The Flexblue system; early considerations on safeguarding

François-Xavier Briffod[a], Caroline Jorant [b]

[a] **DCNS** Paris, France
[b] **SDRI Consulting** Paris, France

Abstract The Flexblue system is an innovative concept that consists in a small size transportable nuclear power plant to be sited on a flat sea bottom together with on shore command and control as well as fuel loading/unloading facilities. This concept includes valuable features from a "safeguardability", point of view, like a reduced access to the fuel during operation, and consolidation of spent fuel in the shared loading facilities.
Although it is only at an early design phase, it seems appropriate to share some considerations on the specificities that this model may entail from an international safeguards perspective.

1. Introduction

Flexblue is a complete nuclear energy system under development by DCNS. It includes a subsea power plant anchored up to a 100 m depth, a ground control centre but also ground facilities for remote operation and maintenance and fuel loading facilities. The system also includes the fuel supply. The energy produced is delivered to the grid by a submarine cable.
The power plant is based on a module or series of modules that are manufactured in France, tested in France and then transported on a dedicated vessel to the energy production location.
Several modules may be grouped in a « farm » concept. Such modularity offers flexibility for operational purposes as well as for the construction and financing schedule.
When compared to a "classical" nuclear power plant build on ground, the Flexblue concept may be characterized by several specific design features that affect the economic model and the construction planning. These specificities also result in very attractive safety and security features for the operator and for the national authorities.
Because of its original design, operational and construction scheme, the Flexblue concept is likely to entail some adaptation of the classical Nuclear Power Plant safeguards scheme that would benefit both the IAEA and the operator.
This presentation will focus on the safeguards aspects of the Flexblue system, and hopefully contribute to the identification of key issues and promote consideration of safeguards items that could be embedded at an early conceptual stage under a "safeguards by design" concept as advocated by the IAEA.

2. Main Safeguards relevant features

2.1. Technical description

The module can be described as a cylindrical hull of about 145 meter long and 14 meters diameter.
It will be brought on site by transport ship - displacement around 20 000 MT- and moored on the seafloor up to 100 meters, where production takes place. The module is monitored, protected but also operated from an onshore control center. It is permanently accessible via a submarine vehicle that connects to access hatches, so that light maintenance, inspection and operation can be performed onboard while on the seafloor. Every 3 years approximately, electricity production stops for refueling. The module is removed and transported back to a coastal facility, which hosts the spent fuel pool. Major overhaul occurs every 10 years, i.e. every three fuel-cycles. The expected lifetime of a module is 60 years.
Since the nuclear technology used is the Pressurized Water Reactor, the concept benefits from a large experience in commercial power plants as well as in the naval environment.

2.2. Operational process and safeguards phases

Globally the safeguards scheme should be based on a PWR model, but a number of elements are worth being taken into account in the safeguards strategy and implementation at the different stages of the project; construction, transportation, installation and operation, loading and maintenance.

2.2.1. Plant construction

The first important differentiating feature regarding safeguards implementation is related to its being produced as a series in France unlike other land based reactors. The typical construction of a nuclear power plants relies on an import of major technology component but all the concrete work, the piping and the assembly of components take place in situ, under the oversight of the operator and the national authority. In the case of Flexblue, the recipient State has no authority on the construction site.
This particularity poses a number of questions related to the timing and identification of the national authority responsible for the early notification of the design and for the IAEA access for design information verification.
Although the possibility of adding new modules on the same site does not seem to greatly affect the safeguards approach, it should be taken into account for the inspection planning.

2.2.2. Transportation

Under the current practice, the main components of the power plant may be shipped from one place to the recipient State and then assembled but this is not subject to international safeguards. It is only the transport of fuel elements to the recipient State that would be subject to international safeguards. The transport of the modules that would normally contain the first core presents an innovative aspect in terms of safeguards since a whole nuclear power plant should be safeguarded during its transportation.

2.2.3 Installation and operation

Depending on the safeguards approach devised, the IAEA may wish to implement some Containment and Surveillance (C&S) devices when the module is installed. Because it is shipped and then anchored in its subsea location birth, its potential mobility is one aspect that the safeguard approach will have to deal with.
An important feature is related to the environment of the plant and its fuel cycle. The modules will be accessible during the construction and before being laid on the seabed but afterwards, they will not be routinely accessible by the safeguards inspectors for regular inspection or Design information verification (DIV) except during unloading/loading and maintenance operation. Besides, the fuel is not accessible outside from an unloading infrastructure. This means that the need to access for safeguards verification during normal operation will be reduced.

