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Comparative Analysis of Display Requirements Generated via a Task-Based and Work Domain-Based Analyses in a Real World Domain: NOVA's Acetylene Hydrogenation Reactor

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Unified Modeling Project

UT/NCL/HTC/NSERC

Comparative Analysis of Display Requirements Generated via a Task-Based and Work Domain-Based Analyses in a Real World Domain: NOVA's Acetylene Hydrogenation Reactor

A Report of work under Tasks 4 ("Task Model Analysis") and Task 5 ("Develop Model Integration Approach") of the NOVA/UofT Task Breakdown (Jan. 13, 1998)

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2. Summary

2.1 Objectives and Outcomes

There are two purposes for this report: (1) to provide display requirements generated by a task analysis of operations of a moderately complex, real-world domain—NOVA's Acetylene Hydrogenation Reactor (AHR), and (2) to compare these requirements to those generated by an Abstraction/Decomposition Space analysis of the same domain (reported in Miller and Vicente, 1998a). Furthermore, the results of this comparison were evaluated against a similar comparison performed on a pair of analyses of a less complex, laboratory domain—Vicente's (1996) DURESS II simulation—and reported in Miller and Vicente (1998b). In that report, we documented unique and complimentary strengths in the types of display requirements generated by each analytic technique, albeit in a laboratory simulation setting. In this report, we have performed a similar set of analyses for a real world work domain. Thus, this comparison is important to validate and refine our conclusions about the relative contributions of each analytic technique.

As in Miller and Vicente (1998b), we chose to investigate the interface *requirements* produced by different analytic tools (instead of interfaces produced from those requirements) because the analyses naturally produce requirements; interfaces must be developed from them through human creativity. The work reported in this document leverages work performed previously, thus we chose to use the same analytic methods to investigate the real-world AHR domain that we had used previously to investigate the DURESS II laboratory simulation. We chose to do this comparative analysis using the Rasmussen's (1985) Abstraction Decomposition Space (ADS) analysis technique (more commonly known as the Abstraction Hierarchy) as a representative work-domain analysis technique, and Hierarchical Task Analysis (HTA--Shepherd, 1989) as a representative task analysis technique.

As in Miller and Vicente (1998b), we were not attempting to conduct a pure, side by side, 'shoot off' comparison designed to show which analytic method was 'better'. Instead, we were interested in the *complimentary* information produced by task analyses and work domain analyses when used in conjunction. Related questions included:

- Would the two techniques produce qualitatively different types of knowledge about how an interface should be designed?
- Would they produce the same types of information but in quantitatively different ways (that is, by using one technique after the other, would it be possible to get more, if similar, display requirements knowledge)?
- Would performing the pair of analyses on the complex, real-world domain support, refute or extend the findings from performing them on the more simple, DURESS II laboratory simulation?

The most general conclusion from our comparison of the two analytic techniques is that, as was seen in the comparative analysis of DURESS II, the two analytic techniques *do* have unique contributions to offer the interface design process, even when performed sequentially. As can be seen from the table in section 5, not only are the sets of display requirements produced by the two analyses substantially different, they are also highly complimentary.

The set of findings largely paralleled those from Miller and Vicente, 1998b. Loosely speaking, the following conclusions seem valid:

The ADS work domain analysis:

- Does a much better job at providing ‘deep knowledge’ about the full set of constraints and capabilities for system behavior which are inherent in the work domain—though the HTA analysis was perhaps better at identifying these constraints for NOVA’s AHR than it had been for DURESS II. The reason for this seems to stem, primarily, from the sources used to perform the HTA—NOVA’s procedures. These procedures themselves contain a substantial amount of ‘deep knowledge’ in the form of explanations, cautions or rationale provided for how and why procedures are to be executed. Where this deep knowledge could be worked into the HTA, it was, but as will be seen in 6.12 below, the HTA was fundamentally incapable of explicitly expressing some types of deep knowledge.
- More readily identifies information requirements for monitoring, controlling and diagnosing the system
- Is more independent of the specific context in which the system is used (e.g., its interface, organizational goals, social structure, etc.) The more complex real-world domain of the AHR has shown that the ADS provides a comprehensive picture of the information about the physical plant equipment and its functions, but that that picture is undifferentiated by roles, task divisions, communication needs among roles, and is insensitive to the social and organizational needs of plant operations (e.g., safety requirements, standard operating procedures, reporting procedures, etc.)

The HTA task analysis:

- Provides ‘compiled’ procedural knowledge which, while being easier to learn and follow for anticipated cases, hides the deeper rationale for why procedures work and risks unexpected behavior in unexpected situations—again, this claim may have been slightly less true for the HTA analysis of NOVA’s AHR than it was for DURESS II.
- Is more ‘human-centered’ in that it focuses more on what the operator must or can do and how s/he divides the set of operational behaviors into discrete chunks (i.e., tasks)—in addition, the HTA analysis of NOVA’s AHR did a better job than either the ADS analysis of the AHR or than the HTA analysis of DURESS II at identifying the individual roles of operators, though it is worth noting that those roles are dependent on current, standard practice and are highly context dependent.
- More readily identifies when, how and with what priority information will be needed to perform expected tasks—in addition, the HTA analysis of NOVA’s AHR did a better job than the ADS of the AHR (and a comparatively better job than the HTA analysis of DURESS II) at identifying ‘normal’ or ‘expected’ values for important system parameters—though it did a worse job of identifying conditions and system manipulations that could achieve those values in specific (especially non-normal) circumstances.
- Is less independent of context and requires a more comprehensive consideration of the full set of factors which influence operator behavior. Importantly for the complex, multi-actor domain of the AHR, these included representation of different roles, different information needs by role, communication needs among roles and the need for supporting information (such as specific plant documents) and for behaviors not dictated strictly by the physical structure of the plant, but nevertheless part of work for NOVA—including roles, communications, standard operating procedures, safety actions, reporting actions, etc.

The complex, real-world domain of NOVA’s AHR did offer some new information about the analytic techniques, however. The fact that the AHR is operated by multiple individuals who divide task roles, share information and coordinate activities, and must exist within a complex social, organizational, corporate and regulatory environment means that there are types of constraints on operator behavior which were not generally present in the simpler DURESS II domain. The ADS analysis was generally blind to these types of information, while they could be incorporated into the HTA as long as they were present in the materials used to construct that analysis. A more interesting difference came in the form of a limitation on the representative power of the HTA. NOVA's written procedures frequently included some information about the rationale behind an action. In and of itself, this inclusion can be taken as evidence that, in the highly practical world of industrial processing, such rationale information provides value beyond the rote task steps. Nevertheless, there was no simple way to include this information explicitly in the HTA analysis.

2.2 Report Organization

Section 3 presents a variety of background information important for understanding the comparative analysis which is the focus of this report including (1) an argument for why a comparison between the two techniques should be done at the level of the display requirements they produce rather than of the displays themselves, (2) a more detailed description of each of the analytic techniques and a conceptual comparison of them, (3) a description of the comparison experiment we performed on the DURESS II system including a description of DURESS II itself, a description of the comparison technique and a summary of the results of the comparison, (4) a detailed description of the current domain of analysis—NOVA's Acetylene Hydrogenation Reactor, and (5) a description of the nature and objectives of the comparison we performed in this experiment. Section 4 and Appendices A and B present the results of the HTA analysis of DURESS II. Section 5 provides, in tabular form, a comparison of the types of display requirements knowledge produced by each analysis. Section 6 reports our observations and lessons learned about the complimentary nature of the two techniques. Section 7 contains our conclusions and a general summary. Section 8 contains the references cited throughout the report, and the two Appendices, as mentioned above, contain the results of the HTA analysis in two different formats.

3. Objectives, Rationale and Caveats

The purpose of this report is to provide a direct comparison of the types of information which a task and a work-domain analysis *of a complex real-world system* can provide for the purpose of interface design. We made claims about complimentary strengths and weaknesses of each analytic approach in the NSERC proposal and in Miller &Vicente, (1998c). In Miller and Vicente (1998b and 1999) we justified these claims by means of a direct, 'face-to-face' comparison of the results produced by the two representative task- and work domain-based analysis methodologies applied to the same display requirements analysis problem. These results will be summarized below. The purpose of this study was to perform the same sort of comparative analysis on a real world domain to provide additional data about types of results each analytic technique produce.

Below, we first justify the study of requirements produced by the alternate analytic techniques as opposed to the study of displays produced from those requirements. Then we describe the two classes of analytic techniques, task-based and work domain-based, as well as the specific analytic methods we chose for this study. Then we discuss the comparative study performed on Vicente's (1996) DURESS II simulation and the results of that comparison, since the conclusions of that study form a hypothesis for this one. In the last two subsections, we describe the domain for this study--NOVA's Acetylene Hydrogenation Reactor (AHR)—and we lay out the nature of the comparison to be performed in the following sections. Much of the material in the first three subsections is repeated from former reports (especially Miller and Vicente, 1998b & c, 1999) because it is relevant to this report as well.

3.1 Why compare requirements?

In this report, we have created lists of requirements for the generation of a visual display from two different analyses of NOVA's Acetylene Hydrogenation Reactor (a component in their Ethylene refining process). While the utility of a list of requirements is ultimately less than a full display, there are various reasons for believing that this may be a more profitable way of comparing the outputs of the alternate modeling and analysis techniques than comparing complete displays. All analysis techniques we are exploring naturally end at the requirements phase of the design process, as illustrated in Figure 1. That is, they don't explicitly tell the interface designer what the display should look like. Instead they provide information about what the display's contents should be and, perhaps, how individual items should relate to each other—that is, requirements for the visual form of the display itself. The designer must then apply creativity, skill and intuition to creating a visual form which meets those requirements, or as many of them as possible.

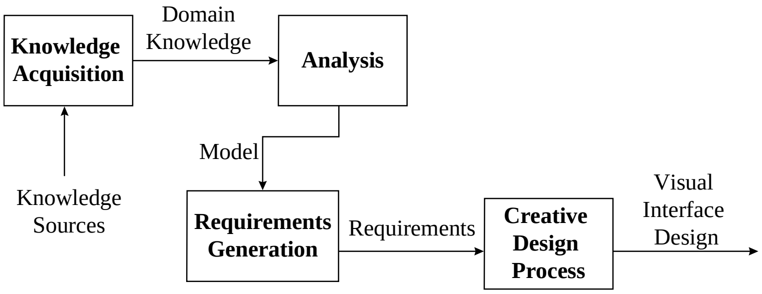

Figure 1. Analysis and design in the interface generation process.

Figure 1 provides some implications for how alternate analytic methods should be compared. First, since the analysis method at best produces requirements which are then interpreted and acted upon by a designer, comparing *designs* (as opposed to requirements lists) introduces the confounding factor of the creativity of the designer. Two designers (or the same designer on different days) might produce better or worse visual designs from the same set of requirements. Similarly, the differences between two designs might be due to the skill and creativity of the designer rather than to the outcomes of the analytic techniques. Second, it is possible that not all requirements can be met (or met equally well) by a given design. Thus, although they *are* requirements, they may not be manifested in the display which is ultimately produced. This, again, is the 'fault' of the designer (and/or of the display resources available) and not of the analytic technique. A final reason for examining the requirements produced by the various analytic techniques is the prevalence of requirements as a means of communicating across diverse and distributed work groups in large, complex industrial work settings. As interface development efforts become larger, the plausibility of a single individual who first performs an analysis and then proceeds immediately to interface design decreases. Thus, awareness of the types of requirements that can be produced using various techniques has important implications in its own right.

For the above reasons, we have decided to examine requirements in this and the previous study (Miller and Vicente, 1998b and 1999) rather than the end product of design as a means of comparing analytic techniques. Nevertheless, there can be little doubt that the ultimate proof is 'in the pudding.' Any analytic technique which consistently fails to produce superior visual interface designs (as measured by comparative performance studies) should be regarded with skepticism.

3.2 Analytic Methods Compared

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The most common work analysis techniques used for the purpose of interface design can be divided into two types based on their primary focus. Task analysis (TA--Kirwan & Ainsworth, 1992; Diaper, 1989) describes the actions that an actor can or should take to accomplish goals. Work domain analysis (WDA) techniques (Rasmussen, Pejtersen & Goodstein, 1994; Rasmussen, 1985), which we have also called "system-based" analysis techniques for reasons described below, examine the functional structure of the domain (specifically, the plant or system) in or on which work must be done.

We have been studying these types of analytic techniques for two years now—with the ultimate goal of unifying them for the purpose of producing superior interface designs. In early work, we claimed (Miller & Vicente, 1998c&d) that each approach has strengths and weaknesses, though ultimately they reflect different perspectives on (and different avenues to) the full set of knowledge needed for good human-centered system design. A comparison of the strengths and weaknesses of these techniques (based on our initial intuitions) is presented in Table 1.

In late 1998, we conducted a comparison of analyses performed using representative analytic techniques from each of the classes described above. This analysis was performed on a comparatively simple, laboratory simulation system called DURESS II. The results of the comparison of analyses of DURESS II largely validated the assumptions in Table 1, and led to new insights about interface design for DURESS II. The purpose of this study was to perform the same sort of comparative analysis on a real world domain to validate the previous findings.

Table 1. Relative advantages and disadvantages of TA and WDA forms of work analysis (and, by extension, of interfaces designed from information obtained via these analytic techniques).

	TASK	WORK DOMAIN
Mental economy	efficient	effortful
Ability to adapt to unforeseen contingencies	brittle	flexible
Scope of applicability	narrow	broad
Ability to recover from errors	limited	unlimited

Below, we describe both task and work domain analysis approaches in separate sections and our selection of specific, representative analytic techniques, used for both the analysis of DURESS II and of the NOVA AHR, within each category. More detail on the results of the comparative analysis of DURESS II are provided in the further subsections which follow.

3.2.1 Task-based analysis and design methods

Task analysis (TA) techniques have a long and productive history in human factors. Kirwan and Ainsworth (1992), in their comprehensive work on the vast variety of TA methods, define TA "… as the study of what an operator… is required to do, in terms of actions and/or cognitive processes to achieve a system goal." Thus, TA methods are explicitly about the actions that an actor can or should take to achieve a goal. The focus of TA is the action, however, not the work domain. Knowledge about tasks captured in analysis typically includes either hierarchical, means-ends relationships (how subtasks may be composed to accomplish higher level tasks) or sequential relationships (how tasks must be performed temporally in order to be successful), or both. Sources of information for TAs are typically user interviews, though observation, experimentation and training or procedural manuals may also be used (Diaper, 1989). Where these sources are absent, and in those circumstances where task knowledge breaks down (e.g., unanticipated situations), TA will be impossible, or worse, misleading. When these sources do exist reliably, however, failure to incorporate them into design will result in inefficiencies or errors in training and operations.

Information needs (both input and output) are typically deduced for the tasks and these, combined with the task relationship information described above, can serve as the basis for prioritizing, clustering, filtering, or sequencing information presentation elements in an interface design. Task-linked information requirements serve as a particularly powerful basis for constructing "context" sensitive (actually, user intent, goal or procedure) interfaces (Miller, 1999) since they can dynamically filter information on the basis of the current user information needs (Rouse, Geddes, and Curry, 1988; Miller, Funk and Hannen, 1997).

For the purpose of our comparative analysis, we chose to use a specific task analysis method known as Hierarchical Task Analysis (HTA--Shepherd, 1989). While not the most complex or representationally powerful TA technique, HTA has the strengths of being extensively used in a wide variety of application areas, familiar to most researchers and practitioners, and is easy to use and to adapt to most analytic needs.

3.2.2 Work domain analysis and design methods

Work domain analysis (WDA) techniques are more recent additions to the repertoire of interface design tools. WDA techniques emphasize the structure of the work domain—that is, the plant or equipment on and with which the user must achieve some set of functional goals. This is why we have also referred to WDA techniques as "system-based" analyses, in contrast with the task-based analyses described above.

Most current work in this area derives from Rasmussen's (1985) abstraction-decomposition space (ADS)—commonly, if somewhat incorrectly, referred to as the 'Abstraction Hierarchy' (AH). An ADS is a two-dimensional modeling tool that can be used to conduct a WDA in complex sociotechnical systems. Rasmussen's approach, shares the Gibsonian (Gibson & Crooks, 1938) emphasis on the importance of the "field" or ecology in which an actor behaves for determining or "constraining" the set of actions which are necessary or appropriate. There is a growing amount of empirical support showing that interfaces based on such work domain analyses can lead to better performance than traditional interface approaches, particularly in abnormal situations (Vicente, 1996).

The ADS provides a comprehensive analysis of the means-ends and part-whole relationships in the functional structure of the process being controlled. It is important to note, however, that while some TA approaches represent means-ends relationships, these are 'action' means-ends (i.e., what actions need to be performed in order to achieve ends at a higher level). By contrast, an ADS represents 'structural' means-ends relationships (i.e., what structural states of the system are required in order to achieve higher level ends).

WDA relies on a detailed knowledge of the plant and its interactions with the environment—and on the rules, equations or models governing these interactions. When these sources are inadequate, the analysis will be correspondingly inadequate—but this situation is less common than might be expected. The greatest threat to the safety of process control systems is events that are not familiar to operators and that have not been anticipated by designers (Vicente & Rasmussen, 1992). Under these challenging circumstances, the operator's role is one of adaptive problem solver. Because the event has not been anticipated by system designers, the available procedures, experience, and automated aids are not directly applicable. The one thing that does remain unchanged, however, is the functional structure of the plant and the principles that govern its interactions with the environment. Further, it is precisely within these constraints that the operator must improvise a solution.

