SKI Report 02:63

Research

Procedures as a Contributing Factor to Events in the Swedish Nuclear Power Plants

Analysis of a Database with Licensee Event Reports 1995-1999

Jean-Pierre Bento

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SKI PERSPEKTIV

Bakgrund

Instruktioner spelar en viktig roll i den dagliga driften och underhållet av en kärnkrafts-anläggning liksom vid hantering av störningar. Industrin har under åren ägnat mycket tid och arbete åt att hålla god kvalitet på instruktionerna och göra ständiga uppdateringar och förbättringar. Trots det visar rapporter från händelser vid kärnkraftsanläggningar att brister i instruktioner eller deras användning fortsatt är en faktor som bidrar till flera händelser. Det gäller inte endast i Sverige utan i alla kärnkraftsproducerande länder. För att få till stånd ett utbyte av erfarenheter om instruktioner var Special Expert Group on Human and Organisational Factors (SEGHOF) inom OECD/NEA intresserad av bidrag som kunde belysa området.

SKI:s syfte

Med detta uppdrag ville SKI få besvarat ett antal frågeställningar om instruktioner som bidragande faktor till händelser vid de svenska kärnkraftsanläggningarna. Detta skedde genom en analys av en databas med rapportervärda omständigheter (RO) och snabbstopp (SS) från svenska kärnkraftverk. Rapporten skulle ligga till grund för erfarenhetsutbyte inom SEGHOF och eventuella tillsynsinsatser.

Resultat

Analyser har gjorts av RO och SS från 1995 till 1999, till vilka brister i instruktioner varit en bidragande faktor. Frågor som författaren bidrar till att belysa är i vilka arbetsuppgifter och driftstillstånd som bristerna förekommit och vari dessa bestått.

Fortsatt verksamhet

SKI avser inte att gå vidare med någon forskning om instruktioner just nu.

Effekt på SKI:s verksamhet

Resultaten presenterades för SEGHOF vid ett möte i september 2001. Flera av deltagarna delade de svenska erfarenheterna av att instruktioner bidrar till händelser i flera olika uppgifter och inte minst vid underhåll, ändringsarbeten och provning. Resultaten från analyserna och det internationella erfarenhetsutbytet är ett stöd för SKI:s tillsynsinsatser exempelvis vid inspektioner av underhållsverksamheten vid kärntekniska anläggningar.

Projektinformation

Projekthandläggare på SKI: Gerd Svensson
SKI Ref: 14.3-010846: 01150

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Jean-Pierre Bento

JPB Consulting AB
Box 68
SE-611 23 Nyköping
Sweden

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SKI Project Number 01150

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Summary

The operating experience from the twelve Swedish nuclear power units has been reviewed for the years 1995 – 1999 with respect to events – both Scrams and Licensee Event Reports, LERs – to which deficient procedure has been a contributing cause. In the present context “Procedure” is defined as all written documentation used for the planning, performance and control of the tasks necessary for the operation and maintenance of the plants.

The study has used an MTO-database (Man – Technology - Organisation) containing, for the five years studied, 42 MTO-related scrams out of 87 occurred scrams, and about 800 MTO-related LERs out of 2000 reported LERs.

On an average, deficient procedures contribute to approximately 0,2 scram/unit/ year and to slightly more than three LERs/unit/year. Presented differently, procedure related scrams amount to 15% of the total number of scrams and to 31% of the MTO-related scrams. Similarly procedure related LERs amount to 10% of the total number of LERs and to 25% of the MTO-related LERs.

For the most frequent work types performed at the plants, procedure related LERs are - in decreasing order – associated with tasks performed during maintenance, modification, testing and operation. However, for the latest year studied almost as many procedure related LERs are associated with modification tasks as with the three other work types together.

A further analysis indicates that “Deficient procedure content” is, by far, the dominating underlying cause contributing to procedure related scrams and LERs.

The study also discusses the coupling between procedure related scrams/LERs, power operation and refuelling outages, and Common Cause Failures, CCF.