2.2.4. Fuel cycle

Unlike current models of nuclear power plants, Flexblue modules will be refuelled only every three to four years and the fuel may be temporarily stored at the ground site or sent in a regional support facility. After sufficient decay time, the fuel assemblies will be evacuated for reprocessing or long-term disposal as in a classical scheme.
As far as the operational aspects are concerned, some specificities of the Flexblue project should facilitate safeguards implementation, other may pose a challenge or at least may necessitate adopting quite innovative approaches. In order to better appreciate or anticipate the practical issues that may surge, it is useful to describe a case study and consider the different tasks to be performed for the implementation of international safeguards.

3. Case study: export from NWS to NNWS

The typical business case for the commercialization of Flexblue modules is based on the manufacturing in France and the export to a "newcomer" in nuclear energy. Hence, from a non-proliferation and safeguards point of view, the case study considered involves a Nuclear Weapon State with a Voluntary Offer Agreement (France) and a Non Nuclear Weapon State with an INFCIRC 153 type agreement.

3.1 Design information and verification

3.1.1. General case

The design information is the « information concerning nuclear material subject to safeguards under the agreement and the features of facilities relevant to safeguarding such material"[1] Design information includes the facility description; the form, quantity, location and flow of nuclear material being used, facility layout and containment features, and procedures for nuclear material accountancy and control. This design information "shall be provided as early as possible before *nuclear material* is introduced into a new *facility."*

Initial information about the design should be provided at least six months before the start of the construction of the project.

According to the French Additional Protocol, the IAEA should be kept informed of the intent to export a nuclear power plant and receive information on " the identity, quantity, location of intended use in the receiving State and date or, as appropriate, expected date, of export"[2]

As soon as the decision is taken to construct, or to authorize the construction of the facility, the State where the facility is to be built, has to provide further information on the safeguards relevant features of the facility design.

In the case of new facilities, such information is to be provided by the State as early as possible before nuclear material is introduced into a new facility. Further, the State is to provide preliminary information on any new nuclear facility in the stages of project definition, preliminary design, construction and commissioning.

This information is necessary for the IAEA to reflect on and prepare the facility safeguards approach, and to identify a number of safeguards relevant locations (material balance areas, key measurement points and other strategic points) and develop verification activities. Facility design information is to be provided for any safeguards relevant changes in operating conditions throughout the facility life and routine verifications are performed on a regular basis, typically every year to confirm that the design information has remained unchanged and that the safeguards approach remains valid.

3.1.2. Implementation specificities

One of the main differences between Flexblue and a land-based reactor is that the manufacturing takes place in France but the operator is located in another country.

The provision of design information and access to the IAEA raises a number of questions in the case of a Flexblue project. Who is responsible to provide early information? In which framework should the construction of a module be notified to the IAEA? Should the timing be affected? Globally would a Flexblue project result in more safeguards activities in relation to the design verification task than another land based project? Would a serial production like Flexblue result in a simplified process and at least lighter verification measures than a land based nuclear power plant?

3.1.3. Proposed implementation scheme for a reference case

The following scheme is proposed where the importer country is referred to as ICO.

ICO is a NNWS, with a Comprehensive Safeguards Agreement, an AP into force (but this is not a determining factor). ICO imports from France a first module, complemented by two other modules in the following year. Under an AP, ICO would inform the IAEA of the plan to develop a nuclear plant

---

[1] IAEA INFCIRC 153, par 8, articles 42 to 48

[2] IAEA INFCIRC 290 add 1, 24 February 2005

project and, when the decision is taken to select the Flexblue technology, it would give some general description of the technology involved and locations envisaged. When the first contract is concluded, the French authorities would provide information on the intent to export to ICO, the type of reactor, the likely location, as appropriate.

In a derogatory and cooperative manner, the French authorities will also provide at an appropriate timing the location and schedule of construction of the first module.

Upon an agreed cooperation process between the French authorities and ICO and a special arrangement with the IAEA a preliminary design information file could be jointly prepared and sent to the IAEA.

At a second stage, and at least in the timeframe recommended before the introduction of material for testing, a "temporary "and "partial " design information file would be presented by the French Authorities. Access for verification on the construction site would be specially granted at the request of the IAEA and under conditions to be accepted by the French authorities, as a measure to facilitate further verification activities in a NNWS.

