European
Commission

# Topical study on fuel related events

*Volume I: Main report*

**Prepared by:**

Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) gGmbH

Institut de Radioprotection et de Sûreté Nucléaire (IRSN)

National Radiation Protection Institute (SURO)

Amri, A.

Finck, D.

Flauw, Y.

Foldenauer, M.

Hrehor, M.

Stuller, J.

Peinador, M. (Editor)

2023

Joint
Research
Centre

**Contact information**
Name: Miguel PEINADOR VEIRA
Address: European Commission, Joint Research Centre (JRC), Westerduinweg 3, Petten, The Netherlands
Email: miguel.peinador-veira@ec.europa.eu

**EU Science Hub**
https://joint-research-centre.ec.europa.eu

JRC132478

PDF ISBN 978-92-76-61948-2 doi:10.2760/024568 KJ-04-23-026-EN-N

Luxembourg: Publications Office of the European Union, 2023



How to cite this report: Foldenauer, M et al., *Topical study on fuel related events*, Luxembourg, Publications Office of the European Union, 2023, doi:10.2760/024568, JRC132478.

Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) gGmbH

# TOER Fuel related Events II
## Volume I: Main report

Deliverable D4

Amri, A.
Finck, D.
Flauw, Y.
Foldenauer, M.
Hrehor, M.
Stuller, J.

December 2022

EU-Clearinghouse

JRC/PTT/2020/OP/0701

European Commission

Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) gGmbH

**Quality Approval Sheet for Management Reports**

**European Commission JRC**
**Framework Service Contract 939770**

**Deliverable D4 of the order No. JRC/PTT/2020/OP/0701**
**"Topical Studies on Nuclear Power Plants Operating Experience"**

**Fuel II**

| | Name | Date | Signature |
|---|---|---|---|
| Author | A. Amri | 04.01.2023 | |
| Author | D. Finck | 29.12.2022 | D. Finck |
| Author | J. Stuller | 04.01.2023 | Ján Stuller |
| IRSN Technical Project Leader | Y. Flauw | 03.01.2023 | |
| SURO Technical Project Leader | M. Hrehor | 04.01.2023 | |
| Administration Manager | G. Niedermeyer | 29.12.2022 | G. Ni |
| Contract Manager | M. Foldenauer | 06.01.2023 | M. Foldenauer |

## Foreword

The European Network on Operating Experience Feedback (OEF) for Nuclear Power Plants, or 'European Clearinghouse', was established by European nuclear safety regulators to promote the regional sharing of operating experience, the dissemination of lessons learned from nuclear power plants (NPP) operation, and the understanding of the role of OEF systems in the safe and reliable operation of existing and new build NPPs. The centralised office of the European Clearinghouse (CH) is operated by the Joint Research Centre (JRC) of the European Commission.

More specifically, the CH project aims to:

- improve NPP safety by strengthening cooperation between licensees, regulatory authorities and the staff of their Technical Support organisations (TSOs) in order to collect, communicate and evaluate information on reactor operational events and systematically and consistently apply the lessons learned in all the European countries taking part;
- establish European best practice for assessing NPP operational events using state-of-the art methods, computer aided assessment tools and information from various national and international sources, e.g. EU national regulatory authorities' event reporting systems and the International Reporting System for Operating Experience jointly operated by the IAEA and OECD-NEA;
- provide staff to coordinate the OEF activities of the European Clearinghouse and maintain effective communication between experts from European regulatory authorities and their TSOs involved in OEF analyses; and
- support the long-term EU policy needs on OEF by harnessing JRC and European TSO research competencies on the methods and techniques of nuclear events evaluation.

The European Clearinghouse (CH) regularly carries out in-depth analyses of events related to a particular topic (the so-called "topical studies") in order to identify and disseminate the lessons learned aiming at reducing the recurrence of similar events in the future.

The present study deals with fuel related events. Its results are presented in two reports:

- The Main Report (Volume 1 – this document) summarises the results obtained by the study, prioritising the recommendations and is intended for unrestricted public distribution.
- The Technical Annex (Volume 2) substantiates the recommendations presented in the Main Report, including details of the events reviewed. It is distributed to the organisations participating in the European Clearinghouse, as well as to authorised users of the IAEA´s International Reporting System for Operating Experience.

## Abstract

Topical studies are a major product of the European Clearinghouse providing in-depth assessment of safety significant events and generic safety issues. This is the second topical study on nuclear fuel from the European Clearinghouse, covering recent events from nuclear power plants in Europe and worldwide. It includes events which occurred during reactor operation, as well as during fuel handling or storage. Taken individually, these events have minor safety significance, but their joint review provides experiences from different countries and reactor technologies that can help nuclear safety authorities to regulate their nuclear installations.

The review of selected events resulted in the formulation of 29 lessons learned. These are discussed and grouped according to various criteria. Thus, this report provides a structured set of generic lessons learned, which may be utilised by regulatory bodies.

## Executive Summary

Topical studies (or Topical Operating Experience Reports, TOERs) are a major product of the European Clearinghouse, providing in-depth assessment of generic safety issues. They are based on the analyses of hundreds of event reports. Their main objective is to identify meaningful lessons to be learned and subsequent recommendations that could be applied by supervisory authorities and NPP operators. Thus, these TOERs contribute to the continuous improvement of nuclear safety.

This topical study includes operating experience on fuel related events in NPPs during in-core operation, fuel handling and during storage on site. These three event types form the main categories of the study with several sub-categories that have been introduced to be better aligned with the first technical report on fuel related events published by the JRC in 2009.

The analyses are not limited to fuel failure events, as they also include those potential events in which fuel has not actually failed, but where fuel design or operating limits have been exceeded or could have been exceeded.

The first step was the search for relevant events in the respective national event databases for NPPs of the Czech Republic, France and Germany. In addition, the International Reporting System for Operating Experience (IRS) is used. This database, jointly operated by IAEA and NEA, is the most important source of significant events from NPPs worldwide. After initial search and pre-selection, a manual screening was conducted to judge the individual events´ relevance for the study which led to the selection of 231 events.

The second step focused on the in-depth analysis of the 231 selected events. These events were grouped in different main categories, sub-categories and various task and cause categories. The main categories and sub-categories used are the following:

- In-core fuel failure events
    - Debris fretting
    - Grid-to-rod fretting
    - Baffle jetting
    - Pellet-cladding interaction
    - Hydriding
    - Corrosion

  - Dimensional changes during operation (rod growth caused by irradiation, fuel/fuel channel bow/twist, etc.)
  - Power oscillation/instabilities
  - Calculation/simulation/calibration/instrument error
  - Manufacturing defects
  - Insufficient cooling
  - Unknown/unspecified.

- Fuel handling events
  - Fuel drop events (outside the core)
  - Fuel handling events (inside the core)
  - Fuel handling events (except fuel drops and in-core events)
  - Core loading errors
  - Other fuel handling events.

- During-storage events
  - Reduction of criticality margin
  - Loss of cooling
  - Actual or potential fuel integrity concerns
  - Radiological impacts.

The results are shown in tables and charts. The comparison with the former technical report on fuel related events, referred to as “Fuel I” in this report, has to consider that it only used the IRS database, as well as a different timeframe of 35 years. In the current topical study, the main categories of “in-core fuel failure” and “fuel handling” present similar shares of about 40 %. In the former study, “in-core fuel failure” made up 54 % of the events reported and “fuel handling” related events only 30 %. This is in contrast to the events reported to the IRS and considered for the current study, where “fuel handling” represents the majority of events (56 %) and “in-core fuel failures” are only about 33 %. In all cases “during storage” presents the lowest shares of reported fuel related events. These differences in reporting shares are also reflected in the sub-categories level, showing differences in individual reported sub-categories. A comparison has been done for IRS events mainly, since they present similar reporting, methodology and coding, while keeping in mind the differences in absolute numbers of events taken into account in the respective studies.

Review of detection mode shows that events are either independent of plant states (e.g. review/analyses) or occur during maintenance/testing (e.g. visual inspection as well as immediate observations). The latter usually demand certain limits to operation or actuate alarms, which are operational in all kinds of plant states. Thus, the consequences in approximately half of the events did not entail significant effects on NPP operation, or the consequences were not relevant to operation and safety. For the remaining events the most frequent consequences included “Exceeding technical specification limits” and “Reduction of safety margins”. Albeit less in number, some resulted in unplanned or significant radiation exposure of personnel or had the potential to result in radiation exposure. The root causes identified and the corresponding corrective actions indicate that the majority of events is attributed to human and organisational factors.

The most important part of the in-depth analysis is the formulation of high-level lessons learned. These are derived from the most important events in each category. All lessons have been assigned to categories and sub-categories and sorted by the predominant root cause. In the Technical Annex, some events are described in detail to illustrate with examples the lessons and recommendations proposed.

The report contains 13 high-level lessons learned in the main category “In-core fuel failures”, 8 lessons in “Fuel handling events” and 8 lessons in “During storage events”.

The 13 high-level lessons learned in the main category “In-core fuel failures” have been assigned to the following root causes:

- Design configuration and analysis (6)
- Maintenance, testing or surveillance (2)
- Written procedures and documents (2)
- Equipment (procurement) specification, manufacture, storage and installation (1)
- Work organization (1)
- Use of operating experience (1).

For the main category of “Fuel handling events”, the 8 high-level lessons learned relate to:

- Work organization (2)
- Written procedures and documents (2)

- Personnel work practices (2)
- Design configuration and analysis (1)
- Training/Qualification (1).

The identified 8 high-level lessons learned in the main category “During storage events” concern:

- Equipment qualification, testing or surveillance (2)
- Work organization and Safety Culture (2)
- Design configuration and analysis (1)
- Personnel work practices (1)
- Work organization and written procedures (1)
- Written procedures and documents (1).

## Content

# 1 Introduction

This Topical Operating Experience Report (TOER) on fuel related events has been developed by Technical Safety Organisations (TSO) – the Czech SÚRO, the French IRSN and the German GRS - on behalf of the European Clearinghouse /1/, /2/. The main basis of the evaluation and assessment have been the national event databases of the Czech Republic, France and Germany. In addition, the international event database IRS (International Reporting System on operating experiences jointly managed by the IAEA and the OECD-NEA) provided input from safety relevant events all over the world.

# 2 Methodology and database screening

## 2.1 Methodology

The TOER on “Fuel related events II” shall complement the findings of the first European Clearinghouse technical report on fuel related events (“Fuel I”) issued in 2009 /3/. The latter was based on reports from the IRS database and covered all the years up to mid-2009 since the database was set up. Conversely, the current TOER is based on the operating experience from July 2009 to September 2021 acquired from the national event databases of the Czech Republic, France and Germany as well as the IRS database.

The development of the study was structured in four steps:

1. Selection of relevant events
2. Analysis of the relevant events in such detail that
    - the events could be attributed to the various categories,
    - the affected systems could be identified,
    - causes of the events could be determined, and
    - lessons learned could be described.
3. Integration of the various events from the different databases to derive generic high-level lessons learned.
4. Compilation of the final report.

The consortium has analysed all the events screened per database. The result of the classification has been documented in a common list of events by adding several sub-categories and code fields, describing key elements of these events such as:

- Event main category,
- Event sub-category (type of failure / direct cause),
- System failed/affected,
- Type of initiator/nature of event ,
- Detection mode of the event,
- Root cause(s),
- Corrective actions,
- Consequences of the event,
- Safety relevance and

- Lessons learned.

In addition to the assessment of fuel related events included in the databases, the consortium considered two IAEA documents: (i) *IAEA-TECDOC-2004 Fuel Failure in Normal Operation of Water Reactors: Experience, Causes and Mitigation (Proceedings of a technical meeting)* - published in 2022 /4/ and (ii) *IAEA Nuclear Energy Series, No. NF-T-2.5 Review of Fuel Failures in Water Cooled Reactors (2006–2015)* – published in 2019 /5/ as Update of IAEA Nuclear Energy Series No. NF-T-2.1. Although the two IAEA documents do not describe individual VVER (or WWER - Water-Water Energetic Reactor) fuel related events in detail (as compared to national databases), the facts which they contain correspond to large extent to the results of the current study (e.g. numerous uncertainties, still insufficient clarity in defining the causes of fuel failures and remedial measures) as far as Czech NPPs are concerned. Considered globally in /5/, the VVER fuel failures, assessed within the framework of the IAEA Technical Working Group on Fuel Performance and Technology, based on information provided to the group for the period spanning from 2006 to 2015, were in-core fuel failures due to debris fretting, grid-to-rod fretting around the antivibration grid and hydriding. Debris fretting has been the major failure mechanism in VVER fuel according to /5/.