An overall conclusion is that procedure related events in the Swedish nuclear power plants do not, on a national scale, represent an alarming issue. Significant and sustained efforts have been and are made at most units to improve the quality of procedures. However, a few units exhibit a noticeable departure from the mean values presented herein, indicating for these units a need for focussed corrective actions.

Finally, this report exemplifies how the plant operating experience can be used for the definition of corrective actions based on the detailed analysis of MTO-related causes contributing to event recurrence and to latent weaknesses in safety functions, systems and components.

Sammanfattning

Erfarenheterna från driften av de svenska kärnkraftverken har utvärderats för åren 1995 – 1999 med avseende på händelser – både snabbstopp och rapportervärdra omständigheter (RO) – där bristande instruktion varit en bidragande faktor. Begreppet ”Instruktion” innefattar all skriven förebild som används i planeringen, genomförande och kontrollen av de arbetsuppgifter som ingår i driften och underhållet av verken.

Studien har använt en MTO databas (Människa – Teknik – Organisation) som för de studerade åren innehåller 42 MTO-relaterade snabbstopp av 87 inträffade snabbstopp, och ca 800 MTO-relaterade RO av ca 2000 rapporterade RO.

Britande instruktion bidrar i medeltal till ca 0,2 snabbstopp/block/år och till drygt 3 RO/block/år. Med andra ord, instruktions relaterade snabbstopp utgör 15% av det totala antalet snabbstopp, och 31% av de MTO-relaterade snabbstoppen. På motsvarande sätt utgör instruktions relaterade RO 10% av det totala antalet RO, och 25% av de MTO-relaterade RO.

Instruktions relaterade RO är kopplade – i avtagande ordning – till arbetsuppgifter genomförda vid underhåll, installation/ändringsarbete, provning/kalibrering och drift. För år 1999 rapporterades emellertid nästan lika många instruktions relaterade RO kopplade till installation/ändringsarbete som till de tre andra arbetstyperna tillsammans.

Analysen indikerar vidare att ”Bristande innehåll av instruktion” är den klart dominerande underliggande felorsaken till instruktions relaterade snabbstopp och RO.

Studien diskuterar även sambandet mellan instruktions relaterade snabbstopp och RO, normaldrift och avställning, samt beroende fel (CCF).

En övergripande slutsats är att instruktions relaterade händelser i de svenska kärnkraftverken inte utgör något alarmerande problemområde. En viktig förklaring är att betydande och långvariga resurser har avsatts och avsätts för att förbättra kvaliteten av instruktionerna. Några block uppvisar emellertid en statistik över instruktions relaterade händelser som markant avviker från de medelvärden som presenteras i denna studie.

Rapporten exemplifierar slutligen hur drifterfarenheter kan användas för att definiera korrektiva åtgärder grundade på en detaljerad analys av MTO-relaterade felfaktorer som orsak till upprepning av händelser, samt till latenta fel i säkerhetsfunktioner, -system och -komponenter.

Study objective

The objective of the study has been to obtain an understanding of "Procedure" as a contributing factor to events in the Swedish nuclear power plants. In order to achieve this aim, the MTO-database – see section 3 for definition – was used for years 1995 - 1999.

The main aspects covered by the study are:

- Quantification of procedure related events.
- Topography of underlying deficiencies to procedures.
- Mapping of the main procedure deficiency for frequent work types.
- Relationship between procedure related events and work practice.
- Quantification of procedure related events with CCF character.

MTO-database

All Licensee Event Reports (LERs) and scrams reported to the Swedish Nuclear Power Inspectorate (SKI) are since many years reviewed from an MTO-perspective (Man – Technology – Organisation).

The event reports are screened independently on a yearly basis. For some plants, all MTO-related event reports have been classified after discussions with plant specialists. For other plants these discussions have taken place on a case by case basis. For some events, the classification is based on exhaustive event investigations performed by the staff of the involved units or by external specialists.

