Safety Assessment of the OSIRIS Research Reactor and Regulatory Process for Final Shutdown

S. Kanamori[1], F. Nicolas[1], E. Grolleau[1], A-C. Jouve[1], T. Adatte[1], C. Bigou[2], C. Kassiotis[2]

[1]Institut de Radioprotection et de Sûreté Nucléaire (IRSN), PSN-EXP/SSRD, PSN-RES/SCA, Fontenay-aux-Roses, France

[2]Autorité de Sûreté Nucléaire (ASN), Montrouge, France

E-mail contact of main author: stephanie.kanamori@irsn.fr

Abstract. The French research reactor OSIRIS, operated by the Alternative Energies and Atomic Energy Commission (CEA) since 1966, is partly used to irradiate enriched uranium targets to produce medical isotopes. In 2009, CEA has partially reassessed the safety of the reactor. Considering that the reactor shutdown was foreseen for the end of 2015, the French Nuclear Safety Authority (ASN) has allowed the operation to continue. In 2011, CEA requested the French Prime Minister to extend the operation until 2018, arguing of a potential lack of medical isotopes due to the late completion of the new Jules Horowitz Reactor (RJH), which is due to replace OSIRIS for isotope production. The Nuclear Safety and Radiation protection Institute (IRSN), as technical support to ASN, has been requested to assess the safety of the reactor and to identify the required modifications to implement in order to meet the current standards. IRSN has mainly recommended carrying out a safety assessment based on the operating conditions approach and reinforcing the reactor containment. ASN has also taken into account the impact of the reactor shutdown on the medical radioisotope supply to make its decision on the CEA request.

Key Words: radioisotope, containment, operating conditions approach

1. Introduction

OSIRIS is a French research reactor operated by the Alternative Energies and Atomic Energy Commission (CEA) in Saclay (30 km south of Paris, France). This open-core pool-type reactor is notably used for the irradiation of enriched uranium targets in order to produce medical isotopes. In operation since 1966, it was expected to be definitively shut down by the end of 2015. This deadline has been taken into account by the French Nuclear Safety Authority (ASN) and the Nuclear Safety and Radiation protection Institute (IRSN), the technical support to ASN, during the partial safety reassessment carried out by CEA in 2009: as a consequence, several safety topics were either not evaluated or evaluated with lower safety requirements.

At the end of 2011, CEA asked the French Prime Minister for the authorization to keep operating the reactor until 2018. CEA motivated its request by the potential lack of medical isotopes supply during the period between the OSIRIS reactor final shutdown and the Jules Horowitz Reactor (RJH) commissioning. The RJH is a new pool-type research reactor under construction in Cadarache, south-east of France, with the ability to produce radioisotopes. Its completion currently suffers from delays.

To assess this demand, ASN had to evaluate OSIRIS reactor compliance with the current standards and the state-of-the-art, like for other perennial reactors. IRSN was asked to conduct a safety assessment aiming at identifying the main modifications that would be necessary to ensure the reactor operation with sufficient safety conditions for a significant time beyond 2015.

In 2013, IRSN has presented its recommendations. The main safety concerns that shall be addressed have been singled out (see paragraph 2), especially on the safety demonstration approach (see paragraph 3) and the reactor containment (see paragraph 4). Concurrently, ASN has considered the impact of the reactor shutdown on the medical radioisotope supply and has submitted its decision on the reactor operation extension (see paragraph 5).

2. Main outcomes of the IRSN review

IRSN has reviewed the safety demonstration of the reactor and has identified the aspects consistent with the state-of-the-art and the current standards and those requiring further analysis or a re-evaluation from the CEA.

The reactor presents several strong elements, like the general design of the reactor and the water-block concept which prevent any core dewatering due to a primary break. Another asset is the use of passive systems to evacuate the residual power which ensures a primary break cannot lead to a core meltdown.

