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A COGNITIVE TASK ANALYSIS OF THE SGTR SCENARIO

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1. SCOPE OF REPORT

This report constitutes a contribution to the NKS/RAK-1:3 project on Integrated Sequence Analysis. As decided at the meeting at Ringhals, May 29-30, 1995, a group consisting of Ola Svenson, Anne Edland and Erik Hollnagel should perform an MTO-type analysis of the SGTR scenario. Following the meeting at Ringhals, the work was proposed to be performed by the following three steps:

- Task 1. Cognitive Task Analysis of the E-3 procedure
- Task 2. Evaluation and revision of task analysis with Ringhals/KSU experts
- Task 3. Integration with simulator data

The Cognitive Task Analysis (CTA) of Task 1 uses the Goals-Means Task Analysis (GMTA) method to identify the sequence of tasks and task steps necessary to achieve the goals of the procedure. It is based on material supplied by Ringhals, which describes the E-3 procedure, including the relevant ES and ECA procedures. The analysis further outlines the **cognitive demands profile** associated with individual task steps as well as with the task as a whole, as an indication of the nominal task load. The outcome of the cognitive task analysis provides a basis for proposing an adequate event tree.

The purpose of Task 2 is to refine the task description resulting from Task 1 and to provide an initial estimate of time available for each task step. The consideration of timing of the operations is important to get a first idea about the **dynamics** of the transients. Based on the description of timing and of the likely working conditions, the CTA will be revised and refined.

In Task 3, the outcome of Task 2 will be evaluated using information from simulators. Based on the revised task analysis, as well as a preliminary identification of likely errors, the simulation analysis can be used to show how the event will develop, i.e., which event sequences are likely to occur. The simulation-based analysis combined with a simple estimation of the likelihood of making a failure, e.g. a cognitive reliability measure, can show how a sequence may change depending on the conditions.

This report describes the results from Task 1. The work has been carried out during September-November 1995. It has included a two-day meeting between the three contributors, as well as the exchange of intermediate results and comments throughout the period. After the initial draft of the report was prepared, an opportunity was given to observe the SGTR scenario in a full-scope training simulator, and to discuss the details with the instructors. This led to several improvements from the initial draft.

2. COGNITIVE RELIABILITY ANALYSIS

A full COgnitive Reliability Analysis (CORA) covers all the steps from the initial task analysis to the quantification of probabilities for specific (erroneous or faulty) actions. The present work does not aim to perform a full CORA, but rather concentrates on the initial steps. It specifically looks at how the representation of possibilities for erroneous actions in the scenario can be made more realistic. This is achieved by including significant contributions from human factors / cognitive ergonomics and cognitive systems engineering in the analysis.

As a point of reference, the full CORA can be described as consisting of the following steps (Figure 1).

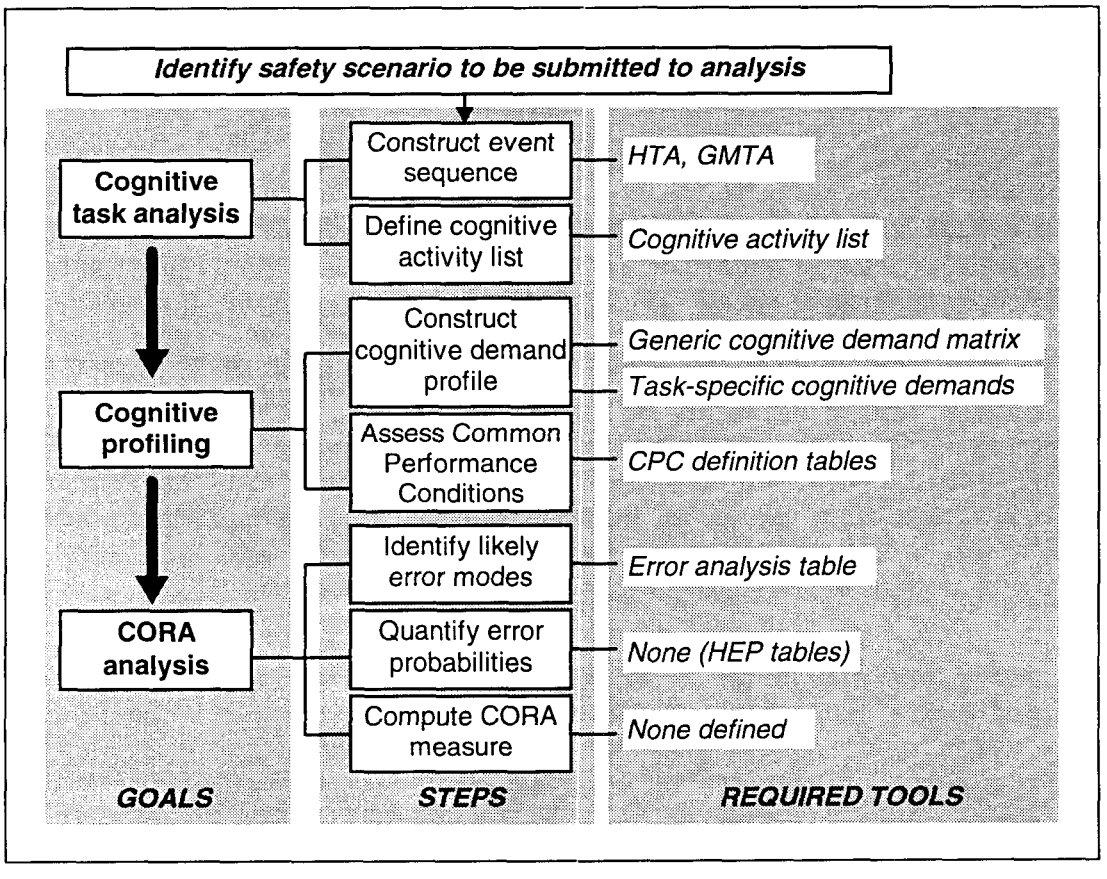

Figure 1: Main steps of a CORA

For each step further details can be provided (Hollnagel & Marsden, 1995). Each step makes use of appropriate tools, which either refer to commonly available techniques - such as task analysis methods - or specialised methods or tools. The present work will cover the phases of cognitive task analysis and cognitive profiling, but will modify these to meet the requirements of the ISA project.

In relation to the RAK project, the fundamental limitation of the CORA method outlined above is that it is essentially a static approach. That is, the CORA makes use of a pre-defined sequence description, without evaluating the appropriateness of that description. In contrast, the RAK project is concerned about the development of a proper and realistic description of

the sequence of events that makes up the scenario. In this phase it is necessary to overcome the limitations of a static approach, e.g. by considering the temporal aspects of tasks and events. The current project does not go all the way to a dynamic analysis method, such as a joint system simulation approach (Hollnagel, 1995). Instead, the solution advocated here can be described as a semi-dynamic approach. This in effect means that the approach tries to consider the temporal and dynamic aspects of the event sequence to the extent that this can be achieved without requiring a full simulation.

2.1 Semi-Dynamic CORA

As a result of that, a semi-dynamic CORA is proposed to have the following steps (Figure 2):

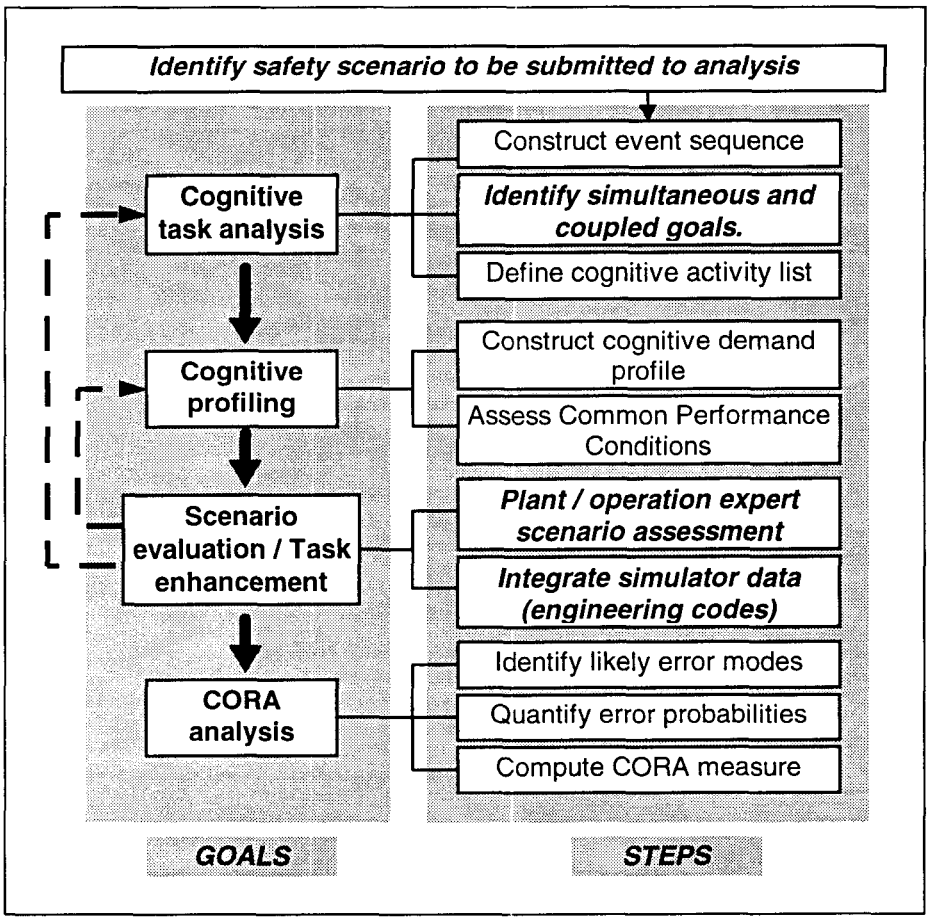

Figure 2: Proposed main steps of a semi-dynamic CORA.