3.2.3 Theoretical Comparison of the Techniques

Task-based models are like directions for navigation: they identify the actions that human operators should take for particular situations; system-based models are more like maps because they emphasize the overall structure of the plant, independent of any particular situation. Task models are efficient because they identify the information and prioritize it for pre-defined classes of situations, whereas system models are more robust because they identify the functional relationships that are potentially relevant for all situations.

Table 1 above shows the comparative strengths and weaknesses of TA and WDA. TAs (and interfaces designed from them) are efficient because they identify what needs to be done, and perhaps how. But as a result of this economy, TAs do not provide the support required to adapt to unanticipated events. TAs are narrow in their generality because they are only applicable to the tasks that have been identified up front, and generally, only to specific ways of doing those task. In task-sensitive interfaces, efficiency is accomplished by suppressing information not pertinent to specific, active tasks, but this may risk loss of accurate, overall knowledge of process state. While context-sensitivity can be accomplished by adapting the interface to specific work domain states, this frequently presupposes an implicit task-orientation and may undercut the comprehensiveness of information availability described above. Again, due to their narrow, brittle, procedural orientation, TAs are also limited in their ability to support recovery from errors.

WDAs (and interfaces derived from them) have a complementary set of strengths and weaknesses. Their primary disadvantage is that they do not tell workers what to do or support them specifically in what they are currently doing. As a result, WDAs put greater demands on workers and may lose efficiency by failing to support specific methods that are known to work in specific conditions. Yet WDAs are generally flexible because they provide workers with the information they need to generate an appropriate response, on-line in real-time, to events which have not been anticipated by system designers. Moreover, WDAs also have a broader scope of applicability. Because they show what the system is capable of doing, they provide workers with the discretion to meet the demands of the job in a variety of ways that suit their preferences or the particular needs of the moment. For the reasons already discussed, WDAs also provide workers with the support they need to recover from errors.

We have assumed that the complementary strengths and weaknesses of TAs and WDAs imply that it would be useful to include both techniques in a single, integrated framework for work analysis and interface design. Initial thoughts about methods for accomplishing this integration can be found in Miller & Vicente (1998c) and in the prior research report from this project (Miller & Vicente, 1998b & d). In the next section below, we will describe research which has demonstrated that each analytic technique provides unique, but complimentary, information about user display needs—even when they are done sequentially for the same domain.

3.3 Experimental Comparison using DURESS II

In Miller and Vicente (1998b and 1999) we report the results of an experimental comparison of ADS and HTA analyses of a laboratory simulation work domain—the DUal REservoir System Simulation, DURESS II. Since it is extremely rare, in both industry and academia, for the same work domain to be analyzed twice using different tools, the purpose of this experiment was to produce data to defend or refute the assumptions about the strengths and weaknesses of each analytic approach summarized in Table 1. Below, we summarize the DURESS II work domain, the approach we used to analyzing it and comparing the resulting analyses, and the findings of that comparison.

3.3.1 Application Problem—DURESS II

The following description is from Vicente, (1999):

> DURESS (DUal REservoir System Simulation) II is a thermal-hydraulic process control microworld that was designed to be representative of industrial process control systems, thereby promoting generalizability of research results to operational settings. The physical structure of DURESS II consists of two redundant feedwater streams (FWSs) that can be configured to supply water to either, both, or neither of two reservoirs. Each reservoir has associated with it an externally determined demand for water that can change over time. The work domain purposes are twofold: to keep each of the reservoirs at a prescribed temperature (generally, 40° C and 20° C), and to satisfy the current mass (water) output demand rates. To accomplish these goals, workers have control over eight valves (VA, VA1, VA2, VO1, VB, VB1, VB2, and VO2), two pumps (PA and PB), and two heaters (HTR1 and HTR2). All of these components are governed by first order lag dynamics, with a time constant of 15 seconds for the heaters and 5 seconds for the remaining components. DURESS II is described in more detail in Vicente, 1996.

We chose to work with DURESS II initially for a variety of reasons: (1) it had been used extensively in experiments and analyses at the University of Toronto and elsewhere, (2) it was simple enough to be readily understood by undergraduate students, it was nevertheless complex enough to permit a wide range of operational strategies and the development of both correct and incorrect mental models when naïve users attempt to interact with it, and (3) while extensive ADS analyses of DURESS II have been performed, task analysis methods had not yet been applied to it. Thus, DURESS II offered the promise of speeding our comparative work while ensuring a measure of independence between the Work Domain Analyses and the Task Analyses we wanted to perform.

3.3.2 Experimental method

As mentioned above, work domain analyses using Rasmussen's (1985) ADS analysis technique had already been repeatedly performed repeatedly on DURESS II. To provide the basis for comparison between the ADS and HTA techniques, we performed an HTA task analysis on the DURESS II system. The primary purpose of each analysis was deriving information requirements for human users of DURESS II. The objective of the analysis is important since both ADS and HTA can be put to other uses (cf. Diaper, 1989; Vicente, 1999) with somewhat different resulting outputs.

The HTA analysis of DURESS II was performed after the ADS analysis and with full knowledge of it. In fact, the sources used to construct the HTA models were only partly the user interviews which are commonly used in HTA. Instead, the analyst used reported observations of user behavior and strategies which had been collected during prior experiments with DURESS II and were part of a strategy analysis of its use.

It might be argued that this makes the results of the HTA less 'pure' than they would have been in a more normal or representative instance of its use. After all, HTAs are typically done as the first and only analysis of a work domain by individuals who don't have access to alternative analytic results. We were ultimately not interested in such a 'pure' analysis, however, and we were not attempting to conduct a side by side, 'shoot off' comparison to show which analytic method was 'better'. To have performed such a comparison fairly and accurately would have demanded double-blind experiments with equally trained design engineers. Not only did we not have such individuals available, but we were ultimately uninterested in which approach was 'better' than the other. Instead, we were interested in the *complementary* information produced by the two types of analyses when used in conjunction. If the goal of the overall Unified Modelling Project (to develop a modeling technique and/or representation which unifies task- and work domain-based analyses) is to be justified, we must show that there are unique contributions from each perspective. In essence, performing one analysis after the other, building on its outputs, is a conservative approach to demonstrating that point. It might be expected that two separate analyses would produce different results, but if a second analysis can be performed with the full knowledge of the first and *still* produce novel information, that would be stronger evidence for the unique contribution of each approach.

3.3.3 Results

A detailed summary of the types of information produced by each analysis is included in Miller & Vicente (1999) and the complete results are included in Miller and Vicente (1998b). The general conclusions from the study were as follows.

The most general conclusion from our comparison of the two analytic techniques for the DURESS II domain is that the analyses *did* have unique contributions to offer the interface design process, even when performed sequentially. Not only were the sets of display requirements produced by the two analyses substantially different, they were also highly complementary. Loosely speaking, the following general conclusions were valid:

The ADS work domain analysis:
- Did a much better job at providing 'deep knowledge' about the full set of constraints and capabilities for system behavior that are inherent in the work domain.
- More readily and directly identified information requirements for monitoring, controlling and diagnosing the system—by contrast, the task analysis tended to reduce the granularity of tasks to an increasingly finer size, making it progressively easier for the analyst to infer information requirements without actually identifying them.
- Was more independent of the specific context in which the system is used (e.g., its interface, organizational goals, social structure, etc.)

The HTA task analysis:
- Provided 'compiled' procedural knowledge which, while being easier to learn and follow for anticipated cases, hid the deeper rationale for why procedures work and risks unexpected behavior in unexpected situations.
- Was more 'human-centered' in that it focused more on what the operator must or can do and how s/he naturally thinks about the domain, dividing the set of operational behaviors into discrete chunks (i.e., tasks).
- More readily identified when, how and with what priority information will be needed to perform expected tasks—and thus was more applicable to prioritizing, sequencing and dynamically configuring information presentations.
- Was less independent of context, but therefore required a more comprehensive consideration of the full set of factors which influence operator behavior.

3.3.4 Conclusions

In general, the results of our first study fit the expectations summarized in Table 1. By providing compiled procedures, the TA identified display requirements associated with a successful method of achieving a goal. Using displays based on those requirements would likely be efficient, but brittle in those circumstances which differed from the assumptions inherent in the procedure. By contrast, the ADS provided better 'deep knowledge' about the nature of the constraints and capabilities inherent in the work domain. Interfaces based on the display requirements generated by this analysis would enable a wider range of procedures to be deduced, including those for unanticipated circumstances, but only at the cost of added effort on the part of the user.

In addition, a few novel distinctions were learned from this study. First, we realized that ADS analyses seem to do a better job of actually identifying information requirements than do most TAs. By contrast, the HTA provided information about the priority, sequencing and likely methods of navigation within information that was mostly absent from the ADS analysis. Finally, we saw that the 'device- and event-independence' which has been claimed for ADS (cf. Vicente, in press) cuts both ways. The ADS analysis focuses on the fundamental constraints and capabilities inherent in what is, arguably, the most fixed portion of the work domain—the physical plant. It is not sensitive to control systems, user capabilities or training, organizational structure, etc. As Vicente has pointed out, taking these elements into account in analyzing a work domain usually leads the analyst to focus on only a portion of the possible set of conditions the work domain may get into—and this leads to incomplete design. Suchman's (1987) work is full of representative examples, where systems are designed for a nominal set of cases but breakdown and become unusable (or worse, misleading) under unanticipated abnormal circumstances. On the other hand, devices and interfaces for them exist within complete world settings and elements from the control systems, user capabilities, organizational policy, training and familiarity, etc. all affect the way work is done in real world settings. While task analyses are more restrictive than WDAs in what they capture of the constraints and capabilities of the physical plant, they are more comprehensive in that they also capture constraints and capabilities imposed by other aspects of the work domain.[1]

3.4 Current Comparison Domain—NOVA's AHR

While highly informative, the results of the above experiment could be criticized because they were derived from analyses of a comparatively simple, laboratory system instead of from a complex, real world domain. To address that issue, as well as to provide useful inputs to one of the sponsors of this work, we have performed a similar pair of analyses on one unit in NOVA Chemical's E1 Ethylene refinery in Joffre, Alberta, Canada. The unit is the Acetylene Hydrogenation Reactor (AHR) and its function will be described below.

The AHR is a relatively small portion of the overall ethylene refining process. While this may prove a disadvantage in the long run, its small size was virtually required to make work manageable for our first year of research. Similarly, interaction with the AHR involves only a small set of tasks or procedures—only 5 during normal operations—although the decision about whether or not to shift to fault management procedures is sometimes critical and difficult to make.

Upsets in the AHR are the single most frequent cause of upsets in the overall ethylene process and down time for the AHR process costs roughly $1000/minute. Of upsets involving the AHR, roughly one third are caused by inappropriate initial decisions on the part of the operator (deciding not to go to flare when he should have), while another 50% are caused by poor execution of the flaring procedure. Furthermore, while an inappropriate flare decision (a false positive) can, *if well-executed*, cost 20 minutes of down time, even a well-executed false negative (deciding not to flare when you should have) will cost 4-6 hours of down time. A poorly-executed false negative can easily double that amount. Thus, there are significant economic benefits to be obtained through displays which *both* enable better, more accurate initial decision making and which enable better execution of the flaring procedure.

The primary overall purpose of the ethylene refinery is to take natural gas (which is composed mostly of ethane—C2H6) and convert it into ethylene (C2H4). This is done by applying heat to it (in a process called pyrolytic conversion) and 'cracking' some of the ethane into ethylene and hydrogen (H2). Trace amounts of various other substances are also produced, the most important of which (for our purposes) are acetylene (C2H2) and carbon monoxide (CO). These products are then separated in downstream subprocesses and the ethane is cycled back for another round of cracking while the ethylene is transported elsewhere for a variety of uses.

In NOVA's E1 plant, the AHR is located downstream of the pyrolytic furnaces. The AHR receives partly processed C2 feed which is composed mostly of ethane (C2H6) and ethylene (C2H4) with various trace elements, the most important of which is acetylene (C2H2). Further subsystems in the plant will separate the ethane and ethylene from the trace elements, but those processes are very sensitive to the presence of acetylene. The reason for the presence of the AHR is to remove this acetylene. The AHR does this by 'hydrogenating' it—that is, forcing it to undergo a chemical reaction which adds an H2 molecule to each C2H2 to convert it to ethylene (C2H4). While the maximization of ethylene production is the overall goal of the E1 plant, the fact that slightly more ethylene is produced by hydrogenation of acetylene is incidental. Instead, the motivation for the removal of acetylene is that it enables the use of downstream processes to

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[1] This fact is well recognized by Vicente. In his 1999 book, he lays out a set of five interacting analytic techniques to capture constraints and capabilities at five 'layers' of a work domain: the physical system, the control tasks, operator strategies, social and organizational structures and worker competencies. The ADS is offered only as a means of analyzing constraints and capabilities at the first of these layers.

separate ethane from the existing ethylene. The AHR process also hydrogenates some of the existing ethylene, thereby turning it into ethane (C2H6). While this is not desirable, the impact on the overall quantity of ethylene and ethane produced is minimal. Instead, ethylene conversion to ethane is undesirable because it runs the risk of using up the available unattached hydrogen molecules, leaving an insufficient quantity to accomplish the removal of the acetylene. The acceptable concentration of acetylene out of the AHR is less than 2 ppm.

The following is a summary of the AHR process used in NOVA's E1 facility. Figure 2 depicts the major components of the AHR and it may be helpful to cross reference this description with that figure.

1. Raw natural gas enters the E1 facility and undergoes pyrolysis in multiple furnaces. This converts some of the ethane and propane in the natural gas to ethylene and hydrogen. Other trace products are produced including carbon monoxide. Pyrolysis is not naturally a part of the AHR subsystem, since it occurs both temporally and geographically distant from the AHR but, for reasons that will become clear as the rest of the AHR process is described, the carbon monoxide present in the output of pyrolysis is critically important to the AHR. Thus, the AHR operator monitors and is given control over one aspect of pyrolysis which affects CO production—the addition of DiMethyle DiSulfide (DMDS) to the natural gas feed into the pyrolytic furnaces. The addition of DMDS reduces CO production--which is somewhat undesirable from the AHR operator's perspective, but it also reduces coke formation in the furnaces, which is desirable from the furnace operator's perspective.
2. Various processes which occur downstream of the pyrolysis furnaces separate and further process the gas mixture. By the time the gases enter the AHR system, they do so in two streams: one (called the feed stream, or the C2 stream) consists primarily of ethylene (C2H4) and ethane (C2H6) with trace amounts of acetylene (C2H2). The other consists primarily of H2 and CO. Each stream is driven by a pressure head produced by upstream compression equipment (K201), not a part of the AHR.
3. The H2/CO stream is heated in a steam-driven heat exchanger (E413s) and then routed to an intersection with the C2 stream pipe.
4. The E1 facility is capable of sharing its hydrogen with another NOVA ethylene facility—E2, or of using E2's hydrogen if needed. E2's H2 can be routed into the E1 stream before or after heating in E413s, but E1's H2 can only be routed to E2 after heating. Differences in the content of H2 and CO in the streams will affect the reactions as described below.
5. Before it reaches this intersection and is mixed with the H2/CO stream, the C2 stream is heated twice. The first time is via the Reactor Cross Exchanger (E410) which uses hot effluent from the reactor (see below) to heat incoming, cooler C2 feed. The second is a steam-driven heat exchanger (E411).

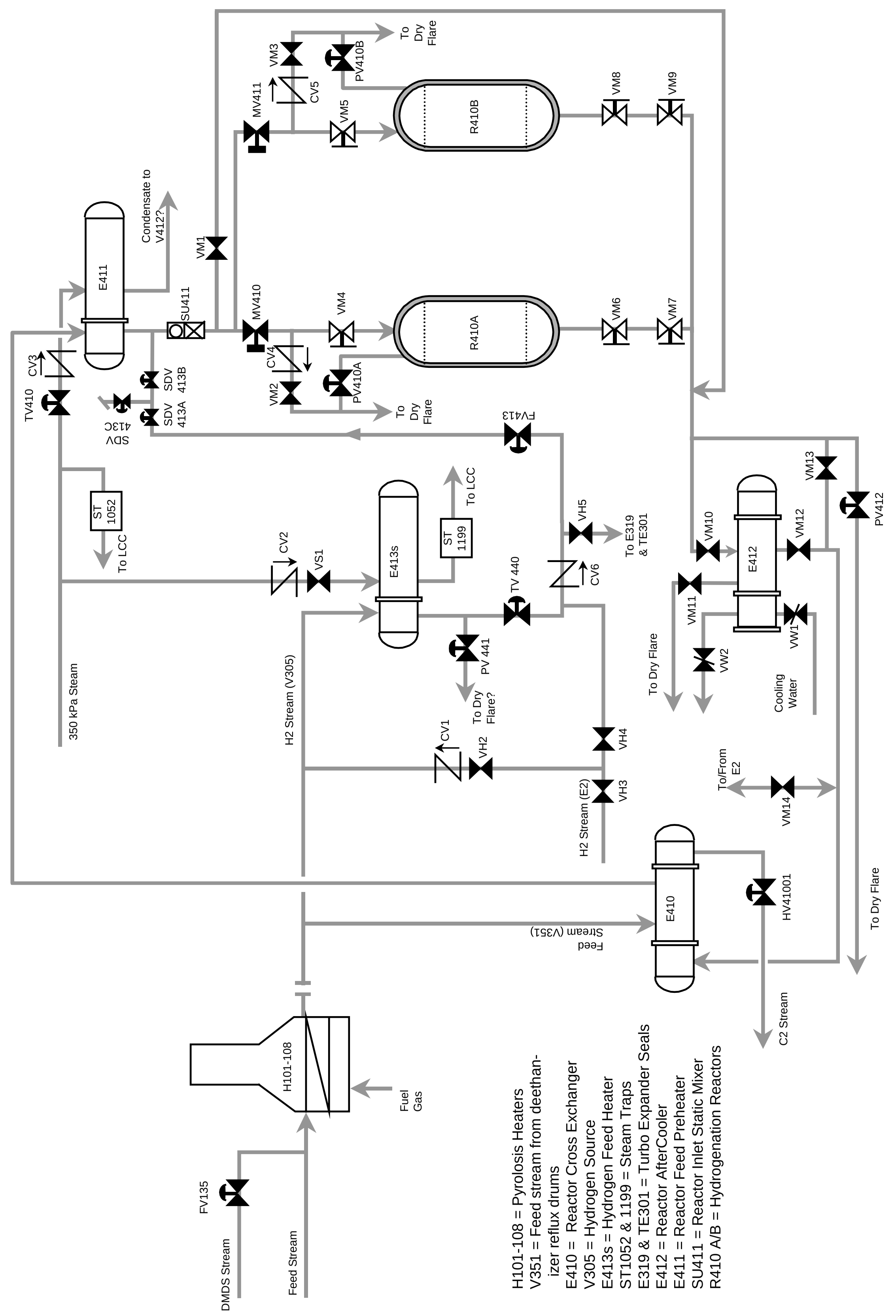


Figure 2. NOVA's E1 Acetylene Hydrogenation Reactor unit.