### 2.2 Description of categories

The database search was performed using specific codes and guidewords appropriate to the language and structure of the respective database. In total 231 reported events could be identified.

The main event categories and their corresponding sub-categories, which are used in the current study, reflect the categories of the 2009 report on fuel related events /3/.

**In-core fuel failure events** were analysed and classified in the following event sub-categories:

- Debris fretting
- Grid-to-rod fretting
- Baffle jetting
- Pellet-cladding interaction
- Hydriding

- Corrosion
- Dimensional changes during operation (rod growth caused by irradiation, fuel/fuel channel bow/twist, etc.)
- Power oscillation/instabilities
- Calculation/simulation/calibration/instrument error
- Manufacturing defects
- Insufficient cooling
- Unknown/unspecified.

**Fuel handling events** were analysed and classified in the following event sub-categories:

- Fuel drop events (outside the core)
- Fuel handling events (inside the core)
- Fuel handling events (except fuel drops and in-core events)
- Core loading errors
- Other fuel handling events.

**During-storage events** include the storage of new and used fuel inside the nuclear power plant. This includes the fresh fuel storage facility and the spent fuel pool. The intermediate dry storage of burnt fuel in fuel containers was not covered by the study, since these are not related to NPP operation even if the dry storage facility is on or adjacent to the NPP site. The events in this event category are analysed and classified in the following event sub-categories:

- Reduction of criticality margin
- Loss of cooling
- Actual or potential fuel integrity concerns
- Radiological impacts.

The focus of the current study was the fuel itself; nevertheless, high-level lessons learned with regard to systems and components were applicable if they clearly aimed at preventing an impact on fuel.

## 3 Screening results

In the following sections, the results of the event analyses are shown in separate tables based on the chosen categories. The results are also shown in simple graphs and are compared with the results of the first report on fuel related events /3/ where applicable.

### 3.1 Fuel event distribution permain category

Tab. 3.1 shows the results of the evaluation of the main categories.

**Tab. 3.1** Results of the event analysis by main category

| **Event main category** | **Number of events** | | |
|---|---|---|---|
| **Timeframe** | **2009-2021** | | **Until 2009 /3/** |
| **Database** | **Overall** | **IRS only** | **IRS only** |
| Fuel handling events | 90 | 29 | 58 |
| In-core fuel failures | 87 | 17 | 105 |
| During-storage events | 54 | 6 | 32 |
| **Total number of fuel related events** | **231** | **52** | **195** |

Fig. 3.1 illustrates a relative distribution of the three main categories of the current study. The numbers of fuel handling events and in-core fuel failures are comparable and prevailing; while events related to fuel storage appear less frequent.

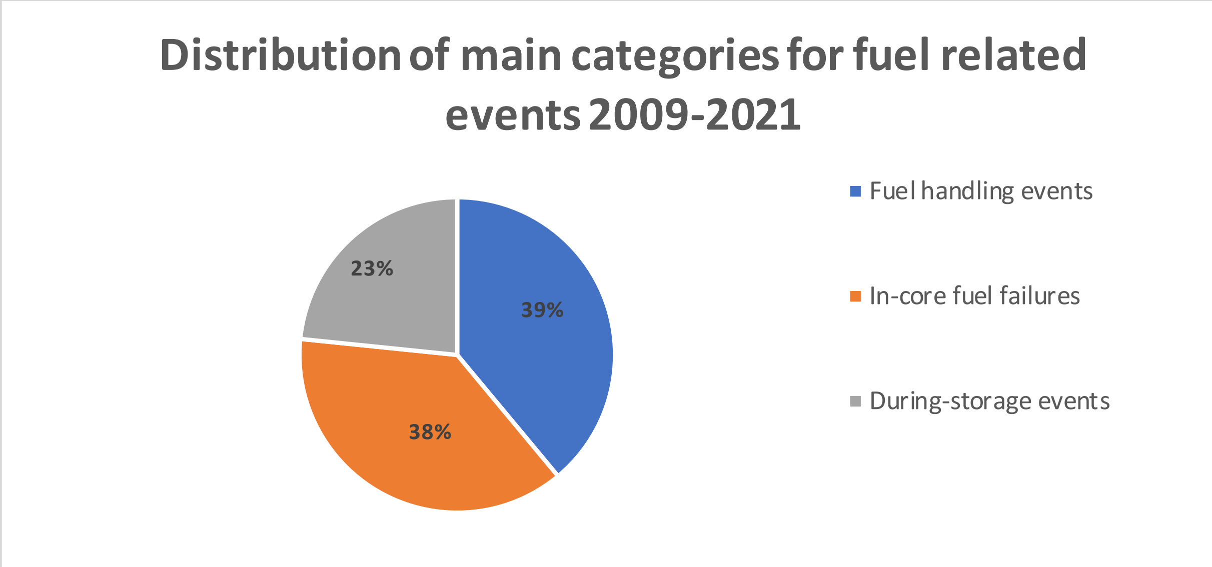


**Fig. 3.1** Distribution of main categories for fuel related events 2009 - 2021

Tab. 3.1 and Fig. 3.1 show that up to 2009 the prevailing fuel related events reported to the IRS were the “in-core fuel failures”, while during the period 2009-2021 the highest number of fuel related events reported concern “fuel handling”.

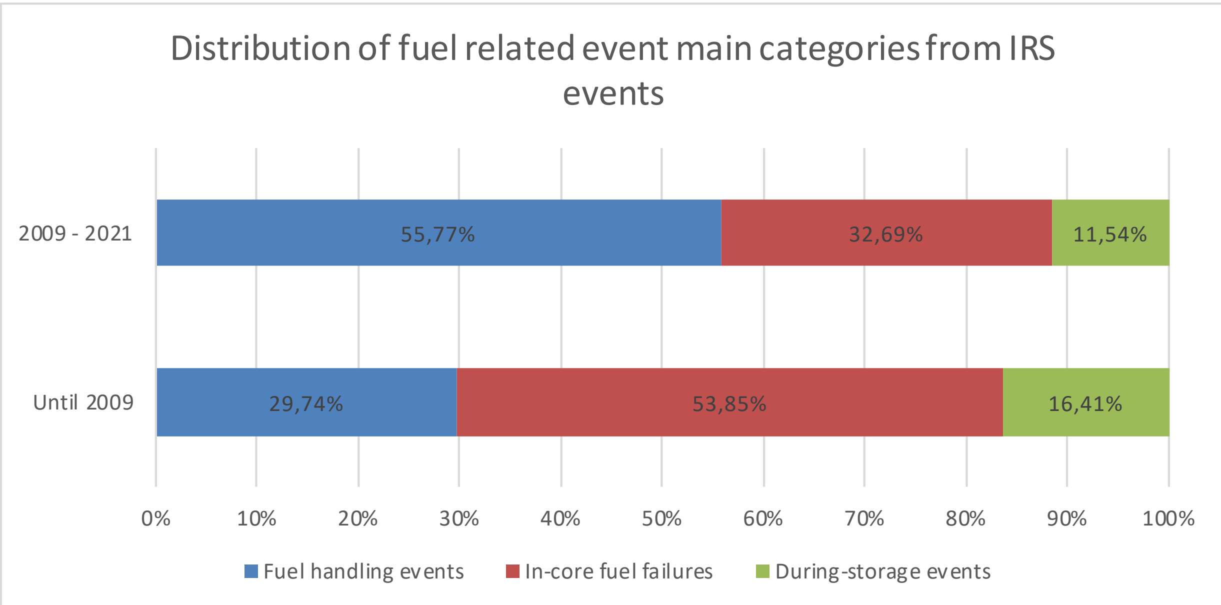


**Fig. 3.2** Distribution of fuel related event main categories from IRS events

### 3.2 In-core fuel failure events

Tab. 3.2 shows the results of the evaluation of the “in-core fuel failure” events in relation to their sub-categories (used in the topical study to describe the direct causes of the events). It is clearly seen that Pellet-cladding interaction (46 %) is the prevailing sub-category in the current study, followed by “corrosion” (15 %).

**Tab. 3.2** Results of the in-core fuel failure event analysis – distribution by sub-categories

| **Sub-categories of the in-core fuel failure events** | **Number of events** | | |
|---|---|---|---|
| **Timeframe** | **2009 - 2021** | | **Until 2009 /3/** |
| **Database** | **Overall** | **IRS only** | **IRS only** |
| Pellet-cladding interaction | 40 | - | 2 |
| Corrosion | 13 | 4 | 15 |
| Debris fretting | 8 | 2 | 8 |
| Calculation/simulation/calibration/instrument error | 8 | 3 | 7 |
| Dimensional changes during operation (rod growth caused by irradiation, fuel/fuel channel bow/twist, etc.) | 6 | 3 | 7 |
| Grid-to-rod fretting | 3 | - | 6 |
| Unknown/unspecified | 3 | - | 7 |
| Baffle jetting | 2 | 2 | 13 |
| Manufacturing defects | 2 | 1 | 4 |
| Power oscillation/instabilities | 1 | 1 | 15 |
| Insufficient cooling | 1 | 1 | 13 |
| Hydriding | - | - | 8 |
| **Total number of in-core fuel failure events** | **87** | **17** | **105** |

In both studies, the event sub-category “Corrosion” prevails among the “in-core failure events” reported to the IRS database. However, in this case, similar conclusions of the analysis could be questioned due to small number of in-core fuel failure events present in the IRS events of the current TOER.

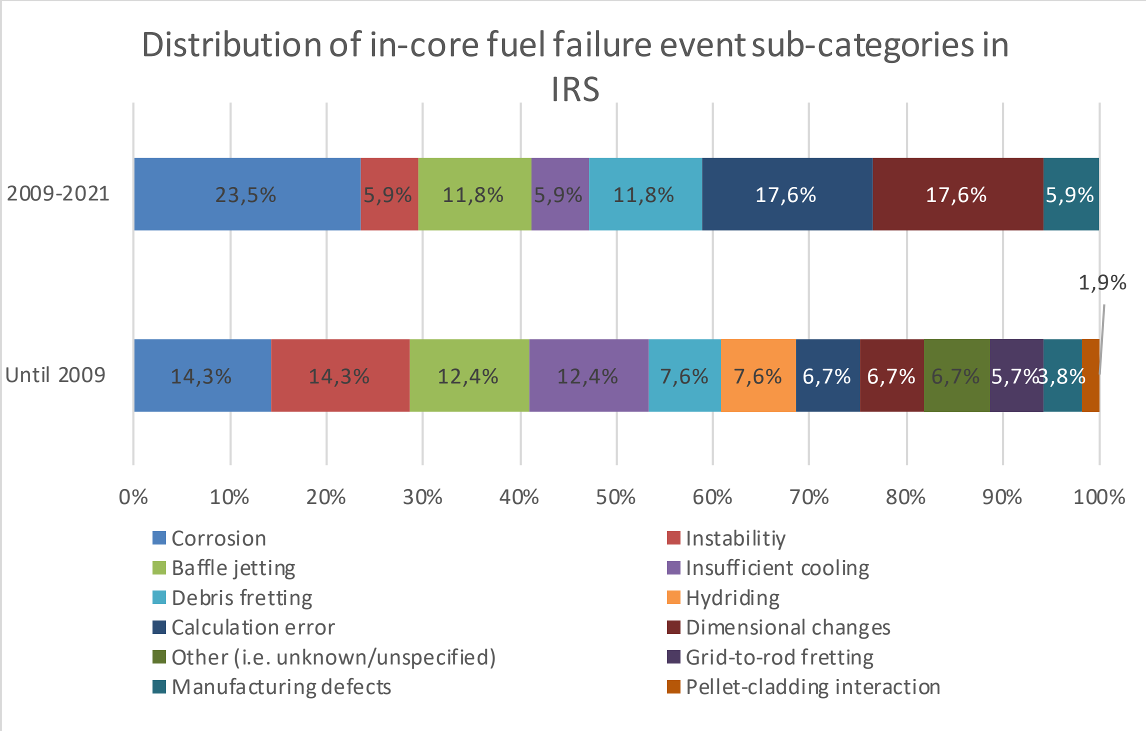


**Fig. 3.3** Distribution of in-core fuel failure event sub-categories in IRS

Notable in the IRS comparison (cf. Fig. 3.3) is the absence of events related to “Pellet-cladding interaction” (PCI). While it represents around 46 % of in-core fuel failure events in the current TOER, no events of such kind have been reported to IRS within the past decade. Another “in-core fuel failure” sub-category which is not present in the IRS reports during the last decade is “Grid-to-rod fretting”, while it represents 3,5 % of in-core fuel failure events of the current study. In the current study no “in-core fuel failure” events were reported to the IRS, which did not match any sub-category, i.e. “Other” in the 2009 study. The only sub-category of “in-core fuel failures”, which is not present at all in the current study is “Hydriding”, which accounted for 7,6 % of in-core fuel failure events of the 2009 study.