Likewise, as the first core is to be loaded before shipment, additional verification activities could be performed in France and containment and surveillance system could be devised to ensure the integrity of the module during its shipment.

At this stage, the final and complete design information including the land based monitoring and fuel-handling facilities would have been transmitted at an appropriate timing to allow the IAEA considering the whole site facilities.

Because there will be no technical possibility and space to open the reactor's lid, once the module is shipped from the maintenance facility, and all the more once installed under water, the need/periodicity for design re-verification will be alleviated. If necessary, a design verification can be performed during the refuelling operation every 40 months. Because the module concept is very compact, the verification will be simplified in comparison with a "classical" nuclear power plant. If appropriate, a thorough design re-verification could be easily performed by the IAEA in France, every 10 years during the full maintenance programme that will be described in the design information document. A special arrangement with the French Authorities will be needed to plan such activity.

3.1.4. Series production, standardized design information and « integrated » verification practices

Since the modules will be strictly identical, when ICO decides to adapt its energy production and orders a few other modules, the same safeguards scheme can be repeated. However, its implementation will be much easier both at the declaration stage for France and ICO who should not need repeating the documentation workload, but also for the IAEA.

A provisional extended design information document could even be provided to the IAEA with the first design information questionnaire and then the schedule of manufacture and deliveries could just be confirmed.

As a matter of fact, since the modules will be produced in a factory, at a single place as a series of identical items, the verification of the design before shipment could be simplified and carried out as a routine task. Depending on the manufacturing and delivery schedule, verification of one or more modules could be carried out simultaneously and possibly on a randomized basis within an integrated approach. Such an original production model compared with the current "in situ" construction practice for land based reactors will certainly contribute to saving human, equipment and financial resources altogether and thus will result in improving the efficiency of IAEA safeguards.

3.2. Material accounting and control and verification

3.2.1 General case and likely evolution

The facility operator and the State system of accounting for and control of nuclear material (SSAC) should allow the IAEA to independently verify the correctness of the nuclear material accounting information in the facility records and the reports provided by the SSAC to the IAEA.

INFCIRC/153 (par29) indicates, "material accountancy shall be used as a safeguards measure of

fundamental importance, with containment and surveillance as important complementary measures."
Indeed, nuclear material reporting by states and its book and physical verification by the IAEA was really the main tool for the IAEA safeguarding task when the international safeguards system was conceived and implemented. While its is still an essential element of the verification activities, the safeguards activities and philosophy has evolved with the broadening of the scope (detection of clandestine activities in addition to the assurance of no misuse and non diversion of declared material and facilities and to non peaceful uses), of the technology and of a resulting wider access to information.
The former "facility level approach "is now encompassed in a broader State level approach. Reporting by States and verification by the IAEA, governed by strict timeliness and quantitative criteria, required to have a regular access – typically between once a year and 14 months for a nuclear power plant. Other tools and means to get equivalent levels of assurances of no-diversion of material or misuse of facility may now complement this approach.
Distinguished safeguards experts[3] have already argued that "With the introduction of new types of nuclear fuel cycle facilities (such as electro-metallurgical processing) and the revolutionary reactor types envisaged under the Generation IV initiative, the traditional model of independent IAEA verification of declared inventories may no longer be applicable ». They consider that « rather than concentrate on maintaining a particular process (in this case, access to all nuclear material) in support of the overall safeguards objective. The IAEA could explore methods of maintaining and attaining an equivalent degree of assurance without independent inventory verification."

3.2.2. The Flexblue reference case

The Flexblue concept is comparable to other PWRs but significant differences need to be assessed in terms of safeguards implications.
While for most nuclear power plants only one material balance area includes the unloading/storage and reactor zone, in the case of Flexblue it may be desired to delineate the on shore loading /unloading facilities and the spent fuel storage especially if this is organized on a regional basis. However this distinction should not result in a significant additional burden.
Basically, the nuclear material accountancy system for the Flexblue modules will not differ from any traditional land based accountancy scheme and should be based on item counting and identification.
However, the situation will differ slightly with the physical inventory verification. As explained earlier, one of the positive aspects of the Flexblue technology is that the fuel is conceived to last about 40 months before needing to be unloaded and stored.
In terms of safeguards, this may be regarded as difficulty since the normal timeframe between two inventories is around one year and not three years.
But because unnoticed access to the core when it is on the seabed is also almost impossible for a would-be proliferator State, the verification/timeline criteria should be adapted based on a risk assessment of a diversion scenario.
It can even be argued that with possible movement detection and other C&S equipment, there is more chance to detect an attempt to remove the fuel from the core from a Flexblue module within a three year period than within a 14 months period in the case of a land based reactor.