6. 'Mixing' the C2 and H2/CO feed streams simply involves allowing them to intersect via a static turbulence inducer (SU-411). Following this, the mixed stream is allowed to flow into one of the two reactor vessels (the other is always off line and either undergoing regeneration or waiting to be put back on line).
7. The reactor vessels are currently filled with Dow Type-P Palladium catalyst which allow the following reactions to take place:
    - $C_2H_2 + H_2 \rightarrow C_2H_4$ + heat = "Acetylene Conversion"
    - $C_2H_4 + H_2 \rightarrow C_2H_6$ + heat = "Ethylene Conversion"
    - $CO + 3H_2 \rightarrow CH_4 + H_2O$ = "CO reaction"
    - (with lots of heat and/or pressure) $C_2H_4 \rightarrow C + CH_4$ + lots of heat = "Ethylene Decomposition"
8. Acetylene conversion is desired. Ethylene conversion is undesired, but tolerable in small quantities. The CO reaction is used to regulate the other reactions as discussed below but it only operates within a narrow range and it produces undesirable side effects. Ethylene decomposition is highly undesirable and dangerous. Since it does not rely on the presence of hydrogen, reducing the H2/CO feed will not affect it. Instead pressure and/or heat must be reduced, and the quickest way to accomplish this is by venting to flare.
9. The catalyst has many weak and a few strong sites.
10. Precedence for reactant being adsorbed on catalyst sites is as follows (assuming adequate H2):
    1. CO on strong
    2. CO on weak
    3. Ethylene on strong
    4. Acetylene on strong
    5. Acetylene on weak
    6. Ethylene on weak
11. Thus, managing the reactor works as follows:
    - ensure that you've got enough CO in the reactor to occupy all of the strong sites
        - otherwise, ethylene will occupy those sites and be converted to ethane. This is both inefficient (you're trying to maximize ethylene content) AND dangerous—excess ethylene conversion can use up available H2 leaving none for acetylene resulting in "acetylene breakthrough" (getting too much acetylene in the AHR output).
    - Try to minimize CO so as to avoid occupying weak sites
        - CO on weak sites can mean not enough sites available for the acetylene reaction, thus, acetylene won't be fully converted and, again, you get breakthrough
    - Thus, acetylene breakthrough can be prevented by adding CO if there was too little in the mix in the first place (and strong sites were going unoccupied by CO) or it can be fueled by adding CO if there was too much in the mix in the first place (and weak sites were being occupied by CO). Since strong and weak sites on the catalyst are not inspectable, this is a source of confusion and error.
    - Try to manage the ratio of H2/CO feed to C2 feed (and the heat of both) to minimize ethylene conversion while sustaining acetylene conversion
        - too little H2 (and/or too little heat) and there won't be enough for total acetylene conversion, thus breakthrough
        - too much H2 (and/or too much heat) and, after all acetylene conversion, the last reaction (ethylene on weak sites) will occur and you'll get undesirable ethane.
12. Thus, CO is said to "improve selectivity of the catalyst" for the acetylene reaction.
13. Increased heat 'quickens' all reactions—that is, makes them more likely to occur. This increases the overall activity of the catalyst, but it reduces selectivity. Heat in the reactors can be increased by increasing the heat of the incoming gas streams which, in turn can be accomplished by increasing heat transfer in E410, E411 and E413.
14. Increased pressure acts much like increased heat in making catalyst more active, but there is no convenient way to increase pressure in the reactor vessels. Decreasing pressure can be accomplished by routing feed or reacted product to flare.

15. All of the above reactions are stated as if they were absolute. They are not. They're stochastic. Because they're stochastic, they're distributed throughout the body of the reactor. Since both ethylene and ethane conversions give off heat, it is possible to detect where in the catalyst bed most of the reaction is taking place by sensing where the greatest rise in temperature is taking place. For various reasons (optimal use of the catalyst, optimal feed flow, minimal use of H2 and CO, etc.) it is desirable to distribute the reaction throughout the bed rather than having it all take place early.
16. Other reactions are possible given the presence of trace elements in the feed such as sulfur compounds, arsine, phosphine, halides and halogen. All of these have the effect of 'poisoning the catalyst'—that is, making it unreactive—but NOVA has never had these problems with the natural gas feed it uses in E1. In addition, a normal trace byproduct of the desired reactions is a complex carbon compound called "green oil". Accumulation of green oil slowly causes catalyst to become unreactive. When this happens, the reactor is taken off-line and regenerated using high pressure steam. The second reactor (see Figure 2), which was previously regenerated, is then put online until it becomes "stale", and then the reactors are again swapped and the stale one regenerated.
17. After reaction, the reacted product flows out of the reactors and downstream to the Reactor After Cooler (E412)—a heat exchanger driven by cool water. This cooler can be bypassed as well.
18. After E412, the reacted product stream can be diverted to E2, but is generally routed through the Reactor Cross Exchanger (E410) where it serves to heat the incoming C2 stream as described above. After E412, the reacted, cooled product stream proceeds out of the AHR subsystem to further refining (especially ethane separation) in the rest of the E1 facility.
19. Once the two input streams are mixed, they can be diverted to flare at many points in the AHR process. These include both before and from within the reactors, and before, from within or after E412. The mixed stream can also be bypassed around the reactors, and the H2/CO stream can be vented to atmosphere before it is mixed with the C2 stream and enters the reactor by a set of automatically controlled, pressure sensitive block and bleed valves.

3.5 Nature of the Current Comparison

The comparative analysis of NOVA's AHR was performed in essentially the same fashion and, using the same two analysis techniques (ADS and HTA) as had been used to perform the analysis of DURESS II described in section 3.3 above. As for that comparison, we were not interested in a 'pure,' side by side comparison designed to show which analytic method was 'better'. Instead, we were interested in the *complimentary* information produced by task analyses and work domain analyses when used in conjunction. Related questions included:

- Would the two different techniques produced qualitatively different types of knowledge about how an interface should be designed?
- Would they produce the same types of information but produce it in quantitatively different ways (that is, by using one technique after the other, would it be possible to get more, if similar, display requirements knowledge)?
- Would doing one type of analysis first facilitate the doing of the other analysis? Would it improve the quality of the results produced?
- Would the information produced by each analytic technique be similar to the types of information produced by that technique in the analyses of DURESS II? Would we find the same types of complimentary display requirements knowledge produced in this analysis that we did there?

As for the analyses of DURESS II, the ADS analysis of NOVA's AHR was performed before the HTA analysis. The one difference in methodology between the AHR analyses and the DURESS II analyses was the data used to obtain information for the HTA. For the DURESS II HTA, this data was obtained primarily from strategy analyses for operation of the DURESS II system provided by engineers who had designed it, and secondarily by students who had learned to operate it in laboratory experiments. For the NOVA AHR HTA, the primary source of data was NOVA's written procedures for operation of the AHR, and a secondary source was the writers of these procedures. Information about AHR operation was also provided by plant engineers and designers and by current operations personnel, but these were tertiary sources.

The results of the ADS analysis of NOVA's AHR are presented in detail in Miller and Vicente (1998a). The results of the HTA task analysis of the AHR are presented in section 4 below and in Appendices A and B. Section 5 provides a summary comparison of the HTA results with those from the ADS, while section 6 contains conclusions and lessons learned from this comparison.

4. Requirements from Task Analysis

4.1 Task Analysis Methodology and its Rationale

We chose to use the Hierarchical Task Analysis (HTA) methodology (Shepherd, 1989) to perform our task analysis of NOVA's AHR. A huge variety of task analysis methodologies exist (cf. Kirwan and Ainsworth, 1992), thus our selection of HTA requires some justification. Our most immediate reason for using HTA is that it was the methodology used in the comparative analysis performed on DURESS II (Miller and Vicente, 1998a), thus repeating its use in this analysis was important for facilitating the comparison of these results with those from the previous study. Our reasons for selecting HTA in the prior study can be summarized as follows. HTA is a simple, informal and comparatively impoverished task analysis method, yet one which can be readily extended to capture and organize information requirements. It is, however, also a 'basic' tool in that it contains (perhaps simplified versions of) most of the characteristics of even the most complex task modeling tools. HTA also has the advantage of being widely known and used in the task analytic community. Thus, not only is there substantial written guidance in how to use it, but using HTA would make it easier to communicate our results to the rest of the academic and industrial community. Finally, we are investigating the use of alternative task representations in another thrust within this project (cf. Miller & Vicente, 1998d).

As Shepherd (1989) and others have pointed out, the purpose for which one performs a task analysis can have a profound impact on the types of information collected. Loosely speaking, there are three primary purposes for which a task analysis can be conducted: (1) to provide knowledge about how an interface to support the tasks should be designed, (2) to identify operational knowledge to be conveyed to a novice user in training, and (3) to create procedures for use by any user in operating the plant. Our primary purpose in this exercise was #1. In fact, we used NOVA's existing operational procedures to help generate the HTA. A task analysis focused on producing design requirements places more emphasis on identifying the information needs of users following the tasks in the analysis—but less emphasis on ensuring that the tasks are decomposed to a fine enough level to ensure performance by a novice.

The use of written procedures to aid in the production of a task analysis is certainly not unknown, but it is generally used cautiously, since the actual method of task performance in any work domain can differ substantially from the set of written instructions—especially in real-world, commercial domains where social, organizational and legal goals for having procedures may conflict with operators' motivations for doing the work. It is generally advisable to at least verify procedure performance with field observations and operator interviews. While we have spoken with field operators, our primary sources for performing this analysis have been the written procedures and interviews with procedure writers (albeit, ones with field experience), and we have done very little field verification of procedure use. We believe that this has less impact on the nature of our study than might be expected. First, the results of a parallel study (cf. Jamieson and Miller, in preparation) show a number of reasons for suspecting that procedures are written, trained and reviewed at such a way in NOVA's 'culture' that they are probably followed more closely than they may be in other industrial settings. Second, since the primary purpose of our review was to compare the types of information captured by a task analysis with the kinds of information captured by a WDA, whether or not the information content is completely representative of actual practice is, in some sense, irrelevant *for the highly academic purpose of comparing analytic outputs*. For example, if a written procedure says that operators should do a certain task by reading a gauge and then adjusting a valve and, in practice, they sometimes do these things in reverse order—I can still conclude that task representations enable the capture of sequential action relationships from either input. I might, however, get into trouble if I tried to design an interface that facilitated doing the task in the first order—since operators don't always do things that way. Thus, while we believe that we have taken a reasonable approach for the analytic comparison which is the purpose of this study, care should be taken in using the results of this task analysis to create displays. Ideally, additional field observations and interviews with active operations personnel should be conducted to validate the task analysis we include here.

Finally, we should say a few words about the short cuts taken in performing this HTA. We began the ADS analysis of NOVA's AHR by identifying the boundaries of the ADS system for our purposes (cf. Miller and Vicente, 1998a). These boundaries were largely physically drawn, and were largely consistent with what plant personnel view as the AHR unit, but we made some simplifying assumptions. For example, we included the valves and piping associated with feeding DMDS into the pyrolytic furnaces as a part of the AHR system even though they are physically located in a separate part of the plant and are sometimes viewed as a part of the 'furnaces' unit. This was because the functional purpose of this DMDS subsystem is entirely associated with the operation of the AHR. Similarly, for the sake of bounding our investigation, we decided not to include equipment for regenerating the AHR with our ADS analysis of that unit, even though much of this equipment is co-located with the AHR, and even makes use of some of the same piping. In short, we drew a 'functional box' around a set of plant equipment and performed the ADS analysis on the equipment which fell within that box. The boundaries of the box itself were somewhat arbitrarily determined with the convenience of the researchers in mind.

In performing the HTA analysis of the AHR, we drew a similar functional box around the tasks associated with the AHR equipment as we had defined them in the ADS analysis. Thus, for example, we ignored regeneration tasks, even though NOVA has a detailed procedure for these tasks. In doing the HTA, we posited a hypothetical AHR control room operator and performed the analysis from his/her perspective with the goal of identifying requirements for displays that s/he might use. In practice, no such operator exists. The AHR is a part of the 'back end' chain of splitters and coolers that take 'cracked' product from the furnaces and further distill it—and a single control room operator generally has responsibility for the whole 'back end'. On the other hand, this single control room (or 'board') operator works with several 'field operators' whose job it is to maneuver themselves to specific locations in the, potentially, multiple square miles of the plant and do jobs that cannot be done from the control room—such as adjusting non-automated valves, inspecting for leaks, reading uninstrumented gauges, etc.

Our emphasis on the 'AHR board operator' had several implications for our review of NOVA's procedures. First, it required us to select portions of numerous NOVA procedures which were pertinent to the operation of the AHR. While there may be only a small action required on the AHR in some of these procedures, this action must come at a critical time with regards to the status of other units in the E1 facility. In practice, a board operator responsible for the back end might be monitoring several units and the status of one of them would inform him or her about the need to perform an action on the AHR. For our purposes, this simply took the form of a required communication about the status of another unit or about the timing for an AHR action. Similarly, we have generally avoided detailed expansion of the information needs of field operators working on the AHR and concentrated on the board operator's needs. These include communications from the field operators about the status of equipment or the progress of field actions.

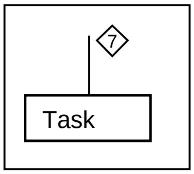
Perhaps not surprisingly, the first level decomposition of the AHR tasks (see Appendix A), shows the same four tasks as the first level decomposition of DURESS II: Start Up, Normal Operations, Shut Down and Fault Management. These are very common task distinctions in industrial process domains. In the analysis of DURESS II, we did very little expansion of the Fault Management branch, representing only a few known faults and their management strategies. This was, partly, an acknowledgement of the fact that representing comprehensive strategies for Fault Management is ultimately hopeless in a task analytic sense in any open system where the complete set of faults (and their causes and management strategies) can never be pre-specified. While this was true of NOVA's AHR as well, there was a comparatively greater richness of procedures under Fault Management than was true for DURESS II. This may represent one of the significant differences between studying a laboratory domain and a complex, long-established, real-world one. NOVA's E1 AHR has been running for over 30 years now and there has been adequate time to identify several classes of faults and develop management procedures for them. While knowing how to handle all possible faults is impossible, there is clearly some value in knowing how to handle some common and/or previously experienced ones.

4.2 Analysis Results and Formalisms

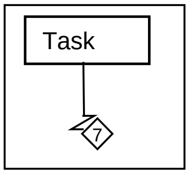
The results of the HTA for DURESS II are presented in two different formats in Appendices A and B (after Shepherd, 1989). Appendix A presents the HTA for DURESS II in tabular form. While it is harder to visualize task relationships in this format, it is easier to link additional information to tasks. We have included three additional columns of information beyond the task relationships themselves. The first, labeled 'Timing', contains information about the tasks' sequencing (shown as shaded boxes spanning the table cells with a named temporal relationship between tasks: e.g., sequential, parallel, etc.) The second column, labeled 'Actors', contains information about the personnel, by role, who will be performing this task. The most common roles in these procedures are 'BO' (for board operator) and OO (for outside, or field operator). Other roles include 'Shift Supervisor', 'Emergency Coordinator', and 'Maintenance'. We have also occasionally used the label 'Not AHR' to indicate, simply, that this task is the responsibility of someone outside the boundaries we have defined for the AHR operator, without stipulating whose task it is. The final additional column, labeled 'IRs', contains information requirements identified for each task. Note that only some cells in the information requirements column are filled in. This is not because the other tasks have no information requirements, but because we have generally only provided information for the lowest level or 'leaf' task in any hierarchy. This implements the heuristic that information requirements for parent tasks are simply the aggregate of the information requirements of their children. Also, we have generally only providing information requirements for tasks to be performed by the BO.

Appendix B presents the task analysis in graphical form, emphasizing the 'layout' of the tasks—their hierarchical and aggregate relationships. In this format, each layer of the the hierarchy represents a series of tasks or actions which accomplish the higher level ('parent') task in some fashion. A 'Plan' is always placed along the vertical line connecting the child tasks to their parent to show how/when/in what order they must be performed in order to accomplish their parent task. The plan is where information about the parallel or sequential relationships among the tasks and their initiation and completion conditions is located.

