and tools will be necessary to succeed in reducing D2 and D3.

Current Status of Dose Reduction in EdF

With this breakdown of the total dose, and its application to *operating units*, to "exceptional maintenance" such as *SGR*, and to *new projects*, the current status of dose reduction is the following:

- **avoiding D3** is in progress for the *operating units*: if all units could achieve the results of some "leading units," the average dose would be ~1.5 man.Sv for a 900 MW unit and ~1 man.Sv for 1300 MW units. Therefore, the dose savings corresponding to avoiding D3 can be estimated to 30% of the 1993 value (0.4 out of 2. man.Sv).

A major part of D3 can be estimated as having been avoided for the *SGR operations*. Drawbacks always are to be expected, but feed-back experience is building-up; this operation will never be of the routine kind, but all efforts are made to standardize it.

At the design stage of *new projects*, the lay-out should be carefully studied to make sure that working conditions for maintenance and operation are taken into account: irreducible jobs should not generate avoidable dose (D3).

- **reducing D2** is the field for optimization (for *new* or *operating units* and *SGRs*): further reduction of doses will require the reduction of sources, and/or dose rates, and/or man-hours that can be achieved but are not costless, or that interfere with safety or other important issues. Thus, cost-benefit analyses will have to be performed. For example:

- reducing dose rates without reducing sources will require additional shielding, either movable or permanent. With an available area fixed by the lay-out, it will be necessary to balance the decrease of dose rates against the possible increase in man.hours (less available space/time to set up the shielding).

- reducing sources for a *new unit* generally will be easier than for an *operating one*: the possibility of backfitting is, unfortunately, limited when extended modifications are necessary (one may recognize, as SIEMENS does, that a major source of cobalt 60 is the in-the-vessel hard facing material with high cobalt 59 -- except CRDMs -- and still not be able to replace these parts on "old" units). This is probably a good reason for the intensive search for "non-intrusive" means to reduce sources, such as pH control, and addition of additives to the coolant (for example, zinc for PWRs).

- to reduce man.hours (after D3 has been avoided) principally for *operating units*, one can try to demonstrate that a particular inspection has little value, or that a limiting value (for example, acceptable leakage flowrate) can be relaxed. Generally, it will be difficult to make a convincing demonstration if safety issues are part of the problem.

- **reducing D1** is the field of R&D and *new plants* (sometimes with a possible application to operating units).

For designing *new units*, efforts will be made to keep the total dose (D1 + D2 + D3) ALARA. EdF adopted an approach and an organization whose acronym is "CIDEM": design and lay-out, taking into account reliability, experience, maintenance requirements, and radiation protection. A dose objective was set with a value of $D = 0.5$ man.Sv.y^{-1} and an uncertainty margin of 50% ($D < 0.75$) at the present stage of the project. It is an average for the whole life of the unit for normal operation and maintenance. This value may appear too high for a unit to be connected to the grid in 2005: it is thought that it can be obtained at a reasonable cost (ALARA is to be applied rather than ALAP). This overall dose is broken down into "dose credits" for the tasks to be performed for operation and maintenance, such as the repartition used in the ISOE system, but with more details.

Tools Useful to Apply the ALARA Methodology

Adequate management and organization of a project in which the ALARA methodology is applied are necessary, and have been described in several papers (OECD, CEPN, NRPB). Adapted tools also are useful; some of them currently used in France and EdF are:

- provision of sources: CEA "PACTOLE" and "PROFIP" softwares for corrosion and fission products respectively

- provision of dose rates: "MICROSHIELD" (GROVE ENGINEERING, Inc.), "MERCURE" (CEA), "PANTHERE-RP V.0" (EdF-SEPTEN)[6]

- provision of work volume: EdF's data bases,

- provision of doses: "TIGRE-RP", "DOSINAT", data bases (EDF), "FRADOSE" data base (FRAMATOME)

- dose management: "DOSI-ANA" (CEPN, FRAMATOME, EdF)[5]

These softwares are sophisticated, but nevertheless, generally user-friendly. Efforts are continuing in that direction: PANTHERE-RP V1.0 will be available in EdF's design departments at mid-1995. A more complete package (version V2.0) comprising the integrated data base (possibly with an expert system) and computer mock-ups of the main parts of the units are currently developed.

