Chapter 9
Conclusion

Given the technical and organisational measures in place for operating nuclear power plants, a core melt accident or severe accident can only occur in a power reactor following a series of malfunctions (multiple failures, involving human errors and/or equipment failures), as evidenced by the core melt accidents that have occurred since nuclear power plants first came into use. Such an accumulation of malfunctions can be caused by a single hazard for which inadequate provision was made. This was the case, for example, of the Fukushima Daiichi accident in Japan in March 2011, which was the result of a major external hazard (see below).

In 1979, the accident on reactor 2 of the Three Mile Island (TMI) plant in the United States demonstrated that a series of failures could lead to a core melt accident, even though containment integrity was maintained virtually throughout the accident, which considerably limited radioactive release and avoided any serious environmental impact.

In 1986, the reactivity accident on unit 4 of the Chernobyl nuclear power plant in Ukraine was the result of reactor design defects and a string of wrong decisions and operator errors that led to the destruction of the reactor core, massive radioactive release to the environment and to large-scale contamination. The accident was classed as an INES level 7 event.

Lastly, in March 2011, the magnitude 9 earthquake in Japan and the ensuing tsunami severely affected the country and had serious consequences for the population and infrastructure. In particular, it devastated a large part of the Fukushima Daiichi nuclear power plant. These natural events caused an accumulation of malfunctions (in particular the loss of all electrical power supplies, including the emergency power supply for four of the plant's reactors, and of the heat sink), which in turn led to core melt in three nuclear reactors and loss of cooling of several spent fuel pools [1]. Explosions also occurred in four of the reactor buildings due to the production of hydrogen induced by fuel damage. Very large quantities of radioactive substances were released to the environment. The accident was classed as an INES level 7 event like the Chernobyl accident.

In 2015, it is not possible to produce detailed descriptions of the accident sequences in the Fukushima Daiichi reactors for want of sufficiently precise data. Operating experience feedback from the TMI-2 accident, where actual damage to the reactor core could not be confirmed until 1986 when the vessel of the stricken reactor was opened, suggests that it will take several years to reconstruct a detailed account of the Fukushima Daiichi accident based on observations of the final state of damage to the reactor cores and containments. Estimations of the release and environmental dispersal of radioactive substances are provisional and subject to uncertainties.

Following the TMI-2 accident in the United States in 1979, research in the field of core melt accidents in nuclear power reactors benefited from increased material and human resources. Significant progress has been made in understanding the physical phenomena involved in this type of accident and simulation tools have been developed. This publication testifies to this research investment and the considerably improved knowledge of the complex phenomena involved.

Knowledge in the field has now reached a state of the art in severe accident physics that can be shared by various stakeholders in the nuclear sector (industry, research institutes and regulatory authorities) around the world.

Although significant progress has been made, uncertainties still remain. Consequently, it is not possible to determine whether or not radioactive substances resulting from fuel damage will remain within the containment in all foreseeable accident scenarios. In addition, there is still room for progress in defining measures to guarantee the integrity of the reactor vessel and its containment in the event of a core melt accident and thus keep radioactive release to the environment as low as reasonably achievable.

Contextual changes relating to the safety of nuclear facilities in France, such as:

- the coexistence of Generation II and III reactors in the near future;
- the possible lifetime extension of Generation II reactors beyond 40 years;
- the intention of the authorities to see more effective action taken to mitigate the impact of core melt accidents following that at Fukushima Daiichi;

have led the licensees, along with IRSN and CEA, to submit new research programmes to the authorities aimed at developing knowledge and computing tools in the field of severe accidents. Essentially, these programmes seek to improve the assessment of existing measures concerning Generation II reactors or even propose new ones with a view to:

- arrest as far as possible the progression of the accident in the reactor vessel, in particular by using reactor coolant water to reflood the partially damaged core (when a debris bed or pool of molten materials is involved) in the reactor vessel in all foreseeable core damage configurations;

– arrest as far as possible the progression of the accident in the containment, in particular by pouring water into the reactor pit above or below the pool of molten materials to cool these materials during MCCI; the aim here is to determine how effective cooling is as a means of preventing the ablation of concrete by the corium - and thus avoid basemat penetration – in all foreseeable configurations involving a pool of molten material and for all types of concrete;
– reduce foreseeable iodine and ruthenium releases in the environment in all accident scenarios, including oxidising conditions in the RCS which promote the transfer of gaseous species of these fission products to the containment;
– reduce further the risk of steam explosion in the event of ex-vessel progression, taking into account interactions between molten corium, debris and water in the reactor pit;
– reduce further the flame acceleration risk in the containment in the event of hydrogen combustion.