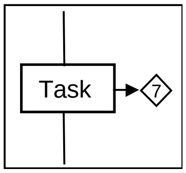
Since the analysis is far too large to fit on a single page, the following conventions were used to link the hierarchical graph across pages:



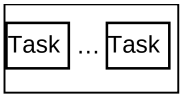
Indicates that the task named in the box is an expansion from a parent task that is found on page 7.



Indicates that the task named in the box is expanded on page 7.



Indicates that other subtasks of the same parent are included on page 7.



Indicates that there were other task(s) appearing in between these two tasks in NOVA’s procedures but that these were not a part of AHR operations as we defined them.

5. Comparison of Results

Table 2 provides a side-by-side comparison summarizing the types of knowledge obtained from the two analyses. It necessarily summarizes the specific data provided by the analyses and, therefore, eliminates many of the critical specifics from the two analyses. Thus, for more detail, the reader should review the analyses themselves carefully as contained in the appendices of this report and of Miller and Vicente (1998a). Further, in the interests of providing a concise comparison, it has occasionally been necessary to make generalizations in the table below. While exceptions to these claims are possible, we believe they hold true in general.

Due to the sequential nature of our analytic method, it is important to keep in mind the cumulative nature of the analyses. Since the HTA was performed *after* the ADS, the presence of an information type in the HTA column does not mean that an HTA alone would have been sure to capture display requirements of that type. Furthermore, the absence of an information type in the HTA column means that the HTA had no reasonable or convenient way of incorporating that type of information, in spite of the fact that the ADS analysis said that it was needed. Since the ADS was performed first, without access to the HTA results, the presence of an information type is evidence that ADS alone can identify that type of information. On the other hand, the absence of an information type in the ADS column means only that the ADS failed to identify that type of information need—not that it could not have incorporated that information, especially if the ADS had been performed after the HTA.

Some explanation should be provided with regards to the entries which claim that an information type was “implicitly” identified by an analytic technique. Note that both HTA and ADS are intended and, in current practice, are generally used as the sole method of identifying display requirements for interface design. Thus, it is not surprising that either approach provides most of the full set of display requirements represented by the union of the outcomes of the two approaches. It is important, however, that some types of information are only ‘implicitly’ provided by each technique. ‘Implicit’ in this context, generally means that some sensitivity to the type of display requirements knowledge was required in order to complete the analysis, but that the knowledge required wasn’t as complete or deep, or as easily or explicitly represented in the ‘implicit’ technique’s outputs as it was in the more ‘explicit’ one. Therefore, the designer using the ‘implicit’ analytic technique *might* do as thorough a job of understanding and capturing that knowledge type as the one using the explicit technique, but that the nature of the technique itself made this less likely. For example, the procedures produced in the HTA require an understanding of the underlying functioning of the DURESS II system, but this knowledge could come in the form of reported procedural rules from domain experts. There is no guarantee that such reports would be complete or even necessarily accurate (though the use of these procedures in NOVA’s operations means that there has been extensive review of them). Further, the understanding of the system’s general capabilities and constraints required to produce accurate procedures is not explicitly captured anywhere in the HTA analysis. Instead, this knowledge is ‘compiled’ (which necessarily means that it is obscured) into procedural rules by the HTA. Thus, an HTA ‘implicitly’ conveys knowledge about the DURESS II system functions, but they do not ‘explicitly’ capture or convey that knowledge in depth (see also sections 6.10 and 6.12 below).

Finally, it is important to remember that the generation of display requirements is only a contributor to the ultimate display which is designed. The fact that an information type is missing from either column leaves open the possibility that a smart designer would have intuitively filled that information in. On the other hand, the absence of that information type in the display requirements places a heavier burden on the designer’s intelligence and creativity, thereby making errors of omission more likely.

To facilitate comparison of the results of this study on the real-world AHR domain with the prior study on the laboratory DURESS II system, we have split the ADS and HTA columns in two and repeated the data from the DURESS II experiment in the first subcolumn of each row. Thus, for example, the first row of the table states that the ADS analysis identified physical appearance and location information about work domain components for both DURESS II and for the AHR, whereas the HTA did not identify this type of information for DURESS II and it only occasionally identified it in the AHR analysis.

The last four rows of the table include types of information that were not included in either analysis of the DURESS II system and were not identified by the ADS analysis of the AHR. Perhaps not surprisingly, these types of information have to do primarily with the coordination of large teams of people—as is generally necessary for the operation of complex, real-world systems which are distributed over a large amount of physical space. The fact that this type of information was not identified in any previous analysis implies that it is not well captured by ADS analyses, and that the DURESS II system, with its single operator, was too simple to require it.

Table 2. Comparison of the types of display requirements knowledge produced by the two analytic techniques.

Type of Interface Knowledge Identified in Analysis	**Identified in ADS analysis?**		**Identified in HTA analysis?**	
	DURESS II	AHR	DURESS II	AHR
Physical appearance and location of work domain components	X	X		Occasionally explicit
Physical connections between components	X	X		
The function and current state of physical components	X	X	X	X
Range of possible states for physical components	X	X	Implicit from multiple comparisons	Occasionally explicit
Actual current behavior of	X	X	X	X

Type of Interface Knowledge Identified in Analysis	**Identified in ADS analysis?**		**Identified in HTA analysis?**	
	DURESS II	AHR	DURESS II	AHR
components (Generalized function states: flows and quantities)				
Range of possible behaviors of components	X	Generally	Implicit from multiple comparisons	Occasionally explicit
Capability to achieve (and constraints on) general functional behaviors given the states of physical components	X	X	Implicit (and partial) in procedures and expectation generation	Generally implicit, occasionally explicit, partial overall
Causal relationships between general functions	X	X	Implicit (and partial) in procedures and expectation generation	Generally implicit and partial, some explicit inclusions
Aggregation of generalized functions into subsystems	X	X	X (with notion that subsystem definition might be dynamic)	Very implicit and occasional based on the equipment a procedure is focused on
Actual current generalized function state at subsystem level	X	X	X (with notion that subsystem definition might be dynamic)	X (though these aren't always available, the need is usually called out)
Range of possible functional states at subsystem level	X	X (though there may be cause for finer granularity than we used)	Implicit from multiple comparisons	Generally explicit
Causal connections between subsystem behaviors	X	X	Implicit (and partial) in procedures and expectation generation	Implicit (and partial) in procedures and expectation generation
Current state of abstract functions at the subsystem level	X	X	X (with notion that subsystem definition might be dynamic)	Generally explicit
Range of possible abstract function states at subsystem level	X	X	Implicit from multiple comparisons	Implicit and occasionally explicit
Capability to achieve (and constraints on) abstract functional behaviors given generalized functional states	X	X	Implicit (and partial) in procedures and expectation	Implicit and occasionally explicit, but partial) in

Type of Interface Knowledge Identified in Analysis	Identified in ADS analysis?		Identified in HTA analysis?	
	DURESS II	AHR	DURESS II	AHR
			generation	procedures and expectation generation
Causal connections between abstract functions	X	X	Implicit (and partial) in procedures and expectation generation	Generally implicit, occasionally explicit
Current state of functional purpose variables for the system as a whole	X	X	X	X
Range of possible states for functional purpose variables	X	X	Implicit from multiple comparisons	Implicit
Capability for achieving (and constraints on) overall functional purpose behaviors given abstract functional states	X	X	Implicit (and partial) in procedures and expectation generation	Generally implicit, occasionally explicit
Specific expected or goal value for physical functions	Implicit from functional behavior capability and constraint information	Implicit from functional behavior capability and constraint information	X	Generally explicit
Specific expected or goal value for general functions	Implicit from functional behavior capability and constraint information	Implicit from functional behavior capability and constraint information	X	Generally explicit or deducible from other explicit values
Specific expected or goal value for abstract functions	Implicit from functional behavior capability and constraint information	Implicit from functional behavior capability and constraint information	X	Generally explicit
Specific expected or goal value for functional purpose	X (demand values)	X	X	X
Extra-system goal information (duration or cumulative volume; start, stop and change requests)			X	X
Social-organizational priority and tradeoff information			X	Occasionally explicit
Social-organizational information about operational expectations (likelihood of faults, demand changes, etc.)			X	Occasionally explicit
Explicit strategy choices and functional implications			X?	Occasionally explicit
Explicit information to support			X	Occasionally

Type of Interface Knowledge Identified in Analysis	**Identified in ADS analysis?**		**Identified in HTA analysis?**	
	DURESS II	AHR	DURESS II	AHR
strategy selection (e.g., sum of D, interface availability)				explicit
Configuration-dependent subsystem groupings and capacities	Static groupings and implicit (derivable) capacities	Static groupings	X	No explicit groupings. Implicit groupings based on task and sequence
Distinction between monitoring and controlling information elements	Capabilities discriminated but no information about when which was needed	Capabilities discriminated but no information about when which was needed	X	X
Task dependent, temporal information clustering (sequential vs. parallel presentation, etc.)	Some capability via means-ends relationships	Some capability via means-ends relationships	X	X
Team coordination information				X
Reference material information				X
Social procedural information (e.g., safety, reporting)				X
Division of information by role				X

6. Conclusions and Lessons Learned

As for the comparative analysis of DURESS II, the most general conclusion that can be drawn from the above table is that the two types of analyses do have unique contributions to offer the interface design process and further, that the nature of these contributions was similar for the complex, real world domain of NOVA's AHR as they were for the comparatively simpler laboratory domain of DURESS II. As can be seen above, not only are the sets of display requirements produced by the two analytic techniques substantially different, they are also highly complimentary. Loosely speaking, the following conclusions, repeated from the DURESS II analyses, still seem valid, with some added refinements derived from this domain:

The ADS work domain analysis:

- Does a much better job at providing 'deep knowledge' about the full set of constraints and capabilities for system behavior which are inherent in the work domain—though the HTA analysis was perhaps better at identifying these constraints for NOVA's AHR than it had been for DURESS II. The reason for this seems to stem, primarily, from the sources used to perform the HTA—NOVA's procedures. These procedures themselves contain a substantial amount of 'deep knowledge' in the form of explanations, cautions or rationale provided for how and why procedures are to be executed. Where this deep knowledge could be worked into the HTA, it was, but as will be seen in 6.12 below, the HTA was fundamentally incapable of explicitly expressing some types of deep knowledge.
- More readily identifies information requirements for monitoring, controlling and diagnosing the system
- Is more independent of the specific context in which the system is used (e.g., its interface, organizational goals, social structure, etc.) The more complex real-world domain of the AHR has shown that the ADS provides a comprehensive picture of the information about the

physical plant equipment and its functions, but that that picture is undifferentiated by roles, task divisions, communication needs among roles, and is insensitive to the social and organizational needs of plant operations (e.g., safety requirements, standard operating procedures, reporting procedures, etc.)

The HTA task analysis:

- Provides ‘compiled’ procedural knowledge which, while being easier to learn and follow for anticipated cases, hides the deeper rationale for why procedures work and risks unexpected behavior in unexpected situations—again, this claim may have been slightly less true for the HTA analysis of NOVA’s AHR than it was for DURESS II.
- Is more ‘human-centered’ in that it focuses more on what the operator must or can do and how s/he divides the set of operational behaviors into discrete chunks (i.e., tasks)—in addition, the HTA analysis of NOVA’s AHR did a better job than either the ADS analysis of the AHR or than the HTA analysis of DURESS II at identifying the individual roles of operators, though those roles are dependent on current, standard practice and are highly context dependent.
- More readily identifies when, how and with what priority information will be needed to perform expected tasks—in addition, the HTA analysis of NOVA’s AHR did a better job than the ADS analysis of the AHR (and a comparatively better job than the HTA analysis of DURESS II) at identifying ‘normal’ or ‘expected’ values for important system parameters—though it did a worse job of identifying conditions and system manipulations that could achieve those values in specific (especially non-normal) circumstances.
- Is less independent of context and requires a more comprehensive consideration of the full set of factors which influence operator behavior. Importantly for the complex, multi-actor domain of the AHR, these included representation of different roles, different information needs by role, communication needs among roles and the need for supporting information (such as specific plant documents) and for behaviors not dictated strictly by the physical structure of the plant, but nevertheless part of work for NOVA—including roles, communications, standard operating procedures, safety actions, reporting actions, etc.

In the remainder of this section, we will detail lessons learned from our comparative analyses. First, we will provide the list of 15 lessons learned from the comparative analyses performed on DURESS II and add commentary about whether or not these lessons proved valid in the comparative analyses performed on NOVA’s AHR. Many of these lessons involve considerations of the strengths and weaknesses of each approach. The final item, in section 6.16, is a lesson learned specifically from performing the comparative analyses on NOVA’s AHR and, thus, represent new findings above and beyond what was learned from the analyses performed on DURESS II.

6.1 Importance of method selection

The HTA analysis for DURESS II showed that the operation of that system could be thought of in terms of a handful of task-like strategies or methods. Much of the user’s interactions with DURESS are determined by strategy choice: initial demands and socio-organizational priorities constrain the set of useful strategies and once a strategy is chosen, it is reasonably straightforward to determine what specific equipment settings and values should be. Expectations and performance monitoring are also determined by strategy choice, and equipment failures may make a current strategy no longer feasible, therefore mandating a transition to another strategy.

While these strategies were, in fact, identified by a Cognitive Work Analysis of DURESS II, based on an initial ADS analysis, they were not present in the ADS analysis itself. The HTA more naturally showed how the strategies were chosen and used by an operator—as well as the information requirements both for making strategy choice and for implementing the strategy.

This prevalence of strategy-based reasoning argues for the inclusion of strategies in any training regime and, perhaps, as first-order, manipulable objects in the work environment. We suggested that any decision aiding offered to DURESS II operators be organized around a shared understanding of the strategy choices between human and machine.

Strategies were less marked or explicit for NOVA’s AHR. If strategy is taken to mean the overall goal or direction for operation of the system, then the highest level tasks in the HTA breakdown (Start Up, Normal Ops, Shut Down and Fault Management) and, perhaps the next level of task breakdown (especially under Fault Management) can be seen as strategies. In that sense, those operational categories were better captured by the HTA analysis of the AHR than by the ADS analysis, and do serve (in current practice at NOVA) as a structure for organizing training, communication of common intent across operators, etc. In this sense, the finding from the DURESS II analyses held true for the AHR analyses.

In another sense, however, the strategies used by NOVA operators were not captured well in either ADS or HTA analyses. If strategies are meant to imply the set of personal choices about how to achieve stated functional goals, then neither analysis captured these well. For the HTA analysis of DURESS II, we relied primarily on an a priori engineering analysis of the possible ways in which functional goals could be achieved in the DURESS II system for our HTA. This analysis was purposely comprehensive and, in fact, observations of subjects interacting in the lab with DURESS II had confirmed that all of these strategies were used by some subjects. By contrast, our task analysis of NOVA’s AHR relied primarily on NOVA’s written procedures. One purpose of these procedures within NOVA’s culture is to provide instruction and common expectations on the ‘correct’ (or ‘best’ or ‘standard’) way to accomplish goals. To a large extent, whenever allowable variation exists in the procedure for accomplishing a task, it is purposely left out of a written procedure to allow operators to do things as they see best. This is not to say that individual variations don’t exist—they certainly do, and are a source of organizational concern. NOVA currently forms ‘work teams’ and attempts to keep these teams of individuals together in schedules and rotations in order to foster and obtain advantages through allowing each team member to learn the others’ ‘styles’. On the other hand, some operators and plant supervisors expressed concerns about the loss in optimal system performance which occurs when one team, operating on the night shift, comes in and has to spend perhaps several hours (during which system performance may be suboptimal) reconfiguring the system so that it operates in the configuration they are used to and expect—all because the day shift had a different notion of what ‘normal operating procedures’ were.

In short, we suspect that the reason neither analytic approach captured the individual strategies for operating NOVA’s AHR had more to do with the method in which task-based information about AHR operations was captured than about the nature of either analytic technique. More time spent interviewing individual operators or, alternatively, a detailed engineering analysis of potential methods of operating the AHR would probably have revealed more different strategies than the review of NOVA’s procedures did. We suspect, based on the outcome of the DURESS II analysis, that such individual differences in operation would have been implicitly derivable from the deep knowledge of the ADS analysis, but would have appeared more explicitly in the HTA analysis.

6.2 Importance of expectations given method/task

A large proportion of the tasks for operating DURESS II involve either the generation of expected values for various DURESS II components or the comparison of current values to the expected ones. By ‘expected values’ here, we mean something like ‘given my understanding of the current state of the system, I expect this value to be X’. Thus, an expected value is not necessarily the same as a commanded value (I’ve commanded a downstream valve to provide 10 units of water, but I know that I’ve constrained the flow to 8 units at an upstream valve, thus my expectation for flow from the downstream valve is only 8 units—after lag effects). It is also not necessarily the same as a goal value (I may want or need 10 units of flow downstream, but the fact that the upstream valve is stuck means there’s no way I can get it.) Nevertheless, in a healthy, steady state, thoroughly understood system expected values should equal commanded values, goal values (and actual values, of course). In fact, in an extremely abstract sense, the Normal Operations task can be thought of as simply a monitoring to ensure that all current states are equal to goal/demand states, Fault Management is initiated whenever these are not true, and Start up and Shut down both involve the translation of high level goal states into specific goal states for each piece of equipment and the generation of intermediary expectation states corresponding to a plan for transitioning from current state to goal state. The information requirements for many tasks in the HTA make explicit this need for expected states or values for many equipment variables.