After review, the events caused by weaknesses in the interaction MTO are classified and entered into the MTO-database[1]. The event reports entered in this database pertain only to events within the plant and its organisation, including contractors. This means that events relating to conditions at, for example, a valve manufacturing company are normally not further analysed, except for those cases where the plant QA-programme reasonably should have identified the deficiency(ies).

The structure of the MTO-database is built on a classification of the event causes at two levels. The first level is defined as the overall causal category level, exemplified by "Plant management & organisation", "Work organisation", "Procedure", etc. The analysis of the Swedish operating experiences indicates that for the vast majority of plant MTO-related events – scrams and LERs – two or more causal factors have contributed to each one of these events.

"Procedure" in the database is defined as all written documentation used for the planning, performance and control of the tasks necessary for the operation and maintenance of the plants. Accordingly, "Procedure" represents both operating-, testing- and maintenance instructions/ procedures, work orders, system documentation including flow charts and logic diagrams, etc.

[1] The so called MTO-database is maintained by JPB Consulting AB.

The second level is defined as the root cause level, exemplified for “Procedure” by “Deficient content”, “Procedure not updated”, etc.

After ten years of use and fine-tuning, the MTO-database structure has presently 11 MTO causal categories and almost 70 MTO root cause categories.

For the period studied, the database covers the operating experience from all twelve Swedish nuclear power units (nine BWRs and three PWRs).

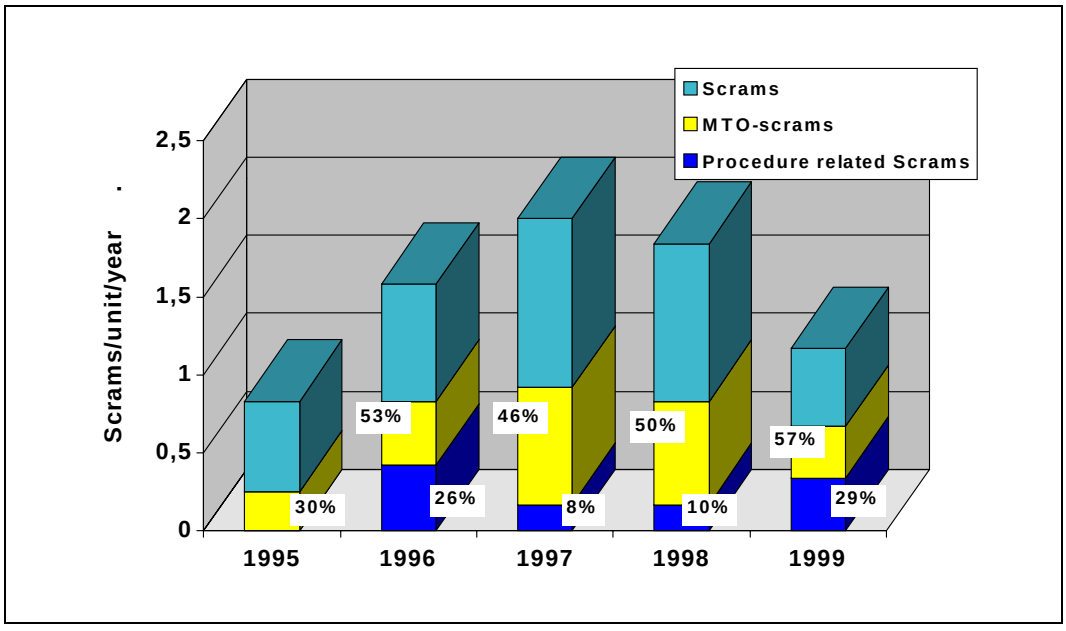
The results presented in the following sections relate mainly to LERs. For scrams, only a general overview is provided, due to the limited data. Some comparative comments to findings from the analysis of the scrams and LERs are however provided.