In comparison with Figure 1, there are three main changes. The first is in the cognitive task analysis, where a step is added to look more closely at the goal structure. The purpose of that is to identify goals that may occur in parallel, or which may be coupled or dependent on each other. The second is the contribution of operational and plant expertise. Thus rather than relying on the scenario as it has been defined by the PSA, operational expertise and experience is used to assess whether the scenario is realistic. The realism concerns both the level of detail of the description and the likelihood of the assumed events and developments.

The third change is the use of data from engineering simulations. These data are essential to describe the dynamics of the interaction, in particular the time limitations that may be associated to specific task steps in specific conditions. Together the effect of these modifications may lead to such changes that the previous steps, cognitive task analysis and cognitive profiling, have to be repeated.

3. GOALS-MEANS TASK ANALYSIS

A prerequisite for producing a cognitive profile of the scenario is that the goal structure has been clarified. The goal structure describes the relations between goals and means that are applicable to the situation. The set of goals-means relations can be used as a basis for defining the contents of the procedure, i.e., for defining the steps or actions that are necessary (and sufficient) to achieve the overall goal (e.g. Lind & Larsen, 1995).

A goals-means description of a procedure may not correspond exactly to the written procedure. For one thing, the order in which actions are defined is usually reversed. A procedure begins with the actions that must be carried out first, whereas a goals-means description begins with the goal that must be met last (the top-level goal). The reason for this difference will hopefully be obvious from the analysis below. The order of the actions in the procedure (the procedure steps) must clearly reflect the temporal structure of the scenario, i.e., the order in which the events in the plant take place.

3.1 SGTR Goals

The goals for the SGTR scenario are defined to overcome the effects of the tube rupture. The causes and developments that are associated with the tube rupture are summarised in Figure 3. This only describes the initial phases of the SGTR, but does provide some of the reasons for actions taken later in the procedure.

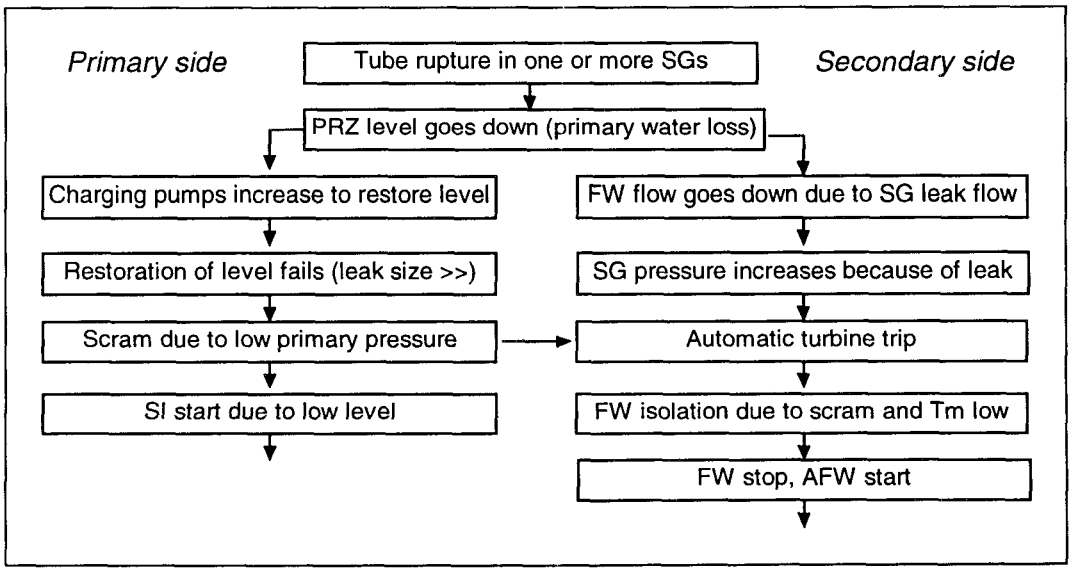

Figure 3: Causal structure of the SGTR (initial phase).

The ultimate goal is to maintain a controlled reaction, i.e., to keep the cooling of the core under control and to avoid any release of radioactive materials. More precisely, the top-level goals are:

- **Reactor pressure has been reduced to stop leakage.** The pressure of the primary system must be lower than the pressure of the ruptured SG, and the pressure must be lower than the setpoint for the SG relief valve. This is also referred to as pressure balance.

and

- **Residual heat removal has been started.** This refers to the residual heat removal of the primary side, the secondary side, and the containment.

Note that in the above the goals are described as system states. This differs from the descriptions given by the procedure, which are descriptions of actions to be taken - or sometimes a mixture of goals and actions. For the purpose of the goals-means analysis it is essential that goals are described as states. It is quite easy from such state descriptions to produce a description of the corresponding action. This can usually be done simply by reformulating the sentence. Thus, the first of the top-level goals could be expressed as "reduce reactor pressure to stop leakage". This would, however, not be a goal description but a description of the means by which the goal can be reached. In most cases this initial description of the means serves as an appropriate starting point for developing a more detailed task description.

In order to accomplish the top-level goals, the operators have to carry out the following main steps. Each of these clearly correspond to a sub-goal of the overall task.

- Identify the ruptured SG. The identification is required in order to be able to isolate the ruptured SG.
- Isolate the ruptured SG. The isolation is necessary to enable a controlled cooling of the primary system by means of the undamaged SGs.
- Reduce temperature of primary system (cool down).
- Re-establish the pressurizer (PRZ) level.
- Reduce pressure of primary system (to stop leak through ruptured SG). This can be accomplished either by using the SG relief valves plus the PRZ spray; or by using the PORVs.
- Activate the residual heat removal systems.

3.2 Goal Structure And Task Load

It is necessary to analyse the goal structure of a scenario because the goals seldom can be described as a simple sequence of individual goals. If that was the case, then obviously the

operators could concentrate on one goal at the time in the prescribed sequence and thereby be assured of reaching the target state. This ideal situation is illustrated in Figure 4.

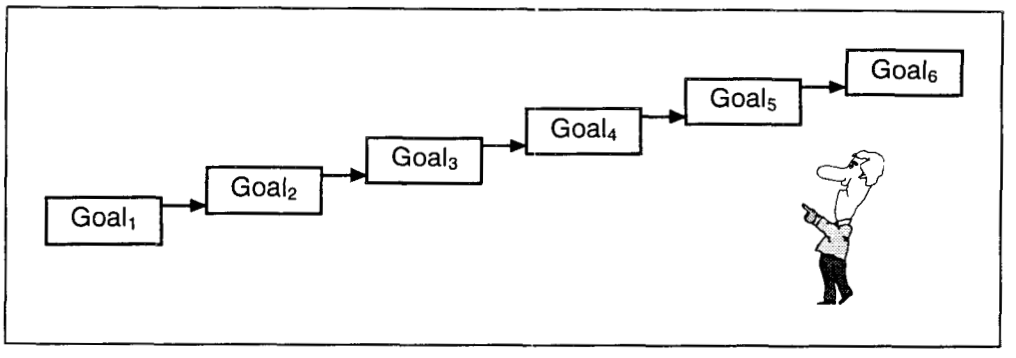

Figure 4: Simple, sequential goal structure.

In this ideal situation there will never be more than one goal at the time to deal with. Assuming that the procedure adequately describes the current situation (and this is an assumption that always must be made), the operators' tasks are relatively uncomplicated.

It is more realistic to consider a situation where there at times can be more than one goal to consider (Figure 5). Even this situation is simplified, because they goals only occur in parallel for a single step. Presumably, if there were simultaneous goals at points in the sequence, but never more goals than operators in a crew, then the situation would still be relatively uncomplicated.

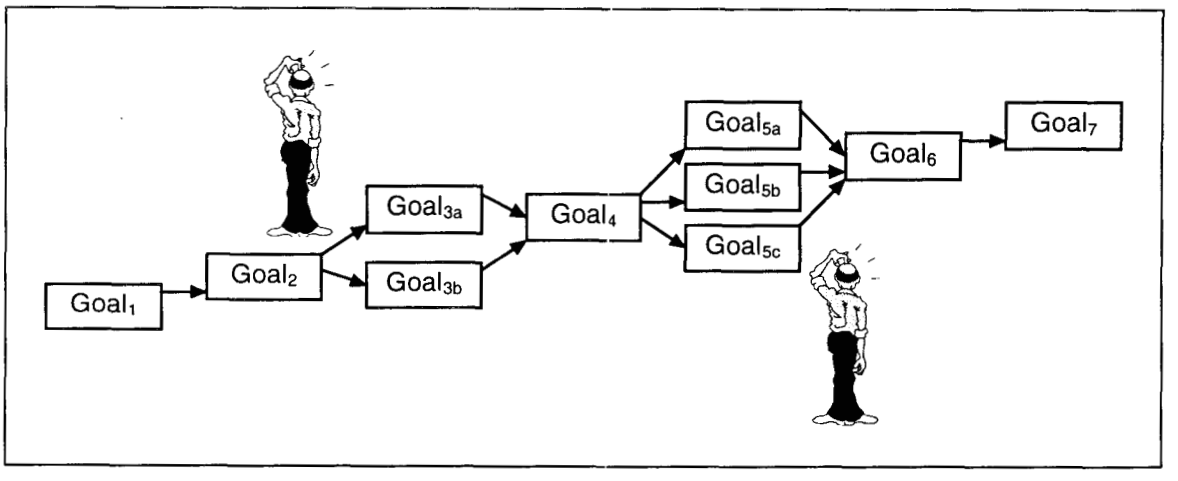

Figure 5: Sequential, multiple goal sequence.