However three fields are significantly under the state-of-the-art and the current standards:

- *The protection against external explosion or airplane crash*. The reactor building is not designed to withstand an external explosion or airplane crash and the concrete falling fragments from the containment in the pool may disturb the cooling of the core. This risk must be taken into account according to the current standards.
- *The approach used for the safety demonstration*. The demonstration shall be updated to be consistent with the other operating research reactors using the operating conditions approach (see paragraph 3).
- *The containment capacity of the building*. The containment strategy in case of overpressure consists in depressurizing the building with the containment exhaust fans. The containment building, made of reinforced concrete only, is supposed to withstand a peak of overpressure during a limited period of time and is designed with a low gas-tightness compared to the other operating research reactors. A more efficient static containment is necessary (see paragraph 4).

3. Safety demonstration based on the operating conditions approach

This approach consists in studying the robustness of the lines of defence associated to the events likely to occur in the facility.

The operating conditions are the different conceivable configurations of the installation during normal reactor operation, operating incident or accident conditions.

All possible events do not have the same probability of occurrence nor the same consequences. The operating conditions are classified according to their frequency of occurrence and the gravity of their consequences: the more probable an event is, the less severe the consequences should be. They are sorted into four categories: normal reactor operation and normal operating transients, incidents of moderate frequency, infrequent incidents and limiting faults.

The operating conditions process requires first to draw up the most exhaustive possible list of internal initiating events which may affect the installation safety functions. Initiating events are classified into the four categories according to their probability of occurrence. Incident or accident sequences of events are established and the final consequences estimated. Then, for each operating conditions categories, the sequences with the most severe radiological effects are selected and the consequences are evaluated using computer codes with penalizing assumptions. It has to be checked that the estimated effects comply with the safety objectives of the category and that the provisions taken are sufficient at the different levels of the defence in depth.

This approach enables to include the analysis of internal events in a structured and clear safety demonstration. It has initially been implemented for the PWR but is now applied in France since the 2000s to the research reactors being designed, like the RJH, or to older ones when their safety is reassessed for periodic safety reviews.

4. Reactor containment

OSIRIS reactor building gas-tightness is significantly below the current standards. Improving the containment to the level of recent reactors would be costly and would face technical difficulties. In order to state on the operation extension, IRSN has analysed the interest of “reasonable” modifications. For this purpose, it has performed several calculations[1] to assess the impact of gas-tightness on the radioactive releases into environment in the event of a BORAX-type accident[2].

4.1. BORAX post-accident management

The dynamic containment of OSIRIS reactor is ensured by a normal ventilation and a reserve ventilation with a lower flow rate capacity. Both are equipped with aerosols and iodine filters. As iodine traps are inefficient when the air is too humid, heaters are therefore installed upstream to dry the air. Their regulation has a significant response time: there is a delay before the adequate power is reached. During normal operation, normal ventilation heaters are off; in the contrary, reserve ventilation heaters are maintained at constant temperature to enable iodine traps to be rapidly efficient in case of accident.

A BORAX-type accident leads to an important overpressure inside the reactor building. The management of such a situation in OSIRIS reactor consists in evacuating this overpressure in order to protect the reactor building from collapsing. The normal ventilation is firstly used to promptly decrease the pressure (only aerosols filtration is efficient). Once the pressure is reduced to the atmospheric level, the normal ventilation is stopped and the reserve ventilation is used, allowing aerosols and iodine filtrations of the exhaust air.

Regarding the standards of recently built reactors, a different post-accidental management based on the static containment of the reactor building only (all ventilation systems off) is possible. It permits to benefit from the radioactive decay of short-lived radionuclides. However, this management cannot be currently applied to OSIRIS reactor because the building is not designed to withstand such a high and continuous overpressure. Improvements on the gas-tightness of the reactor building would allow a post-accidental management based on the static containment of the reactor building only. The calculations performed by IRSN aimed at evaluating the gain that could bring such a management, taking into account reasonably reachable leakage rate after a global reinforcement of the building containment.