Results for Scrams

87 scrams occurred during 1995 - 1999. Almost half of these (42) were assessed as MTO-related. The causal category “Deficiencies in Procedures” was one of the contributing factors to 13 MTO-related scrams. These 13 scrams are for short called procedure related scrams and amount to 15% of the total number of scrams, and to 31% of the MTO-related scrams.

Figure 1 provides the number of scrams per unit and year from year 1995 to 1999, and the yearly share of MTO-related, respectively procedure related scrams. All percentages relate to the yearly number of scrams. On an average, deficient procedure thus contributes to about 0,2 scram/unit/year. 40% of this value are related to the performance of operational tasks. The remaining 60% are equally divided between modification, maintenance and testing tasks - see section 6.2 for definitions.

Figure 1: Scrams, MTO- and procedure related Scrams



For the correct understanding of figure 1, it should be noted that one unit was not operating during 1995, due to extensive modernisation works. This unit has on an average experienced 4,5 scrams/year for the years 1996 – 1999.

Due to the limited number of scrams, it is not possible to make any robust conclusions.

Results for LERs

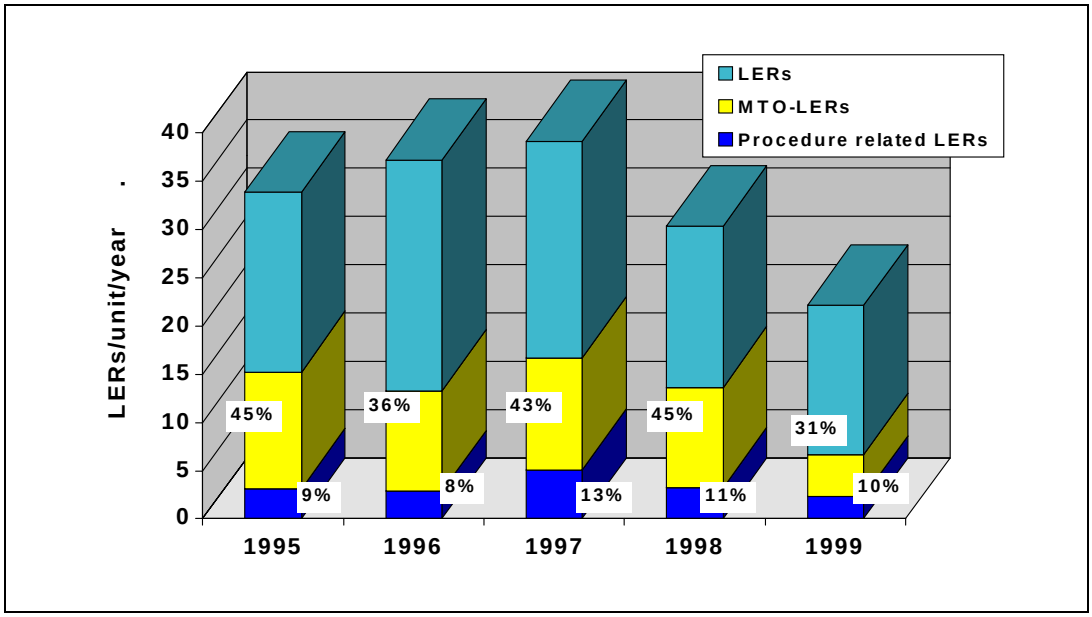
General results

During 1995 – 1999, close to 2000 LERs have been reported to the Swedish Nuclear Power Inspectorate. Nearly 800 of these were assessed as MTO-related. The causal category "Deficiencies in Procedures" was one of the contributing factors to 200 MTO-related LERs. Presented differently, the causal category "Deficiencies in Procedures" has in average contributed to 10% of the total number of LERs, and to 25% of the MTO-related LERs.

Figure 2 provides the number of LERs per unit and year from year 1995 to 1999, and the yearly share of MTO-related, respectively procedure related LERs. All percentages relate to the yearly number of LERs. On an average, deficient procedure thus contributes to slightly more than three (3) LERs/unit/year.