It is not difficult to see how more complex structures could be described, for instance by having goals that overlap each other or that depend on each other in various ways. Even for simple systems, such as a central heating system, there coupling between goals can be quite complex, e.g. Lind, 1994. Due to the complexity of physical systems and the couplings between various control loops and subsystems, the goal structure will in practice never be a simple, linear sequence. For a system as complex as an NPP there will always be multiple and simultaneous goals. Whereas in the simple goal structure the task load depends on the complexity of each goal taken by itself, a more complex goal structure will lead to different

types of task load. It is important to be able to account for this as a basis for developing a realistic set of scenarios for a PSA.

3.3 A Simplified SGTR Goal Structure

The sequential goal structure for the SGTR scenario is typically described as follows. The descriptions are taken more or less directly from the SGTR procedure, and reformulated as goals for the reasons explained above.

Table 1: Sequential goals in the SGTR

Task segment	Goal
Segment 1	Identification: Ruptured SG has been identified.
Segment 2	Isolation: Ruptured SG has been isolated
Segment 3	RCS cooling: RCS temperature has been reduced to target value
Segment 4	Re-establish PRZ level: Pressure of primary system has been reduced.
Segment 5	SI stop: SI has been stopped / reset
Segment 6	Pressure balance: pressure between RCS and ruptured SG is equalised

The goals listed in Table 1 are clearly not the complete set, but only describe the first parts of the procedure. Thus the activities involving the residual heat removal are not included. This reduction is made in order to limit the analysis to the more critical parts of the scenario.

In terms of a goals-means analysis, the starting point must, however, be the final goal, i.e., the end state to be achieved. Using a simple indentation to indicate goal-subgoal relations, the SGTR can be describes as follows:

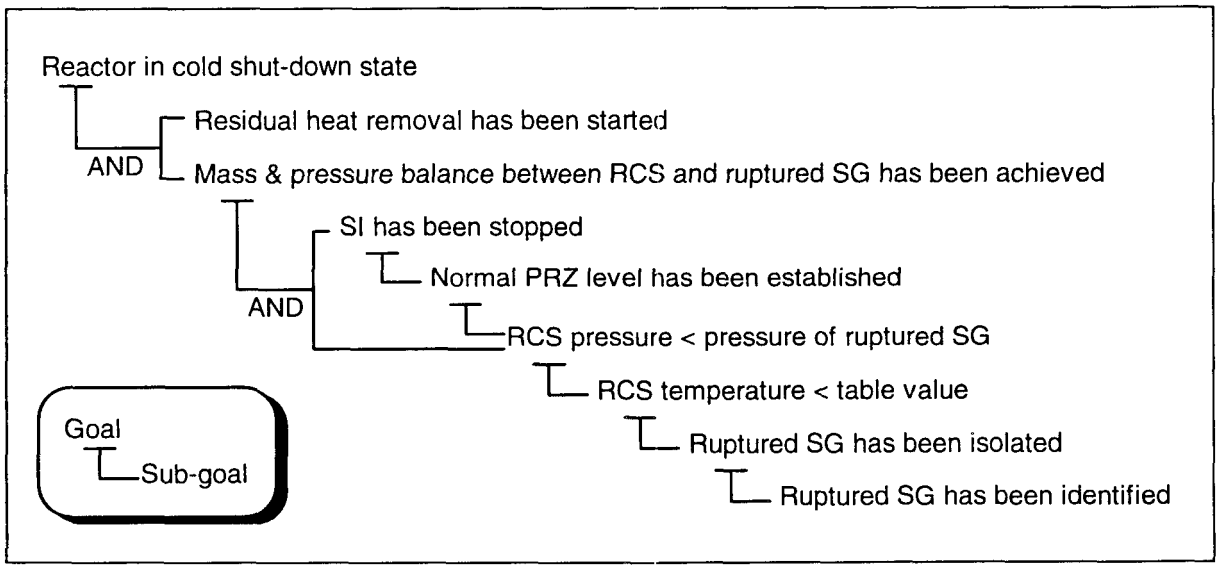

Figure 6: SGTR goal structure

Even this rough description shows that there are several cases of multiple goals, and on several levels. It also shows that at least one goal, that RCS pressure has been reduced, is a sub-goal or pre-condition for two different goals. In order to understand how this may affect

the procedure, it is necessary to show how the various goals correspond to parts of the procedure.

3.4 Segmentation Of SGTR Procedure

First, the procedure is reproduced in a step-by-step list, indicating the major segments corresponding to Table 1 above. (In order to limit the extent of the analysis, the procedure steps are only included to the point where residual heat removal is about to begin.)

Table 2: Basic goal/event sequence for SGTR procedure.

Step	Segment	Goal
1	Identification	RCP stop conditions have been checked
2		Ruptured SG has been identified
3	Isolation	Ruptured SG has been isolated
4	RCS cooling	FW flow to ruptured SG has stopped
5		Emergency organisation has been alerted
6		PRZ PORVs are in satisfactory working condition
7		No SG has rupture on secondary side
8		Level of intact SGs has been checked
9		SI has been reset
10		Phase A & B signals have been reset
11		Instrument air is available in containment
12		All 6kV rails have external power supply
13		RH pumps have been stopped
14		Pressure of ruptured SG > 15 barö
15		RC cooldown has been achieved
16	Re-establish PRZ level.	Pressure of ruptured SG is not decreasing.
17		RC subcooling is within specified limits.
18		Leak through rupture SG has been minimised. PRZ water level has been restored
19		Leak through rupture SG has been minimised. PRZ water level has been restored
20		RC pressure is increasing
21	SI stop	SI has been stopped
22		One charging pump is running
23	Pressure balance	Charging flow has been established
24		BIT has been isolated
25		PRZ level is stable
27		Containment spray pumps have been stopped
28		"Make-up" is in auto mode
29		Letdown has been established
30		Charging pump inlet has been changed from RWST to VCT
31		RC pressure and charging is controlled to minimise break flow
...		...

The relation between the various segments can be made more conspicuous by representing the procedure in a graphical form. Figure 7 show the extent of each segment as a horizontal bar against the procedure steps (from 1 to 31). Each segment is named in accordance with established practice. Note, however, that this representation does not capture the goal-subgoal

dependencies illustrated by Figure 6. Neither does it represent the dependencies that are explicitly described in the procedure.

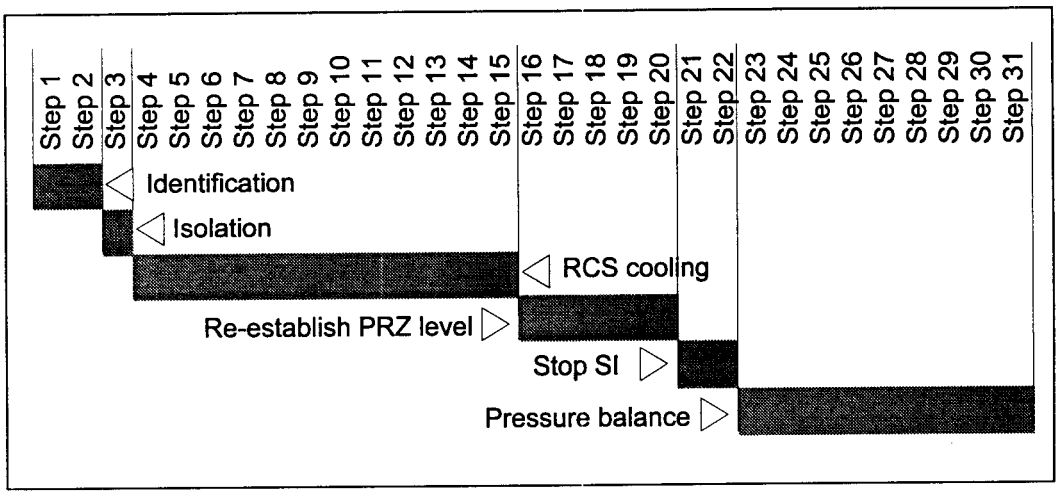

Figure 7: Graphical representation of SGTR procedure segments

In reality, the EOP does not have a linear structure but prescribes a number of branching conditions or loops. This can indirectly be seen from the fact that step 18 and step 19 achieve the same goal, but in two different ways. Another important aspect is that the order of the steps differ depending on whether the ruptured SG has been identified and isolated from the start. A more realistic representation of the structure of the procedure requires a graphical form, as in Figure 8, which shows the situation where the ruptured SG has been successfully identified from the start.

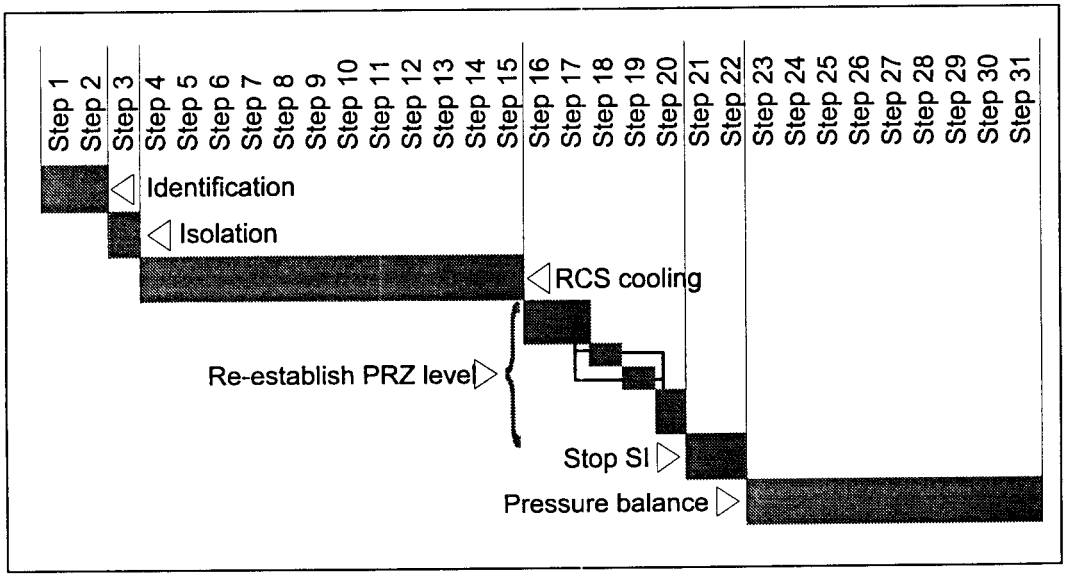

Figure 8: SGTR procedure with fast SG identification.