3. 3. Containment and surveillance

3.3.1 General approach

As recalled above, The IAEA's safeguards approach for a facility is based on nuclear material accountancy as a safeguards measure of fundamental importance, complemented by containment and surveillance measures and monitoring.

[3] Revisiting the practices and technical objective of safeguards. Paper presented to the Annual Meeting of the Institute of Nuclear Materials Management, Baltimore, Maryland, 11-15 July 2010
Russell Leslie, Craig Everton, John Carlson, Australian Safeguards and Non-Proliferation Office
RG Casey Bldg, John McEwen Crescent, Barton, ACT 0221, Australia

Containment is defined as "the structural features of a facility, containers or equipment which are used to establish the physical integrity of an area or items (including safeguards equipment or data) and to maintain the continuity of knowledge of the area or item by preventing undetected access to, or movement of, nuclear or other material, or interference with the items "[4]
The containment devices include basic elements like walls, doors, containers and different types of seals to make sure the opening of containments structures will not be unnoticed.
Surveillance is defined as "the collection of information through inspector and/or instrumental observation aimed at detecting movements of nuclear material or other items, and any interference with containment or tampering with IAEA equipment, samples and data. Surveillance may also be used for observing various operations or obtaining relevant operational data. IAEA inspectors may carry out surveillance assignments continuously or periodically at strategic points
Surveillance includes optical systems as CCTV cameras or 3 D cameras, sensors like neutron collar equipments and radiation passage and reactor power monitors.
C&S equipments are installed to detect any undeclared or unexpected movements of handling equipment and confirm the absence of removal of material.
The use of the operators or national authority C&S equipment allows to reduce the investment for the Agency but it has to be authenticated to be sure that information obtained is trustworthy and that the measurements data and equipments are not altered or replaced.

3.3.2 Flexblue reference case

In the reference case, IAEA would have verified the facility and the first core in France, before shipment.
Some specific sealing and/or surveillance devices will have to be devised to make sure that there would be no access to the fuel during the transportation. Continuity of knowledge would allow not repeating the safeguards verification once on site.
The IAEA may wish to install or rather to get authenticated signals from the operator's surveillance system and perhaps reflect on the need to ensure that no unannounced movement of the module takes place between two unload/load operations. The possibility to get or develop submarine cables/lockers and sensors should be examined with the requirement to provide for safety measures. C&S equipment should be installed on the equipment to lift the module for refueling and also perhaps on the submarine vessel dedicated to the light maintenance and surveillance. On line signals could be sent to the IAEA in case such activities were to be performed.
The C&S equipment for land based fuel handling and storage facilities would not differ from classical other NPPs.

3.4. Consolidation of fuel handling facilities and spent fuel storage

The Flexblue concept is more than just a nuclear power plant. It is a comprehensive system and includes the supply of fuel and maintenance services, but also of fuel handling and storage facilities.
Depending on the actual commercial development of the Flexblue concept, the sharing of fuel handling and fuel storage facilities within a multinational or even national approach is an original feature that should contribute in reducing the safeguards effort.
Instead of having to safeguard a number of fuel handling facilities and storage capacities associated with each power station or modules, the reference case would be to develop a national or regional storage and fuel handling facility to serve the needs of all modules located in one or several countries.
The transportability of the modules allows such scheme whereas other land based SMRs will need to have at least their own fuel handling facilities, if not storage.
This consolidating of nuclear materials and facilities will allow IAEA to concentrate its efforts on one facility and save inspection, equipment and financial resources.

4. Safeguards by design concept and need for R&D?

[4] Safeguards glossary IAEA International nuclear verification Series, N°3

4.1. Safeguards by design concept

Safeguards by Design (SBD) may be defined as "an approach whereby international safeguards requirements and objectives are fully integrated into the design process of a nuclear facility, from initial planning through design, construction, operation, and decommissioning. This process is not unique to international safeguards and it represents good project management to include safeguards requirements in the overall design and construction process. By including awareness of all regulatory issues, including international agreements that concern international safeguards project management can schedule consideration at the appropriate time and level of detail and subsequently reduce the project risk. The SBD process is a multidisciplinary interactive process of optimizing the design features and process parameters of the facility to ensure that safeguards obligations can be reasonably met."[5]

Applied to the design of nuclear facility the scope of SBD concerns three types of activities: the design information verification, the verification of nuclear material accountancy and control measures and the confinement and surveillance infrastructure, methods and equipments. Any measure that would facilitate the implementation of the IAEA's activities in these three fields should be incorporated within a SBD.

