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Operating Experience with Containment Buildings at Nuclear Power Plants

A summary report from the European Clearinghouse

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2021

Joint Research Centre

EUR 30764 EN

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JRC125565

EUR 30764 EN

PDF	ISBN 978-92-76-40145-2	ISSN-1831-9424	doi:10.2760/161133

Luxembourg: Publications Office of the European Union, 2021

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How to cite this report: Ballesteros Avila, A., Peinador Veira, M. and Simic, Z., ***Operating Experience with Containment Buildings at Nuclear Power Plants***, EUR 30764 EN, Publications Office of the European Union, Luxembourg, 2021, ISBN 978-92-76-40145-2 (online), doi:10.2760/161133 (online), JRC125565.

Contents

Abstract

This report summarizes the results of a review of available recent international operating experience on events related to containment buildings, which have been reported by nuclear power plants (NPP). Event reports, retrieved from the IAEA IRS (Incident Reporting System) and the US NRC LER (Licenses Events Reports) databases, are characterised and used to derive insights and lessons learned. These lessons learned cover topics such as maintenance deficiencies, design issues, deficiencies in documents/procedures, effectiveness of the inspection and monitoring programmes, management and communication issues and safety culture. It is hoped that the findings of this study will help the licensees to improve the safe operation of nuclear power plants and the regulatory authorities to exercise their oversight role.

Acknowledgements

This summary report has been prepared by the European Clearinghouse on NPP Operating Experience Feedback at the Joint Research Centre (JRC), Petten, The Netherlands. The IRS database of NPP events managed by the IAEA and the US NRC Licenses Events Reports database were used for this study.

1. Introduction

This summary report presents relevant results of the topical operating experience study on containment systems carried out by the European Clearinghouse in 2020, [1]. Although other similar reviews have been conducted in the past, as more and more reactors continue to extend their lifetime beyond the originally intended 30 or 40 years, a close monitoring of the trend in the performance of containment buildings and systems is particularly relevant.

The objective of the study was to draw generic and case-specific lessons learned. The lessons are derived from the analysis of containment related events occurred in nuclear power plants (NPP) in a period of ten years (i.e., from 01/01/2010 to 31/12/2019) and reported either to the IAEA Incident Reporting System (IRS) database or to the US NRC Licenses Events Reports (LER) database, [2] and [3] respectively. The study covers not only the structural elements of the containment building (basemat, walls, liners, dome ...) but also other systems required to ensure the safety functions (containment spray systems, pressure suppression pool, instrumentation for containment monitoring, hydrogen control, etc.). All power reactor technologies and containment types were included in the scope of the study.

This summary report is organised as follows: Section 2 provides background information; Section 3 describes the methodology used; Section 4 presents results from the statistical analysis; Section 5 presents derived lessons learned and Section 6 the conclusions.

2. Background information

Many reviews of operating experience related to the safety performance of existing containment systems have been conducted in the past. The Nuclear Energy Agency OECD/NEA published in 1988 one of the first studies with international coverage, including different reactor technologies, [4]. Its scope included not only experience related to the containment passive structures, but also associated systems and equipment. The report analysed 67 events submitted to the IRS database between 1980 and 1987. Some of the most relevant types of events found were isolation valve failures, wrong alignment of systems after maintenance, and events defeating the pressure suppression function of the containments in BWRs. In general, the human factor was behind the vast majority of the highlighted events.

Since then, most international reviews of containment operating experience have been focused on specific aspects, like the corrosion of steel liners or ageing-related degradation mechanisms. For instance, a report from the IAEA published in 2000 examined in detail the cases of corrosion found in BWR steel liners, mostly in Mark I containments during the '80s and '90s, [5]. The report concludes that although the performance of the steel liners in BWRs has been good, "as these structures age, incidents of ageing degradation are likely to increase the potential threat to their functionality and durability". Corrosion of the steel liners, together with stress corrosion cracking of the bellows were identified as the main degradation mechanisms, particularly in areas inaccessible for inspection (e.g., areas adjacent to floors or other equipment or structures).