Figure 2 indicates further that the average number of procedure related LERs varies between slightly more than two and five LERs/unit/year. Year 1998 represents a distinct trend break in the number of LERs reported.

Figure 2: LERs, MTO- and procedure related LERs.



Procedure related LERs for different work types

This section presents to which extent procedure related LERs are associated with some of the most frequent work types. The following work types have been studied:

- Operation: this work type includes all tasks performed by the operation department, except Technical Specifications related testing (se below) and fuel handling which represents a separate category.
- Testing, Calibration & Configuration Management Control: this category (in the following called "Testing") includes all "testing" tasks performed as periodical testing by the operation and other departments. This category includes also testing after maintenance.
- Maintenance: this work type includes both preventive and corrective maintenance during power operation and refuelling outages.
- Modification & Installation: this category includes system modifications, and installation of new components/systems.

Figure 3: Procedure related LERs for different work types.

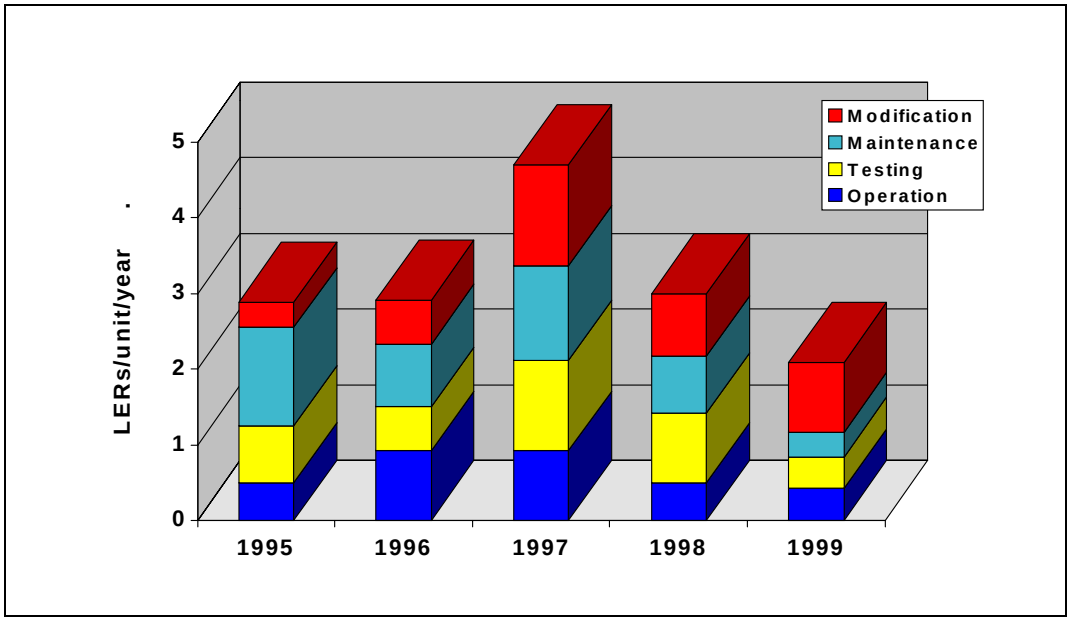


Figure 3 shows that maintenance activities are, on an average, associated with most procedure related LERs. More precisely, 27% of the total number of procedure related LERs are associated with maintenance tasks. The equivalent figure is 24% for modification tasks, 23% for testing activities and 20% for operational tasks.

The above percentages mean that, on an average, between 0,6 and 0,9 procedure related LER/unit/year is associated with each one of the four discussed work types. For year 1999, the results indicate that weaknesses in procedures contribute to approximately 0,3 LER/unit/year for each one the three work types maintenance, testing and operation.

A further analysis shows that, on an average, there is no difference in the type of maintenance and testing involved, i.e. electrical, mechanical and I&C.

Procedure deficiencies

Deficient procedures are classified into four categories in the MTO-database:

- Deficient content
- Deficient format
- Procedure not updated
- Missing procedure.