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[1] Calculations were performed with a computation software developed by the Crisis Management Unit of IRSN.

[2] The BORAX-type accident is due to a sudden reactivity insertion, and can lead to a complete melting of the core and a vapour explosion. The important volume of vapour thus created implies a significant overpressure in the reactor building. This accident is the design accident for the French research reactors.

4.2. Incertitude on operating parameters

In order to maintain the iodine traps at constant temperature, heaters power is adapted to the flow rate. The regulation time is unknown and directly impacts the iodine traps efficiency. To take this delay into account, IRSN has considered the iodine traps efficiency equal to 90% immediately after switching on the reserve ventilation to full flow rate and to 99.9% three minutes later (arbitrarily assuming a linear increase in the efficiency versus time).

The leakage rate of the reactor building is periodically measured by depressurizing the reactor building and measuring the necessary flow rate to maintain a constant vacuum; these tests are carried out with the vacuum relief valves opened. Thus the measured flow rate is not representative of the current leaks of the over-pressurized reactor building in case of BORAX accident. Moreover, the overpressure could lead to the creation of cracks in the concrete of the building – as noticed in the 2009 safety review – which could significantly diminish its gas-tightness.

IRSN has no reliable data related to the evolution of the leakage rate of the reactor building depending on the pressure or related to the time for heaters to adapt their power to the full flow rate. Consequently the radioactive releases estimated by IRSN are only orders of magnitude.

4.3. Calculation scenarios

IRSN has performed several calculations taking into account different levels of the reactor building tightness and different ventilation systems management, including momentarily static containment only (all ventilation systems shut down).

The first assessment of radioactive releases into environment due to a BORAX accident constitutes the "reference" evaluation. IRSN has supposed that the accident generates inside the reactor building a 20 mbar overpressure without degradation of the containment. The nominal leakage rate of the reactor building is considered equal to 2,400 m^3/h for a 20 mbar overpressure. The normal ventilation system operates for 3 minutes, before it is switched on the reserve ventilation. During the first 100 seconds after the accident – the estimated period of overpressure in the building – the air escapes into environment through the leaks of the building.

For the second evaluation of the radioactive releases, IRSN has supposed that the post-accidental overpressure of 20 mbar degrades the reactor containment, for example by creating cracks. IRSN has arbitrarily considered a leakage rate of 7,200 m^3/h: this stands for a 200 % increase compared to the "reference" evaluation.

IRSN performed five evaluations of the radioactive releases assuming a strengthening of OSIRIS containment, for example through the installation of an internal liner or the renovation of the seals at the penetrations of the reactor building. IRSN has arbitrarily considered different leakage rates equal to 1,000, 500, 300, 100 and 50 m^3/h for an overpressure of 20 mbar – depending on the quality of the gas-tightness of the reactor building. In those cases, the post-accidental management of the reactor containment is modified as follows:

- Thanks to the strengthening of the building gas-tightness, the ventilation systems is shut down, the containment being only static, which makes it possible to take advantage of the radioactive decay of short-lived radionuclides. Thus, IRSN has considered that the ventilation systems (normal and reserve) are stopped during the first 10 hours after the BORAX accident;

- IRSN has arbitrarily assumed that the overpressure in the reactor building is only due to the huge volume of vapour generated by the fusion of OSIRIS core[3]. The 20 mbar overpressure – corresponding to 200 m^3 of air – is discharged to the environment through the leaks. The duration of the releases depends on the gas-tightness: respectively 12 min, 25 min, 40 min, 2 h or 4 h for leakage rates of 1,000, 500, 300, 100 or 50 m^3/h;
- After 10 hours of static containment, the reserve ventilation is switched on (flow rate of 500, 250, 150, 50 or 25 m^3/h, depending on the tightness, to maintain -0.5 mbar inside the building), and the efficiency of filtrations of both radioactive aerosols and iodine is considered equal to 99.9 %.