Another report studied the occurrences of containment liner corrosion reported by US plants in the period 1999-2009, in particular where corrosion starts at the interface between the liner and the concrete wall, [6]. The operating experience from 55 PWRs and 11 BWRs with concrete containment and liners was reviewed, and instances of liner corrosion initiated from the outer liner surface were observed at four plants. In these cases, foreign materials (wood, worker's materials such as gloves, and organic materials such as felt) from initial construction were embedded in the containment and in contact with the liner. On the other hand, corrosion initiated on the inner side of the liner, due to damaged coatings, was found to occur more often than corrosion from the outer side.

More recently, an IAEA report on ageing of concrete structures used in NPPs included a review of experience with concrete in different countries, mostly over the period 2000-2010, [7]. In addition to issues linked to initial design and construction, the most significant problems reported were related to the following: the tendons in pre-stressed containments (corrosion of the wires, leaching of tendon gallery concrete, low prestressing forces and leakage of corrosion inhibitors from tendon sheaths), cracking and spalling of concrete due to freeze-thaw effects, steel liner corrosion and concrete cracking due to alkali-silica reaction.

3. Methodology

A first query of the IRS and LER databases yielded 738 events of potential interest. After a more detailed review, 391 of them (357 from the NRC LER database and 34 from IRS) were deemed relevant for the scope and were used for further study.

Annex 1 of [1] provides the list of the 391 selected events. These events were classified according to eleven categories: plant status, containment type, the means of detection, the systems affected, the components affected, materials affected, hazard type, the direct cause, the root causes, the safety functions affected and the corrective actions. Each category was split into families. A total of 69 families were considered for the complete classification. This classification was needed for the statistical analysis of the events, as described in the following Section.

Further to the classification of events, the reports are also reviewed to identify the aspects of the event that can be used as feedback from operating experience. Initially identified «low-level lessons learned» are stemming from specific events, and generally can be understood only in the context of those events. For this reason, an effort was done to then define «high-level lessons learned», or simply «lessons learned» (LL), which are not too specific (so that they are applicable only to one single plant) nor too wide (so that they can be considered as common sense, and already known to everybody).

Finally, several representative events were selected to illustrate the lessons learned identified during the analysis. These events are described in detail in [1]. Figure 1 below summarizes the methodology followed in the topical study.

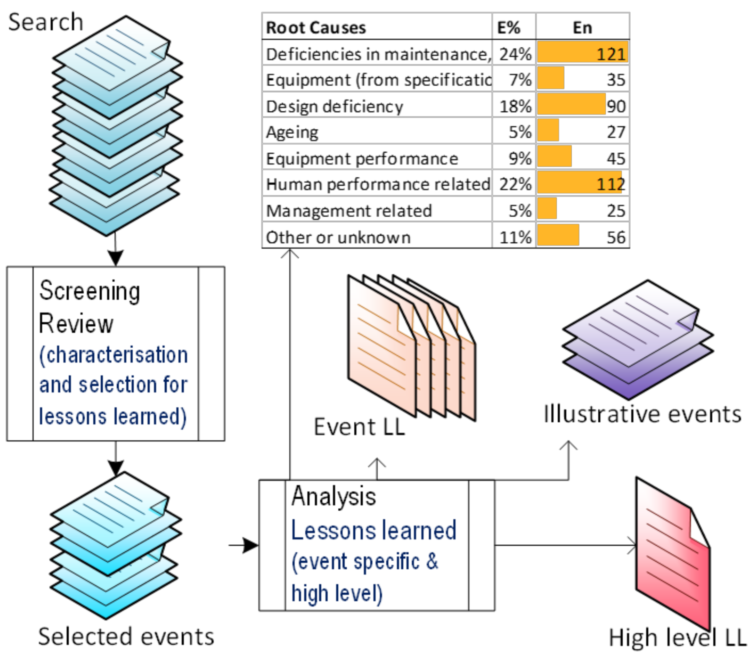
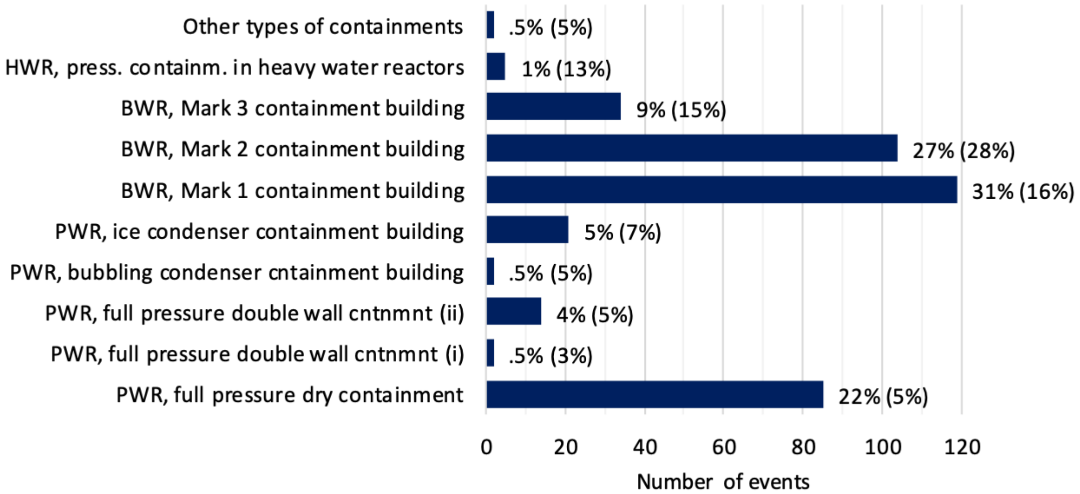