The use of sophisticated tools is required for the accurate provisions that have to be made when trying to reduce D2.

CONCLUSION

EdF experienced the fact that what apparently was a rather satisfying **control of sources and dose rates was not sufficient to control the dose** for operation and maintenance of its PWR units. Even though sources and dose rates have been, and still are, maintained at a moderate to low level, after 10 years ending in 1988 with excellent results in terms of annual doses per unit or produced energy, an increasing trend was observed up to 1991. Analyses showed that this resulted mainly from a large increase in work volume for maintenance.

Meanwhile, the **successful management of doses for the SGR** operations (DAM1, BGY5, GRA1 units) **demonstrated the potentialities of the ALARA approach.** Thus, ALARA organizations have been created at different levels (plant sites, central management of all NPPs) and attempts have been made to apply this approach to normal operation and maintenance of the units.

The reverse of the increasing trend in 1992 and 1993, despite the problem of penetration cracks in the vessel head that added 6 to 9% to the normal dose, is the result of the extended ALARA approach.

SGRs operation at BUGEY 5 (1.54 man.Sv) and GRAVELINES 1 (1.36 man.Sv) show that an ALARA approach ensures some **reproducibility** in the results (although drawbacks should always be expected).

The total dose in the next fifteen years or so for SGRs at EdF's units (supposing that 31,900 MW units will have to ensure this) can be estimated to lie in the range **30 to 45 man.Sv.** This is far less than the present **annual dose for all EdF's units** which is about **100 man.Sv.**

Thus, a decision was taken at the end of 1993 to apply the ALARA approach to normal maintenance operations more strictly (known in EdF as the ALARA Project), as well as to new projects (e.g., units with a new design, auxiliary facilities to NPPs).

A goal of 1.6 man.Sv/unit/year (averaged on all units) in 1995 is under discussion.

For a new design, the dose objective, averaged over the lifetime of the plant, has been set at 0.5 man-Sv (with an uncertainty of 50%). Although lower or equal values already have been obtained for a few units (inside and outside France), this goal will be maintained to take into account the economical parameters (**ALARA** approach, as opposed to **ALAP**).

The methodology is a classical one, and corresponds to EdF's CIDEM organization of the project. Many tools are available to help to implement the prediction of the dose parameters (sources, dose rates, work volume), taking into account varied options in the design and the lay-out.

Finally, we point out that we believe that **setting a dose objective implies a rational approach, and this is probably as important as the value of the goal itself. The radiation protection component has a pronounced transverse turn** that should be taken into account. When an ALARA methodology is fully applied, there is confidence that radiation protection aspects are part of the decision process.

REFERENCES

1. P. Beslu. CEA France: "Computer code PACTOLE to predict activation and transport of corrosion products in a PWR" BNES, January 1978.

2. Ph. Berge et al. France: "Expérience française sur le contrôle chimique de l'eau et le contrôle des produits de corrosion des REP" IAEA-SM-264/7, November 22-26, 1982.

3. A. Brissaud Ph.Ridoux: "Characterization and analysis of EdF PWRs radiation fields" EPRI seminar Berkeley, March 16-18, 1988.

4. S. Anthoni CEA France: "French experience on PWR's contamination data acquisition" Westinghouse REM Seminar, October 28-31, 1990.

5. G. Vessieres C. LeFaure "DOSI-ANA: a software package for maintenance operations dose management at PWRs" BNES 1991, Guernsey.

6. A. Brissaud Ph.Ridoux: "PANTHERE-RP, a tool for provision of dose rates" 1990 Radiation Exposure Management Seminar.

Authors' Biographies

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DISCUSSION

Andersen: Are you discovering any actual facility design modifications that look cost effective for existing facilities out of this process, or is it mostly accomplished through other means?

Brissaud: Yes, but I think it is not a very new dicovery. The idea is when one is designing a plant, also one should design the maintenance. Think about the people that are going to work, because some maintenance will have to be carried out. It's better to think about it beforehand, not afterwards. Not so many new things, nothing revolutionary.