4.4. Results and conclusion

Improving the gas-tightness of the reactor building leads to reduce the releases of noble gases and iodine into environment by more than half in comparison with the current configuration. The decrease in iodine emissions is the consequence of the early shutting down of the ventilation systems. Moreover the static containment makes it possible to take advantage of the radioactive decay of noble gases and to give time to secure population.

Nevertheless emissions of radioactive aerosols increase because of more unfiltered transfers – all the overpressure is discharged through the leaks of the reactor building. IRSN however underlines that those releases are evacuated at ground level over a long period, thus limiting the transfer of aerosols over long distances.

These assessments show that an improvement of OSIRIS containment could reduce the total activity released into environment in case of a BORAX accident, although this trend is not the same for all the radionuclides. Only the evaluation of the radiological impact on the environment and the population in the short, medium and long terms would have allowed to conclude on the interest of enhancing the containment of the reactor.

5. Radioisotope supply and final shutdown decision

OSIRIS is an experimental reactor with a capacity of 70 MW. It is mainly intended for the technological irradiation of materials and fuel for power reactors. It is also used for industrial applications, notably for the irradiation of enriched uranium targets in order to produce medical isotopes, including molybdenum-99 (^{99}Mo).

The reactor was allowed by decree in June 8, 1965 and commissioned in September 1966. This reactor is therefore one of the oldest nuclear facility in operation in France. ASN indicated thus in 2004 that, given the current safety requirements and the aging of the installation, the continued operation of the reactor would not be allowed beyond 2010. CEA then proposed in 2006 to precisely study the technical feasibility of an extension beyond 2010 without exceeding 2015. On the basis of this commitment, ASN therefore issued a resolution[4] in September 2008. CEA presented in this context a partial safety review file in 2009.

Despite these elements, from March 2011, CEA has called the French Prime Minister for

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[3] The overpressure is the consequence both of the created vapour and the increase in temperature in the building. In this case, this second phenomenon could be significant since the gas-tightness is strengthened and the ventilation systems are shut down. IRSN underlines that the overpressure should be accurately calculated if the decision of improving the reactor building containment is taken.

[4] ASN resolutions prescribe in a legal framework to the licensee.

OSIRIS operation extension beyond 2015, until 2018. CEA motivated its request by the potential lack of medical isotopes during the period between OSIRIS final shutdown and the Jules Horowitz Reactor (RJH) commissioning. RJH is due to replace OSIRIS for radioisotope production.

In this framework, CEA has proposed various plans to ASN, but none of them with works that would lead to major safety improvements before 2018. The implementation of these modifications would indeed require the reactor to be in a shutdown mode. For ASN, these plans where not sufficient due to:

- the lack of major improvement between 2015 and 2018;
- the uncertainties about the effective implementation of the planned work after 2018.

5.1. OSIRIS impact on the production of radiopharmaceuticals ^{99}Mo/^{99m}Tc

The metastable technetium 99 (^{99m}Tc) is a radioisotope derived from the decay of molybdenum 99 (^{99}Mo) and produced by irradiation of uranium targets. Given the international and European health challenges on its supply, ASN has initiated and supported for many years regular exchanges with foreign counterparts to promote a better coordination. ASN has thus alerted the various industry players of the recurrent difficulties of the sector and has stressed the need to anticipate the scheduled shutdown of OSIRIS in 2015. ASN has hold in January 2009 an international seminar to gather the nuclear safety authorities of the countries involved in the production of radiopharmaceuticals, with the participation of the medical and industry representatives.

In Europe, at present, the production is mainly provided by the HFR reactor in the Netherlands and BR2 in Belgium. These two reactors are each able of covering all European requirements. The first, from the same generation as OSIRIS, was returned to service in June 2013 after extensive work. It is not planned to stop on the 2016-2019 period, but the reactor has been recently shut down temporarily by the Dutch authorities for safety culture failure. Regarding BR2, also of the same generation, it is expected to shut down from March 2015 to June 2016 and to restart in July 2016, after refurbishment.