Figure 1. Methodology used for the analysis of the containment events

4. Statistical analysis

This section provides the distributions of events for the following four families: containment types; affected systems and components; root causes. The distribution of events' root causes is given per three families: reactor types, hazard sources and affected systems.

The distribution of events per containment type is given in Figure 2. This includes the number of events and the percentage share (the percentage share in brackets is normalised to the number of reactors). Events for three types of containments are dominating, i.e.: PWR full pressure dry, BWR Mark 2 and Mark 1 (with 22%, 27% and 31% of events, respectively). The normalised percentage share, 5%, is very low for PWR full pressure dry containment type, since this type of containment is present in 45% of the reactors. One of the reasons why BWR plants report more events is that secondary containments in BWR are usually accessible for staff during normal operation, resulting in events related to the frequent access through double hatches.



(i) Inner concrete (with or without steel liner) + outer concrete shield building: French reactors P4/P´4/N4

(ii) Inner self standing steel containment + outer concrete shield building: US reactors in "steel containment" and German PWRs (type KONVOI)

Figure 2 Number of containment related events per containment type

The event distributions for the two categories "systems and components affected" are presented in Figure 3 and Figure 4. Two systems are dominant with one third of the events each: HVAC and venting, and I&C for isolation and monitoring. All other systems are affected with 9% or less events. Air locks, door and hatches are worth special mention because of their similarity and very low safety significance. Active and passive mechanical components are the most affected with 36% and 39% of the events, respectively. I&C components are concerned by 18% of the events. Electrical and structural components are significantly less affected (by only 6% and 2% events, respectively).