In the case of Flexblue this would apply both in France and in the importer country in a broader approach; continuity of knowledge will be an important element of the SBD.

4.2. Designer's expectations

4.2.1. Early understanding of IAEA technical objectives and timely response

The designer expects the IAEA and State System for Accounting and Control (SSAC) to provide information on their own constraints early enough to allow not simply a reactive process based on IAEA's requests but rather an interactive relationship. A real cooperation between IAEA/SSAC and the designer should be initiated early.

In order to be inventive and to really take into account the safeguards constraints at the design stage, it is of utmost importance that designers understand the general objectives and know the technical objectives and tools of the inspectorate in order to reflect on, and possibly propose inventive solutions to contribute to the "safeguardibility" or rather the neutrality/cost effectiveness of safeguards measures. Likewise, the designer expects the IAEA to respond to the supply of design information and to its proposals in a timely fashion to keep pace with the design and industrial process.

4.2.2. Predictability of costs and operation

It is often recalled that safeguards should not hamper the normal operation of facilities.

Predictability is an important asset for the designer at each stage of the design and construction, and for the operator who needs to supply electricity in a planned manner and who needs to reduce outage periods to reduce costs.

What a cooperative designer would legitimately expect from the safeguards team and its national authorities is to get an approval on the safeguards constraints and equipment he needs to provide and that any additional later requirements would not incur unexpected costs for the operator or delays. Smart, innovative but also robust technical solutions should also benefit the IAEA.

4.2.3 "Safeguardibility" assurances

[5] IAEA Nuclear Energy Series Technical Reports International Safeguards in Nuclear Facility Design and Construction
No. NP-T-2.8, 2013

With a series production as with Flexblue modules, the possibility to include the entire safeguards technical environment for all modules without necessitating a review of all safeguards requirements is a very positive element for all safeguards stakeholders.
IAEA could reflect on the possibility to certify the "safeguardibility" of the modules, and thus re-assure the potential customers and facilitate public acceptance.
At least, as an incentive or reward addressed to the designer, IAEA could communicate on the efforts to integrate safeguards measures in a SBD approach.

4.3. Infrastructure and Equipment sharing

Simple infrastructure elements should be designed having in mind the specific needs of the inspectorate. These include power supply (and redundant generators), special protected space for computer or C&S equipment, access for possible analysis or measurement tools.
Another perspective for a "safeguards by design" approach is an increased sharing of the operator's monitoring and C&S equipment. This can be done if the signals can be authenticated and when necessary, if the equipment can be adapted to respond to safeguards requirement (for instance install hooks or devices to attach seals or to block the unnoticed removal of an equipment).

4.4. R&D on specific equipment

In the case of Flexblue some development of specific tools, namely water resistant surveillance/localization tools like satellite imagery, GPS could be developed either by the designer or by the IAEA with the support of the designer.
Another area of development rests with the automation of signal generation and their transmission to the IAEA to complement physical access between two inspections, so as to limit the number of required routine inspections.

Conclusion

The Flexblue concept is based on a conventional nuclear technology associated with quiet innovative features relating to the production and operation processes. These features will entail some adaptation to the safeguards approach developed for land based PWRs and possibly a few technological developments. However, at this conceptual phase, no major hurdles are expected. On the contrary, the first analysis points to the intrinsic positive factors of the Flexblue system in terms of safeguardibility.
The situation may be even improved through an early cooperation between the safeguards and design teams. The Flexblue project team is aware of the benefits for all of incorporating the safeguards equipment requirements at an early stage and is already committed to take into consideration appropriate adaptation that the IAEA might suggest in this regard.
The Flexblue project is a promising candidate for the implementation of the Safeguards by Design concept in both its operational but also construction phases.
Apart of the technical aspects, one of the original characteristics of the project is the construction of the complete modules in France.
This situation will call for a few technical developments in connection with the subsea environment but also specific administrative arrangements with the IAEA and increased cooperation between the Importer State and the French authorities not only on safety aspects but also on the safeguards interface with the IAEA.