As for alternative production, several other existing reactors may produce small quantities of ^{99}Mo in Europe (in Poland, Czech Republic and Romania). Furthermore, the German reactor FRM II (commissioned in 2004) is likely to cover a large share of European production. The authorization process for the necessary changes to enable the plant to produce ^{99}Mo is ongoing.

At the international level, the OECD Nuclear Energy Agency (NEA) is involved in global efforts to ensure a secure supply of ^{99}Mo/^{99m}Tc. Since June 2009, NEA and its High-level Group on the Security of Supply of Medical Radioisotopes (HLG-MR) have examined the causes of supply shortage and have helped to address them with a policy and regulatory approach. NEA reviews the global ^{99}Mo supply situation periodically. In a 2014 report, NEA expressed that the shortage of ^{99}Mo during the 2015-2020 period is likely to occur but would have limited consequences, even without new production capacity and with OSIRIS reactor and Canadian NRU reactor (the top worldwide supplier) unavailability. It stressed that the main risk on the chain supply is the processing capacity of ^{99}Mo/^{99m}Tc and not the irradiation capacity. It also called for further work to coordinate producers, but considered that the threat may be tempered if the commissioning of the current projects is realized and is not significantly postponed. These delays could be increased by keeping subsidies to aging facilities: this perpetuates an economically unsustainable model, damps investments and is therefore prejudicial to the supply security. The last meeting of the HLG-MR (July, 7th-9th,

2015) confirms this trend.

5.2. ASN position

ASN considers having no guarantee that the recurring difficulties of the sector will be solved in 2018. Indeed, foreign reactors are often as old as OSIRIS and cannot be considered as permanently reliable means of production: some have already experienced technical failure and had to be shut down. Furthermore the completion of the projects to replace this generation of reactors cannot be guaranteed in a close future. In France, CEA is not able to ensure the completion of RJH by 2018.

Due to these delays, ASN considers that OSIRIS operation beyond 2015 could be actually extended up to ten more years, and would therefore require a significant increase of the safety level. This could not be achieved before several years, in the best case. For these reasons, ASN is currently opposed to any operation extension of the plant beyond 2015.

However, to take into account public health safety issues that would come to be proven, ASN may consider a new request in the following conditions:

- A proven risk to public health, duly certified by the health authorities for lack of ^{99m}Tc;
- An operation of OSIRIS strictly dedicated to the production of ^{99}Mo, to the exclusion of any other activity;
- An adapted improvement of the safety of OSIRIS;
- Specific provisions for the management of organizational and human factors to ensure the safety of an installation whose operation should be episodic and could be concomitant with preparation of subsequent decommissioning operations.

ASN had decided to publish its decision of July, 25th, 2014. CEA has since been informed in July 2014 that the Government will not continue funding the facility beyond 2015. The management of the transition between definitive shutdown and decommissioning has started in 2015 thanks to an update of the decommissioning plan and will lead to the submission of a final shutdown and dismantling file by the licensee before the end of 2016.

Remark: Canada announced in February 2015 its decision to cease the routine production of ^{99}Mo from the NRU on October 31st, 2016 but allowed Canadian Nuclear Laboratories (operator of the NRU) to maintain the capability to produce ^{99}Mo on a stand-by basis to be used only in the event of unexpected shortages that cannot be mitigated through other means. This strategy is very similar to the one proposed by ASN.

6. Conclusion

Following ASN request to evaluate the possibility to extend OSIRIS reactor operation until 2018, IRSN has recommended three majors improvements: a new safety demonstration in accordance with the operation conditions approach, a reinforcement of the containment concerning its containment capacity and its resistance to an external explosion and airplane crash.

For ASN, the improvement works proposed by CEA on the containment were not sufficient on the short term to authorize the reactor operation within the current framework. However, ASN has proposed to consider operating OSIRIS reactor for isotope production only, in case of a proven radioisotope shortage during the 2016-2018 period. This option has not been chosen by the authorities in charge of CEA.