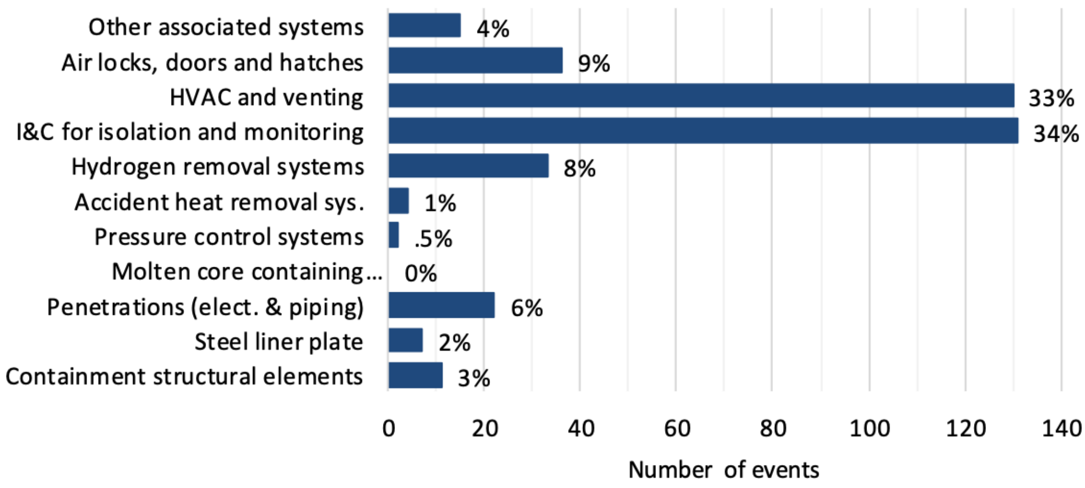


Figure 3 Number of containment related events per affected systems

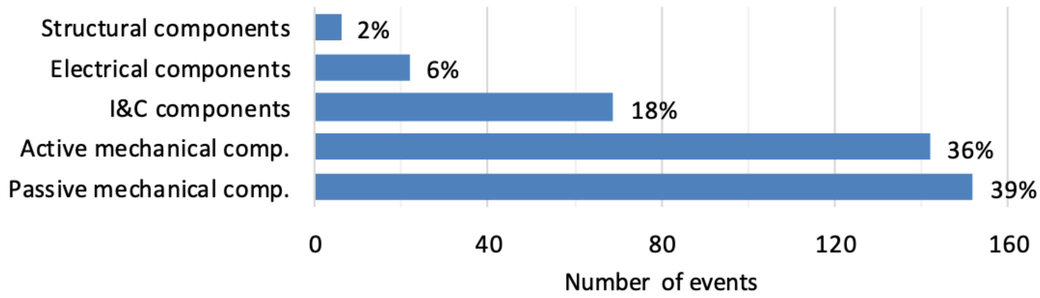


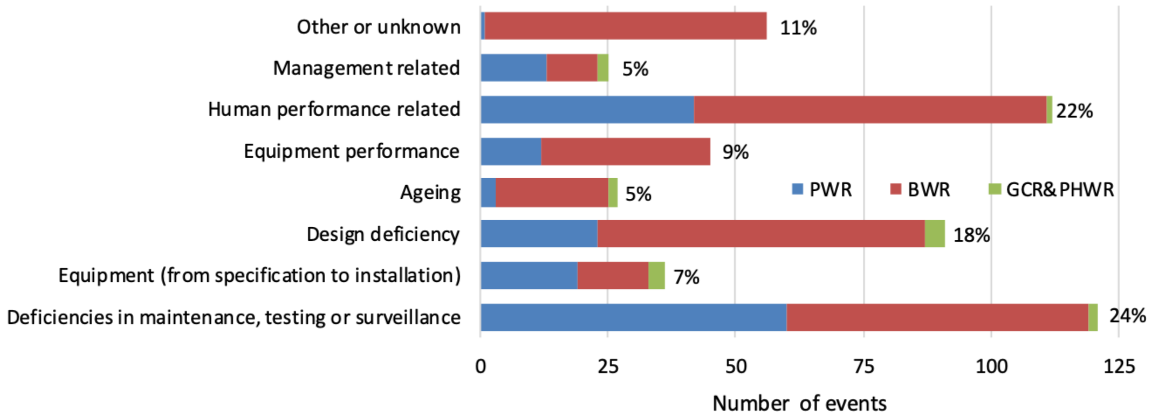
Figure 4 Number of containment related events per affected components

Figure 5 presents the distribution of events per root cause (RC) family and reactor type with total percentage share for each RC family, including all reactor types.

The largest number of events has root cause related to deficiencies in maintenance, testing or surveillance (24%). The second dominant RC family is related to human performance while the third one is related to design deficiencies with 22% and 18% events, respectively. These three RC families are similarly the most dominant for all reactor types. Except for the RC family related to equipment specification, manufacturing, storage and installation - which is the second most important for other reactor types (GCR & PHWR).

Figure 6 shows the event distribution per RC family and hazard source (internal 'IH' and external 'EH').