### 3.3 Fuel handling events

Tab. 3.3 shows the results of the evaluation of the sub-categories related to “Fuel handling” events.

**Tab. 3.3** Results of the fuel-handling event analysis – distribution by sub-categories

| **Sub-categories of the fuel-handling events** | **Number of events** | | |
|---|---|---|---|
| **Timeframe** | **2009 - 2021** | | **Until 2009 /3/** |
| **Database** | **Overall** | **IRS only** | **IRS only** |
| Fuel handling events (except fuel drops and in-core events) | 43 | 10 | 21 |
| Other fuel handling events | 26 | 7 | 3 |
| Fuel drop events (outside the core) | 7 | 5 | 14 |
| Fuel handling events (inside the core) | 7 | - | 15 |
| Core loading errors | 6 | 4 | 5 |
| Unknown/unspecified | 1 | - | - |
| **Total number of fuel-handling events** | **90** | **26** | **58** |

The most frequent events in the current study, besides those fuel handling activities, which did not include fuel drops and in-core handling (48 %), are other fuel handling manipulations (29 %). The least frequent events were fuel handling inside the core and fuel drop events outside the core (8 % each) as well as core loading errors (6 %).

In relation to IRS only, the event sub-category “Fuel handling events (except fuel drops and in-core events)” also prevails among the fuel handling events. Making similar conclusions for other sub-categories could be questioned due to small numbers of IRS 2009-2021 fuel handling events.

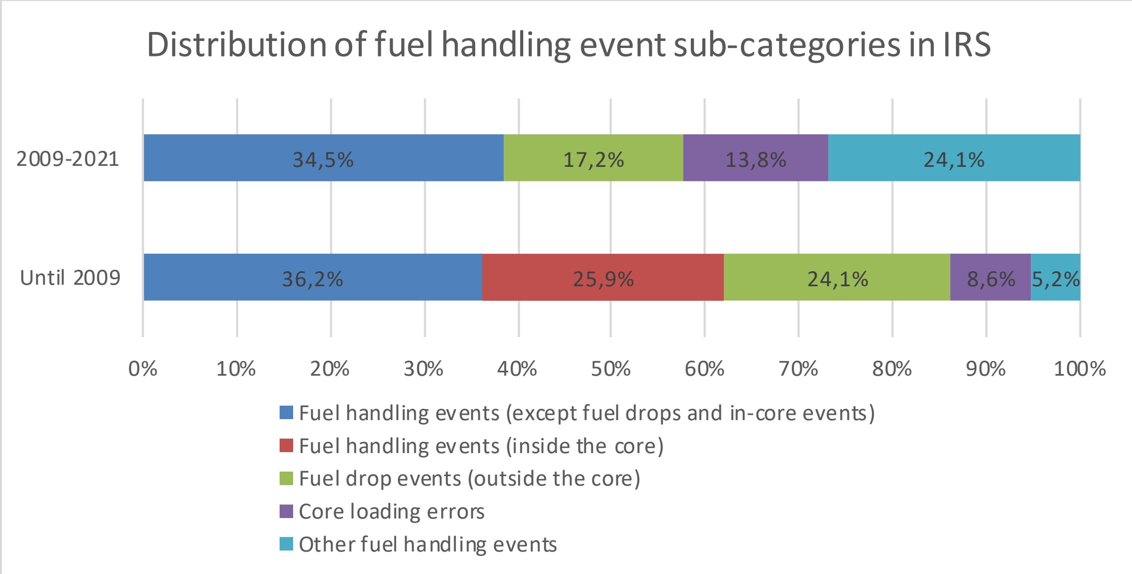


**Fig. 3.4** Distribution of fuel handling event sub-categories in IRS

The overall number of fuel handling events reported to the IRS during the current study´s timeframe equates to half the number recorded in the first study. Fig. 3.4 shows the relative distribution of sub-categories in both studies. While the percentage of "Fuel handling events (except fuel drops and in-core events)" remains roughly the same for the IRS comparison, the integrated data (i.e. taking into account all the databases) shows a higher percentage of 48 %. The share of events related to "Fuel handling events (inside the core)" have dropped from a quarter of reported events in IRS (until 2009) to none in IRS (2009 – 2021). „Fuel drop events (outside the core)", which also made up a quarter of events reported in the first study, have dropped in reporting to 17 % in IRS (2009 – 2021). Both sub-categories still share an equal, albeit lower percentage for the integrated data (~8 %). The "Core loading errors", which have been reported to IRS have risen percentage-wise from 9 % to 14 %, while it has dropped to 6 % overall in the integrated data. A clear distinction overall can be made for "Other fuel handling events". The share of such events has increased not only compared within IRS , but as well as for the integrated data.

### 3.4 During storage events

Tab. 3.4 shows the results of the evaluation of the sub-categories related to "During storage". The prevailing sub-category for this event category was the "Loss of cooling".

Tab. 3.4 Results of the during storage events analysis - distribution by sub-categories

| **Sub-categories of the during storage events** | **Number of events** | | |
|---|---|---|---|
| **Timeframe** | **2009 - 2021** | | **Until 2009 /3/** |
| **Database** | **Overall** | **IRS only** | **IRS only** |
| Loss of cooling | 30 | 1 | 16 |
| Radiological impacts | 15 | 1 | 11 |
| Actual or potential fuel integrity concerns | 7 | 4 | 3 |
| Reduction of criticality margin | 2 | - | 2 |
| **Total number of during storage events** | **54** | **6** | **32** |

Fig. 3.5 illustrates relative distribution of sub-categories (considered in the study as direct causes of the events), which are related to events during the fuel storage.

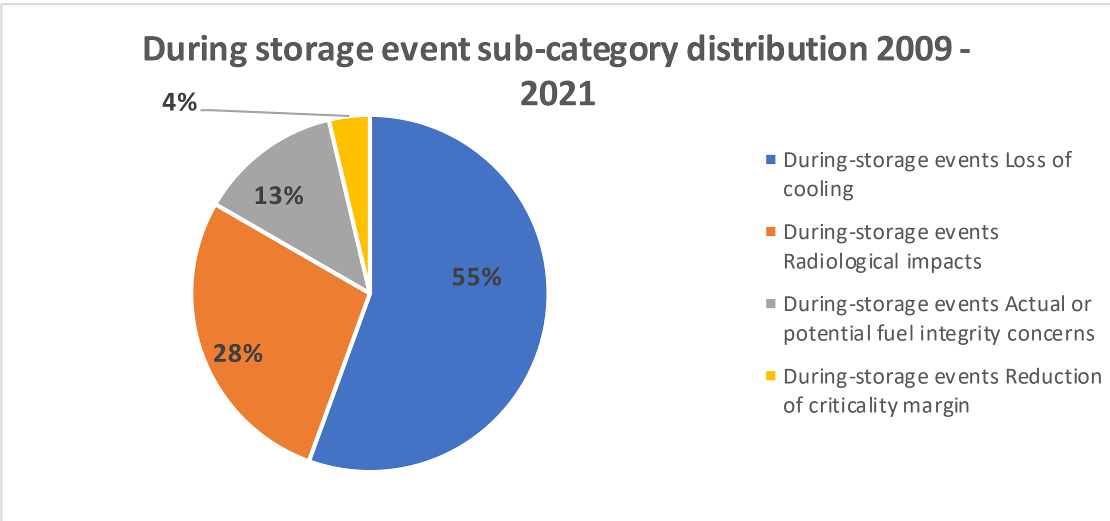


**Fig. 3.5** Results of the during-storage event analysis by sub-categories (all databases)

Due to the small number of during storage events selected from the IRS database 2009-2021, a comparison between the two studies is not meaningful.

When compared to the integrated data, the distribution of subcategories is similar in order and magnitude, with individual shares varying by 7 % at most (cf. Fig. 3.5 and Fig. 3.6).

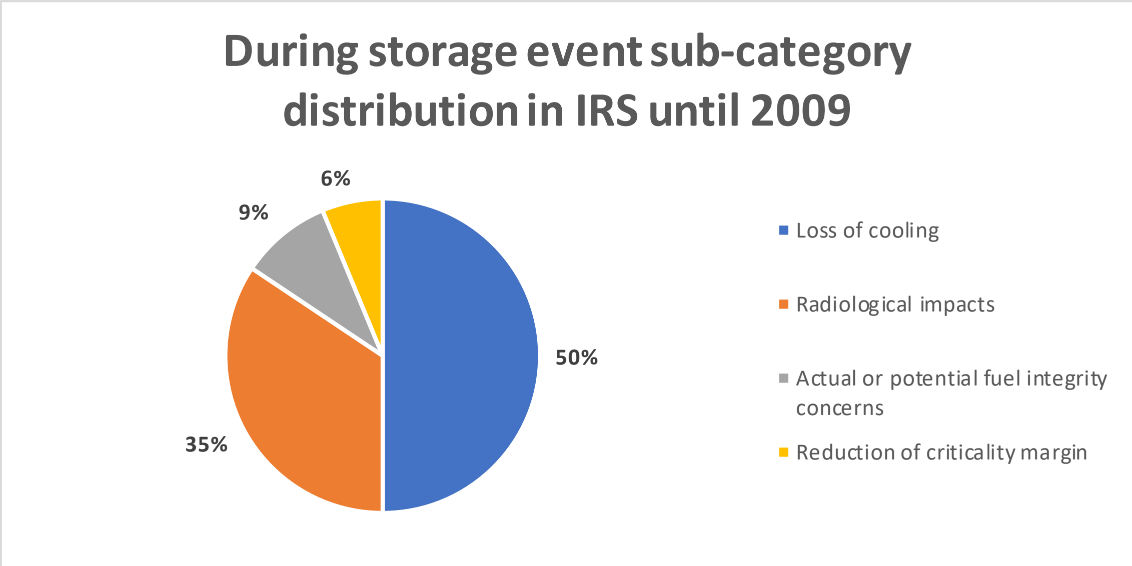


**Fig. 3.6** Results of the 2009 during storage event analysis – distribution by sub-categories (IRS database only)

### 3.5 Distribution of code fields used in the current study

The following subchapters describe distributions of further code fields, which have been utilised in analysing the events. Since similar data is non-existent from the first study ("Fuel I") /3/, no comparisons have been made regarding these code fields.

#### 3.5.1 Detection Mode, Type of initiator and Consequences

As fuel failure occurrences are considered in the design of NPPs, measures and procedures are established to cope with this type of hazards. The detection mode of an event is important for identifying whether the event was detected correctly and on time and has therefore been added as code field.

Furthermore, the "Detection Mode" impacts the coding "Type of initiator/nature of event" depicted in Fig. 3.7. This coding allows to distinguish whether the initiating event has really occurred ("actual") or whether the event could limit or degrade the ability of the NPP to control a potential event as foreseen in the design ("potential"). A third choice named "actual/potential" reflects those reports that include several events that involved “actual” initiators as well as “potential” initiators or “actual” initiators, which had the potential to further affect fuel.