With the exception of mass and temperature output goals, specific expectation states are not produced by the ADS analysis of DURESS II, nor are they generally included in the DURESS II interfaces. This is in keeping with the goal of ADS to capture the constraints present in the work domain, and not the specific targets associated with any single methodology or trajectory through the work domain. Not surprisingly, therefore, the DURESS II interface tends to be good at conveying absolute equipment-based constraint boundaries, but less good at indicating whether, for example, a specific valve setting is in keeping with a strategy or method of achieving the overall goal.

These conclusions generally proved true for the analyses of NOVA's AHR as well. The ADS analysis of NOVA's AHR identified the specific, constrained values of C2H2 out of the AHR, but did not identify specific, target values for other parameters of AHR operation (e.g., expected delta temperatures across the reactor beds, expected mole percentages of H2, etc.) Instead, the ADS analysis identified specific constraining values (such as the temperatures at which spontaneous acetylene decomposition occurs) and the deep knowledge required to deduce the desired operating ranges from the stated target value for C2H2 ppm in the feed output. By contrast, many specific or expected values were identified in the HTA, but these were tied to specific (and only occasionally explicit) assumptions about the operating conditions.

The prevalence of expectation values in the HTA tasks suggests that some method of graphically conveying these values, perhaps in a manner sensitive to the current approach or strategy the operator is using, would be helpful to users. Such target values or ranges are occasionally included in NOVA's current displays, but they are almost always static and not sensitive to context, operating strategy or conditions.

6.3 Sequencing Constraints/Practices should be supported

As in the analysis of DURESS II, the HTA analysis of the AHR identified a number of places where multiple tasks must be done in sequence. The ADS does not explicitly identify sequential relationships, though some of them are captured via the means/ends and causal chain relationships which the ADS does identify. Because the HTA represents trajectories through the set of possible work domain actions, it is possible to represent any kind of sequential constraint which can be identified—but the HTA gives only weak analytic power for identifying those sequential constraints in the first place. As we discussed in the results for DURESS II, the sequential relationships captured in the HTA can come either from constraints inherent in the work domain (e.g., it is critical to ensure that a fresh reactor is still under an N2 cap before beginning the reactor swing process), some are imposed by the nature of human cognition (e.g., it is necessary to determine the degree of deviation from a H2 mole percentage target before adjusting H2, CO or temperature) and some are imposed by the socio-organizational system (e.g., open the MOV no more than 10% on the first move). These latter are arbitrary in the sense that there are multiple other methods by which the procedure could be accomplished, but they are important for setting expectations for team coordination in the multiple actor setting for this work domain. While such sequential constraint information can be very useful for interface design, it is important to note that the HTA does not distinguish between these different sorts of constraints. Thus, an interface designed from HTA information alone might present information in such a way as to encourage operators to view all such sequential constraints in the same way—with equal 'hardness'—and since the consequences of the violation of the first sort of constraint are much more serious than the violation of the third, this view would be suboptimal at best and wrong or misleading at worst.

6.4 Importance of Parallelism/Continuousness/Repeating/Potentiality

The HTA also identifies other forms of temporal relationships between process steps or activities. These include instances where multiple tasks must be done in parallel, where tasks must be done continuously during a period, where tasks must (or may) repeat for some specified number of iterations or until some other condition holds, and where tasks must be done only potentially. Again, the ADS does not explicitly identify these relationships, although it may suggest them via its identification of means/ends and causal relationships. ADS is perhaps slightly better at implying (though not by explicitly identifying) the potentiality relationship than any of the others.

6.5 Distinction between Display and Control

In the comparative analysis of DURESS II, we noted that, due to its ability to better represent the sequential nature of different circumstances and their associated information needs, the HTA did a better job than the ADS at capturing the distinction between circumstances under which the values of information were needed, versus circumstances in which both information values and control over those values were needed. While the ADS does identify those variables which can be controlled (as well as the means for exerting control over them) versus those which can only be monitored, it does not support the identification of periods during which display alone might be acceptable because it does not explicitly include the notion of sequencing or temporal flow.

While still generally true in this comparison, this distinction seemed of less utility in the AHR domain than for DURESS II. There were comparatively few classes of occasions in which only information values were needed (though one could argue that the sheer temporal duration of Task 2.1 ‘manage normal operations’ means that, in fact, monitoring only is needed of the time). This discrepancy might have been an artifact of the specific differences between the two work domains. In addition to being much simpler than the AHR domain (in terms of both number of components and unpredictability in process behavior), the DURESS II domain was operated in a manner consistent with batch processing while most AHR operations are continuous. These two factors, simplicity plus batch process, meant that operators could do substantial planning and pre-run computation in support of work with DURESS II, while such circumstances are comparatively rare in the operation of the AHR. Since this was the chief set of circumstances in which presentation of information values alone was relevant, the comparative scarceness of those circumstances in the AHR domain may account for the reduced relevance of this distinction.

6.6 Importance of Social-Organizational Knowledge (organizational priorities)

In the analyses of DURESS II, we noted that socio-organizational knowledge was required to enable operators to chose between startup and operations strategies including information about the importance or priority of speed to completion, speed to initiation, consistency of output, and the operator’s perceived likelihood of demand changes, faults, excessive workload levels, etc. The need for this type of information was captured explicitly by the HTA analysis but was not included in the ADS analysis.

This comparative strength of the HTA over the ADS analytic technique remained true in the AHR domain. NOVA’s procedures include statements and branching logic about some socio-organizational priorities such as ensuring that the flare is not run for lengthy periods of time, instructing operators to prefer the use of H2 levels and temperature to control the AHR reaction over the use of CO , etc. These types of instructions are easily included in the sequences represented by the HTA. Interestingly, however, NOVA’s procedures rarely include explicit rationale information about why such priorities might exist within the organization—and the HTA would not be well suited to including such rationales, even though they might be deducible from the information contained in the ADS.

6.7 Tasks/Procedures require assumptions about all aspects of work domain

This point is essentially a generalization of 6.6 and 6.8, but it is significant enough to call it out separately. The need to reason about an effective procedure requires information (or assumptions) about all aspects of the work domain. For example, the procedures we reviewed (and the HTA we constructed from them) made very explicit assumptions about the nature and layout of the plant, about the availability of control and display information, about the competencies of workers and about the general, overall goal of the operation. Of these, the ADS analysis only explicitly included information about the first and last.

During the performance of an HTA, making these assumptions constrains the set of tasks or procedures which are represented which, in turn, hides work domain capabilities and/or potential means of interacting with the AHR. For example, experience at the plant, as well as the ADS analysis, shows (see Miller and Vicente, 1998a) that the reactor can be cooled during a rapidly rising temperature situation in several ways; at least two of which are incompatible: removing all feed (especially H2 feed, though it is occasionally impossible to separate this from C2 feed) and therefore ceasing reactions, or by continuing to pass cool feed (preferably C2 feed only) through the reactor. The current procedure implicitly constrains the latter approach to be used when temperatures rise above 200 degrees C and the former to be used at temperatures below this value. In fact, either approach can be used at either temperature and may be effective. The rationale for making the separation has to do with the likelihood of various causes of the temperature runaway and the degree of disruption that either approach causes in the rest of the plant—though the neither the procedures nor the HTA make this clear.

It is obvious that the kind of work domain information described in the previous paragraph might be of great utility to operators in certain specific situations. NOVA’s current procedures don’t make that information clear (although it is taught in training and it is available in case studies at the plant)—therefore a display designed only on the outputs of an HTA would likely not include this information. On the other hand, the control, socio-organizational, strategic, user competency, prioritization and team coordination information which is generally included in the procedures is also highly important. For example, users should know to follow lock-out, tag out procedures, but the explicit operational procedures for AHR actions include reminders about these at especially critical points. Since the ADS does not identify this type of information, a display conducted from its outputs alone would likely miss these needs. Thus, one virtue of an HTA in conjunction with an ADS is that each broadens the other—the ADS provides ‘deep knowledge’ about the structure and relationships in the work domain that the HTA will be likely to miss, while the HTA requires integration across multiple layers of considerations and thus provides control task, strategy, social-organizational, worker competency, and even interface-imposed information requirements that the ADS alone would miss.

6.8 Sensitivity to Current Displays = Lack of Device Independence

From the comparative analysis of DURESS II, we concluded that while both the ADS and the HTA require certain assumptions about the device being analyzed, it would appear that the HTA requires more extensive assumptions than the ADS. This conclusion remained valid in the analysis of the AHR. The ADS had to assume the existence and use of a specific chemical reaction method for removing C2H2, and even the behavioral characteristics of a specific type of catalyst, as well as the existence of a specific configuration of pipes, valves and heat exchangers. Even so, the only ‘device’ ADS was sensitive to was the physical plant itself. It makes no assumptions about control equipment, interfaces, operational procedures, etc. The HTA must make the same assumptions about the physical plant, but must make additional assumptions about the specific operating capabilities of controls and sensors, and even about the interface available to perform the tasks being examined. For example, our HTA of the AHR, based on NOVA’s procedures, goes into great depth and specifics in dividing tasks between those done by the Board Operator in the control room and those done by the Field Operator out on the unit itself. Much of this could be made irrelevant ‘overnight’ if new remote control capabilities were incorporated into the control room—or if more distributed control systems enabled control room operators to move into the field. Similarly, some of NOVA’s procedures reference specific control screens to view when performing the procedure, or specific schematics to reference. These must be updated whenever a relevant aspect of the plant changes—and operators frequently complain about procedures being ‘out of date’. On the other hand, inclusion of such information obviously makes the resulting procedures much more immediately relevant to the operators’ tasks.

While it might be possible to create a more device-independent HTA, it would certainly be more difficult and would likely be of less value. It would be more difficult because the ability of operators and analysts to reason about how to accomplish given goals is facilitated by the ability to remember or envision oneself in a work environment. It would be made less valuable because, in the absence of specific interactions with human-level interface devices, the notion of 'task' must be abstracted and generalized to a level which is likely to have less overall utility for the specific questions of interest in interface design.

6.9 Lack of Physical Form information

As with our comparative analysis of DURESS II, there was a general absence in the display requirements generated from the HTA (compared with those from the ADS) in the inclusion of physical form, appearance and location information. While this type of information was completely absent from the HTA analysis of DURESS II, it was occasionally present in our analysis of NOVA's AHR. Again, this was because NOVA's procedures, on which our HTA was primarily based, occasionally included such information. Procedures would occasionally describe the location or appearance of a field valve or the method of manipulating a control in the control room, for example. We will have more to say on the 'hybrid' nature of NOVA's procedures in section 7 below. For now, it should be noted that, when such information is included in the sources from which the HTA is derived, it is possible to include such information in the HTA itself. Though whether or not such information would generally tend to be included in an HTA remains to be seen. The fact that NOVA's procedures (and the NOVA personnel we talked with) tended to reference physical form and appearances in their discussion argues that such information would typically be included in an HTA, but probably not in a comprehensive fashion.

In Miller and Vicente (1998b) we offered several potential explanations for the lack of physical form information in the HTA analysis of DURESS II. These were:

1. That it was an artifact of the fact that the work domain upon which actors are acting is, in fact, a simulation; the physical appearance and behavior of the interface *was* the physical form with which operators are interacting. Thus, the need for considering, monitoring or interacting with a separate physical reality simply wasn't present in the tasks associated with operating DURESS II.
2. That our focus in the HTA was explicitly on the DURESS II operator—equivalent to a Board Operator in refinery operations. Physical form knowledge is far more important for the field operator who must locate, monitor, and manipulate the actual equipment in the field.
3. That our lack of expansion of the Root Cause Diagnosis branch of Fault Management caused us to miss physical form information.
4. That the lack of physical form requirements is another manifestation of the lack of 'deep knowledge' obtained via HTA relative to that from ADS. The trajectory-based, directions-like aspect of procedures captured and represented via HTA effectively eliminate the need for 'deep knowledge', including knowledge about the physical form and location of equipment—as long as the contextual assumptions under which the trajectories were created hold true. That is, if I wish to provide feedwater at a specified flow rate and temperature via DURESS II, I can do it by following the instructions in the HTA (as long as initial assumptions hold true), I don't need to know anything more about the system.

Of these explanations, the findings from the HTA analysis of the AHR seem to support explanation #1 over the others. We found that physical form information *was* provided in NOVA's procedures for both the board operators and for the field operators, though it was perhaps more common for field operations. We also found no significant concentration of physical form information when analyzing tasks on the Fault Management branch of the AHR HTA. Finally, we found that physical form information was provided specifically to facilitate the execution of procedural trajectories rather than to provide the ADS's form of 'deep knowledge'.

It should be noted that although some physical form information was included in our HTA it was sporadic and very incomplete. Furthermore, there was essentially no inclusion of information about physical connectivity between devices and objects in the plant in the HTA or NOVA's procedures. In short, when physical form information supported or aided the performance of 'rote' procedures, it was included, but this type and amount of physical form information would do little toward providing an operator with general, ‘deep’ knowledge about the workings of the plant.

6.10 Lack of relationship propagation knowledge

Perhaps the most serious lack noted in the comparative analysis of DURESS II, was that the display requirements generated by the HTA showed a complete absence of requirements to convey information about the propagation of effects from one equipment variable or state to another. That is, the HTA showed little need to include the relationships identified and represented as equations in the ADS analysis.

Again, the primary reason for this stemmed from the philosophy and approach taken in the HTA. The intention is to produce (or describe) effective procedures or rule-like plans for accomplishing specific goals. Thus, the designer must reason about the propagation relationships and ‘compile’ them into rules or procedures. This strategy of performing some work at ‘design time’ so that the operator doesn’t have to do it at ‘run time’ is where the effectiveness of procedures (and interfaces built to support them) comes from. Of course, again, if the designer has not correctly and completely anticipated the set of procedures needed, then the operator at run time will be forced to generate a new procedure on the fly. If the operator does not understand the propagation effects between various work domain variables (something which the interface could and should support), then that new procedure may very well be critically flawed.

The comparative analysis for NOVA’s AHR showed a similar trend, but the contrast was somewhat less marked than for DURESS II. First, we did not always drive the ADS analysis to the point where equations representing a computational prediction of the propagation of effects was possible. The stochastic nature of the chemical reactions makes such equations probabilistic at best, even when one can identify them. On the other hand, the procedures upon which the HTA was based did occasionally include at least very loose predictive effects. The most obvious of these is the inclusion of target or expected values for critical unit variables under different circumstances. Another example can be seen in the occasional inclusion of cautions and effects to monitor for—for example, when swinging reactors, the operator is told to monitor for reactor runaway conditions. Again, these are a pale substitute for the qualitative, equation-based predictions which are possible from a thorough ADS in at least some domains, but they are nearer to ‘relationship propagation knowledge’ than we saw in the HTA for DURESS II—and when they are identified and properly structured, they can be at least partially included in the HTA.

6.11 Simplifications for procedure’s sake

In the HTA analysis of DURESS II, we noted the tendency for the analyst to create procedural simplifications that help to ensure that the user of the procedures is ‘on track’—that is, that s/he is entering the procedure from an expected state to which the procedure applies, rather than from any of the possible system states. This behavior is quite explicit in NOVA’s procedures, each of which begins with sections titled “Pre-requisites” and “Safety Precautions”. Each of these sections makes an explicit claim about the assumptions under which this procedure is valid. The “Pre-requisites” section lays out a series of conditions under which the procedure is assumed to be valid, while the “Safety Precautions” section typically includes a number of conditions which are expected to be true, and to hold true, throughout execution of the procedure (e.g., that the fire water monitors are functional and directed at the reactor).

It was possible to place many of these assumptions as ‘check’ tasks in the HTA representation. This helps to ensure that the procedure is to be executed under conditions which will ensure its accuracy, but such assumptions are not (and, in principle, can never be) exhaustive. More interestingly, these assumptions serve to isolate conditions (many of which are generally achievable) and make it possible to write one procedure under conditions which either are generally true or which can generally be made to be true—all to release the procedure writer from having to write a much broader set of procedures for specific, variable conditions which might prevail.

The problem is that writing procedures for all possibilities becomes exponentially difficult. Instead of tackling that problem, the procedure writer is tempted to enforce conservative ‘good practice’ rules such as the first example above, or to build ‘parking configurations’ into the procedures which get the work domain into a state where a more simplified procedure can be applied to it. Another, more common simplification practice which was observed in NOVA's procedures (and used in our HTA) is the use of "variable terms"—words and phrases like "if desired", "when appropriate", "as needed", etc. Each of these simplifications has the effect of reducing workload for the analyst/designer, but only at the 'cost' of placing more of the onus of operationalizing the procedure at execution time in the hands of the operators on the scene. What is omitted are capabilities and relationships in the work domain which operators may know or be able to deduce, but then again they may not.

6.12 Implicitness of rationale for procedural knowledge/Lack of "Deep Knowledge"

While the HTA is obviously better than the ADS at capturing and representing procedural knowledge, it is important to note that this benefit comes at the cost of losing some of the 'deep knowledge' required to understand the rationale for those procedures. In the comparative analysis of DURESS II, the HTA never contained information about why one should choose one strategy over another. In NOVA's procedures, interestingly, such information is frequently included. For example, in NOVA's procedure 410.03 for swinging reactors (which has been used to formulate our plan 2.3), the reason for the step "Establish double block and bleed when [the fresh reactor] is depressured" (our task 2.3.2.7.2) is given as to "maintain a pressure of 15-30 kPa when depressured to stop air from getting in." Similarly, the reason for slowly pressuring up the fresh reactor via an outside line once the outlet valve has been opened (our task 2.3.2.9.2) is "it is important not to disturb downstream flows. . . . If it is pressured up too quickly, T-365 bottom level will drop."