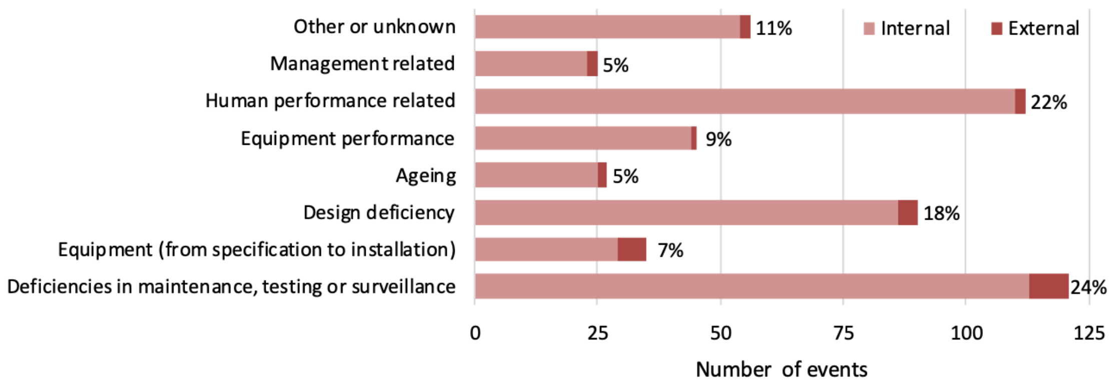
The three most dominant RC families for internal hazards are the same as for the aggregated events since IH events are dominant (95% of the total). They are, as previously noted, related to human performance, maintenance (testing and surveillance) deficiencies and design deficiencies. The most dominant first and third RC family for EH events are the same, while the second one is related to equipment specification, manufacturing, storage and installation.



- Equipment root cause includes specification, manufacturing, storage and installation (including non-conformance/deficiencies during construction)

Figure 5 Number of containment related events per root cause and reactor type (percentage shows total share for the root cause family including all reactor types)

Finally, Table 1 presents the distribution of events per RC family and affected system. As a result of the aggregated distribution, the two most dominant affected systems for all RC families are HVAC and airlocks (doors and hatches). Table 1 also shows the relevance of the contribution of the RC family maintenance, testing and surveillance to the affected systems penetrations, pressure control system and containment I&C (where contribution from human performance related RC is also noticeable).



- Equipment root cause includes specification, manufacturing, storage and installation (including non-conformance/deficiencies during construction)

Figure 6 Number of containment related events per root cause and hazard source

Table 1 Number of events per root cause and affected system

Affected sys.\Root cause#	Maintenance	Equipment	Design	Ageing	Performance	Human	Management	Oth./unkn.	Total/sys.
Containment (structural)	7	4	3	1	0	2	1	1	**19**
Steel liner plate	4	3	1	0	0	0	1	0	**9**
Penetrations	17	4	1	0	0	7	4	0	**33**
Eq./struct. for molten core	0	0	0	0	0	0	0	0	**0**
Pressure control	16	6	7	0	3	10	4	2	**48**
Heat control	1	0	0	0	0	0	0	1	**2**
Hydrogen control	2	1	0	1	0	0	0	1	**5**
Containment I&C	14	5	5	2	5	14	1	2	**48**
HVAC	37	7	26	9	21	22	5	33	**160**
Air locks, doors & hatches	17	1	46	13	16	53	8	13	**167**
Other associated systems	6	4	1	1	0	4	1	3	**20**
Sum per RC	**121**	**35**	**90**	**27**	**45**	**112**	**25**	**56**	**511**

See full name of the root cause families in Figure 6.

5. Lessons learned

The review of the operating experience based on numerous (178) event-specific insights, led to the identification of the following 15 high-level lessons learned (LL) applicable to a wide range of reactor technologies and operational situations, [1]:

LL#01 – The effectiveness of the maintenance programme should be checked periodically. To do that, sufficient data must be captured and held readily retrievable on how equipment failures are detected, what their causes are and what corrective actions are taken.

LL#02 – Learning from plant's own maintenance history and a comprehensive human reliability analysis provide useful means for identifying weaknesses in plant maintenance practices and procedures.

LL#03 – Ensure that robust design is applied, and proven engineering practices are adhered to, in the design of NPP; in this way ensuring that the fundamental safety functions are achieved for all operational states and for all accident conditions.

LL#04 – Preventative measures can be taken in the design and construction phases of containment buildings to eliminate or mitigate material degradation during operation.

LL#05 – Procedures and documents should be clear and technically accurate, provide appropriate direction, and contain sufficient information for users to understand and perform activities effectively.

LL#06 – If the work is high hazard to staff or complex, prior training and/or rehearsal of the procedure should be performed, to familiarize users and to verify the controls and appropriate contingency actions.