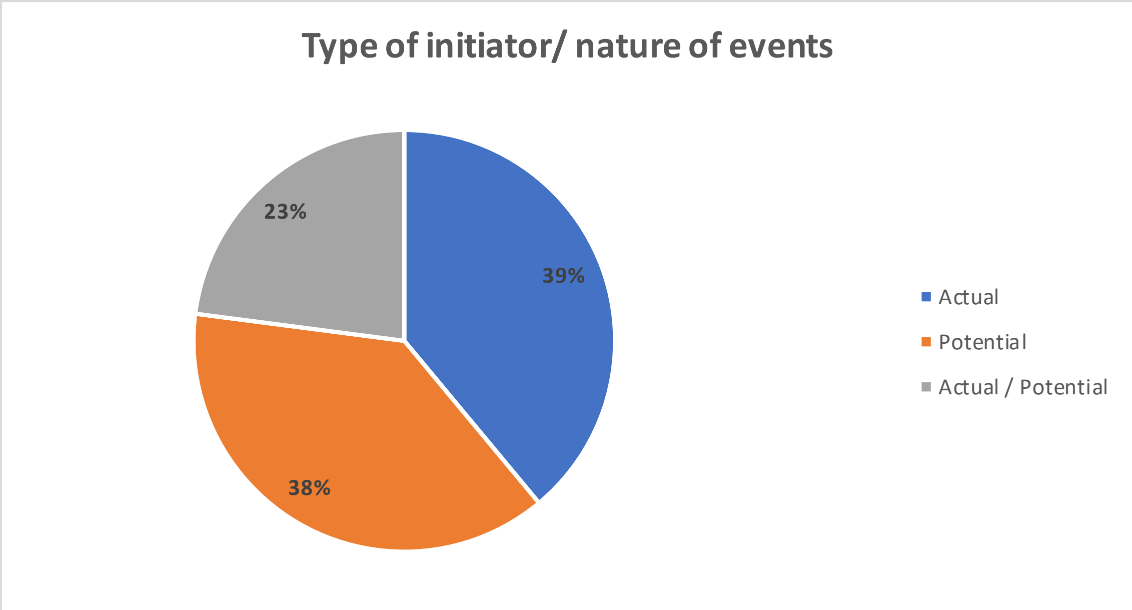


**Fig. 3.7** Relative distribution of events by their initiator/nature

The result of the event evaluation regarding the ”Detection Mode” shows that most of the 231 events were detected by reviews/analyses and immediate observations (each ~24 %). These are followed by visual inspections (~ 18 %) and alarms (~ 14%) (e.g. in the main control room). The further detection modes amount to a common share of about 20 %. In general, more than one detection mode could be attributed to a single event.

Resulting from the “Detection Mode” and “Type of initiator”, the code field “Consequences” was used to illustrate the impact fuel related events had on safety and operation of the NPPs, which includes unplanned or significant radiation exposure of personnel or public, or which potential consequences could have resulted, if not detected on time.

The “Detection Mode” already hints at the “Consequences” an event might entail. The aforementioned main modes of detection are either independent of plant states (e.g. review/analyses) or occur during maintenance/testing (e.g. visual inspection as well as immediate observations). The latter usually demand certain limits to operation or actuate alarms, which are operational in all kinds of plant states. Thus, in approximately half of the events there was no significant effect on NPP operation, or the consequences were irrelevant to operation and safety.

For the second half of events, the most frequent consequences included “Exceeding technical specification limits” and “Reduction of safety margins” (~20 % each of all events). Albeit less in number (~6 %) some events resulted in unplanned or significant radiation exposure of personnel or had the potential to result in radiation exposure.

### 3.5.2 Safety relevance

The common definition (cf. /7/) of safety relevance is related to the conditional core damage probability (CCDP) of the event. This probability can be assessed by precursor studies. The common definitions are:

- high safety significance: CCDP > 10 E-4
- medium safety significance: CCDP < 10 E-4 but > 10 E-5
- low safety significance: CCDP < 10 E-5 but > 10 E-6
- no safety significance: CCDP < 10 E-6

This definition is not applied in the same manner in different countries. For many events (e.g. events reported to IRS), the CCDP is unknown to the consortium analysts. In addition, a number of events are related to the fuel in the spent fuel pool and consideration of conditional fuel damage probability (CFDP) in these cases is more relevant than a CCDP. Another challenge concerns unplanned or significant radiation exposure of personnel or public related events, which cannot be evaluated in terms of CCDP.

In /7/, a further classification principle was applied:

- high safety significance: more than one safety function affected
- medium safety significance: one safety function affected
- low safety significance: safety function redundancy affected
- no safety significance: no safety function safety function affected

In this context, a safety function is a means to prevent or mitigate potential radiological consequences of normal operation, anticipated operational events and accident conditions.

In order to overcome the difficulty of lack of information on CCDP or CFDP, the coding was named “safety relevance” instead of “safety significance” and events with low or no safety relevance have been put into the same category “low safety relevance”.

The consortium analysts have distinguished the “safety relevance” of events with respect to the impact on plant safety and/or unplanned or significant radiation exposure of personnel or public. In most cases, this was based on expert judgement due to a lack of information provided.

The analysis shows that ~94 % of the events are of low safety relevance and ~4 % of the events of medium safety relevance.

### 3.5.3 Root Causes and Corrective Actions

Identifying root causes is crucial for defining and implementing remedial measures and corrective actions, which will effectively prevent the recurrence of similar events and thus strengthen the safety of NPPs.

The root causes have been assigned according to the codes used in /6/. More than one root cause could be attributed to a single event. The prevailing root causes are “design configuration and analysis” (20 %), “written procedures and documents” (19 %) and “work organization” (12 %). They are followed by further human and organisational factors, e.g. “Personnel work practices” (8 %), “Supervisory methods (e.g. standard setting, emphasis of safe work practices & questioning attitude, self-checks)” (7 %), “Training/qualification” (6,3 %) and “Safety Culture” (5,7 %).

The identified corrective actions are aimed at eliminating, or at least minimizing to the extent practicable, the recurrence of similar events. They present an important basis for eliciting lessons learned, and hence recommendations. The most frequent corrective actions reflect the identified main root causes and comprise “improvements in procedure revision process, work oversight and review” (23 %), “repairs or replacements of systems/equipment”, “personnel training” (12 %), “changes in operating mode documents and procedures” (11 %), “analysis” (9 %) and “design modification” (8 %). It has to be noted that more than one corrective action could be attributed to a single event.

# 4 Summary of screening result analysis

## 4.1 Comparison to Fuel I

The comparison of the results of this topical study and the technical report on fuel related events from 2009 (“Fuel I”) /3/ has to reflect the differences between them. In the first study all IRS reports in the database at that time have been screened and taken into account respectively, resulting in 195 events over a timespan of ~35 years. In comparison (cf. Tab. 3.1), the current study relies on 52 IRS reports (out of 231 events in total) in the considered timeframe (2009-2021). This matches roughly if extrapolated to the timespan considered in the first report. For this reason and to avoid ambiguities, which may result from the different number of events taken from the individual national databases, a comparison was made only for IRS events since they present a common basis for reporting, methodology and coding.

In /3/ events related to “in-core fuel failure” were the most reported (~ 56 %), followed by fuel-handling related events (~ 30 %). These reporting shares switched positions in the events reported to IRS and considered in the current study, cf. Fig. 3.2. For the integrated data, there is no clear distinction, with even shares of “in-core fuel failures” and “fuel handling” (~40 %), cf. Fig. 3.1. In all cases “during-storage” events were the least reported. Notable in the comparison of IRS reports is the absence of events related to “Pellet-cladding interaction” (PCI), with only two events in /3/ and none in the current study, cf. Fig. 3.3. On the contrary PCI represents ~ 46 % of “in-core fuel failure” events in the current TOER. Another “in-core fuel failure” sub-category which is not present in the IRS reports during the last decade is “Grid-to-rod fretting”, while it represents 3,5 % of “in-core fuel failure” events of the current study. The only sub-category of “in-core fuel failures”, which is not present at all, neither in IRS nor in the other databases used for the current study is “Hydriding”, which accounted for 7,5 % of "in-core fuel failure” events in 2009 /3/. The overall number of fuel handling events reported to the IRS during the current study´s timeframe equates to half the number recorded in the first study /3/.

While the percentage of “Fuel handling events (except fuel drops and in-core events)” remains roughly the same (~35 %) for the IRS comparison, the integrated data shows a higher percentage of 48 %. The share of „Fuel drop events (outside the core)“ and “Fuel handling events (inside the core)“ have both significantly dropped in the IRS. While each one presented ~25 % of events related to “fuel handling” in the first study /3/ “Fuel handling events (inside the core)“ have not been reported to the IRS in the timeframe considered in the current study. Both of these sub-categories still share an equal, albeit lower percentage for the integrated data (~8 %). The share of the sub-category “Other fuel handling events” has thereby increased five times, representing a similar amount of shares in IRS as well as for the integrated data in the current study. “Core loading errors” have also seen a rise in shares in IRS reports, while the integrated data points to a lesser reporting rate.

The fuel related events concerning “During storage” have the lowest share of reported events. For the 2009 report they present ~16,5 % and 23 % in the current study. A comparison of the IRS reports is not meaningful in this case, since only 6 events from the IRS contributed to the current study. The distribution of sub-categories is similar in shares and magnitude when compared to the integrated data of the current study, varying by 7% at most. “Loss of cooling” presents half of the events in both studies. Second are events related to “radiological impacts”, followed by ”Actual or potential fuel integrity concerns” and events related to “Reduction of criticality margin”.

### 4.2 Results of code field analysis

For the current study, the “Detection Mode” illustrates that the main modes of detection are either independent of plant states (e.g. review/analyses) or occur during maintenance/testing (e.g. visual inspection as well as immediate observations), which usually demand certain limits to operation or actuate alarms, which are operational in all kinds of plant states. Thus, the consequences in approximately half of the events did not entail significant effects on NNP operation, or the consequences were not relevant to operation and safety. For the remaining events the most frequent consequences included “Exceeding technical specification limits” and “Reduction of safety margins”. Albeit less in number, ~6 % resulted in unplanned or significant radiation exposure of personnel or had the potential to result in radiation exposure.

The root causes “design configuration and analysis”, “written procedures and documents” and “work organization” are prevailing, followed by further human and organisational factors such as, “Personnel work practices”, “Supervisory methods (e.g. standard setting, emphasis of safe work practices & questioning attitude, self-checks)”, “Training/qualification” and “Safety Culture”. Overall, human and organisational factors, indicated by the corresponding codes, present the majority of root causes. This is reflected in the most frequent corrective actions, which comprise “improvements in procedure revision process, work oversight and review”, “repairs or replacements of systems/equipment”, “personnel training” , “changes in operating mode documents and procedures”, “analysis” and “design modification”.

# 5 Derivation of High-Level Lessons Learned

The lessons to be learned from the review of operating experience, as reflected in the event reports, have been grouped in event categories and sub-categories, with a few duly justified exceptions.

The extraction of high-level lessons learned from operating experience has been completed in two steps. First, the detailed, event-specific insights were grouped under the main event category. Then, for each category, all information was reviewed in search of common concepts underlying the detailed insights.These concepts were used to define high-level lessons learned for each topic.

In this synthesis effort, lessons learned have been defined in a way that they are neither too specific (so that they would have a too limited applicability) nor too generic (so that they could be considered as common sense) .

High-level lessons learned have been elaborated by considering the following elements:

— The recommended actions in the event reports (what is recommended, e.g. to prevent, to mitigate or to protect the NPP from recurring the same or similar events) including their purposes.
— The actual (observed) consequences motivating the recommended action based on event specific causes or specific lessons learned, which support or justify the high-level lessons learned.

Furthermore, the high-level lessons learned have been grouped according to the corresponding predominant root cause, while in some individual cases these high-level lessons learned may partially reflect other root causes too.

The report contains 13 high-level lessons learned in the main category “In-core fuel failures”, 8 high-level lessons learned in the main category of “Fuel handling events” and 8 high-level lessons learned in the main category “During storage events”.