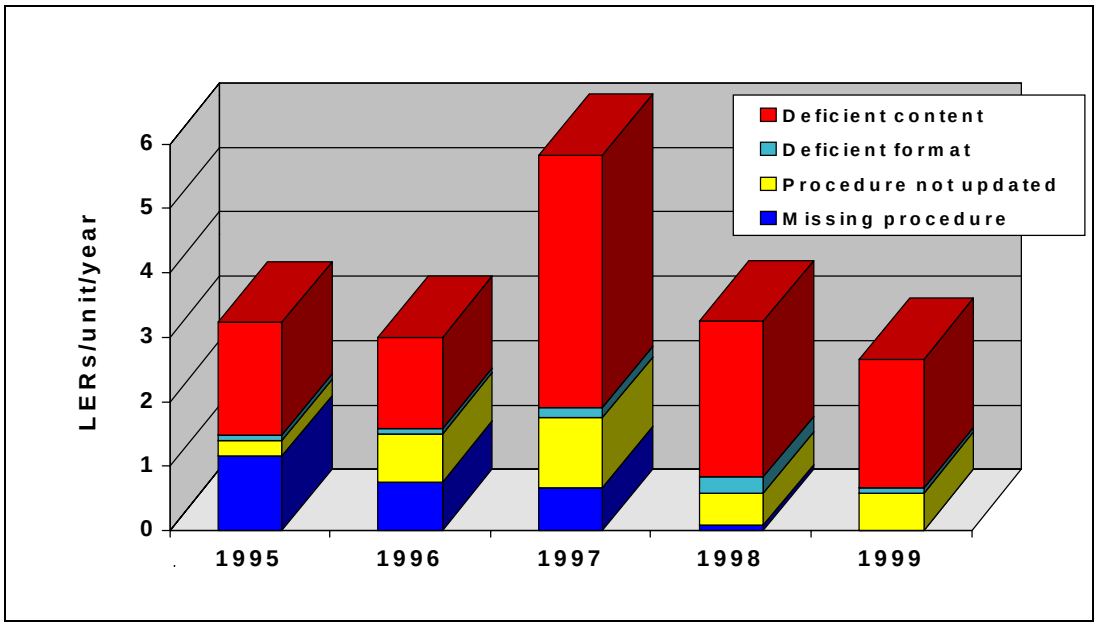
Procedure content pertains to the comprehensibility of the text, to the wording and spelling utilised, to references made to other procedures/documentation, etc. Procedure format pertains to the "physical" format and readability of the written material, including diagrams.

Figure 4 shows to which extent each one of the four categories has contributed to LERs in the Swedish nuclear power plants. The dominating contribution from "Deficient procedure content" is evident, amounting to 70% of the procedure related LERs. This contribution is almost twice the sum of the contributions from the other three.

The vanishing contribution from "Missing procedure" is also noticeable. This category contributed to slightly more than one LER/unit/year in 1995. For the two latest years studied, this contribution is almost zero for 1998 and zero for 1999.

Considering scrams, the dominance of "Deficient procedure content" is even more pronounced, having contributed to 85% (or 11 out of 13) of the procedure related scrams.

Figure 4: Procedure deficiencies having contributed to LERs.