Conversely, Figure 9 shows the situation when there are problems in identifying the ruptured SG. In this case the operators have to carry out steps 5-13 of the procedure while at the same time being ready to perform steps 3-4 whenever sufficient information to identify the ruptured SG becomes available. This will in practice mean that the operators at some time will have to

interrupt the sequence they are carrying out, only later to resume it. Such conditions of suspended execution are known to be a major source of errors that occur later, and must therefore be accounted for in the sequence description.

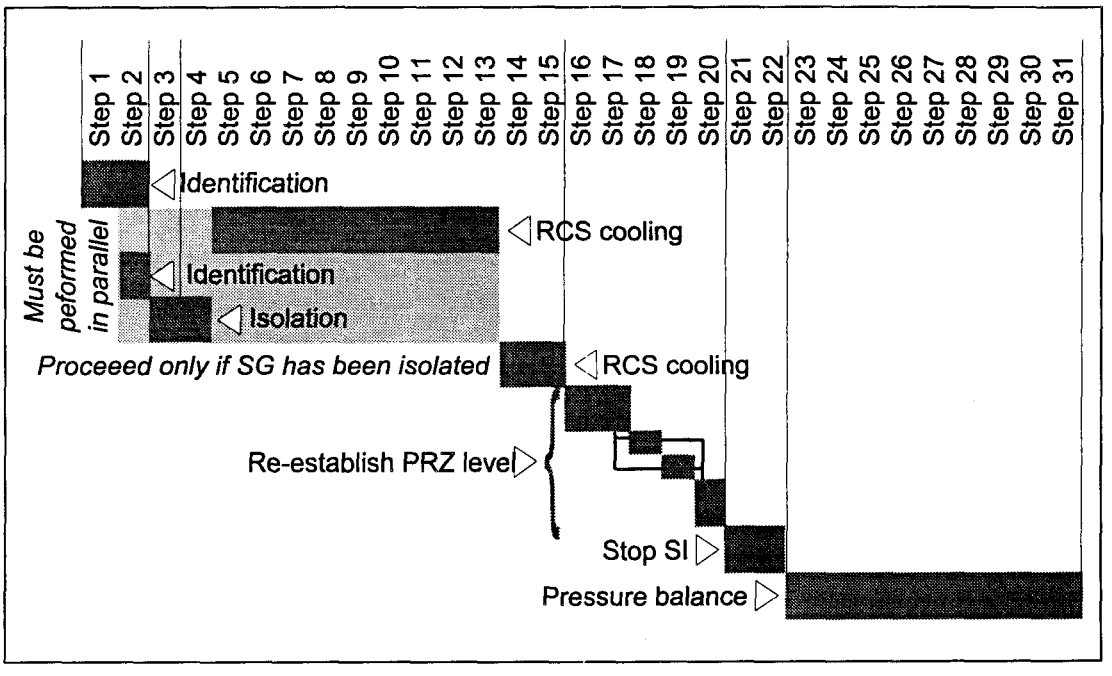

Figure 9: SGTR procedure with delayed SG identification.

Even Figure 9 only shows part of the complexity of the procedure. In Figure 9 (and Figure 8) the size of the procedure segments is shown relative to the procedure steps. It is, however, necessary to show the segments relative to an event time-line, i.e., relative to the speed by which the sequence develops. In this case the task steps shown in the shaded area would occur during the same time interval. The requirement to include temporal conditions is by itself a sufficient reason for a semi-dynamic analysis. In the preceding we have analysed the structure of the procedure as it currently exists, and supplemented that by a initial goals-means analysis. This has already revealed some of the dependencies and possible complications of the procedure. But in order fully to appreciate this, and in particular to assess the potential consequences for human action, it is necessary also to have a good appreciation of the plant dynamics under the various conditions and of the time constraints. This cannot be achieved by a static analysis, but requires the inclusion of information and results from simulator studies, operations experts and trainers, etc. The GMTA, and cognitive profiling below, provides a basis or a framework for integrating the various sources of information, but cannot by themselves constitute the complete answers.

3.5 Temporal Characteristics Of SGTR Procedure

An adequate characterisation of how a procedure is performed can be derived in a number of ways. One possibility is to use data from training simulators for a representative number of crews. Another is to use simulations of plant process developments, since the temporal characteristics of the process obviously are essential. Neither of these options have been

available in the preparation of this report, though both should be considered as part of the further work in Integrated Sequence Analysis.

As an illustration of the basic temporal features of the SGTR EOP, the E-3 procedure was demonstrated by Bengt Ljunquist and Urban Carlsson in the training simulator at KSU. The procedure was carried out in a step-by-step fashion, and the duration of each step was noted. The E-3 was preceded by the E-0 procedure. Altogether the demonstration lasted about 45 minutes, which must be considered very close to optimal performance both because the "operators" were highly skilled and because the scenario developed according to the book. The main results from the timing are shown in Table 3. The time indications are relative to the start of the E-3 procedure.

Table 3: Duration of E-3; times taken from exemplary demonstration

Step	Goal of step	Time	Comment
1	RCP stop conditions have been checked	00:00	
2	Ruptured SG has been identified	01:10	
3	Ruptured SG has been isolated	02:20	
4	FW flow to ruptured SG has stopped	03:30	
5	Emergency organisation has been alerted	03:50	
6	PRZ PORVs are in satisfactory working condition	04:00	
7	No SG has rupture on secondary side	04:30	
8	Narrow range level > 4%	04:50	
9	SI has been reset	05:20	
10	Phase A & B signals have been reset	05:30	
11	Instrument air is available in containment	05:40	
12	All 6kV rails have external power supply	05:50	
13	RH pumps have been stopped	06:00	
14	Pressure of ruptured SG > 15 barö	06:30	
15	RC cooldown has been achieved	06:50	
16	Pressure of ruptured SG is not decreasing.	08:50	
17	RC subcooling is within specified limits.	09:10	
18	Leak through rupture SG has been minimized. PRZ water level has been restored	09:20	
18c	*RC pressure is stable*	17:40	
19	Step 19 is an alternative to step 18		
20	RC pressure is increasing	17:50	
21	SI has been stopped	18:00	This step was carried out at 10:40, during step 18. The conditions were quickly rechecked after step 20.
22	One charging pump is running	18:10	
23	Charging flow has been established	18:30	
24	BIT has been isolated	18:50	
25	PRZ level is stable	19:10	
26	SI flow is no longer required	19:20	
27	Containment spray pumps have been stopped	19:50	
28	"Make-up" is in auto mode	20:10	
29	Letdown has been established	20:30	
30	Charging pump inlet has been changed from RWST to VCT	22:20	

Step	Goal of step	Time	Comment
31	RC pressure and charging is controlled to minimise break flow	23:00	The actual regulation (step 31b) lasted from 25:00 to 31:40. The demonstration was stopped when pressure had been equalised,
32	Diesels have been stopped	26:40	Step carried out during step 31.
33	Secondary side has been checked	27:00	Step carried out during step 31.
34	Pressure balance is maintained	27:20	Step carried out during step 31.

The relative duration of each of the steps is easier to see from the graphical representation in Figure 10. This clearly shows that most of the steps in the procedure are of relative short duration (due partly to the high skill level of the "operators"), and that two of the steps are very long. These steps, step 18 and step 31, take time because of the nature of the process. Whereas most of the other steps are either relatively simple checks or manual actions, step 18 and step 31 involve bringing about a change in the RC pressure (for step 31 also the charging) until a prescribed equilibrium has been obtained. Since this speed by which this can take place is determined by the physical characteristics of the process, the steps cannot be hurried. Note, however, that in this case the "operators" try to use the time by carrying out some of the following steps simultaneously. In the current example the gain in time is marginal.

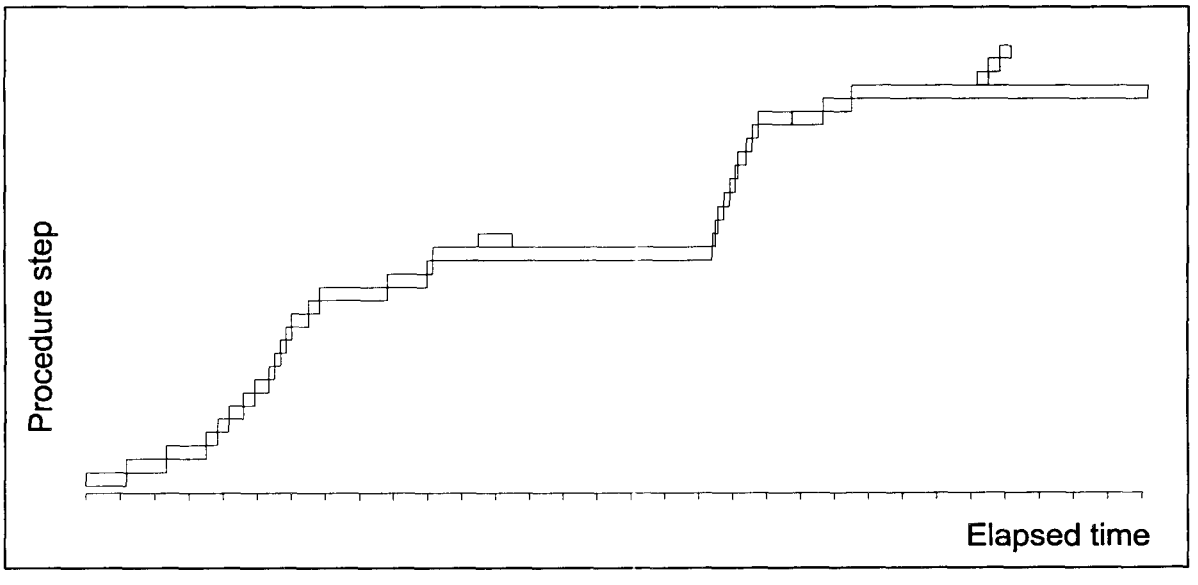

Figure 10: Temporal distribution of steps from E-3 demonstration.