The 13 high-level lessons learned in the main category “In-core fuel failures” and its sub-categories have been assigned to the following root causes:

- Design configuration and analysis (6)

- Maintenance, Testing or surveillance (2)
- Written procedures and documents (2)
- Equipment (procurement) specification, manufacture, storage and installation (1)
- Work organization (1)
- Use of operating experience (1)

In the “Fuel handling events” category, the 8 high-level lessons learned relate to:

- Work organization (2)
- Written procedures and documents (2)
- Personnel work practices (2)
- Design configuration and analysis (1)
- Training/Qualification (1)

The identified 8 high-level lessons learned in the “During storage events” category concern:

- Equipment qualification, testing or surveillance (2)
- Work organization and Safety Culture (2)
- Design configuration and analysis (1)
- Personnel work practices (1)
- Work organization and written procedures (1)
- Written procedures and documents (1)

## 5.1 In-core fuel failure events

The main category “In-core fuel failure events” comprises 13 high-level lessons learned for the sub-categories of

- Corrosion,
- Fretting,
- Dimensional changes during operation,
- Pellet-cladding interaction,
- Insufficient cooling,
- Baffle jetting,
- Manufacturing defects and

- Calculation/simulation.

### 5.1.1 Corrosion

As pointed out in /3/, corrosion builds up differently depending on the coolant flow regime due to different water chemistry and different sources of corrosion products.

Corrosion not only affects fuel rod cladding, whereby it can lead to fuel failure and leakage of fission products to the reactor coolant system, but can also affect the mechanical integrity of the fuel bundle by severely damaging fastening components (bolts, screws, springs etc.).

#### 5.1.1.1 High level lessons learned

The low-level lessons learned and corrective actions indicated by the events classified in the sub-category “Corrosion” led to five high-level lessons learned that are provided according to the following root causes:

- Lessons Learned ICFF#1 to ICFF#3: “Design configuration and analysis”,
- Lesson Learned ICFF#4: “Equipment (procurement) specification, manufacture, storage and installation”,
- Lesson Learned ICFF#5: “Maintenance, testing or surveillance”.

**Tab. 5.1** High-level lessons learned for In-core fuel failure events – Corrosion

| **In-core fuel failure – Corrosion related high-level lessons learned** |
|---|
| ICFF#1 - Consider stress corrosion cracking sensitivity for iron materials at the mechanical behavior design by ensuring sufficient margin of material resistance |
| ICFF#2 - Improvement of visual inspections by adequate high-resolution cameras and defining inspections as important activity for improved detection means of fuel behavior anomalies and subsequent investigation |
| ICFF#3 - While waiting for curative measures, implement adequate compensatory measures in order to avoid spreading and development of excessive cladding corrosion and CRUD or to mitigate unexpected consequences. |
| ICFF#4 - Improve the assessment of the manufacturing fuel assembly modification effects on in-reactor behavior |
| ICFF#5 - Visual examination of fuel assembly pins before inserting the upper core structure and before lowering the core structure as well as following the cycle. |

##### 5.1.1.1.1 Design configuration and analysis

- LL ICFF#1 - Consider stress corrosion cracking sensitivity for iron materials at the mechanical behavior design by ensuring sufficient margin of material resistance.

Operators and fuel vendors should clearly identify materials sensitive to stress corrosion cracking during reactor operation. Design margins should consider the additional stress induced on fuel assemblies by expected water chemistry changes and to interactions between different materials of fuel assembly components.

- LL ICFF#2 – Improvement of visual inspections by adequate high-resolution cameras and defining inspections as important activity for improved detection means of fuel behavior anomalies and subsequent investigation.

Licensees should improve visual inspections by using adequate high resolution cameras. Furthermore, these inspections should be defined as important activity and should address all components of the fuel assemblies (FA), e.g. cladding and rods, grids, bottom and upper nozzles, in order to improve detection means of fuel behavior anomaly, such as excessive corrosion or CRUD and initiate timely investigations with regard to consequences of FA behavior. Additionally, licensees should perform visual inspections even directly after the first operation cycle in order to verify the expected behavior. Especially FAs known to be sensitive to CRUD and modified FAs should be taken into account in this instance.

- LL ICFF#3 - While waiting for curative measures, implement adequate compensatory measures in order to avoid spreading and development of excessive cladding corrosion and CRUD or to mitigate unexpected consequences.

While waiting for curative measures for instance coming from fuel assembly manufacturing, licensees should sufficiently limit the spread and further development of cladding excessive corrosion or CRUD deposit and its consequences on fuel assembly behavior via compensatory measures (e.g. selection of fuel assemblies to be reloaded, operation at limited power, modification of the stretch entry sequence, changes of the coolant chemistry, improvement of the condensate purification system, …) for the further reactor operation.

##### 5.1.1.1.2 Equipment (procurement) specification, manufacture, storage and installation

- LL ICFF#4: Improve the assessment of the manufacturing fuel assembly modification effects on in-reactor behavior.

Following the implementation of manufacturing fuel assembly (FA) modification, manufacturers should adapt a qualified quality examination method, allowing to identify potential manufacturing defects of any component equipping the FA before its delivery to the NPPs. In general, the change in manufacturing process should be reported to all the stakeholders and the qualification of the equipment and its manufacturing method should be maintained and re-evaluated in order to ensure the FA integrity.

##### 5.1.1.1.3 Maintenance testing or surveillance

- LL ICFF#5 - Visual examination of fuel assembly pins before inserting the upper core structure and before lowering the core structure as well as following the cycle.

To prevent the rupture of FA alignment pins of the upper core and lower core structure of the FAs, licensees should visually check that the pins are not inclined before inserting the upper core structure as well as before lowering the core structure. Indeed, due to the susceptibility of the material and to intergranular stress corrosion cracking, FA pins can break and further degrade during handling operation in the core or the positioning of a bent fuel assembly, and become loose as foreign material in the primary circuit. These checks should also be performed during the outages in order to ensure that no pins were loose during the cycle.

### 5.1.2 Fretting

As explained in chapter 2, the sub-categories of fretting are the same as in the first report on fuel related issues from 2009 /3/, i.e. “Debris fretting” and “Grid-to-rod fretting”. While “Debris fretting” is addressed in this section, it was found more relevant to address “Grid-to-rod fretting” in Section 5.1.3 on the sub-category “Dimensional changes during operation”.

In general, the “Debris fretting” phenomenon consists in failure of the fuel rod cladding due to wear caused by a piece of hard debris trapped in a spacer grid of a fuel assembly. Vibrations induced by the coolant flow affect the debris, which rubs against the cladding and eventually causes its failure. The origin of this debris may either be foreign material (e.g. metal cuttings, screws, wires, tools, welding rods, sawblades, dosimeters, etc.) from maintenance work which ended up in the reactor coolant system during outages, or detached materials from the vessel internals, as well as other parts of the reactor coolant system (e.g. bolts, nuts, fragments of spacer grids, fuel rod end plugs, steam generator plugs, etc.). The size, shape and weight of the debris are such that the coolant flow can carry it through the bottom of the core /3/.

The phenomenon of “Grid-to-rod fretting” occurs when the induced vibrations in the rods of the fuel assembly prevent the grid springs from maintaining the rod in contact with the grid dimples. This allows for an alternating relative displacement between the fuel rod and the grid. The continuous rubbing movement eventually erodes the fuel rod cladding, causing cladding penetration /3/. As pointed out above, this phenomena has mainly been addressed in Section 5.1.3.

#### 5.1.2.1 High Level Lessons Learned

For the sub-category “Fretting” one high-level lesson learned was deduced from the corresponding events provided according to the following root cause:

- Lesson Learned ICFF#6: “Written procedures and documents”.

**Tab. 5.2** High-level lessons learned for In-core fuel failure - Fretting

| **In-core fuel failure – fretting related high-level lessons learned** |
|---|
| ICFF#6 - Improve safety reference against foreign material exclusion and foreign materials noxiousness analysis by identifying safety risk in a reference document |

##### 5.1.2.1.1 Written procedures and documents

- LL ICFF#6 - Improve safety reference against foreign material exclusion and foreign materials noxiousness analysis by identifying safety risk in a reference document.

In order to ensure foreign material exclusion (FME) and thus ensure the fuel assembly integrity, core coolability and core reactivity control, FME training, work organization and written documents and procedures should minimize the FME risk and create an awareness of the risks among the employees. This can be supported, among other things, by additional reactive FME training, additional monitoring in FME areas, additional control steps in the procedures, special signage indicating FME risk, the issuance of appropriately secured tools, and prohibitions on the misuse of tools. Moreover, in case a foreign material is in the core, the noxiousness has to be analyzed and well-documented by licensees.

### 5.1.3 Dimensional changes during operation

Dimensional changes of fuel assemblies can be caused by several different phenomena. It includes both, changes in the initial geometry of the fuel assembly, and changes of the water channel canisters.

As described in /3/, axial forces on the fuel assemblies, exerted by the hold-down springs of the top nozzle, the weight of the fuel assembly, and the lift force driven by the coolant flow, can cause fuel assemblies to bow. On the other hand the neutron irradiation reduces the strength of the hold-down springs and the spacer grid springs, thereby reducing both the axial forces on the fuel assembly and its rigidity. But, at the same time, it causes linear expansion of the fuel assemblies due to material growth, the effect of which is a great increase in the axial forces. This latter effect is predominant, and directly depends on the burnup.

Other contributors to fuel assembly and channel bow are differential irradiation growth caused by fast fluence gradients, residual stress relaxation under irradiation, and initial manufacturing.

Growth, bow, bulge or twist of these elements have the following main safety implications:

a. It affects the thermal hydraulic conditions, by modifying the cross-sectional area for the coolant flow. The coolant flow can be reduced or augmented with respect to design conditions, which can lead to reduced dryout margins, or local power increases in some areas due to over-moderation.
b. The fuel assembly or the channel box can interfere with the control rods or control blades, increasing the insertion time, or even preventing them from reaching their full inserted position. Regarding channel bow, the friction with the control blades during insertion can additionally lift the fuel assembly and transfer the stresses to the reactor internals.
c. If the bow is excessive, the structural integrity of the fuel assembly can be jeopardised and the fuel rods might fail.

#### 5.1.3.1 High Level Lessons Learned

The individual lessons learned and corrective actions regarding the sub-category "Dimensional changes during operation" indicate two high-level lessons learned and are provided according to the following root causes:

- Lesson Learned ICFF#7: "Design configuration and analysis",
- Lesson Learned ICFF#8: "Maintenance, testing or surveillance".

**Tab. 5.3** High-level lessons learned for In-core fuel failure - Dimensional changes during operation

| **In-core fuel failure – dimensional changes related high-level lessons learned** |
|---|
| ICFF#7 – Reduction of the in-core FA deformation by sufficient transverse stiffness and adequate spacer corner design |
| ICFF#8 – Optimization of fuel management strategy and placement of the FA in the core in order to reduce FA deformation |

##### 5.1.3.1.1 Design configuration and analysis

- LL ICFF#7 – Reduction of the in-core FA deformation by sufficient transverse stiffness and adequate spacer corner design

To avoid fuel assembly (FA) deformations during operation and thus to prevent FA damaging and safety functions impairments (e.g. grid-to-grid-fretting, increase in the drop time of control rods, damage of FA and control rods), manufacturers should ensure sufficient transverse stiffness or adequate spacer corners at the design stage.

##### 5.1.3.1.2 Maintenance, testing or surveillance

- LL ICFF#8 - Optimization of fuel management strategy and adequate placement of the FA in the core in order to reduce FA deformation.

To avoid fuel assembly (FA) deformations during operating and thus to prevent from FA damaging and safety functions impairment (e.g. grid-to-grid-fretting, increase in the drop time of control rods, damage of FA fuel assemblies and control rods), licensees should ensure an appropriate fuel management strategy and an adequate FA placement in the core, taking into account different sources of relevant operating experience (e.g. increase in cycle-to-cycle deformation).

### 5.1.4 Pellet-cladding interaction

The phenomenon of “Pellet-cladding interaction” (PCI), in general can be explained the following way, as pointed out in /3/:

“During irradiation, fuel pellets experience changes, such as cracking, relocation, or crack healing, which modify their initial shape and which could result in direct mechanical contact between the fuel pellet and its cladding. This contact can exert high local stresses. Additionally, fission products released through cracks from the irradiated fuel may chemically attack the cladding inner surface at the points of contact. As a consequence of the combined stress and the chemical attack, stress corrosion cracking may develop. Breaks or defects in the fuel pellet surface (chipping) also contribute to high local stress on the cladding. In steady state, the cracks may or may not propagate to the outer surface of the cladding.