LL#07 – The adequacy and effectiveness of the inspection programme should be periodically reviewed to maintain plant safety and to ensure feedback and continuous improvement. The technology and method used should consider the need for early detection of unexpected damage.

LL#08 – A lack of sharing of information, both outside and inside the plant, on operating experience is one of the major contributors to some events. If previous similar events had been recognized, their recurrence might have been avoided. This conclusion implies that it is important to disseminate information on operating experience, incorporate the appropriate corrective actions based on the lessons learned from previous events, and to prepare and execute training programmes for plant personnel and contractor staff.

LL#09 – Managers at all levels in the organization, taking into account their duties, should ensure that their leadership includes actions to encourage the reporting of safety related problems, to develop questioning and learning attitudes, and to correct acts or conditions that are adverse to safety.

LL#10 – Training should be conducted to ensure that individuals are knowledgeable of the relevance and of the importance of their activities, and of how their activities contribute to ensuring safety in the achievement of the organization’s goals.

LL#11 – Prior and during the execution of plant activities (such as maintenance, inspection, etc.) the operator must treat equally its own staff actors and contractor personnel to ensure the same level of communication, information, training and knowledge to perform the tasks.

LL#12 – Communication interfaces should be defined between groups (e.g., maintenance and operation) involved in a specific work. Pre-job briefing should be held at the preparation stage and include all the relevant actors. If contractors are involved, they should be permitted to participate as if they were plant staff.

LL#13 – Post-job briefings are very effective in supporting the policy of collating the lessons learned and in enhancing safety culture. In addition, pre-job briefings need to include safety issues as well as technical instructions.

LL#14 – The involvement of individuals in examining the effectiveness of activities for which they are responsible, or in which they are involved, can help them to understand the need for improvement and should lead them to identify improvement actions.

LL#15 – IRS and LER reports contain information on events of safety significance with important lessons learned which assist in reducing recurrence of events at other plants. Reporting on events needs to be coupled with effective programmes to ensure that the lessons learned from previous events are properly applied.

6. Conclusions

For this study, the IAEA IRS and US NRC LER databases were screened to select relevant events related to containment buildings, from the period between 01.01.2010 and 31.12.2019. In total 34 relevant events were selected from the IAEA IRS database and 357 from the NRC LER database. The examination of the selected events resulted in their classification into 11 categories and 69 families.

HVAC and venting systems, together with I&C systems for isolation and monitoring comprise two thirds of all reported events, but most of them are of very low safety significance. The most common root cause is related to deficiencies in maintenance, testing or surveillance (24% of events), followed by human performance (22%) and design deficiencies (18%), across all reactor types with few exceptions.

This study has identified 178 low level lessons learned (specific for the events) and 15 high level lessons learned (generic). These lessons learned cover different areas, such as maintenance deficiencies, design issues, deficiencies in documents and procedures, effectiveness of the inspection and monitoring programmes, management and communication issues and safety culture.

This study highlights that the continuous analysis of containment related events and the efficient utilization of operational experience provides important insights for preventing the occurrence of unusual events. In particular, some latent deficiencies present in containment structures since their initial construction may remain hidden for decades and become relevant only during the long term operation of nuclear power plants. Thorough and rigorous inspection programmes, as well as a proactive attitude, when the first symptoms of these latent failures begin to appear, are the best line of defence against the ageing of containment buildings.

It is believed that the findings of this study will help the licensees to improve the safe operation of nuclear power plants and the regulatory authorities to exercise their oversight role.

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List of abbreviations and definitions

EH	External Hazard
HVAC	Heating, Ventilation and Air Conditioning system
IAEA	International Atomic Energy Agency
IH	Internal Hazard
IRS	Incident Reporting System for operating experience jointly operated by the IAEA and OECD/NEA
I&C	Instrumentation and Control
JRC	Joint Research Centre of the European Commission
LER	Licenses Events Reports database operated by the US Nuclear Regulatory Commission
LL	Lesson Learned
NRC	US Nuclear Regulatory Commission
NPP	Nuclear Power Plant
OECD/NEA	Nuclear Energy Agency of the Organisation for Economic Co-operation and Development
RC	Root Cause

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KJ-NA-30764-EN-N

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doi:10.2760/161133
ISBN 978-92-76-4015-2