The speed of the process determines not only the duration of step 18 and step 31, but also how fast the other steps must be carried out. It is, for instance, desirable to be able to start step 18 as soon as possible in order to minimise the leakage through the ruptured SG. This means that the preceding group of steps, steps 4-17 which mainly constitute the RCS cooling, must be performed quickly. Just as the nature of the process imposes a slowdown of the pace in step 18, it imposes an increase in the pace for the preceding steps. In terms of actions the operators have much to do and a motivation to do it quickly. This clearly influences the performance conditions, hence the reliability of the performance.

4. COGNITIVE PROFILING

The cognitive profile of the SGTR can be developed by following a relatively simple procedure. The objective of the cognitive profile is to identify and characterise the required performance in terms of characteristic cognitive functions, and in particular to identify the possibilities for faulty performance. This is done by using a simplified, but powerful, description of cognitive functions in control tasks. In order to make the assessment manageable, the principle is throughout to look for the **dominant** or **most likely** characteristics, rather than to cover all possible conditions and circumstances. This requires sound engineering and operational judgement of the analyst. The places where such judgement is applied are, however, clearly marked, and it is therefore possible at a later stage to revise the judgements if so required.

4.1 Cognitive Activity List

The first step is to produce a cognitive activity list for the scenario. This is basically an additional task description which lists the cognitive components of the task being analysed. The cognitive activity list is based on two sources: (a) a list of critical cognitive activities, and (b) description of the event sequence.

The current version of the list of critical cognitive activities is shown in Table 4. It contains a number of general cognitive activities related to process control and also provides a definition for each. Experience has shown that the definitions in most cases allow a cognitive activity to be assigned uniquely to a task steps. There may, however, be cases where the assignment requires some degree of judgement. In cases where the analyst is uncertain about which assignment to make it is recommended that the reasons for the final choice are documented as part of the analysis, in order to provide an adequate audit trail.

Table 4: List of critical cognitive activities

Cognitive Activity	General Definition
CO-ORDINATE	Bring system states and/or control configurations into specific relation required to complete task step.
COMMUNICATE	Pass on or receive person-to-person information needed for system operation by either verbal electronic or mechanical means.
COMPARE	Examine the qualities of two or more entities for the purpose of discovering similarities or differences.
DIAGNOSE	Recognise or determine the nature or cause of a condition by means of consideration of signs or symptoms or by the performance of appropriate tests.
EVALUATE	Appraisal or assessment of situation
PLAN	Formulate path by which goal will be successfully achieved
VERIFY	Confirm the correctness of a system condition or measurement
EXECUTE	Performance of a previously specified action or plan
IDENTIFY	Establish the identity of a plant state or sub-system state
MAINTAIN	Sustain a specific operational state. (This is different from *maintenance.*)
MONITOR	To keep track of system states over time, or follow the development of a set of parameters.
RECORD	Set down or log system event.
REGULATE	Alter speed or direction of control systems in order to attain a goal.

Cognitive Activity	General Definition
SCAN	Quick or speedy review of displays or other information source to obtain a general impression

The basic event sequence for the SGTR was shown in Table 2 above. Although it was expressed in terms of the goals for each step, it is quite easy to turn this into a description of the corresponding events or tasks. In performing the GMTA it was, however, evident that not all steps were described at the same level of detail. (Compare, for instance, step 22 and step 27.) In fact, some steps of the SGTR EOP specify a single activity, while others list a set of activities and even logical conditions. This difference is due to a number of factors, such as the importance of the step, the training and experience of the operators, etc. For the purpose of a systematic task analysis and a following cognitive profiling and reliability analysis it is, however, important that the description of the task is as uniform as possible. For that reason the basic event sequence shown in Table 2 has been augmented in places where sufficient details were available in the procedure. The cognitive activity list has been constructed on the basis of the augmented event sequence, and the outcome is shown in Table 5. The event sequence is described in terms of the goal and the means for each step. Additional detail, relative to Table 2, is shown in *italics*.

Table 5: Cognitive activity list for SGTR

Step	Event sequence description		Cognitive activity
	Goal	Means	
1	RCP stop conditions have been checked	Check that SI works	Evaluate
		Check whether subcooling is outside allowed area	Evaluate
		Otherwise stop all RCP	Execute
2	Ruptured SG has been identified		
2a	*Level changes in SGs have been checked*	*Check level changes in SGs*	Compare
2b	*Increased activity of SG test lines has been checked*	*Check activity of SG test lines*	Diagnose
2c	*Increased activity of steam lines have been checked.*	*Check level of activity of steam lines.*	Compare
2d	*Increased activity of ejectors has been checked*	*Check activity of ejectors*	Compare
3	Ruptured SG has been isolated		
3a	*SG relief valve has been set to 79 barö*	*Set SG relief valve to 79 barö*	Execute
3b	*SG relief valve is closed*	*Check that SG relief valve is closed*	Verify
3c	*Steam line from SG to steam driven AFW pump has been closed.*	*Close steam line from SG to steam driven AFW pump.*	Execute
3d	*"Bottenblåsning" from ruptured SG is isolated.*	*Check that "bottenblåsning" from ruptured SG is isolated.*	Verify
3e	*MSIV & bypass valve have been closed.*	*Close MSIV & bypass valve*	Execute
3f	*Steam isolation signal has been reset; supporting valves have been closed.*	*Reset steam isolation signal; close supporting valves.*	Execute
3g	*Steam dump valves are isolated.*	*Check that steam dump valves are isolated.*	Verify
3h	*FW to ruptured SG is isolated.*	*Check that FW to ruptured SG is isolated.*	Verify
4	FW flow to ruptured SG has stopped		

Step	Event sequence description		Cognitive activity
	Goal	Means	
4a	*Level on "narrow range" > 4%*	*Check level*	Compare
4b	*Level is constant or increasing*	*Stop FW*	Execute
5	Emergency organisation has been alerted	Alerting in accordance with instructions	Communicate
6	PRZ PORVs are in satisfactory working condition	Check PORVs are closed	Verify
		Ensure at least one isolation valve is open	Verify
7	No SG has rupture on secondary side		
7a	*Pressure of all SGs is stable*	*Check pressure of each SG*	Verify
7b	*No SG has lost pressure*	*Check pressure level of each SG*	Verify
8	Narrow range level > 4%	Regulate FW flow	Regulate
	50% > narrow range level > 4%	Regulate FW flow	Regulate
9	SI has been reset	Reset SI signal	Execute
10	Phase A & B signals have been reset	Reset phase A & B signals	Execute
11	Instrument air is available in containment	Check instrument air is available in containment.	Verify
12	All 6kV rails have external power supply	Check that all 6kV rails have external power supply	Verify
13	RH pumps have been stopped		
	RC pressure > 16 barö	Check RC pressure	Compare
		Stop RH pumps	Execute
14	Pressure of ruptured SG > 15 barö	Check pressure of ruptured SG > 15 barö	Compare
15	RC cooldown has been achieved		
15a	*Target temperature has been found.*	*Read values and use table*	Evaluate
15b	*P-12 = 289.40C*	*Dump to condenser from undamaged SGs*	Regulate
15c	*Bypass for dump has been established.*	*Establish bypass for dump.*	Execute
15d/e	*RC temperature < target temperature*	*Dump steam to condenser and check temperature*	Regulate
15f	*Cooling has been stopped*	*Stop cooling*	Execute
15g	*Target temperature is maintained*	*Maintain target temperature*	Regulate
16	Pressure of ruptured SG is not decreasing.	Follow pressure level of ruptured SG.	Monitor
17	RC subcooling is within specified limits.	Use table for subcooling margin	Verify
18	Leak through rupture SG has been minimized. PRZ water level has been restored		
18a	*Spray is operational*	*Check that spray is operational. IFNO GoTo Step 20*	Verify
18b	*RC pressure is within specified limits*	*Use spray to reduce pressure*	Regulate
18c	*RC pressure is stable*	*Close spray valves and check pressure. Continue to step 21*	Monitor
19	Leak through rupture SG has been minimized. PRZ water level has been restored		
19a	*At least one isolation valve is operational*	*Check that at least one isolation valve is operational*	Verify
19b	*RC pressure is within specified limits*	*Use PORV to reduce pressure*	Regulate
19c	*PORV has been closed*	*Close PORV*	Execute
20	RC pressure is increasing	Check that RC pressure is increasing	Monitor
21			