However, during abrupt power variations, the local stress on the cladding increases substantially, due to the swelling of the fuel pellets, thus increasing the possibility of cladding failure due to propagation of the cracks. Operation at an intermediate power level for long periods can initiate the phenomenon."

#### 5.1.4.1 High-Level Lessons Learned

The sub-category "Pellet-cladding interaction" led to one high-level lesson learned:

- Lesson Learned ICFF#9: "Design configuration and analysis".

**Tab. 5.4** High-level lessons learned for In-core fuel failure - Pellet-cladding interaction

| **In-core fuel failure – Pellet-cladding interaction related high-level lessons learned** |
|---|
| ICFF#9 - Improve the means to better detect power gradient limit during operational power changes to prevent fuel rod failure by Stress Corrosion Cracking induced Pellet-cladding Interaction |

##### 5.1.4.1.1 Design configuration and analysis

- LL ICFF#9 - Improve the means to better detect power gradient limit during operational power changes to prevent fuel rod failure by Stress Corrosion Cracking induced Pellet-cladding Interaction.

In order to prevent fuel rod failure by Pellet-cladding interaction due to Stress Corrosion Cracking, reaching the power gradient upper limit during operational power changes of the reactor should be better detected. Therefore, licensees should ensure that the control rod drive sequence is set appropriately for each cycle, start-up procedures preclude normal operation exceeding the power gradient's upper limit, an ergonomic device is in place to alert the operating team to the power increase gradient (as specified in Operating Technical Specifications) to be respected, the operator's competence is given**.**

### 5.1.5 Insufficient cooling

The phenomenon of fuel not experiencing sufficient cooling can have several causes. Among these potential causes are degradation of the heat transfer, unexpected heat generation (e.g. by excessively increased oscillations of the nuclear power, exothermic oxidation of the fuel cladding), or inappropriateness of the coolant flow or coolant density.

The subsequent heat up of the fuel cladding can ultimately cause it to fail. The phenomenon of “Insufficient cooling” can occur during all kinds of operations on irradiated fuel, i.e. during regular power operation, while the fuel is stored in the spent fuel pool, or when fuel is being handled or cleaned. For routine operations during storage, handling or cleaning, spent fuel pool cooling systems, refuelling machines and refuelling operations are designed to remove the residual heat from spent fuel. Appropriate means have also been devised for monitoring spent fuel cooling. For special non-routine operations, special systems and procedures are designed and built to cool the spent fuel. /3/

#### 5.1.5.1 High-level Lessons Learned

The events assessed and their related individual lessons learned and corrective actions indicated one high-level lesson learned regarding the sub-category “Insufficient cooling”:

- Lesson Learned ICFF#10: “Work organization”.

**Tab. 5.5** High-level lessons learned for In-core fuel failure - Insufficient cooling

| **In-core fuel failure – insufficient cooling related high-level lessons learned** |
| --- |
| ICFF#10 - Perform risk analysis prior to maintenance on the reactor and spent fuel pool cooling systems, with special emphasis on electrical power supply systems |

##### 5.1.5.1.1 Work organization

- LL ICFF#10 - Perform risk analysis prior to maintenance on the reactor and spent fuel pool cooling systems, with special emphasis on electrical power supply systems.

To ensure the cooling of the reactor and the spent fuel pool, licensees should perform specific risk analysis prior to maintenance on the respective systems, taking into account the availability of the redundant trains, the deviations (not solved) impacting the unit as well as the need for compensatory measures. Special care should be taken for electrical power supply of these respective systems.

### 5.1.6 Baffle jetting

The so called “core baffle” is a polygonal structure formed by vertical plates bolted together and secured to the core barrel through horizontal plates. In some nuclear power plants, a fraction of the coolant flow is diverted through holes and directed downwards until it mixes with the upflow coolant to cool the region between the baffle and the core barrel.

Under nominal operating conditions existing pressure differentials between the annular space and the core area lead to a situation where at the highest axial level of the plate the gaps between adjacent plates open or widen. Other phenomena, such as failure of the baffle joint bolts due to intergranular stress corrosion cracking (or other mechanisms) may cause larger openings. As a result, lateral (horizontal) jets of coolant coming out of these gaps may impinge on the rods in fuel assemblies located in the core periphery, near the baffle. This high velocity jet may induce severe vibrations in the fuel rods that can eventually cause them to fail. /3/

#### 5.1.6.1 High Level Lessons Learned

The sub-category “Baffle jetting” provided one high-level lesson learned, assigned to the following root cause:

- Lesson Learned ICFF#11: “Use of operating experience”.

**Tab. 5.6** High-level lessons learned for In-core fuel failure - Baffle jetting

| **In-core fuel failure – Baffle jetting related high-level lessons learned** |
|---|
| ICFF#11 – Integration of OEF on Lower Internals Upflow Conversion modifications to avoid baffle jetting |

##### 5.1.6.1.1 Use of operating experience

- LL ICFF#11 - Integration of OEF on Lower Internals Upflow Conversion modifications to avoid baffle jetting

Two baffle jetting events were identified on reactors which followed a different approach and therefore did not implement the Lower Internals Upflow Conversion (LIUC) modification, which most other affected plants had applied in the past. Thus, OEF showed that plants that have full edge baffle bolting arrangements and have a downflow configuration can still experience baffle jetting. In order to prevent baffle jetting impact on fuel rods, the LIUC which allowed nowadays to significantly reduce this phenomenon, should be taken into account by licensees even if further or other corrective actions have been implemented in the reactor.

### 5.1.7 Manufacturing defects

In general, undetected manufacturing defects can eventually result in fuel failure when the fuel assembly is exposed to power operation conditions. For example, as stated in /3/ frequent fabrication defects experienced in the past, included leaking in end plugs caused by internal voids. These voids resulted from different deformation of internal and external cladding surfaces by manufacturing defects such as welding defects, presence of moisture and impurities. In any case, manufacturing errors can result from any step of the manufacturing process and thus pose different potentials to negatively affect fuel during power operation.

#### 5.1.7.1 High Level Lessons Learned

One high-level lesson learned regarding the sub-category “Manufacturing defects” was elicited from the corresponding events and provided according to the following root cause:

- Lesson Learned ICFF#12: “Design configuration and analysis”.

**Tab. 5.7** High-level lessons learned for In-core fuel failure events - Manufacturing defects

| **In-core fuel failure – Manufacturing defects related high-level lessons learned** |
|---|
| ICFF#12 –Implement design as well as human and organizational measures to comply with the specifications related to fuel pellets |

##### 5.1.7.1.1 Design configuration and analysis

- LL ICFF#12 - Implement design as well as human and organizational measures to comply with the specifications related to fuel pellets.

Fuel manufacturers should continue to improve manufacturing and inspection techniques as well as establishing and implementing stricter quality assurance practices aimed at preventing fuel failure events caused by manufacturing defects.

For example, to improve the operational behavior of the MOX pellets, the following design measures should be implemented, in addition to better consideration of human and organizational factors (cleaning and maintenance): (a) Installation of a grid at the level of the presses at the MOX manufacturing plant to retain the non-conforming plutonium particles; (b) reduction of the grid mesh and reinforcement of the cleaning and control process of the grid.

#### 5.1.8 Calculations/simulation

In the nuclear industry mathematical models, calculations and simulations are used during design, as well as operation of nuclear power plants. These help designers and operating personnel to understand the behaviour of NPP systems and components under defined conditions. Furthermore, they are used to establish design basis limits, licence and safety limits, limiting conditions for operation, normal points of operation, etc. and to calculate the margins to operating, licence or design basis limits.

While models, calculations and simulations are well established nowadays in the nuclear industry, their application and subsequent results for design and operation is dependent on the correct input data to be used. User mistakes in applying the correct input data therefore may result in operation outside established margins and safety limits.

##### 5.1.8.1 High Level Lessons Learned

The sub-category "Calculation/simulation" and its corresponding events indicate one high-level lesson learned, which is provided according to the following root causes:

- Lesson Learned ICFF#13: "Written procedures and documents".

**Tab. 5.8** High-level lessons learned for In-core fuel failures – Calculation/simulation

| **In-core fuel failure – Calculation/simulation related high-level lessons learned** |
|---|
| ICFF#13 – At site level, the adequacy between the current state of the fuel reloads and the initial data implemented in the calculation procedure related to Pellet-cladding interaction assisted by Stress Corrosion Cracking with respect to the operating technical specifications should be verified |

#### 5.1.8.1.1 Written procedures and documents

- LL ICFF#13 – At site level, the adequacy between the current state of the fuel reloads and the initial data implemented in the calculation procedure related to Pellet-cladding interaction assisted by Stress Corrosion Cracking with respect to the operating technical specifications should be verified.

Despite fuel designers' efforts in developing fuel designs with improved materials, phenomena such as Pellet-cladding interaction assisted by Stress Corrosion Cracking (PCI-SCC) might still be of concern for some nuclear fuel designs and fuel management. Computerized approaches (e.g. software) are often necessary to justify the operation of the plant with respect to PCI-SCC and are developed at the corporate level to be normally integrated into the operating technical specifications (OTS) at the site level. To avoid non-conformity with the OTS and to reduce PCI risks, the impact analysis of the amendment of the OTS related to PCI should be performed and communicated inside of the document integration process to be considered at the site level. Additionally, relevant communication between the corporate level and the site level as well as adequate consideration by the latter of the procedure related to the evolution of the OTS should be implemented, as applicable. Moreover, a professionalization action should be established for all the personnel involved in the use of the relevant software, for example the personnel who have the rights to initialize or modify a fuel cycle.

## 5.2 Fuel handling events

The main category "Fuel handling events" comprises 8 high-level lessons learned for the sub-categories of:

- Fuel handling in general,
- Fuel handling events (inside the core),
- Fuel handling events (except fuel drops and in-core events),
- Other fuel handling events.

### 5.2.1 Fuel handling in general

Refuelling of nuclear power plant reactors is a well-established and routine operation. The shutdown refuelling systems are semi-automatic and require human intervention.

Typically, refuelling is done once every 12, 18 or 24 months, and a fraction of the fuel assemblies in the reactor core are replaced.

The shutdown refuelling systems are designed to maintain nuclear safety by guaranteeing subcriticality, fuel cooling, fuel integrity and radiation protection. In case of damaged fuel rods, the need to replace them during plant shutdowns or outage extensions also entails recalculation of the core loading pattern. Events during fuel handling may also cause loss of coolant, damage to the fuel or to the core internals, damage to the spent fuel pools and their internals (e.g. racks), as well as radiation exposure to personnel. Furthermore, some fuel handling events can cause debris generation or introduction of foreign material into the core or spent fuel pools. /3/

#### 5.2.1.1 High Level Lessons Learned

The individual lessons learned and corrective actions indicate one high-level lesson learned regarding the whole category "Fuel handling" under "Work organization" root cause.

**Tab. 5.9** High-level lessons learned for Fuel Handling events – General

| **Fuel handling – General high-level lessons learned** |
|---|
| FH#1 – To safely perform fuel handling operations and prevent hazardous events, clearly define the roles among the different staff involved in fuel handling who need to have detailed instructions and the required technical competence |

- LL FH#1: To safely perform fuel handling operations and prevent hazardous events, clearly define the roles among the different staff involved in fuel handling who need to have detailed instructions and the required technical competence.

To safely perform fuel handling operations and prevent hazardous events, special attention should be given to human and organizational factors. The roles among the different staff involved in fuel handling activities should be well defined and they should work in a coordinated way that facilitates the circulation of information in an effective manner during the activity performance. In that respect, activity preparation meeting should be held in such a way that the key phases of the activity are focused on, and a risk analysis is considered. This work organization should be complemented by written procedures including detailed and clear instructions (e.g. on how to act in case of inconsistent or ambiguous values of signals and readings on the refueling machine to assure safe transfer of nuclear fuel) and adequate training of all the staff involved.