There are two particularly interesting observations related to this phenomenon. The first is that even though this information was included in NOVA's written procedures, it was essentially impossible to include it in the HTA representation in any natural fashion. We can include the effects or related phenomenon (for example, creating a task such as 'Monitor T-365 bottom level' and a subsequent task to adjust reactor pressure if T-365 pressure drops), but this merely captures the effects, not the deep knowledge that embodies the rationale. The fact that the HTA cannot represent rationale information of this sort lends powerful support to the claim that the ADS captures and represents 'deep knowledge' about the relationships in a work domain which an HTA is essentially incapable of capturing explicitly.

The second interesting observation is that the fact that NOVA, in its written procedures (primarily a task-based representation), finds it necessary or useful to include such deep knowledge rationales. This is, also, strong naturalistic evidence that trying to operate a complex work domain via strictly task-based protocols (that is, compiled 'scripts' for action) is incomplete at best.

This is an implicit acknowledgement that, in the real world domain of the AHR, where successful and safe operations are more important than the conceptual purity of the representation used to store knowledge, the representation which NOVA has evolved is neither completely task-based nor completely work domain based. Instead, it mixes elements of the two.

This might imply that a task-based approach makes a poor foundation for training and, while there is some truth to that claim, the reality is more complex. In fact, a procedural, task-based training approach will probably enable a novice operator to conduct useful work more quickly than can be accomplished by learning the deep, structural and functional knowledge about the system. As Vicente has noted (Vicente, in press) however, this operator will be lost when the situation deviates from that anticipated in the procedures (either because the procedures are in error or incomplete) while the deeply trained operator will have the knowledge required to, perhaps, invent a new procedure on the fly in reaction to a novel situation.

6.13 Limitation of operational behaviors (Hiding work domain capabilities)

Related to the above point about "deep knowledge", the HTA clearly imposes some limits on the set of possible behaviors available to the operator. This is, in part, how it achieves the efficiency (or 'speed to productive work') described above. There are various reasons for this. First, as discussed in 6.12 above, it is difficult to represent all the possible combinations of actions and machine states in separate task trajectories, even in as comparatively limited a domain as DURESS II—the problem is still worse in the AHR task domain. Second, by preparing task trajectories, the analyst is acting as a filter on those trajectories: bad trajectories should be screened out for efficiency's sake. But what exactly is a "bad" trajectory? Certainly, ones which fail to accomplish the goal are bad, but what about those which are generally inefficient or unsafe? If the HTA is to be prescriptive at all (and, it must be if it is to make decisions about what to facilitate and what to inhibit via interface design), then shouldn't it filter those trajectories out too? Even so, these inefficient or unsafe trajectories might be the appropriate or the only available ones in some contexts.

In the HTA for NOVA's AHR we conducted, there are a few obvious examples of this screening, mostly for safety's sake. For example, in plan 2.3, it would be entirely possible to introduce feed into the reactor without stroking the Motor Operated Valves (MOV), or before opening the outlet MOV, but the first action would reduce a safety margin built into the procedure and the second would cause a lack of low pressure to draw the feed into the reactor. Both trajectories are possible, but neither is desirable. The HTA (and NOVA's procedures) generally omit the undesirable trajectories without describing them and without describing why the ones which were included are more desirable.

6.14 Difficulty of being comprehensive using HTA

In the HTA analysis of DURESS II, we noted that the HTA technique becomes increasingly unwieldy the more one tries to represent the full set of possible task- and work-domain state situations in it. It is far easier for operators and analysts to report 'the normal case' or 'what I usually do'—and this is how HTA has been generally used. In the DURESS II HTA, I had to continually remind myself about the possibility that the operator might be using the Continuous Flow, Variable Volume input strategy since this is an uncommon and complex strategy in the trials I have been exposed to—though it has significant implications for what steps should be taken for start up, shut down and normal operations.

Such instances were harder to spot in the HTA for NOVA's AHR, though I suspect that this was due more to the complexity of the domain and my comparative lack of experience with it than it is to a fundamental difference in the way the HTA was conducted. Nevertheless, the set of procedures themselves illustrate some difficulty in either exhaustively representing the set of possible states under which procedures might need to be executed, or of keeping straight the combinations of procedures that might need to be executed in conjunction with each other. A simple example can be seen in the emergency procedure for reactor temperature runaway (NOVA's Procedure EM.3, our plan number 4.1). The safety precautions for this procedure assume (explicitly) that a liquid seal is maintained in T-330 and T-320, but the procedure gives no indication of what should be done if this assumption is violated—nor is there a procedure for the combination of a loss of liquid seal in either tower *and* an emergency temperature runaway. This is not necessarily a flaw with NOVA's procedures per se—such a combination might be trivial to deal with, might be covered in training, might be easily deducible from general background knowledge that operators have—it is rather an illustration of how difficult it is to create procedures for all possible cases.

An even more general example stems from the fact that NOVA has procedures (and our HTA has branches) for what to do when temperatures rise sharply in a reactor in normal service (NOVA's EM.3, our plan 4.1) and for what to do when temperatures rise sharply in a reactor which is out of service, having been regenerated and under an N2 pad (NOVA's 0.FINMSC.3, our plan 4.2). There are not, however, plans for what to do if temperatures start to rise during startup or shut down, or during regeneration. Again, such combinations and circumstances might be trivial, covered elsewhere or easily deducible, but the fact that the procedures do not deal with them is evidence of the difficulty in creating a truly comprehensive set of procedures or a comprehensive task analysis.

The following implications are repeated from our DURESS II analysis since they seem relevant here as well:

> The fact that familiar or salient task trajectories are easy to report, and that unfamiliar ones are difficult to remember or incorporate has three implications for analysis. First, it stresses the importance, and the difficulty, of maintaining comprehensiveness in analysis. ADS is a good approach to this since it captures functional capabilities and constraints of the work domain without trying to articulate all possible trajectories. Second, it stresses the ease of capturing familiar procedures—and the ease with which naïve workers understand procedures. This suggests both that we miss an important opportunity to facilitate learning and operations if we don't make use of known, familiar trajectories, and that we are very likely to be incomplete if we only rely on those trajectories. Finally, it also shows the advantages of doing a task analysis after doing an ADS analysis: the comprehensiveness of the ADS analysis serves as a framework for the HTA, reminding the analyst about alternatives that need to be investigated and showing him or her where tasks ought to 'fit' once they are captured.

6.15 Leap to Information Requirements

From the HTA performed on DURESS II, we concluded that an HTA carried out to the depth we used and for the purpose of interface design was most useful for generating requirements about how to organize information (spatially and temporally) for presentation. The HTA seemed less useful (or at least less systematic) than an ADS for actually *identifying* the information to required for the tasks. It is far more common, in practice, to decompose tasks via the HTA to a fine level of granularity and then use introspection or operator reports to generate a list of information requirements for the tasks *without* creating explicit sub-procedures for performing them. We refer to this as making the "leap" to information requirements. By making this leap, the designer/analyst is making two assumptions: (1) that s/he has the *right* set of information requirements, and (2) that the operator will know how to combine them in order to perform the task. The argument supporting this claim, and illustrative examples, are provided in Miller and Vicente, 1998b.

This claim was amply demonstrated in the HTA for NOVA's AHR. For example, tasks which use the "variable terms" described in 6.11 above are indicative of the need for the analyst (ideally, in conjunction with the domain expert) to make judgements about the typical, desired and possible ranges of information variables. Less overtly marked are cases such as, to pick an example almost at random, task 4.2.7.2 "Cool Reactor with Fire Monitor" (in NOVA's procedure 0.FINMSC.3). This task name (and the task description in NOVA's procedure) states explicitly that there must be a reactor and a Fire Water Monitor and leaves us to make inferences about the fact that the reactor has a temperature and the Fire Water Monitor has some set of controls. The notion that "control, status and flow of firewater monitor fire water; temperature, trend and delta trend of hot reactor" are information needs during the performance of this task are all the result of inferences on the part of the analyst from an understanding of how the task is to be performed.

If the Fire Water Monitor task were decomposed still further, we would eventually arrive at a fine enough granularity that information needs and the procedures for combining or using them to perform work would be made explicit. The result would be tasks at a fine enough level of decomposition that they *explicitly* referenced information requirements and described what to do with them. An example might be 'Adjust Fire Control elevation lever to point nozzle at reactor midpoint.' We saw an example of this level of description in the DURESS II HTA analysis where one task involved the computation of a total demand value by adding two separate demand rates. This task explicitly identified two information requirements and a process for using them to perform a parent task. Similar tasks were rare in the HTA for the AHR.

It may be argued that the 'leap to information requirements' is simply the result of laziness on the part of analysts using HTA. While there might be truth to that charge, it is worth investigating why this 'laziness' may be prevalent. My belief is that, at least in industrial settings, the reasons revolve around the fact that the 'deeper' one drives the HTA, the bigger the branching logic becomes. Working through this combinatorial explosion becomes tedious and far too costly (at a point in the design cycle where organizations are unused to paying large sums for human factors analyses). Thus, while an HTA driven to the level of fine-grained cognitive procedures is entirely possible, it is generally far too tempting to make the ‘leap to information requirements’ illustrated above.

6.16 Additional Information Types for Real-World HTA

A number of novel information types were identified as requirements in the HTA for NOVA’s AHR that had not been present in either the HTA for DURESS II, or in the ADS analyses for either DURESS II or NOVA’s AHR. These were primarily related to the complexity and socio-organizational structure of the AHR task domain. Among these information types were:

- *Role information*—the AHR is a large, complex piece of equipment. NOVA’s organizational structure is not designed to have a single operator responsible for the AHR alone and there are typically 3-5 personnel responsible for the “finishing end” of the ethylene operation which includes (but is not limited to) the AHR. Operators include a shift supervisor, a board operator and, generally, multiple field operators. Special circumstances (such as a startup or an emergency) involve the designation of individuals to play special roles (e.g., emergency coordinator or start up coordinator) and the procedure for these circumstances may include a task for doing such designation (cf. Plan 1.4). The different roles and the association roles with different tasks are generally representable in the HTA format, but are ignored by the ADS.
- *Division of information by role*—as mentioned above, the fact that multiple individuals are engaged in different roles in the operation of the AHR means that they will each have somewhat different information needs for their tasks. The HTA supports this division of information needs by associating an actor or actors (by role) with each task and then a list of information requirements for that actor for that task. The ADS analysis may provide a comprehensive list of information needs, but it does not divide them by role. On the other hand, of course, role designations are not always followed and it may be helpful or even critical for an operator to have information outside his assigned role in some circumstances.
- *Communication requirements among roles*—Of course, when tasks are divided across multiple roles/actors, coordination becomes necessary among those tasks and actors. HTA explicitly handles this situation by including coordination tasks. Tasks 2.3.2.6.3 & .4 are examples of included coordination tasks within the personnel working on the AHR, and 2.4.1 is a coordination task between the AHR and another unit.
- *Reference material information*—Many of NOVA’s procedures explicitly contain pointers to NOVA’s own reference materials (the paper procedures themselves, schematics, reporting forms, etc.) as needed information requirements to support performance of the procedure. The HTA makes it easy to include tasks to obtain or investigate these reference materials. Task 2.4.3 is an example.
- *Social/Procedural information*—Another source of tasks not related to the physical work domain are tasks included to facilitate coordination, safety or simply to provide a common method of operation to the improve team members’ ability to anticipate and understand each other’s behaviors (“standard operating procedures”). Again, the fact that the HTA examines the broad context within which tasks are performed means that such non-physically constrained tasks can be easily represented as well. An example is 2.3.5.3 where a specific task is included to adhere to NOVA’s tagging procedure—a method of notifying others that a specific piece of equipment is out of service and of preventing their attempting to use it. The process of tagging out a piece of equipment has nothing directly to do with the physical functioning of the plant, and thus the whole notion of ‘tags’ is omitted from the ADS.

In all of the above cases, the information requirements were related to tasks involving the actions of multiple operators in a complex social, organizational and physical domain. No such information requirements were uncovered by the HTA analysis of DURESS II. This is certainly because DURESS II is not such a domain; it involves only a single operator and, since it takes place in a laboratory environment, the set of social and organizational supporting information is comparatively impoverished. The analysis of NOVA’s AHR, thus, revealed another dimension to the type of information required to do good display design—one which the HTA supports if sufficient information is present in the analysis materials, but the ADS does not support by itself.

7. General Conclusions

In our prior comparative analysis of the DURESS II work domain (Miller and Vicente, 1998b), we provided the first practical steps towards a unified task- and work-domain based analysis approach for interface design. We showed that each type of analysis provides unique and complimentary knowledge about how an interface to support work in the domain should be designed, and we identified at some ways in which the modeling approaches should be linked or integrated.

In this analysis, we have largely verified, as well as extending and refining, the results of the prior comparison. The summarized results of this study, presented in Table 2 above show that the patterns of strengths and weaknesses of the ADS analysis versus the HTA analysis remain largely the same when applied to a complex, real world domain such as NOVA’s AHR as they did for the more simple DURESS II simulation. As for the DURESS II comparison, the ADS analysis did a better job of providing complete, comprehensive ‘deep knowledge’ including the relationships between work domain parameters, than did the HTA. The ADS analysis was more nearly device, procedure, personnel and organization independent than was the HTA. The ADS provides more of the full set of information required for diagnosing and managing the system under abnormal and unanticipated contexts.

On the other hand, as for the analysis of DURESS II, the HTA provided sequential information about what activities must or generally are done in parallel, sequence, conditionally, and with what priority, frequency and importance than did the ADS. The HTA was less independent of specific context (equipment, personnel, regulations, etc.) in which the work was performed than was the ADS and it identified display requirements which were dependent on that context. This meant that it was less good at identifying how the plant equipment could be used in a different context, but better at identifying the set of non-equipment dependent constraints on current plant practices. In the more complex domain of NOVA’s AHR, we discovered several types of non-equipment information which the HTA could express which had not been needed for the DURESS II analysis. These were primarily concerned with the coordination of teams of workers in a complex, organizational setting—information about the roles workers play, the division of information among those roles, the needs for communication among the roles, information about specific non-equipment constrained plant practices (such as safety practices, reporting practices, etc.)

The majority of these lessons are summarized in the comparisons presented in Table 1. The prevalence of differences stemming from the types of knowledge captured in each analysis leads us to add a line to the summary, however. The revised version is presented below in Table 3.

Table 3. Relative advantages and disadvantages of TA and WDA forms of work analysis (and, by extension, of interfaces designed from information obtained via these analytic techniques).

	TASK	WORK DOMAIN
Mental economy	efficient	effortful
Ability to adapt to unforeseen contingencies	brittle	flexible
Scope of applicability	narrow	broad
Ability to recover from errors	limited	unlimited
Coverage	Broad & partial	Narrow & complete

It seems to consistently be the case that work domain methods provide a broad and comprehensive view of the capabilities and constraints of the *physical equipment* elements of the work domain, but generally omits considerations of other factors affecting work outside the physical plant. In this sense, then, the ADS technique is broad and comprehensive within this one layer of considerations, but does not venture outside it. The HTA analysis, by contrast, provides information about constraints from a broader range of aspects of the work domain—including the work methods, control and monitoring capabilities, personnel, socio-organizational considerations, ‘arbitrary’ procedural concerns, etc. In this sense, the work domain analysis techniques such as ADS are narrow in their range of coverage, but comprehensive within that range, while the task analysis techniques such as HTA have a much broader range of coverage, but their need to represent specific trajectories within the work domain makes their coverage of that range less comprehensive.

We also learned some interesting lessons by examining the procedures which have evolved for performing work in a complex, real-world work domain. Procedures are, by their nature, essentially task-based—that is, they convey a step-wise trajectory through the space of possible actions or states a system can exhibit. We might, therefore, expect the procedures to exhibit all the strengths and weaknesses of the ‘TASK’ column of Table 1. NOVA’s procedures did exhibit most of the strengths expected for a task-based approach. They were efficient in the sense that they provided instructions for how to accomplish a goal in some circumstances and did not require the operator to deduce that procedure from an understanding of the raw capabilities of the work domain. Moreover, they provided specific target values and information about known variance—again minimizing the amount of deduction operators had to do. NOVA’s procedures were also broad in their range of coverage. As we have discussed above, procedural steps included tasks pertinent to specific control operation, to socio-organizational norm adherence, to communication and coordination among operators, etc. Finally, we have also presented data above to support the claim that NOVA’s procedures included information that cut across multiple considerations in plant operations—though they did a less complete job of presenting physical plant information than we got from the ADS analysis.

NOVA’s procedures, however, also exhibited some of the strengths and mitigated some of the weaknesses of task analytic methods. In addition to simple task steps, NOVA’s procedures frequently included rationale for those steps and expected interactions and effects on other system variables. These were, admittedly, incomplete but they were nevertheless more ‘deep knowledge’ than could be incorporated in a straightforward HTA. The use of such rationales serves to make NOVA’s procedures a bit less brittle, narrow and error-prone than they would be without such supplemental information. NOVA also made some attempts to overcome the necessary partial nature of task trajectories in two ways. First, procedures are generally treated as guidelines at plants. There is an explicit acknowledgement that ‘you can’t have a procedure for everything’ and that operators may need to deviate from written procedures. Thus, procedures are written at an abstract level with an emphasis on goals to be accomplished and not on rote scripts by which to accomplish them. Again, this format is not universally adhered to, but it is a goal. Second, procedures explicitly include a statement of the pre-requisites and safety precautions assumed for the procedure. Together, these represent an attempt to articulate the applicability conditions under which the task trajectory represented by the procedure will be valid. It is up to the operator to determine whether these pre-conditions hold true (or to make them true), but their explicit inclusion makes it clearer that the procedure represents one method of accomplishing a goal, and that it may not be applicable under all circumstances.