Step	Event sequence description		Cognitive activity
	Goal	Means	
21a	*RC subcooling is within specified range / limits.*	*Check that RC subcooling is within specified range / limits.*	Verify
21b	*Secondary side heat sink is available.*	*Check that secondary side heat sink is available.*	Verify
21c	*RC pressure is stable or increasing*	*Check that RC pressure is stable or increasing*	Verify
21d	*PRZ level > 5%*	*Check that PRZ level > 5%*	Compare
22	One charging pump is running	Stop all pumps except one	Execute
23	Charging flow has been established	Go through steps a - d	Execute
24	BIT has been isolated	Close according to steps a & b	Execute
25	PRZ level is stable	Regulate charging flow	Regulate
26			
26a	*RC subcooling is within specified limits*	*Check that RC subcooling is within specified limits*	Verify
26b	*PRZ level > 4%*	*Check that PRZ level > 4%*	Compare
27			
27a	*Sprinkler pumps are working*	*Check that sprinkler pumps are working*	Verify
27b	*Containment pressure < 2.0 baro*	*Check that containment pressure < 2.0 baro*	Compare
27c	*Sprinkler signal has been reset*	*Reset sprinkler signal*	Execute
27d	*Sprinkler pumps have been stopped*	*Stop sprinkler pumps*	Execute
28	"Make-up" is in auto mode	Check that "make-up" is in auto mode	Verify
29	Letdown has been established		
29a	*PRZ level > 20%*	*Check PRZ level > 20%*	Compare
29b	*Normal letdown has been established*	*Establish normal letdown*	Execute
30	Charging pump inlet has been changed from RWST to VCT	Change charging pump inlet from RWST to VCT	Execute
31			
31a	*Pressure / flow are controlled according to table*	*Control pressure / flow according to table*	Regulate
31b	*Normal spray is used as required*	*Use normal spray as required*	Regulate

Even though Table 5 contains more detail, it is still not a complete representation of the procedure. Although a procedure nominally is divided into a number of steps, which each describe one or more observations and actions, there may be additional information in the form of notes and warnings. For the analyst it is sometimes difficult to understand when something is expressed as a warning and when as an observation / action. It is reasonable to assume that the operators do not maintain a strict separation between the various categories, but look for the meaning of the procedure.

As an illustration, the SGTR procedure contains notes and warnings of the following type:

- Verify / Execute support. Here the operators are supposed to check a plant state, and if it is not as required then follow the procedure to achieve the state. To do so may involve either an unspecified plan (i.e., not given directly by the procedure) or branching to a different part of the procedure - or even to a different procedure.

- Evaluate support. In these cases the operators are reminded about the effects of prior actions for an abnormal plant state which may generate indications that are hard to

understand. For instance, abnormal conditions in the relief tank may depend on partly malfunctioning PORVs.

- Verify past state. This is similar to the first category, except that there may be little detail given about the relevant actions. Presumably, the operators will know what to do from training and experience.

- Monitor support. In this case the operators are reminded that they should check an important parameter for a prolonged time period.

In the present report the analysis is based on the actions explicitly mentioned in the procedure steps. It does, however, seem reasonable to extend the analysis to include notes and warnings as well, since these in practice may require specific activities from the operators. The extension of the analysis to cover these additional details will be considered at a later stage, pending the advice from operations experts.

4.2 Cognitive Demands Profile

Based on the cognitive activity list it is possible to produce a cognitive demands profile. The purpose of the cognitive demands profile is to describe the overall cognitive nature of the task. This serves to indicate whether the task as a whole is likely to depend on a specific set of cognitive functions. If so, the conditions where these cognitive functions are required should be analysed further to determine whether it is likely that they can be performed correctly.

The basis for constructing a cognitive demands profile is a table of the predominant cognitive demands associated with each of the critical cognitive activities. This table, shown in Table 6 below, is based on a Simple Model of Cognition (SMoC) which has been applied in a number of cases (Hollnagel & Cacciabue, 1991; Cojazzi et al., 1993).

Table 6: A generic cognitive-activity-by-cognitive-demand matrix

Activity type	SMoC functions			
	Observation	Interpretation	Planning	Execution
CO-ORDINATE			◆	◆
COMMUNICATE				◆
COMPARE		◆		
DIAGNOSE		◆	◆	
EVALUATE		◆	◆	
PLAN			◆	
VERIFY	◆	◆		
EXECUTE				◆
IDENTIFY		◆		
MAINTAIN			◆	◆
MONITOR	◆	◆		
RECORD		◆		◆
REGULATE	◆			◆
SCAN	◆			

The model underlying Table 6 assumes that there are four basic areas of cognitive functions that have to do with observation, interpretation, planning, and execution. Each typical cognitive activity can then be described in terms of which of the four cognitive functions it requires. As an example, co-ordination requires planning as well as execution. The planning is used to specify what is to be done, and the execution is used to carry it out or perform it. Similarly, communication refers to execution only, i.e., performing the act of communicating. Note that it is not possible to make unique assignments of the cognitive functions to the cognitive activities. This is because the cognitive functions cannot be combined in an arbitrary way. Thus ***diagnose*** and ***evaluate*** both refer to the cognitive functions of interpretation and planning. The reason why they are separate cognitive activities is that they refer to different characteristic tasks.

In the first hand, the contents of Table 6 is combined with the contents of Table 5 to produce a summary description of the cognitive demands (Table 7). This table presents the total number of times each activity type occurred in the task. For each activity type the corresponding cognitive functions are counted, providing a total which can be seen as an overall characterisation of the task At later stages of the CORA this information will be used to determine the likely error modes.

Table 7: Cognitive demands profile for SGTR

Activity type	*N*	Cognitive Demand			
		OBS	INT	PLAN	EXE
Communicate	1	0	0	0	1
Compare	10	0	10	0	0
Diagnose	1	0	1	1	0
Evaluate	3	0	3	3	0
Execute	19	0	0	0	19
Monitor	3	3	3	0	0
Regulate	10	10	0	0	10
Verify	19	19	19	0	0
Totals		32	36	4	30

As shown by Table 7 and Figure 11, the task prescribed for the SGTR is dominated by ***execute*** and ***verify***, i.e., carrying out well-rehearsed actions and checking that the appropriate conditions have obtained. This is supported by ***compare*** and ***regulate***, which are tied to some of the important functions in the E-3 procedure. The relative absence of diagnosis is due to the fact that this refers to the E-3 procedure, rather than the E-0. The absence of planning is also in good accordance with this being a procedure. In fact, if a procedure called for significant planning it would, by definition, be incomplete or inappropriate.

In terms of cognitive demands, the SGTR depends heavily on observation, interpretation, and execution but has little need of planning. A simpler procedure would be expected to have the highest demands on ***observation*** and ***execution***, and fewer demands on ***interpretation***. The SGTR procedure, however, appears to require a substantial amount of interpretation, which makes it susceptible to incorrect interpretations. The interpretation is due linked to the procedure steps that require re-establishing specific conditions in the plant. This becomes important at a later stage when the specific error modes are considered.

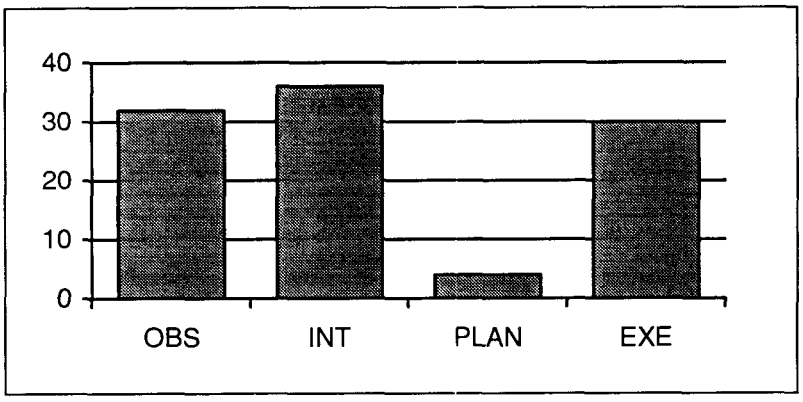

Figure 11: Cognitive demands profile for SGTR procedure

4.3 Cognitive Profile For Procedure Segments

In addition to providing the cognitive demands profile for the SGTR procedure as a whole, it may be useful to consider it for the individual segments as well. As the preceding analysis showed, it may be important to consider the various performance segments relative to the available time. In this respect information about the cognitive profile for a segment is clearly also of importance. The results for the first six segments are shown in Table 8. (The following segment, regulate RCS pressure and charging, is not included because it is not completely described by the preceding steps. In the interpretation of the results, it must be remembered that the individual activities are based on the descriptions given by the SGTR EOP. The terms used there may to some extent bias the distribution of activities and functions found by the analysis.)

Table 8:

	Identification	Isolation	RCS cooling	Re-establish PRZ level	SI stop	Balance pressure
Communicate			1			
Compare	3		3		1	3
Diagnose	1					
Evaluate	2		1			
Execute	1	4	6	1	1	6
Monitor				3		
Regulate			5	2		3
Verify		4	6	3	3	3

As seen from Table 8, the six segments differ considerably in terms of the cognitive activities that are involved.

- The first segment, identification, is dominated by diagnostic type activities, such as comparison, evaluation and diagnosis.

- The second, fourth, fifth, and sixth segments (isolation, re-establish PRZ level, SI stop, and balance of pressure) are dominated by performance related activities, mainly in the

form of a combination of execution and verification. This is because both sets of activities are well-trained sequences, neither of which require significant deliberation.

- The third segment, cooling, is the most complex and involves the largest number of activities. It involves both observation (verification) and the execution of actions.

This difference between the six segments becomes more pronounced if they are described in terms of the constituent cognitive functions. Just as Figure 11 showed the cognitive demands profile for the procedure as a whole, Figure 12 shows the individual profiles for each segment.