### 5.2.2 Fuel handling events (inside the core)

In general, fuel handling events that occurred inside the reactor core are either fuel drops in the reactor core or fuel damage caused by operations while loading or unloading the core, such as introduction of foreign material to the core, interaction between fuel assemblies and core internals during insertion and removal, etc.

The consequences of such events can be manifold. A failure of fuel rods, mechanical damage to the fuel such as bending of fuel rods and/or damage to the fuel grids, which can develop into a structural problem. /3/

#### 5.2.2.1 High Level Lessons Learned

Two high-level lessons learned regarding the sub-category “Fuel handling events (inside the core)” were identified and provided according to the following root causes:

- Lesson Learned FH#2: “Written procedures and documents”,
- Lesson Learned FH#3: “Design configuration and analysis”.

**Tab. 5.10** High-level lessons learned for Fuel Handling - Fuel handling events (inside the core)

| **Fuel handling – Fuel handling events (inside the core) high-level lessons learned** |
|---|
| FH#2 – Make available appropriate and precise procedures to be followed during fuel handling inside the core to avoid the insertion of fuel assembly at high speed, or after maintenance to prevent foreign material drop into the reactor vessel |
| FH#3 – Include in the design of the loading machine a safety measure to detect the spurious resetting of the altimetry and integrate this event in the training of loading machine operators |

##### 5.2.2.1.1 Written procedures and document

- LL FH#2 - Make available appropriate and precise procedures to be followed during fuel handling inside the core to avoid the insertion of fuel assembly at high speed, or after maintenance to prevent foreign material drop into the reactor vessel.

During fuel handling inside the core, appropriate and precise procedures should be available and carefully followed as to avoid the insertion of fuel assembly at high speed, which can threaten the inserted as well as the neighboring fuel assemblies and/or the lower core plate. The same procedures should reflect foreign material exclusion good practices, and include clear instructions to properly reposition, after maintenance, those metal parts that could eventually come loose from their fasteners and fall into the reactor vessel.

#### 5.2.2.1.2 Design configuration and analysis

- LL FH#3 - Include in the design of the loading machine a safety measure to detect the spurious resetting of the altimetry and integrate this event in the training of loading machine operators.

As part of the means to reduce the risk of fuel handling events, the design of the loading machine should include a safety measure to detect spurious resetting of the altimetry. This event and its consequences should be integrated and implemented in the training of loading machine operators.

### 5.2.3 Fuel handling events (except fuel drops and in-core events)

The fuel handling events (except fuel drops and in-core events) address for example fuel handling events which are related to technical provisions which need to be in place in order to perform fuel handling, e.g. containment ventilation settings, or relate to the spent fuel pool.

#### 5.2.3.1 High-level lessons learned

The related individual lessons learned and corrective actions indicate two high-level lessons learned regarding the sub-category “Fuel handling events (except fuel drops and in-core events)” that are provided according to the following root causes:

- Lesson Learned FH#4: “Personnel work practices”,
- Lesson Learned FH#5: “Work organization”.

**Tab. 5.11** High-level lessons learned for Fuel Handling events - Fuel handling events (except fuel drops and in-core events)

| **Fuel handling (except fuel drops and in-core events) related high-level lessons learned** |
|---|
| FH#4: Adapt the speed of the canisters movement and divide the task in different steps during handling activity |
| FH#5: Share, with all the teams involved, the feedback from the event on the requirements for compliance with the organization on the uninterruptibility of lineages/consignation and on operating agreements. |

#### 5.2.3.1.1 Personnel work practices

- LL FH#4 - Adapt the speed of the canisters movement and divide the task in different steps during handling activity.

To prevent collision of canisters with structures or components during lifting/insertion activity, it is recommended to adapt the speed of the canister movement to compensate its oscillations during lifting and divide the task in steps in order to monitor its progress, especially when turbulent flow conditions exist in the pool water.

#### 5.2.3.1.2 Work organization

- LL FH#5 - Share, with all the teams involved, the feedback from the event on the requirements for compliance with the organization on the uninterruptibility of lineages/consignation and on operating agreements.

A process should be identified and integrated in the working organization so to improve the installation of consignation regimes during refueling outages, by sharing, with all the teams, the feedback from the event on the requirements for compliance with the organization on the uninterruptibility of lineages/consignation and on operating agreements.

### 5.2.4 Other fuel-handling events

The “Other fuel-handling events” comprise events which address issues such as radiation protection for personnel, risk mitigation, as well as compliance to procedures for fuel-handling operations.

#### 5.2.4.1 High level lessons learned

The related individual lessons learned and corrective actions indicate three high-level lessons learned regarding the sub-category “Other fuel handling events” that are provided according to the following root causes:

- Lesson Learned FH#6: “Personnel work practices”,
- Lesson Learned FH#7: “Training/Qualification”, and
- Lesson Learned FH#8: “Written procedures and documents”.

**Tab. 5.12** High-level lessons learned from Fuel Handling events – Other fuel handling events

| **Fuel handling events – other fuel handling events related high-level lessons learned** |
|---|
| FH#6 – Protection of workers from radiation by physical barriers |
| FH#7 – Qualification of the staff involved in fuel handling and of the equipment for a high-quality remote visual inspection (RVI) |
| FH#8 – Procedures for container sealing for storage and transport of radioactive materials |

##### 5.2.4.1.1 Personnel work practices

- LL FH#6 - Protection of workers from radiation by physical barriers.

Special preparation of work and hazard analysis should be performed to ensure the safety of workers from radiation. Physical barriers (e.g. hatch blocks, doors, etc.) protecting the personnel from radiation should be implemented and verified before commencing works in order to prevent any hazardous radiation exposure of workers. These physical barriers should be supported by a clear and understandable procedure, with permit systems and managerial approval in case any barrier should be removed in the framework of a special request.

##### 5.2.4.1.2 Training and qualification

- LL FH#7- Qualification of the staff involved in fuel handling and of the equipment for a high-quality remote visual inspection (RVI)

Remote visual inspection (RVI) is one of the important means to reduce risks (e.g. inappropriate fuel assembly behaviour in the core) during fuel handling. To ensure a high-quality RVI, the licensee should precisely specify its expectations, target competent and well trained RVI service providers, and require the formal qualification of the equipment before its use for the RVI.

#### 5.2.4.1.3 Written procedures and documents

- LL FH#8 – Appropriate design of the procedures for container sealing forstorage and transport of radioactive materials.

The procedures for sealing containers for storage and transport of radioactive materials as well as the ergonomics should be designed by suitable measures such as control steps or technical conditions such as the use of different screw lengths or thicknesses in such a way that a specification-compliant sealing of the containers is also ensured if human errors occur during the execution of the procedure, e.g. incorrect use or mix-up of necessary components (screws, seals, gaskets, etc.).

## 5.3 During storage events

During storage events include the storage of new and used fuel inside the nuclear power plant. This includes the fresh fuel storage facility and the spent fuel pool. The intermediate dry storage of burnt fuel in fuel containers was not covered by the study, since these are not related to NPP operation even if the dry storage facility is on or adjacent to the NPP site. Fuel which has been burned up, or is rejected for further irradiation cycles, is stored in a storage facility. Some countries have closed fuel cycle management strategies, where spent fuel is taken to reprocessing facilities after a short period of cooling while in other countries, the fuel is stored until it is disposed of. In both cases, the spent fuel needs to be stored after being deloaded from the reactor until it is reprocessed or disposed of. In order to guarantee the safety of the spent fuel, also in the long term the storage facilities and the corresponding handling equipment are designed to maintain subcriticality in all anticipated conditions, extract the decay heat, limit the radioactive dose to the public and to the workers, and maintain the integrity and confinement of the spent fuel, thereby ensuring compliance with safety criteria for spent fuel. /3/

The main category “During storage events” contains eight high-level lessons learned for the sub-categories of:

- Actual or potential fuel integrity concerns
- Reduction of criticality margin
- Loss of cooling and
- Radiological impacts.

### 5.3.1 Actual or potential fuel integrity concerns

The integrity of fuel assemblies must be maintained throughout the whole storage time. The structural integrity is fundamental for handling of fuel assemblies. Maintaining the fuel geometry ensures adequate cooling, due to the coolant being able to circulate along and inbetween fuel assemblies and transferring residual heat.

Potential causes for loss of fuel integrity during storage can be fuel handling events, corrosion and long-term hydrogen assisted fuel cladding failure. /3/

#### 5.3.1.1 High level lessons learned

The individual lessons learned and corrective actions indicate two high-level lessons learned regarding the sub-category “Actual or potential fuel integrity concerns” that are provided according to the following root cause:

- Lessons Learned DS#1 and DS#2: “Equipment qualification, testing or surveillance”.

**Tab. 5.13** High-level lessons learned from During storage events - Actual or potential fuel integrity concerns

| **During storage related high-level lessons learned** |
|---|
| DS#1 - Qualification of equipment following a design modification |
| DS#2 - Obtain from the contractor a committed action plan allowing to avoid re-producing a gap between the design and the construction of maintenance devices close to the spent fuel pool |

##### 5.3.1.1.1 Equipment qualification, testing or surveillance

- LL DS#1 - Qualification of equipment following a design modification.

The maintenance and periodic testing procedures of the systems, structures and components (SSC) involved in the SFP cooling system should be evaluated and updated regularly. In case of implementation of design modifications the modified equipment should be qualified and functionally tested. The licensee should make sure that no qualification tests were omitted in the past. The updated procedures and tests should be aimed at ensuring the proper functioning of the SFP equipment and at the integrity of the spent fuel elements.

- LL DS#2 - Obtain from the contractor a committed action plan allowing to avoid reproducing a gap between the design and the construction of maintenance devices close to the spent fuel pool.

To reduce the risk of foreign material drop in the spent fuel pool during maintenance activities performed by a service provider, the licensee should obtain from the contractor a committed action plan allowing to avoid reproducing a gap between the design and the construction of maintenance devices close to the spent fuel pool. That action plan should be included in the contractor assessment file for follow-up and monitoring.

### 5.3.2 Reduction of criticality margin

During storage, subcriticality has to be maintained in all anticipated conditions. In spent fuel pools this is achieved by a combination of boron dissolved in the spent fuel pool coolant and neutron absorbers which are embedded in the storage racks. Subcriticality is demonstrated through sound calculation methods which are verified by comparing their results with acceptable standards (other calculation methods, experiments, etc.).

The acceptance of the results of the calculations is based on the safety margin imposed by the regulatory authorities, to be demonstrated with a minimum statistical confidence level, and must include biases, uncertainties, etc.

Therefore, the shutdown margin (a measure of subcriticality) can be reduced by inadequate (insufficient) boron concentration in the spent fuel pool water, either as a consequence of inadequate dosing, or due to dilution, inhomogeneities or damage caused by degradation of the solid neutron absorbers in the storage racks, calculation errors or storage errors. /3/

#### 5.3.2.1 High Level Lessons Learned

The individual lessons learned and corrective actions indicated two high-level lessons learned regarding the sub-category “Reduction of criticality margin” that are provided according to the following root causes:

- Lesson Learned DS#3: “Work organization and Safety culture”,
- Lesson Learned DS#4: “Design configuration, risk analysis and written procedures”.

**Tab. 5.14** High-level lessons learned from During storage events – Reduction of criticality margin

| **During-storage events – Reduction of criticality margin related high-level lessons learned** |
|---|
| DS#3 – Remind the expectations in terms of activity implementation, adapt the monitoring program to address monitoring of administrative lockout-related risks and complete the risk analysis of the activity to implement questioning attitude to the extent possible |
| DS#4 - Complete the risk analysis taking into account all situations that could lead to boron dilution and modify the design or working procedures as necessary. In addition, ensure updating of operating documentation. |

##### 5.3.2.1.1 Work organization and Safety culture

- LL DS#3 – Remind the expectations in terms of activity implementation, adapt the monitoring program to address monitoring of administrative lockout-related risks and complete the risk analysis of the activity to implement questioning attitude to the extent possible.

The expectations in terms of appropriation of the activity file as well as the stakes of the activity should be reminded to and well known by the responders. Moreover, a support to facilitate the sharing between the intervention manager and his team on the expectations of the activity should be created. In support of this, the licensee should adapt the monitoring program to address monitoring of administrative lockout-related risks and conduct a high-stakes briefing on the significance of an administrative lockout to the contractor's teams. Additionally, the risk analysis of the activity should be complete and should reflect the need for a questioning attitude to the extent possible.