We take these aspects of NOVA’s procedures as additional evidence of the importance of an integrated approach to analysis of work domains and the identification of display requirements. NOVA has not been dedicated to either of the two approaches we have studied in any pure, academic sense. Instead, as most businesses, they have striven to be practical in their pursuit of profit, product and safe operating conditions. They have evolved their procedures and their displays over time on the basis of what they have found that works. As such, task-based procedures are helpful, because they are efficient representations of action trajectories that are known to successfully accomplish desired goals, at least in some circumstances. But task trajectories on their own have not been sufficient for NOVA’s needs. Instead, they have folded into their procedure some of the types of knowledge that are better provided by a work domain analysis. What NOVA has arrived at through evolution, we hope to arrive at more systematically via the future integration of these two types of modeling and analysis techniques.

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9. Appendix B

HTA in Tabular Format

KEY

▭	indicates a leaf plan (we're not going to expand it any further
text	information requirements have been established
seq.	These task(s) must be done in sequential order
spont	This task may happen spontaneously (and therefore may need to be monitored for)
cont	These task(s) must be done continuously (throughout some portion of the plan)
paral	These task(s) will happen in parallel
xor	only one of these tasks will be done (within the context of the plan instance)
any	These task(s) may be done in any order
rpt	These task(s) must be repeated more than once (see plan)
pot	This is a potential task(s) (see plan)
BO	Board operator(s) will be involved. BO is the default. If no operator is shown, assume BO.
OO	Outside operator(s) will be involved in this task
other	Other operators and/or supervisors will be involved in this task

Task	Plan	Timing	Actors	IRs
0. Operate AHR				
	Plan 0: Upon request, do 1. When temps, pressures, H2 and CO levels are normal, do 2. Upon request, do 3. Upon fault detection, do 4.			
	1. Start Up	seq.		
	2. Normal Operations			
	3. Shut Down			
	4. Fault Management	spont.		
1. Start Up				
	Plan 1: Do only in context of complete plant startup (0.FINMSC.6). Do 1-3 in any order. Then do 4 about 1 hour before procedure startup and then 5 in sequence. Then do 6 if desired.			
	1. Ensure prereqs	any		
	2. Perform safety precautions			
	3. Obtain references			
	4. Inside manpower meeting/designate roles	seq		
	5. Do Start up			
	6. Switch to E1 H2	pot		
1.1 Ensure Pre-reqs				
	Plan 1.1: Do only in the context of a complete plant startup (0.FINMSC.6). Do 1-16 in any order			The procedure coordinator will have ensured these before procedure start. Thus, need his assurance and evidence of continued truth of these assumptions
	1. Ensure TDC3000 fully functional and pts verified	any		
	2. Verify All work completed			
	3. Ensure all equipment detagged, deblinded and mastercards signed off			
	4. Ensure all systems recommissioned and leak checked			
	5. Ensure all tracing lines in service and hot			
	6. Ensure Pre-start up check list complete			

Task	Plan	Timing	Actors	IRs
	7. Ensure cooling water system exchangers full and in service	any		communication with utilities
	8. Ensure SMART system up wit RES available		Rot Eqip specialist	
	. . .			
	9. Ensure procedure reviewed by Panel Ops and Finishing coordinator			This procedure
	10. Do morning job and concern meeting			
	11. Ensure resource people available			
	. . .			
	12. Ensure adequate 4160 steam available			4160 steam pressure
	13. Ensure cracking ready for feed on hot standby			feed flow from cracking
	14. Ensure R-410 lined up for E2 H2		BO & FO	(at least) VH3, VH2, CV1, VH4, PV441 and TV440 position and flow-- as well as some information about E2 H2 temp and composition
	15. Ensure unit to PV-412 at ~2500kPa with N2	only done occasionally		pressures in unit before PV412 (e.g., at reactors)
	. . .			
	16. Ensure HV-41001 closed			HV41001 position and flow
	. . .			
1.1.14. Ensure R-410 lined up for E2 H2				
	Plan 1.1.14: As for Plan 2.4.4.1 and .2 (Procedure 410.11)		OO	position and flow for VH3, VH4, VH2 and TV440
1.2 Perform Safety Precautions				
	Plan 1.2: Do 1 and 2 in any order. Then do 3-7 continuously during Plan 1.			
	1. Ensure all outsiders wearing protective equipment	any	Proc Coord	outsiders, their positions & status
	2. Ensure Radios functioning			radios and assigned channels (generally finishing on ch 1, cracking on ch 2)
	3. Ensure only Ops and leak response crews in unit	cont	Proc Coord	outsiders, their positions

Task	Plan	Timing	Actors	IRs
	4. Monitor for leaks at all pts that were opened	cont	FO	reports from FO, history of repair work?
	. . .			
	5. Monitor pipe shoes for movement		FO	reports from FO
	6. Monitor start up speed for safety		Proc Coord	elapsed time vs target and profile. Too fast is bad too. 4 hours is the goal.
	7. Monitor flare systems for overtaxing		BO	color of flare tip, black tip is indicator of uncleanness & overtaxing
1.3 Obtain references				
	Plan 1.3: Do 1-3 in any order			all PIDs
	1. Obtain Training Manuals 1&2	any		training manuals 1&2
	2. Obtain Procedures for bringing systems on-line			
	3. Obtain Pre-start up manpower meeting checklist			Prestart up meeting procedure/checklist
1.3.2 Obtain procedures for brining systems on-line				
	Plan 1.3.2: Do 1-3 in any order			
	1. Obtain 410.03			Procedure 410.03
	2. Obtain 410.06			Procedure 410.06
	3. Obtain 410.11			Procedure 410.11
1.4 Do Inside Manpower Meeting/Designate Roles				
	Plan 1.4: Do 1-6 in any order. Do 7 if Coordinator desires.			manpower plan is required for most designation decisions. May be preestablished, though. Thus, general requirement is manpower list, qualifications, etc.
	1. Designate PO1	any		
	2. Designate PO2			will be concerned with the AHR as well as feed to and from reactor (driers and splitter)
	3. Designate PO3			
	4. Designate Coordinator			
	5. Designate RES			
	6. Designate 1 or 2 GC Technicians			
	7. Designate Alarm Summary Manager	opt	coordinator	coordinator does this if desired

Task	**Plan**	**Timing**	**Actors**	**IRs**
1.5 Do Start Up				
	Plan 1.5: Do only in context of complete start up plan (0.FINMSC.6). Do 1. When K201 is online, chilling train is stabilized and T330 and T320 are stabilized, Do 2. When T420 and T430 are online and stabilized, Do 3 and 4 in order. Then continue 0.FINMSC.6			general needs include 'system status and equipment status'. A white board is typically brought in for reporting status and team coordination during startups
	1. Set up furnace feed . . .	seq		implicit timer. Means feed will hit reactor in about 2 hours, all things being equal
	2. Stabilize T-350 to PV-412 . . .			
	3. Set up R-410 A or B			
	4. Feed to T-411 A or S			
1.5.1 Set up Furnace Feed				
	Plan 1.5.1: Do 1-2 in order. Do 3 & 4 continuously until K-201 stabilizes. Then do 5.			These are not strictly AHR operator activities. But they should be monitored by the AHR op, or the AHR op might also be the Furnace op
	1. Ensure operators are in unit and ready	seq	BO	
	2. Ensure all valving is set on panel			furnace feed flow and valve position. Also, position, status and flow of PC412 (should be closed and on manual). These are the only valves pertinant to AHR.
	3. Monitor furnace feed flow rate	cont	adjusting furnace feed isn't AHR op job	furnace feed flow rate. Alternatively, a stability report
	4. Monitor for K201 stability			K201 flow, temp and pressure. Alternatively, a stability report

Task	Plan	Timing	Actors	IRs
	5. Adjust Mercaptan with FC-135	seq	BO	DMDS flow rate and control. Vlave FV135 position and flow. Knowledge of previous or typical DMDS flow setting '3-5' is typical. This isn't really the AHR BO's responsibility and, besides, they're on E2 H2, so the setting is more just to be about normal for when they switch back to E1H2. Still, CO ppm vs. threshold of 500 ppm would be nice to know.
Plan 1.5.1.5 Adjust Mercaptan with FC-135				
	Plan 1.5.1.5: If CO> ~500ppm, do 1. Else, do 2.			
	1. Adjust FV135 open		BO	position and flow through FV135, CO ppm.
	2. Adjust FV135 closed		BO	position and flow through FV135, CO ppm.
1.5.2 Stabilize T-350 to PV-412				
	Plan 1.5.2: Do 1-2 in order. Only if feed forward from T-320 or T-330 shows <.5% methane, do 3. Then do 4-6 in order. Do 7 continuously and, if needed, do EM.3. Else do 8-10 in order.			
	1. Review all flaring points	seq	FO	
	2. Block in all flaring points possible		FO	only source of flaring should be outlet of reactor, FO reports in, PV412??
	3. Open both outlet block valves on R-410 A/B	pot seq	FO	location and status of 2 manual 16" valves downstream (VM6/7 or VM 8/9); report in
	4. Ensure PC-412 on auto @ 2500 kPa		BO	location, status and control of PC-412. Current pressure set point vs. target
	5. Open inlet manual block valve fully		FO	location and status of inlet manual block valve (VM4 or VM5), report in

Task	Plan	Timing	Actors	IRs
	6. Open MOV for reactor to be used slowly	seq	BO	watch pressures more than temps because temps should rise to feed temp (no reaction); once pressure is equalized, then you can open the MOV fast; location, status and precise control of reactor MOV (MV410 or MV411). Reactor temps and pressures, delta temps and pressures and trends. Reactor temps vs. feed temp target, and reactor pressure vs. flow target?? This step should be done in about 10% bumps waiting for pressure to equalize between bumps-- but you can open quickly if R410 is already at pressure due to N2 chilling pressure up.
	7. Monitor reactor temps	cont	BO	as above. Should get a gradual rise to temp of feed, but no reaction. Temps rising above that of feed are a bad sign.
	8. Set up E-350		not AHR	
	9. Establish reflux flow and V-351 control		not AHR	
	10. Set heat on E-411			
1.5.2.10. Set heat on E-411				
	Plan 1.5.2.10: Do 1. Do 2 as needed to help temperature.			
	1. Set TC-410 at 60C	seq	BO	location, control and status of TC-410. Current temperature and direction and rate of change. Communications with FO.
	2. Flow condensate to grade	pot	FO	Valve manipulation
1.5.3 Set up R410 A or B				
	Plan 1.5.3: Do 1. Then do 2 and 3 in order. Do 4 as needed.			
	1. Ensure reactor bed temps >= 60C	seq		temperatures throughout bed to be used compared to target. 60C is nominal. Actually should be = feed inlet temp

Task	Plan	Timing	Actors	IRs
	2. Introduce H2 from E2	seq		
	3. Monitor temps & C2H2			
	4. Monitor and Controll R-410 flows	pot		
1.5.3.2 Introduce H2 from E2				
	Plan 1.5.3.2: Do 1-2 in order. Do 3 as needed.			
	1. Check E2 H2 composition	seq	BO	E2 H2 composition (CO & H2 % are most important) vs. targets/expectations -- implication is that this isn't very important, but maybe because they don't know what to do with these numbers except note that they are not as expected. Better target might mean more precision in stpt.
	2. Open FC-413 to allow correct flow		BO	location, control and status of FC-41. Target setpt is 1.5-2 H2 ratio
	3. Adjust FC-413 to maintain a 1.5-2.0 H2 ratio	pot	BO	location, control and status of FC-413, flow status vs. 1.5-2 H2 ratio
1.5.3.3 Monitor temps and C2H2				
	Plan 1.5.3.3: Delta temps across bed should be 18-20C. If greater, watch for EM.3 conditions. If less, troubleshoot.		BO	delta temps across bed vs target range of 18-20C. Rate of change for temps, C2H2 in output vs target (2 ppm)
1.5.3.4 Monitor and control R-410 flows				
	Plan 1.5.3.4: Do 1. If threatened, do 2 and 3 in order as needed.			Continous monitoring of bed delta temps and C2H2 ppm in outpu (vs. target) history and trend.
	1. Maintain flow > 38 Mgs/hr on FI-411	seq		position and flow on FI-411 vs target (target is >38Mgs and <50 Mgs) or report of flow
	2. Use low flow bypass if needed	pot seq		knob control for FC411. FC411 is done via the same physical valve as PC412-- that is, PV412 in my figure.
	3. Increase furnace feed to 50 Mgs/hr			position and flow on FI-411 vs target (target is now 50 Mgs) or report of flow

Task	Plan	Timing	Actors	IRs
1.5.4 Feed to T-411 A or S				
	Plan 1.5.4: When on spec and stable, Do 1. Then do 2 for 15 minutes. Then do 3.	seq		Continous monitoring of bed delta temps and C2H2 ppm in output. Must be on spec (C2H2<= 2ppm) to continue
	1. Start feed to T-411 A or S			Location, control and status of HV41001, flow of reacted feed.
	2. Purge through 2" dry flare on T-411A for 15 min		not AHR	
	3. Feed forward to T-365		not AHR	
	. . .			
1.5.4.1. Start feed to T-411 A or S				
	Plan 1.5.4.1: Do 1			
	1. Slowly open HV-41001 to 100%			location, control and status of HV-41001 and of flow through HV-41001
1.5.4.3. Feed forward to T-365				
	Plan 1.5.4.3: Do 1 while doing 2 continuously			
	1. Unblock T-411 A or S	seq	not AHR	
	2. Keep R-410 flows steady	cont		
1.5.4.3.2 Keep R-410 flows steady				
	Plan 1.5.4.3.2: Do 1			R410 flows and historical trends
	1. Use PV-412 to cut back			location, control and status of PV-412. Pressures and flows through PV-412. With new control schemes, this is just switching from flow control (FC411) to pressure control (PV412)-- same valve.
1.6 Switch to E1 H2				this happens about 12 hours after 1.5 above. Not considered part of Start Up. Generally similar to H2 swing (Procedure 410.11, task 2.4.5), but starting up E413 is different (but pretty easy and mostly OO tasks.)
	Plan 1.6: If E413s has been shut down, do 2 then 1			
	1. Swing H2 Feed fromn E2 to E1	seq		
	2. Start up E-413S			

Task	Plan	Timing	Actors	IRs
1.6.1 Swing H2 Feed From E2 to E1				
	Plan 1.6.1: As for Plan 2.4.5			
1.6.2 Start up E-413S				
	Plan 1.6.2: (Procedure 410.06) Do 1-3 in any order. Then do 4-6 in order.			
	1. Perform Leak test	any	OO	
	2. Choose H2 source			
	3. Drain condensate from steam supply and E413S			
	4. Set TIC 440 @ 0C	seq		
	5. Introduce Steam			
	6. Introduce H2			
1.6.2.1 Perform leak test				
	Plan 1.6.2.1:Do 1 or 2			
	1. Perform Snoop test	xor	OO	Communication with BO
	2. Perform Gas Tester Test		OO	Communication with BO
1.6.2.2 Choose H2 source				
	Plan 1.6.2.2: Do 1, then 2.			
	1. Evaluate Considerations			normally E2, but lack of H2, impurities, or cracking down would invalidate. Hence, communication with other units
	2. Ensure proper H2 line to supply			
1.6.2.2.2 Ensure proper H2 line to supply				
	Plan 1.6.2.2.2: As for plan 2.4.4 or 2.4.5			
1.6.2.3 Drain condensate from steam supply and E413S				
	Plan 1.6.2.3: Do 1. If winter, do 2 and 3 in order. Then do 4. When condensate flow ends, do 5.			
	1. Ensure drain ellbow points away	seq	OO	location and appearance of correct drain
	2. Attach hose	pot	OO	
	3. Route hose to drain		OO	location and appearance of drain
	4. Open drain	seq	OO	condensate level
	5. Close drain		OO	condensate level

Task	Plan	Timing	Actors	IRs
1.6.2.4 Set TIC-440 at 0C				
	Plan 1.6.2.4: Do 1, then do 2.			
	1. Ensure Valtek valve is open	seq	OO	location, status and control of valtek valve
	2. Input console command		BO	console controls for TIC-440. Temperature (current and historical trend vs. target). Position and flow through TV440.
1.6.2.5 Introduce Steam				
	Pllan 1.6.2.5: Do 1 and then 2 iteratively until target temp (0C?) is reached. Do 3 if temperature is exceeded			E413S temperature (current, historical trend, vs target)
	1. Open orange globe valve slightly		OO	location, appearance and status of orange globe valve (VS1?). Flow through valve (current and historical trend)
	2. Monitor E413S outlet temp		BO	E413S outlet temp (current and historical trend vs. target-0C?)
	3. E413S overheat recovery			
1.6.2.5.3 E413S overheat Recovery				
	Plan 1.6.2.5.3: Do 1 and 2 in order. When temp reaches target (0C?) do 3			
	1. Close Globe Valve		OO	Globe valve position, location, flow and control
	2. Monitor E413S outlet temp		BO	E413s outlet temp vs. target, trend
	3. Retry Plan 1.6.2.5			
1.6.2.6 Introduce H2				
	Plan 1.6.2.6: Do 1-3 in order			
	1. Open inlet block valve to E413	seq	OO	location and appearance of E413S inlet BV. Flow through (current and historical?) Not an AHR valve?
	2. Open outlet block valve to E413		OO	location and appearance of E413S outlet BV. Flow through (current and historical?) Not an AHR valve?
	3. Inform panel op E413S online		OO	telephone, email, radio. PO address

Task	Plan	Timing	Actors	IRs
2. Normal Operations				
	Plan 2: Do 1 and 2 continuously unless: When on-line reactor must be operated at inlet temp >= 65C and H2 ratio of >= 2.0, or on-line reactor has been poisoned by ethyl mercaptan or DMDS, or when on-line reactor is exhausted, and when off-line reactor has been regenerated (and when convenient), then Do 3, Do 4 if a feed swing is needed, Do 5 if a furnace swing is needed.			for on-line reactor: inlet temp, H2 ratio, poisoning indicators?, exhaustion indicators. For off-line reactor, regen status.
	1. Manage Normal Ops	cont paralle		
	2. Do Fault Detection			
	3. Swing Reactors	xor		
	4. Swing H2 Feed			
	5. React to Furnace Swing			
2.1 Manage Normal Ops				
	Plan 2.1:Do 1-5 continuously, Do 6 whenever ranges vs. targets and expectations are exceeded. If 5 is unsuccessful, go to Plan 2.2			delta temps, reactor efficiency, C2H2 outlet
	1. Monitor delta temps across beds.			target is 16-20C, but gets bigger as days in service go on. An indicator of how well (in terms of mass and heat efficiency) you can do. 25C is about the limit of normal.
	2. Monitor C2H2 out of reactor			2 ppm is a pretty hard limit. Normal is .1 to 1, with some bumps to show you're at the line.
	3. Monitor H2 out of reactor			1000 ppm is normal target, lower is better ("600 ppm is all you need"). Kerry says 200 ppm. An indicator of excess use of H2
	4. Monitor heat and mass efficiency tags			computed tags. Start at around 80% and decline as reactor ages.
	5. Monitor CO content (at K201? Into AHR?)			Spikes out of furnace (at K201) will mandate adjustments at AHR in 30 minutes. Normal is 200 ppm.