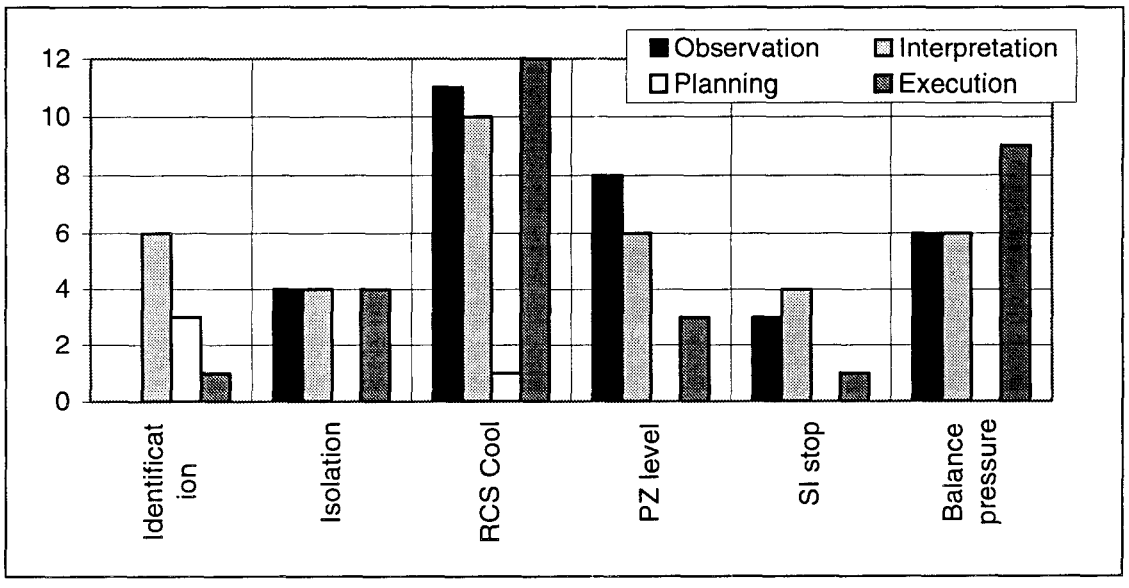

Figure 12: Cognitive demands profile for SGTR segments

There are several observations that can be made from Figure 12. Firstly, ***observation*** and ***interpretation*** are closely associated throughout the procedure with the exception of the first segment (identification). Secondly, RCS cooling is clearly the most complex segment. Thirdly, the all segments involve a measure of interpretation. This suggest that it may be worthwhile to consider this aspect in more detail, since it potentially is a weak spot.

As noted before, the significance of the cognitive demands profile will not become clear before it can be seen in relation to a temporal description of how the scenario develops. For instance, the amount of interpretation associated with a segment must be seen in relation to the time available. It is thus the relative rather than the absolute numbers that are important. This more detailed analysis is planned to be performed at a later stage in the project.

4.4 Assess Common Performance Conditions

The last step of the cognitive profiling is to assess the Common Performance Conditions. The reason for this step is that the cognitive demands to the operator will be affected by the performance conditions.

It is possible to define a relatively small set of Common Performance Conditions (CPC) that describe the general determinants of performance, hence the **common modes** for actions in a

given context. In contrast to the usual PSFs, the CPCs are applied **before** actions are analysed. The CPCs that are used here are shown in Table 9. For practical reasons, the context is described in terms of a limited number of factors or dimensions; the proposed CPCs are intended not to be overlapping, although they are not independent of each other. Table 9 also shows the basic qualitative descriptors that are recommended for each CPC.

Table 9: Common Performance Conditions.

CPC name	Level / descriptors
Adequacy of organisation	Very efficient / Efficient / Inefficient / Deficient
Working conditions	Advantageous / Compatible / Incompatible /
Adequacy of MMI and operational support	Supportive / Adequate / Tolerable / Inappropriate
Availability of procedures / plans	Appropriate / Acceptable / Inappropriate
Number of simultaneous goals	Fewer than capacity / Matching current capacity / More than capacity
Available time	Adequate / Temporarily inadequate / Continuously inadequate
Execution mode	Explicit, attention required / Skilled or automatic
Adequacy of training and preparation	Adequate, high experience / Adequate, limited experience / Inadequate

There is obviously a significant overlap between the CPCs and the traditional PSFs. This is because the actual possible conditions that may affect performance are limited. The difference between the CPCs and the PSFs is therefore not so much in the actual categories that are used, but in **how** they are used. The main difference is that the CPCs are applied at an early stage of the analysis to characterise the context for the task as a whole, rather than as a simplified way of adjusting probability values for individual events. This means that the influence of CPCs must be closely linked to the task analysis.

The assignment of values to the CPCs must necessarily refer to a set of specific assumptions about the situation. The validity of the assignment depends on the knowledge about the plant, the working conditions, and the team of operators. It is clearly not possible to make a realistic assignment for a general situation. It must at the very least refer to known characteristics of the organisation, as shown, for instance, by accumulated incident reports. Since such information was not available for the task reported here, a generic assignment has been made as shown in Table 10.

Table 10: CPCs for SGTR.

CPC name	Abb.	Level
Adequacy of organisation	Org	Efficient
Working conditions	Work	Compatible
Adequacy of MMI and operational support	MMI	Adequate
Availability of procedures / plans	Proc	Appropriate
Number of simultaneous goals	Goals	Matching current capacity
Available time	Time	Temporarily inadequate
Execution mode	Mode	Explicit
Adequacy of training and preparation	Train	Adequate, limited experience

4.5 Identify Likely Error Modes

Based on the principle of systematic manifestations of erroneous actions, it is possible to produce a complete list of error modes (e.g. Hollnagel, 1993). For the purpose of a performance reliability analysis it is, however, not necessary to use the complete set. In the carrying out of a procedure there are clearly some error modes that are of greater interest than others. These "procedure specific" error modes are listed in Table 11, relative to the cognitive functions of the associated model.

Table 11: Procedure error classification scheme

SMoC function	Potential error modes	
Observation errors	O1	Observation of wrong object
	O2	Wrong identification made
	O3	Observation not made (i.e., omission)
Interpretation errors	I1	Faulty diagnosis
	I2	Decision error
	I3	Delayed interpretation
Planning Errors	P1	Priority error
	P2	Inadequate plan formulated
Execution Errors	E1	Execution of wrong type performed
	E2	Action performed at wrong time
	E3	Action on wrong object
	E4	Action performed out of sequence
	E5	Action missed, not performed (i.e., omission)

The purpose of identifying the likely error modes is not to consider all the possible ways in which each step - or a specific step - of the procedure can fail, but rather to look at what the predominant type of error is expected to be for the procedure as a whole. The error modes assigned to the procedure steps are selected from Table 11. The assignment is based on the description of the scenario and likely performance conditions produced by the preceding steps of the performance reliability analysis. It nevertheless requires some familiarity with and understanding of the characteristic error modes.

Consider, for instance, step 1 of the procedure. This is constituted by three different actions, an ***evaluation*** that SI works, followed by an ***evaluation*** of whether subcooling is outside the established limits, followed finally by an ***execution*** whereby all the CRP pumps are stopped. The ***evaluation*** is described in terms of two cognitive functions, namely ***interpretation*** and ***planning*** (cf. Table 6). In assigning the likely failure mode for the evaluation, it is therefore necessary to consider the three interpretation error modes and the two planning error modes, to chose the one that is most likely under the given conditions. Based on the general knowledge about this step in the procedure, it was decided that the most likely error mode was *I1: Faulty diagnosis*. For the following step the selection was *I2: Decision error.* In the case of the execution, there are five possible execution error modes. Of these *E2: Action performed at wrong time*, was chosen as the most likely.

The same type of argumentation can be provided for each of the actions listed by the procedure. The resulting the assignment of error modes is shown in Table 12. (Note that the description of the activities has been abbreviated to minimise the physical size of the table.) It

is quite possible that other experts may question some of the assignments. The important point is, however, that the assignment takes place in a systematic way, and that the process is open for inspection. It is therefore reasonable to assume that a group of experts quite quickly will be able to reach a consensus.

Table 12: Credible error modes for SGTR EOP

			Type	Error types												
				Observ.			Interp.			Plan		Execute				
				1	2	3	1	2	3	1	2	1	2	3	4	5
1	RCP stop conditions	SI works	Eval.				◆									
		Subcooling	Eval.					◆								
		Stop all RCP	Exe.										◆			
2	Ruptured SG identified															
2a		Check level changes in SGs	Comp.				◆									
2b		Check activity of SG test lines	Diag.				◆									
2c		Check activity of steam lines.	Comp.				◆									
2d		Check activity of ejectors	Comp.				◆									
3	Ruptured SG isolated															
3a		Set SG relief valve to 79 barö	Exe.									◆				
3b		Check SG relief valve is closed	Verify		◆											
3c		Close steam line from SG to AFW.	Exe.											◆		
3d		Check that blow-down is isolated.	Verify		◆											
3e		Close MSIV & bypass valve	Exe.									◆				
3f		Reset steam isolation signal	Exe.										◆			
3g	.	Check steam dump valves	Verify		◆											
3h		Check that FW to ruptured SG	Verify		◆											
4	FW flow to rupt SG stopped															
4a		Check level	Comp.				◆									
4b		Stop FW	Exe.										◆			
5	Emergency org. alerted	Alerting as per instructions	Comm.										◆			
6	PRZ PORVs OK	Check PORVs are closed	Verify		◆											
		At least one open isolation valve	Verify					◆								
7	No SG ruptured on sec. side															
7a		Check pressure	Verify	◆												