#### 5.3.2.1.2 Design configuration and analysis

- LL DS#4 - Complete the risk analysis taking into account all situations that could lead to boron dilution and modify the design or working procedures as necessary. In addition, ensure updating of operating documentation.

To minimize boron dilution risks, the risk analysis to take into account all situations that could lead to boron dilution, including possible input of Nuclear Island Demineralized Water Distribution System, should be completed and, if necessary, modified. Subsequently, the design or working procedures should be modified, as necessary, and the updating of operating documentation, including the documentation used by the contractors, should be ensured. In that respect, the licensee should request the contractor to modify its operating documents to integrate the operations of de-consignation and consignation and the hold point(s) of the operator (fuel service).

### 5.3.3 Loss of cooling

The spent fuel pool (SFP) cooling systems are designed to remove the residual heat from the spent fuel and control the temperature of the spent fuel pool coolant inventory. The main objective is to protect the spent fuel from degrading due to high temperatures.

The operating spent fuel pool coolant pump provides forced circulation of spent fuel pool coolant through heat exchangers, where the perceptible heat is transferred to the cooler water stream. Inside the pool, the coolant inventory cools the fuel assemblies by means of natural circulation. Usually, a source for spent fuel pool water level makeup is also available.

The SFP cooling system sucks in water from the SFP at an elevation that precludes level drop in the event of SFP piping breaks, and is usually equipped with anti-siphoning devices (holes in the pipes) so that line-up errors do not lead to a SFP drainage. Depending on the specific design, the SFP can be connected to other plant cooling systems which could provide alternative cooling. /3/

#### 5.3.3.1 High Level Lessons Learned

The related individual lessons learned and corrective actions indicate two high-level lessons learned regarding the sub-category “Loss of cooling” that are provided according to the following root causes:

- Lesson Learned DS#5: “Personnel work practice”,
- Lesson Learned DS#6: “Work organization and Written procedures”.

**Tab. 5.15** High-level lessons learned from During storage events – Loss of cooling

| During-storage events – Loss of cooling related high-level lessons learned |
|---|
| DS#5 – Implement compliance checks by reading the component cooling system heat exchanger flow rate associated with a reference configuration and share operating experience feedback sheets with the shift teams |
| DS#6 – Identify in the shutdown preparation phase the risk of the planning tasks, include adequate control of correct blockage of protection output signals, require the use of written procedures and share event feedback |

##### 5.3.3.1.1 Personnel work practices

- LL DS#5 - Implement compliance checks by reading the component cooling system heat exchanger flowrate associated with a reference configuration and share operating experience feedback sheets with the shift teams.

The licensee should implement a compliance check by reading the component cooling system heat exchanger flowrate, associated with the reference configuration when lifting administrative lockout. The licensee should modify the Reactor Cavity and Spent Fuel Pit Cooling and Treatment System (PTR) alarm cards to facilitate referral to local alarms. In addition, an operating experience feedback sheet should be drafted and presented to the shift teams, with focus on the implementation of compliance monitoring, the justification of deviations on monitoring walkdowns and the systematic application of alarm sheets.

#### 5.3.3.1.2 Work organization and written procedures

- LL DS#6 – Identify in the shutdown preparation phase the risk of the planning tasks, include adequate control of correct blockage of protection output signals, require the use of written procedures and share event feedback.

The licensee should identify, in the shutdown preparation phase, the risk of the planning tasks including those, which are associated with the prerequisites of the switchboards under boundary condition for intervention. Shutdown procedures and documents should include adequate control of correct blockage of protection output signals during equipment failure simulation tests so as to eliminate loss of function of equipment and system necessary for safety of nuclear fuel. Written procedures should be required to be applied when performing activities and after each event the licensee should write an internal feedback sheet within the operating department, describing the event, the requirement and the actions taken, and share this feedback in the working group on adherence to procedures.

### 5.3.4 Radiological impacts

Radiological impacts, such as radiation exposure can occur as a consequence of spent fuel pool coolant leakage through the spent fuel pool structure or auxiliary systems, or as a consequence of operations being carried out in the spent fuel pool, e.g. during loading or deloading.

The release of radiation to other areas of the plant, or even to the environment, can be a consequence of leakage of the contaminated spent fuel pool coolant from the structures (steel liner, seals, concrete structures) or leakage from systems (e.g. SFP auxiliary systems, SFP cooling and cleaning systems, ventilation systems, etc.). Leakages can be caused by damage to or imperfections in structures (leaks or untightness of the spent fuel pool liner, leaks of seals, etc.) or operational problems, such as clogging of the drainage system (e.g. by boric acid crystallization or foreign material). Operating errors can also cause the release of spent fuel pool radioactive products to the environment.

#### 5.3.4.1 High Level Lessons Learned

The related individual lessons learned and corrective actions indicated two high-level lessons learned regarding the sub-category "Radiological impact" that are provided according to the following root causes:

- Lesson Learned DS#7: "Work organization and Safety culture (and Personnel qualification)",
- Lesson Learned DS#8: "Written procedures and documents".

**Tab. 5.16** High-level lessons learned from During storage events - Radiological impacts

| **During-storage events – Radiological impacts related high-level lessons learned** |
|---|
| DS#7 - Make a reminder of essential radiation safety procedures and present to both the operator teams and the logistics teams the OEF of events. Consider a set of actions for work organization improvement to avoid significant exposures, which should include setting-up a physical system to indicate temporarily contaminated area, Stop&Go on radiological cleanliness and the rules for managing contamination for all agents on the site. |
| DS#8 - Considering the OEF, integrate, in the procedures and documents, the sanitation phase of the equipment and the interfaces between the operators and the logistics managers, and clarify the effluents management to avoid contamination of staff involved in activities related to spent fuel storage. |

##### 5.3.4.1.1 Work organization and Safety culture

- LL DS#7 - Make a reminder of essential radiation safety procedures and present to both the operator teams and the logistics teams the OEF of events. Consider a set of actions for work organization improvement to avoid significant exposures, which should include setting-up a physical system to indicate temporarily contaminated area, Stop&Go on radiological cleanliness and the rules for managing contamination for all agents on the site.

The licensee should make a strong reminder of essential radiation safety procedures for the team members performing defuelling and present the OEF of events to both the operator teams and the logistics teams to highlight the need for a clear set-up point prior to the start of the planned activity and a good coordination during its execution. The licensee should consider, in coordination with service providers, a set of actions for work organization improvement to avoid significant exposure. These should among others include the mappings of the adjoining zones in order to define the work area, the traffic zones, the withdrawal zones and the exclusion zones and minimization of risks of significant exposures of the divers involved in activities close to the spent fuel pool by setting - up a physical system to indicate temporarily contaminated areas and exclusion zones and by implementation Stop&Go on radiological cleanliness and the rules for managing contamination for all personnel on the site.

#### 5.3.4.1.2 Written procedures and documents

- LL DS#8 - Considering the OEF, integrate, in the procedures and documents, the sanitation phase of the equipment and the interfaces between the operators and the logistics managers, and clarify the effluents management to avoid contamination of staff involved in activities related to spent fuel storage.

To avoid contamination of staff involved in activities related to spent fuel storage, the licensee should take into account relevant OEF and integrate, in the procedures and documents that need to be strictly followed, the sanitation phase of the equipment and the interfaces between the operators and the logistics managers and should clarify the effluents management.

# 6 References


/1/ Framework Contract 939770 “NL-Petten: Topical studies on nuclear power plants operating experience”, 2020

/2/ Terms of Reference - Offer: Topical Operational Experience Report (TOER) on Fuel-Events, European Clearinghouse on Operational Experience Feedback, finally signed by the consortium 22.11.2021

/3/ Manuel Martin Ramos, European Clearinghouse: Analysis of Fuel related Events Technical Report, DG JRC – Institute for Energy and Transport 2009

/4/ IAEA, IAEA-TECDOC-2004 Fuel Failure in Normal Operation of Water Reactors: Experience, Causes and Mitigation (Proceedings of a technical meeting), 2022 https://www-pub.iaea.org/MTCD/publications/PDF/TE-2004web.pdf

/5/ IAEA, IAEA Nuclear Energy Series, No. NF-T-2.5 Review of Fuel Failures in Water Cooled Reactors (2006–2015), An Update of IAEA Nuclear Energy Series No. NF-T-2.1, 2019 https://www-pub.iaea.org/MTCD/publications/PDF/PUB1864_web.pdf

/6/ IAEA/NEA Service Series 20: IRS Coding Manual 2022 Edition https://www.iaea.org/publications/15056/manual-for-irs-coding

/7/ Šimić Z., Fernández Andújar B, European Clearinghouse, Events Related to Flooding at NPPs – Topical Study, 2018

## List of Abbreviations

| | |
|---|---|
| AL | (Administrative Lockout in France) |
| CCDP | Conditional Core Damage Probability |
| CCS | Component Cooling System |
| CFDP | Conditional Fuel Damage Probability |
| DB EVENT | (Czech event database) |
| EDG | Emergency Diesel Generator |
| EU | European Union |
| FA | Fuel Assembly |
| FME | Foreign Material Exclusion |
| GRS | GRS: Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) gGmbH |
| IAEA | International Atomic Energy Agency |
| IRS | International Reporting System for operating experiences |
| IRSN | Institut de Radioprotection et de Sûreté Nucléaire |
| JRC | Joint Research Centre |
| LIUC | Lower Internals Upflow Conversion |
| MOX | Mixed Oxide Fuel |
| NEA | Nuclear Energy Agency |
| NL | Netherlands |
| No. | Number |
| NPP | Nuclear Power Plant |
| OECD | Organization for Economic Co-operation and Development |
| OEF | Operating Experience Feedback |
| PCI | Pellet-cladding interaction |
| PIREX | Plateforme Intégrée de Retour d'EXpérience, database |
| PTR | (Reactor Cavity and Spent Fuel pit Cooling and Treatment system in France) |
| RVI | Remote Visual Inspection |
| SCC | Stress Corrosion Cracking |
| SFP | Spent Fuel Pool |
| SÚJB | Státní Úřad pro Jadernou Bezpečnost |
| SURO | Statni Ustav Radiacni Ochrany |
| TOER | Technical Operating Experience Report |
| TSO | Technical Support Organization |
| VERA | VERtiefte Auswertung |

## List of Figures

## List of Tables

).

## GETTING IN TOUCH WITH THE EU

### In person

All over the European Union there are hundreds of Europe Direct centres. You can find the address of the centre nearest you online (european-union.europa.eu/contact-eu/meet-us_en).

### On the phone or in writing

Europe Direct is a service that answers your questions about the European Union. You can contact this service:

— by freephone: 00 800 6 7 8 9 10 11 (certain operators may charge for these calls),

— at the following standard number: +32 22999696,

— via the following form: european-union.europa.eu/contact-eu/write-us_en.

## FINDING INFORMATION ABOUT THE EU

### Online

Information about the European Union in all the official languages of the EU is available on the Europa website (european-union.europa.eu).

### EU publications

You can view or order EU publications at op.europa.eu/en/publications. Multiple copies of free publications can be obtained by contacting Europe Direct or your local documentation centre (european-union.europa.eu/contact-eu/meet-us_en).

### EU law and related documents

For access to legal information from the EU, including all EU law since 1951 in all the official language versions, go to EUR-Lex (eur-lex.europa.eu).

### Open data from the EU

The portal data.europa.eu provides access to open datasets from the EU institutions, bodies and agencies. These can be downloaded and reused for free, for both commercial and non-commercial purposes. The portal also provides access to a wealth of datasets from European countries.

## The European Commission's science and knowledge service

Joint Research Centre

### JRC Mission

As the science and knowledge service of the European Commission, the Joint Research Centre's mission is to support EU policies with independent evidence throughout the whole policy cycle.

**EU Science Hub**
joint-research-centre.ec.europa.eu

@EU_ScienceHub

EU Science Hub - Joint Research Centre

EU Science, Research and Innovation

EU Science Hub

EU Science

Publications Office of the European Union