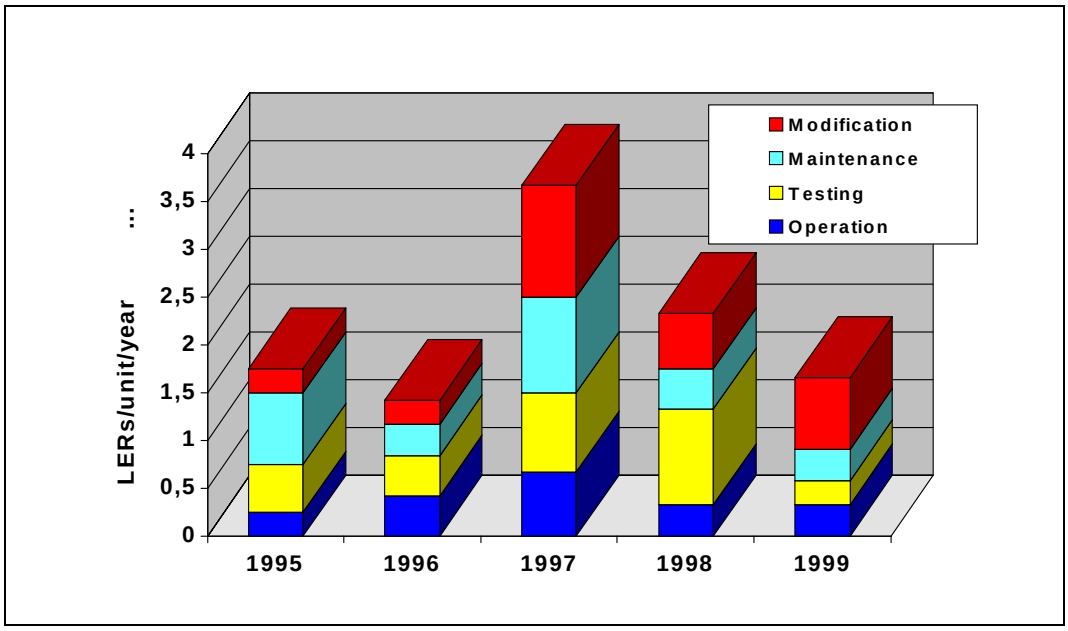


Procedure content and work type related LERs

Due to its importance, “deficient procedure content” has been further analysed for the previously discussed work types. Figure 5 shows to which extent deficient procedure content associated with some of the most frequent work types has contributed to LERs in the Swedish nuclear power units. This figure indicates that the contribution of deficient procedure content associated with operational tasks is, on an average, approximately half the contribution for each one of the three other work types studied.

The contribution of deficient content of procedures associated with plant modifications is, for the latest year studied, almost equal to the sum of the contributions from maintenance, testing and operational activities. Each one of the latter has contributed to approximately 0,3 LER/unit for year 1999.

Figure 5: Deficient procedure content as contributor to LERs för different work types.



Work practice and procedure

“Work practice” is another one of the 11 causal categories utilised for classification of events into the MTO-database. Two underlying causes pertaining to this category are “Procedure not used” and “Procedure not followed”.

An analysis was made to assess the number of LERs related to each one of these two and to “Procedure”. The results are presented against the background mentioned in section 5.1, indicating that 200 LERs are related to deficient procedure.

For the five years studied, only ten LERs have been classified with “Procedure not used” as contributing root cause. One of these events was classified with deficient procedure as another contributing cause.

“Procedure not followed” is a contributing root cause in 85 LERs in 1995 - 1999. Almost 20 of these LERs were moreover classified with deficient procedure as another contributing cause. The latter being dominated by more than 50% by deficient procedure content.

Procedure and CCF related events

Considering the need to better link human reliability models in PSA and MTO-related operating experience, the MTO-database was studied in order to assess the presence of Common Cause Failures (CCF) in procedure related scrams and LERs. In this context a CCF associated to a procedure related LER means that more than one component (similar or different components in the same or different system subdivisions/systems or even units) were affected by the procedure deficiency(ies).

The analysis shows that almost 35% of the procedure related events (both scrams and LERs) in the Swedish nuclear power plants exhibit a CCF character. At the most, a CCF of 8:th order was identified, i.e. eight valves were mistakenly closed during a periodical operability test. Among the contributing factors to this event were deficient procedure content and format, and procedure not followed.

Discussion

The aim of this section is to complement with comments and reflections the factual presentation of the analysis results.

LER trend break

To provide correct explanations for the trend break observed in the number of LERs - see figure 2 - year 1998 is not an obvious task. As a prime explanation, it is tempting to connect this trend break to the publication of SKI’s new regulation (SKIFS 1998:1) and the interpretation of it made by the licensees. This interpretation has most probably resulted in the reporting of fewer LERs.