			Type	Error types												
				Observ.			Interp.			Plan		Execute				
				1	2	3	1	2	3	1	2	1	2	3	4	5
		of each SG														
7b		Check pressure level of each SG	Verify	◆												
8	Narrow range level > 4%	Regulate FW flow	Reg.									◆				
	50% > narrow range > 4%	Regulate FW flow	Reg.									◆				
9	SI has been reset	Reset SI signal	Exe.										◆			
10	Phase A & B signals reset	Reset phase A & B signals	Exe.										◆			
11	Instrument air is available	Check instrument air	Verify		◆											
12	All 6kV have external power	Check all 6kV rails	Verify		◆											
13	RC pressure > 16 barö	Check RC pressure	Comp.					◆								
		Stop RH pumps	Exe.										◆			
14	Ruptured SG > 15 barö	Check pressure of ruptured SG	Comp.				◆									
15	RC cooldown achieved															
15a		Read values and use table	Eval.				◆									
15b		Dump to condenser	Reg.											◆		
15c		Establish bypass for dump.	Exe.											◆		
15d/e		Dump steam to condenser	Reg.		◆											
15f		Stop cooling	Exe.										◆			
15g		Maintain target temperature	Reg.		◆											
16	Ruptured SG pressure stable.	Follow pressure level.	Monitor				◆									
17	RC subcooling OK.	Use subcooling table margin	Verify					◆								
18	PRZ water level restored															
18a		Check that spray is operational.	Verify					◆								
18b		Use spray to reduce pressure	Reg.												◆	
18c		Check pressure.	Monitor					◆								
19	PRZ water level restored															
19a		one isolation valve is OK	Verify		◆											
19b		Use PORV to reduce pressure	Reg.												◆	
19c		Close PORV	Exe.											◆		
20	RC pressure is	Check RC	Monitor				◆									

			Type	Error types												
				Observ.			Interp.			Plan		Execute				
				1	2	3	1	2	3	1	2	1	2	3	4	5
	increasing	pressure														
21	SI has been stopped															
21a		Check RC subcooling	Verify		◆											
21b		Check heat sink is available.	Verify		◆											
21c		Check that RC pressure is stable	Verify		◆											
21d		Check that PRZ level > 5%	Comp.					◆								
22	One charging pump running	Stop all pumps except one	Exe.											◆		
23	Charging flow established	Go through steps a - d	Exe.												◆	
24	BIT has been isolated	Close according to steps a & b	Exe.												◆	
25	PRZ level is stable	Regulate charging flow	Reg.									◆				
26	SI flow is no longer required															
26a		Check that RC subcooling	Verify		◆											
26b		Check that PRZ level > 4%	Comp.					◆								
27	Cont. spray pumps stopped															
27a		Check sprinkler pumps work	Verify		◆											
27b		containment P < 2.0 baro	Comp.					◆								
27c		Reset sprinkler signal	Exe.												◆	
27d		Stop sprinkler pumps	Exe.											◆		
28	"Make-up" is in auto mode	Check "make-up"	Verify		◆											
29	Letdown established															
29a	PRZ level > 20%	Check PRZ level > 20%	Comp.					◆								
29b		Establish normal letdown	Exe.									◆				
30	Charging pump RWST to VCT	Change charging pump inlet	Exe.											◆		
31	Control RC press./charging															
31a		Control pressure / flow	Reg.									◆				
31b	Normal spray is used	Use normal spray as required	Reg.									◆				
				2	16	0	10	10	0	0	0	8	8	7	5	0

The total number of occurrences for each error mode is shown at the last row of Table 12. This result can also be shown graphically as in Figure 13. It is easy to see that the dominating error modes are related to execution, followed by error modes related to observation and interpretation. Considering the nature of a procedure this is not very surprising. The predominant actions are of the execution type, and the error modes will necessarily match that.

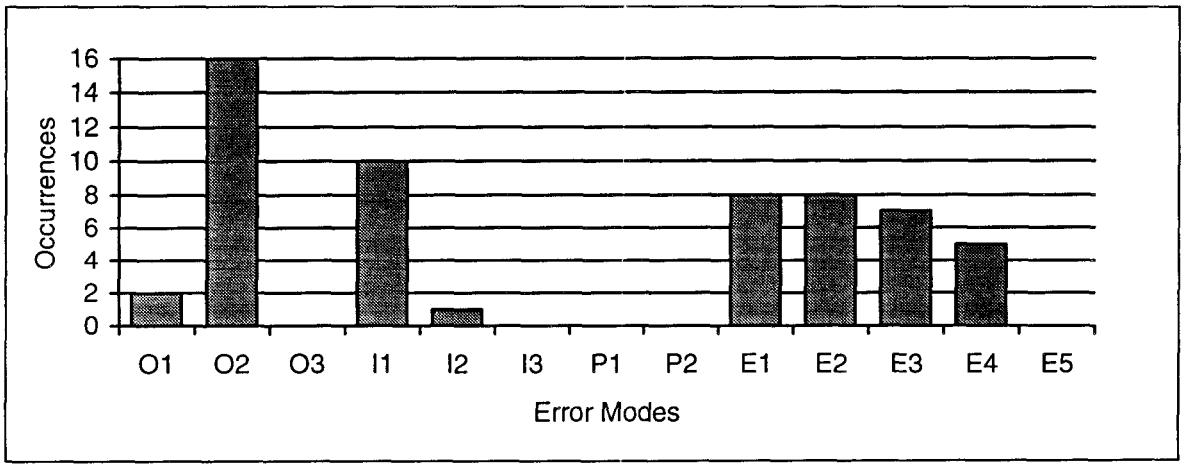

Figure 13: Distribution of error modes for SGTR EOP

Additional information can be gained by seeing the distribution of the error modes over the six stages of the procedure. In Figure 14, the error modes are lumped together for each main group. The figure shows clearly that there is a clear difference between the early and the later stages. In the early stages - which correspond to the events until SI has been isolated - there is a relatively high proportion of error modes linked to observation and interpretation. Conversely, the later stages are dominated by execution type error modes. The third stage, RCS cooling, requires a combination of observation/interpretation and execution. As illustrated above (Figure 10), this stage is carried out in less time than the following stage. From this it is not unreasonable to assume that this part of the procedure will be more susceptible to the error modes associated with observation and execution. This is nevertheless a possibility that need to be further investigated e.g., by using more detailed time estimates and/or information from engineering simulations. Figure 14 indicates that different types of remedial actions are required for different stages of the procedure. Or to put it differently, the procedure is vulnerable in different ways depending on which stage of it is considered.

According to the steps in an integrated sequence analysis (Figure 2), the identification of the error modes leads on to the calculation of error probabilities. In the present case, however, it is necessary further to extend the basis for the assignment of error modes by critically evaluating the description of the event and by providing additional data about the duration of the various stages and actions. These are activities that must be carried out in Task 2 and Task, as described in the beginning of this report.

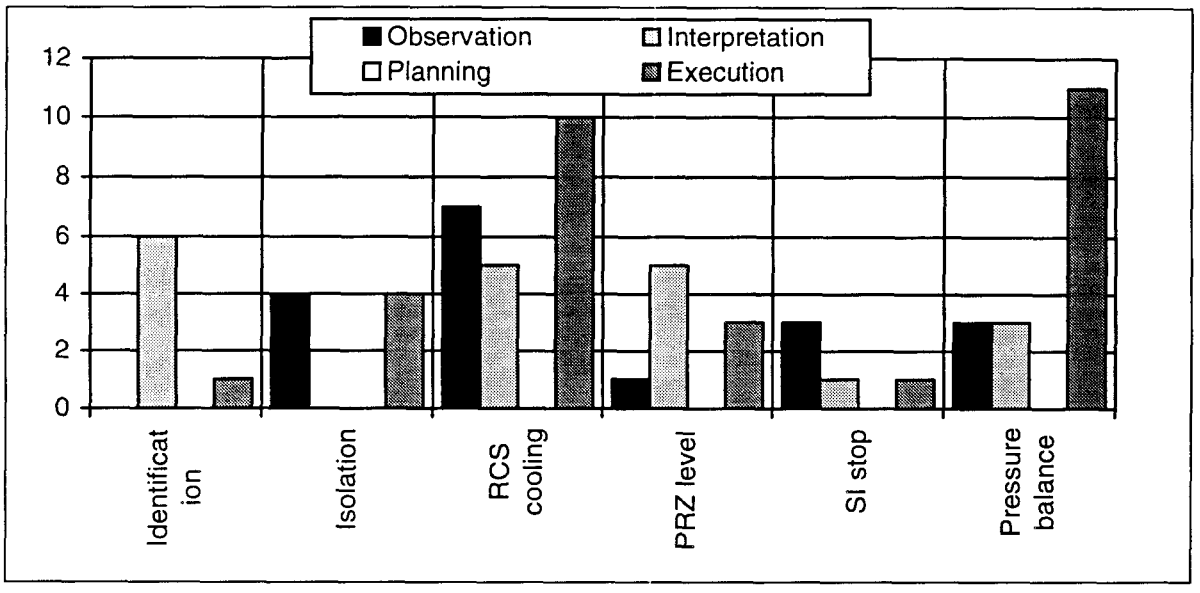

Figure 14: Distribution of error modes for stages of the SGTR EOP

The present report has endeavoured to show how a systematic cognitive task analysis can be used to develop a cognitive profile, which serves as a description of the potential problems in the procedure. In the true spirit of an integrated sequence analysis this step should be carried out by a team of specialists representing the various fields of expertise. In practice the report has been written by human factors experts with some valuable inputs from others. In the context of the RAK project, the integration will be taken further through the next tasks. It is hoped that the present report will serve as a useful starting point for this.

5. ACKNOWLEDGEMENTS

This report has had the benefit of the support of the whole NKS/RAK-1:3 team. The assistance of Bengt Ljunquist and Urban Carlsson in particular is gratefully acknowledged. They took considerable time to explain the seemingly obvious to people who are not even technicians. Any misrepresentations of the details of the SGTR EOP in this report therefore persist despite their best efforts.

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