The acquired knowledge will be used in physical models developed for integral codes, such as ASTEC, and for probability safety analysis to better assess accident risks and their consequences. The results of research on core melt accidents have already had a positive impact on the design of Generation III reactors, like the EPR, with the implementation of equipment and measures aimed at mitigating the consequences of these accidents through the confinement of radioactive substances; the corium catcher is an example of this. Further studies should help to show how effective the systems and measures implemented for this type of reactor are.

It will be important to continue efforts to preserve and develop high-level expertise, drawing on the results of the severe accident research programmes described above. Such efforts should be aimed at:

– improving safety levels for Generation II reactors currently in service by developing increasingly reliable measures to prevent core melt accidents and mitigate their impact on these reactors (not only PWRs but also other reactor systems operated outside France);
– helping to strengthen measures for Europe-wide management of a major nuclear emergency, as the impact of a core melt accident would reach well beyond the borders of any one country;
– for countries like France, which design and export nuclear reactors, sharing their national approach to safety – especially regarding core melt accidents – with countries seeking to develop their nuclear sector.

It will be many years before we have learned all there is to know about reactor safety in light of the Fukushima Daiichi accident, which demonstrated how overlooking natural phenomena at the facility design stage could lead to a severe nuclear accident. Nevertheless, under initiatives such as European stress tests or complementary safety assessments in France, licensees put forward proposals in 2011 for providing nuclear facilities with greater protection against extreme hazards that were previously considered highly unlikely. These proposals were examined by IRSN [2]. Ongoing investigations into the need for more effective accident risk reduction measures might also lead to calls for new severe accident research programmes. The accident at the Fukushima Daiichi nuclear power plant shows that stakeholders in the nuclear sector must continue to unite their efforts to prevent and mitigate the impact of severe accidents for even safer nuclear facilities.

References

[1] Fukushima, un an après, Premières analyses de l'accident et de ses conséquences, Report IRSN/DG/2012-001, www.irsn.fr, 2012.

[2] Évaluations complémentaires de sûreté post-Fukushima: comportement des installations nucléaires françaises en cas de situations extrêmes et pertinence des propositions d'améliorations, IRSN report No. 679, www.irsn.fr, 2011.

Science and Technology Series

Nuclear Power Reactor Core Melt Accidents

Current State of Knowledge

Didier Jacquemain, Coordinator

For over thirty years, IPSN and subsequently IRSN has played a major international role in the field of nuclear power reactor core melt accidents through the undertaking of important experimental programmes (the most significant being the Phébus-FP programme), the development of validated simulation tools (the ASTEC code that is today the leading European tool for modelling severe accidents), and the coordination of the SARNET (Severe Accident Research NETwork) international network of excellence. These accidents are described as «severe accidents» because they can lead to radioactive releases outside the plant concerned, with serious consequences for the general public and for the environment.

This book compiles the sum of the knowledge acquired on this subject and summarises the lessons that have been learnt from severe accidents around the world for the prevention and reduction of the consequences of such accidents, without addressing those from the Fukushima accident, where knowledge of events is still evolving.

The knowledge accumulated by the Institute on these subjects enabled it to play an active role in informing public authorities, the media and the public when this accident occurred, and continues to do so to this day.

The Institute for Radiological Protection and Nuclear Safety (IRSN) is a public body undertaking research and consultancy activities in the field of nuclear safety and radiation protection. It provides the public authorities with technical support. It also carries out various public service missions entrusted to it under national regulations. In particular, these include radiological monitoring of French territory and of workers, management of emergency situations, and provision of information to the public. IRSN expertise is available to partners and customers both in France and abroad.

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IRSN
INSTITUT
DE RADIOPROTECTION
ET DE SÛRETÉ NUCLÉAIRE

Head Office
31, avenue de la Division Leclerc
92260 Fontenay-aux-Roses
RCS Nanterre B 440 546 018
Telephone +33 1 58 35 88 88
Postal address
B.P. 17 - 92262 Fontenay-aux-Roses Cedex – France
Website: www.irsn.fr