Other explaining factors, as a reduction of the exposures to mistakes and failures, i.e. the amount of activities during power operation and refuelling outages (system modifications and major repairs), can not be identified distinctly from the operational experience.

Procedure improvements

As mentioned earlier, slightly more than three procedure related LERs/unit/year are on an average reported to SKI. This number can be considered in light of the exhaustive and far-reaching “re-construction” projects started in Sweden after the Barsebäck 2 event in 1992. As a result of these projects, the quality of the technical documentation, Safety Analysis Report (SAR), procedures, etc has significantly improved.

More specifically, significant human and monetary resources have been allocated during the years to the focussed improvement of operational procedures. This focus has mainly resulted from the importance and the number of operational procedures, and the span of their complexity. Operational procedures encompass both power operation and refuelling outages, and emergency operating procedures.

In addition, increasing efforts have been made during the latest years to improve both test and maintenance procedures.

In light of the previous comments, the BWR units have reported, on an average for the years studied, approximately half the number of procedure related LERs compared with PWRs. This means 2,7 procedure related LERs/BWR/year and 5,1 LERs/PWR/year.

Satisfactory level

For the latest year studied, 0,3 LER/unit was due to deficient procedure associated with each one of the three work types operation, maintenance and testing. This value is half the average value for years 1995 – 1999. These facts are most probably related to the previously given comments. This conclusion has moreover to be considered outgoing from the significantly higher number of operational procedures existing and utilised at the plants, compared with procedures associated with other work types.

In a realistic perspective and with due consideration taken to the tremendous number of tasks performed yearly at each unit, the results for years 1999 are not alarming. A potential for improvement exists however, in particular for the PWR units.

LERs during refuelling outages

One issue often discussed is to what extent MTO-related LERs originate from work tasks performed during power operation and during refuelling outages.

Considering the reporting of events, each LER includes the date for the failure discovery, not the date(s) for different causes behind the reported LER. When entering MTO-related LERs in the database, efforts are made to assess if the event causes were created during power operation, and/or refuelling and other shutdown outages.

For the five years covered by the study the total number of MTO-related LERs for power operation is almost twice the total number of MTO-related LERs during refuelling outages. Furthermore, the study indicates that maintenance, respectively testing, during power operation results in 50% more, respectively 100% more, procedure related LERs compared to the same work types during refuelling outages.

In line with this, contractors (working mostly during refuelling outages) are involved in fewer procedure related events than the plant maintenance staff.

Care should be exercised when drawing conclusions since several deviations are not subject to reporting according to the Technical Specifications during outages.

Procedures and departments

The analysis showed that procedure related events pertain more to maintenance, testing and modification tasks (74%) than to operational tasks (20%). However the operation department is involved in more procedure related LERs and scrams than the maintenance department.

A possible explanation is that the operational department takes part into most activities performed by others, for example in the establishment and control of work orders, permits to work, system configuration control prior and after modification, maintenance and testing tasks, etc

Quality and respect of procedure

One question arises from time to another as whether a deficient procedure – i.e. content, format and update - is prone to increase the probability for involved personnel to disregard or not follow a procedure.

Based on the study of the actual LERs presented in section 5.5, a direct and tight coupling does not in general exist between the disregard or non-respect of a procedure, and the eventually deficient procedure content. However, for relatively few LERs, a direct coupling has existed, as mentioned during interviews performed during detailed analyses of the events.

Procedures and CCF

A specific analysis of the share of procedure related events exhibiting a CCF character indicates that this share was approximately 35% CCF for both scrams and LERs. This is considered to be a rather high ratio. This fact should motivate a more detailed analysis as ground for focussed and sustained improvement of procedures affecting several components, systems and even units.

The relative high share of CCF should also be considered, at least in Sweden, in light of the performed probabilistic safety analyses. In many of these, the contributions from CCF and human factors dominate the calculated probabilities for core damages.