Task	Plan	Timing	Actors	IRs
	6. Make changes to improve reaction.			
2.1.6 Make changes to improve reaction				
	Plan 2.1.5: Do 1 whenever a new 4 day shift takes over. Do 2 to make coarse moves whenever H2 and/or heat use is high relative to expectations or heat & mass efficiency calculations are low. Do 3 and 4 (in that order) to make fine moves for same circumstances as 2. Do 5 whenever C2His high. Do 6 if 5 is unsuccessful. Do 7 if 6 is unsuccessful.			
	1. Opimize for shift			shift memebers, manpower lists, preferences and operating style
	2. Decrease CO			*as for 2.5.4*
	3. Increase H2			*Invert 2.3.4.6.3*
	4. Increase feed inlet temp			*Invert 2.3.4.6.1*
	5. Decrease H2			*As for 2.3.4.6.3*
	6. Decrease feed inlet temp			*As for 2.3.4.6.1*
	7. Increase CO			*Invert 2.5.4*
2.2 Do Fault Detection				
	Plan 2.2:Do 1-9 continuously.			
	1. Monitor for reactor temp runaway			
	2. Monitor for temp rise in padded reactor			
	3. Monitor for K201 trip			
	4. Monitor for K601 trip			
	5. Monitor for K651 trip			
	6. Monitor for reactor offspec			
	7. Monitor for loss of turbos			
	8. Monitor for loss of DMDS			
	9. Monitor for loss of cooling water			

Task	Plan	Timing	Actors	IRs
2.2.1 Monitor for reactor temp runaway	*Plan 2.2.1 If high temp (~90C) or rapidly rising temp or large delta temp (>25C) detected on in-use reactor, do 4.1*			bed temps, delta temps across bed, targets and trends, thresholds
2. Monitor for temp rise in padded reactor	*Plan 2.2.2 If temps in padded reactor begin to rise, do 4.2*			bed temps, delta temps (long history, low threshold), trends
3. Monitor for K201 trip	*Plan 2.2.3 If notified of K201 trip, do 4.3*			status of K201
4. Monitor for K601 trip	*Plan 2.2.4 If notified of K601 trip, do 4.4*			status of K601
5. Monitor for K651 trip	*Plan 2.2.5 If notified of K651 trip, do 4.5*			status of K651
6. Monitor for reactor offspec	*Plan 2.2.6 If C2H2 out >2 ppm and if Plan 2.1 is unsuccessful, do 4.6*			C2H2 out, trends and targets
7. Monitor for loss of turbos	*Plan 2.2.7 If notified of turbo loss, do 4.7*			turbos status
8. Monitor for loss of DMDS	*Plan 2.2.8 If DMDS input falls sharply without command, do 4.8*			DMDS flow (position, status and flow through FV135)
9. Monitor for loss of cooling water	*Plan 2.2.9 If cooling water flow falls sharply or if E412 heat sink fails, do 4.9*			position, status and flow through VW1, heat exchange flow in E412.

Task	Plan	Timing	Actors	IRs
2.3 Swing Reactors				
	Plan 2.3:(Procedure 410.3) Do 1-6 in order.			Inlet temperature relative to target (65 deg. C). H2 ratio relative to threshold (2.0). Poisoning: Efficiency of catalyst (moles of acetylene selectively converted to ethylene. To get moles of ethylene to ethane. Also on a delta T calculation. 60-70% at start; 0 or negative is threshold). Regen status
	1. Do safety precautions	cont		
	2. Pressure up off-line reactor	seq		
	3. Achieve parallel flows			
	4. Determine servicability of fresh R410	seq or para.		
	5. Isolate fouled reactor			
	6. Depressure fouled reactor and prep for regen	seq		
2.3.1 Do safety precautions				
	Plan 2.3.1: Do 1-5 in order, do 6 continuously			
	1. Review EM.3 procedure		OO, BO	EM.3 procedure
	2. Ensure PSV-410 for fresh reactor is in service	seq	OO	reported PSV410 status (a pressure relief valve for the reactor)
	3. Dbl blk regen inlet and outlet w/ bleeds open and tagged for fresh reactor		OO	reported regen I/O status
	4. Redirect fire monitor to fresh reactor		OO	reported fire monitor status
	5. Ensure dbl blk & bleed vlvs and taggs remain in place for regen system on stale reactor		OO	reported regen I/O status
	6. Monitor bed temps and vents	cont	BO (temps), OO (vents)	bed temps, vent status and flow, monitor for temp runaways (delta temp over time), high temps (>inlet temp on fresh reactor), temp anomalies (evidence of poisoned catalyst?)

Task	Plan	Timing	Actors	IRs
2.3.2 Pressure up off-line reactor				
	Plan 2.3.2: Do 1 and 2 in order,Do 3-5 in any order, then Do 6-11 in order, then Repeat 9 and 10 and do 12 in that order.			
	1. Ensure all process and regen valves closed for fresh reactor	seq		
	2. Ensure I&O regen blds (4) are open and tagged for both reactors			
	3. Ensure fresh reactor is under N2 pressure	any		
	4. Check for liquids			
	5. Ensure fresh reactor PSV in service			
	6. Remotely stroke 16" process inlet MOV	seq		
	7. Depressure reactor N2 to flare			
	8. Fully open upstream 16" process out block vlv			
	9. Introduce feed to fresh reactor	rpt		
	10. Equalize pressures btn reactors			
	11. Depressure fresh reactor to flare			
	12. Open 16" I&O process vlvs	seq		
2.3.2.1 Ensure all process and regen valves closed for fresh reactor				These may be a "check to make sure" step instead of a "do" step. These may be a part of the end of regen procedure.
	Plan 2.3.2.1: Do 1-5 in any order			also will require a check-in to BO
	1. Ensure 2 16" process I&O vlvs closed		OO & BO	location, status and control of two 16" process I&O vlvs (MV410/411, VM4&5)
	2. Ensure all process I&O vents to flare closed		OO	location, status and control of I&O vents to flare
	3. All 8" regen gas I&O vlvs for both reactors closed and tagged		OO	location, status and control and tag status of 8" regen gas I&O vlvs for both reactors
	4. All 3" dry flare vlvs off process inlet closed		OO	location, status and control of all 3" dry flare vlvs off process inlet (VM2/3, PV410A/B)
	5. All body bleed vent block vlvs closed		OO	location, status and control of all body bleed vent vlvs

Task	Plan	Timing	Actors	IRs
2.3.2.2 Ensure I&O regen blds (4) are open and tagged for both reactors				
	Plan 2.3.2.2: Do 1-4 in any order			
	1. Chk R410A inlet bld	any	OO	reported status
	2. Chk R410B inlet bld		OO	reported status
	3. Chk R410 outlet bld		OO	reported status
	4. Chk R410 outlet bld		OO	reported status
2.3.2.2.1 Chk R410A inlet bleed				
	Plan 2.3.2.2.1: Do 1-3 in any order			
	1. Ensure bld open	any	OO	reported status
	2. Ensure bld tagged		OO	reported status
	3. Chk vents to determine if blk vlvs are passing N2		OO	reported status
2.3.2.2.2 Chk R410B inlet bld				
	Plan 2.3.2.2.2 as for 2.3.2.2.1		OO	reported status
2.3.2.2.3 Chk R410B inlet bld				
	Plan 2.3.2.2.3 as for 2.3.2.2.1		OO	reported status
2.3.2.2.4 Chk R410B inlet bld				
	Plan 2.3.2.2.4 as for 2.3.2.2.1		OO	reported status
2.3.2.3 Ensure fresh reactor is under N2 pressure				
	Plan 2.3.2.3: Do 1 and 2, if pressure has been lost, do 3.			
	1. Chk pressure gauge	seq any	OO	Reactor pressure
	2. Check bleed valve vents to see if they are passing		OO	Listen for gas
	2. Purge fresh reactor to flare	pot	OO	location, control and status of purge valve, reactor pressure
2.3.2.4 Check for liquids (in fresh reactor)				
	Plan 2.3.2.4: Do 1&2 continuously, Do 3-5 in any order. If significant liquids are detected, halt swing procedure (plan 2.3) and Do 6.			
	1. Beware hazards of venting N2	cont	OO	
	2. Wear goggles for blowing down		OO	
	3. Chk reactor bottoms	any	OO	report status
	4. Chk inlet process low pt drains		OO	report status

Task	Plan	Timing	Actors	IRs
	5. Chk outlet process low pt drains	any	OO	report status
	6. Contact Process Engineering for liquids problem	pot	OO	phone, radio or email, address of process engineering
2.3.2.5 Ensure fresh reactor PSV in service			OO	report status (Blind Off)
2.3.2.6 Remotely stroke 16" process inlet MOV				
	Plan 2.3.2.6: Do 1. If bed temps <= 100C, then Do 2 until <=100C, then Do 3. When command completes, Do 4. If not fully closed, Do 5 and repeat 3 & 4 until successful.			Is the actual control taking place from the control room or is the decision made in the control room and radioed to the OO?
	1. Chk bed temps in fresh reactor	seq	BO	fresh reactor bed temps, communication with outside operator
	2. Lower bed temps	pot	BO	??
	3. Issue board command to close 16" process inlet MOV	rpt	BO	controls for 16" process inlet MOV (MV410/411)
	4. Field chk that process inlet MOV is closed		OO	phone, radio or email
	5. Repair MOV	pot		maintenace request??
2.3.2.6.2 Lower bed temps				
	Plan 2.3.2.6.2: Do one or more of 1-3 as needed			
	1. Reduce feed inlet temperature			
	2. Reduce H2 input %			
	3. Reduce reactor bed pressure			position, control and flow through PV412 to flare. Color and temp of flare
2.3.2.6.2.1 Reduce feed inlet temperature	*As for 4.1.3.4*			location, status and flow through TV-410 (steam flow). C2 feed inlet temps, history trends vs 'normal'. Heat exchange rates at E410 and E411. Cutting heat is more drastic; losing delta temp in bed will cause C2H2 to go off spec more quickly. Inlet temp should normally be 40-42C for a fresh reactor.

Task	Plan	Timing	Actors	IRs
2.3.2.6.2.2 Reduce H2 input %	*As for 2.3.4.6.3*			H2 gives quicker response, better for runaway suppression; location, control and commanded and actual flows of H2 (vs. 'normal'?). H2 can be adjusted primarily at TV440 and FV413, but also at a number of check valves, manual lockout valves and the SDV413 cluster. H2 to C2H2 ratio should normally be 1.2-1.6 for a fresh reactor.
2.3.2.7 Depressure reactor N2 to flare	*Plan 2.3.2.7: Do 1. When pressure is 15-30 kPa, Do 2.*		OO	Pressure Gauge
	1. Open 1" vent on top of fresh reactor	seq	OO	communication of status
	2. Establish dbl blk & bld.		OO	communication of status
2.3.2.8 Fully open upstream 16" process out block vlv	*Plan 2.3.2.8: Do 1-3 in order.*			
	1. Ensure downstream 16" process outlet blk vlv closed	seq seq	OO	communication of location, status and control of 16" process outlet blk vlv (VM7/9)
	2. Ensure 1" pressure up line on reactor outlet blocked in to flare		OO	communication of status
	3. Open upstream 16" process out blk vlv		OO	communication of status--location, status and control of 16" process outlet blk vlv (VM6/8), report back in; note: only one of two valves preventing flow
2.3.2.9 Introduce feed to fresh reactor	*Plan 2.3.2.9: Do 1, then 2. Do 3-5 continuously. If anomaly detected (sharp temp rise, no rise, hot spots), Do 6.*			continuous monitoring of bed temps at multiple points vs targets, each other, and expectations. Recent history trends.
	1. Open 1" pressure up line on fresh reactor outlet	seq	OO	location, control and status of 1" pressure up line on reactor outlet
	2. Slowly open valve on fresh reactor		OO	location, control and status of 'valve on fresh reactor' (VM4/5??)

Task	Plan	Timing	Actors	IRs
	3. Monitor reactor temps	cont	BO	Temps on both old and new reactor temps, delta temps, history. All vs. target (feed inlet temp??)
	4. Monitor regen block valve vents		OO	status and flow through regen block valve vents-- listen for hissing
	5. Maintain constant downstream flows		BO	Downstream flowrates from spent reactor (as indicated by low level alarm for T365). Monitor splitter flow from online reactor (FT-366). Np measurement available at HV41004. Control over pressure and flow rates into fresh reactor.
	6. Reduce flow to fresh reactor	pot	BO and OO	position, control and flow over 1" pressure up line valve
2.3.2.10 Equalize pressures btn reactors				
	Plan 2.3.2.10: Do 1 and 2 continuously until pressures are equal, then do 3			
	1. Continue flow input as in 2.3.2.9	cont	OO	location, control and status of 1" pressure up line on reactor outlet; location, control and status of 'valve on fresh reactor'; bed temps for both reactors; status and flow through regen block valve vents; downstream flow rates
	2. Monitor reactor(s) pressures	seq	OO	pressures both reactors
	3. Close 1" pressure up line	seq	OO	location, status and control of pressure line
2.3.2.11 Depressure fresh reactor to flare			OO	location, control and status of depressure valves. flare video??. Position, flow and status of PV412, PV410 A/B,
	Plan 2.3.2.11:			
2.3.2.12 Open 16" I&O process vlvs				
	Plan 2.3.2.12: Do 1 and 2 in any order. Then do 3 and 4 in any order, then do 5			
	1. Isolate 1" pressure up line	any	OO	position, status and flow of 1" pressure up line.
	2. Ensure process inlet MOV is closed		OO	location, status and control of Process inlet MOV (MV410/411)

Task	Plan	Timing	Actors	IRs
	3. Fully open 16" process outlet blk vlv	any	OO	location, status and control of 16" Process outlet blk vlv; report in (VM 6/8, VM 7/9)
	4. Fully open process inlet blk vlv		OO	location, status and control of Process inlet blk vlv; report in (VM4/5)
	5. Transfer control of MOV back to BO		OO,BO	At some point control must shift from the OO to the PO. A switch? A verbal communication?
2.3.3 Achieve parallel flows in reactors				
	Plan 2.3.3: Do 1. If drastic temperature differences, do 2; if not,skip 2. Then do 3 and 4 in order.			
	1. Chk temps across new bed	seq	BO	bed temps in fresh reactor, comparison across beds, not over time.
	2. Stabilize temps	pot	BO	
	3. Crack open 16" inlet MOV on fresh reactor	seq	BO (OO monitors)	location, control and status of 16" inlet MOV, control granularity and method may differ: "5 threads = 10 seconds" (MV410/411)
	4. Watch for temp differential in fresh bed		BO	bed temps in fresh reactor (compared to each other). Looking for about 10C differential no greater than that on any individual thermocouples. Also looking for 18-20C differential over bed. PCC trip is activeated when MOV is opened. Thus, 110 C temp will trip. Alarmed at 100C
2.3.3.2 Stabilize bed temps				
	Plan 2.3.3.2: If temp increases are localized to a few thermocouples, do 1 then do 2.3.2 again. If still localized, do 2. If temps are unrealistically low, do 3. If no problems, do 2. If temps are high, or added safety margin needed, do 4.			temps at multiple points in reactor vs. normal or expected. Temps across both beds for comparison. Inlet and outlet feed temps. Delta temps.
	1. Pressure Purge			as for 3.1.5.6
	2. Regenerate Reactor		not AHR	see procedure 410.05
	3. Check thermocouples		Maint	commo to maintenance or sensor ops

Task	Plan	Timing	Actors	IRs
	4. Allow fresh reactor to cool outlet temp of stale reactor.		BO	temps in fresh reactor bed, trends over time, outlet temp of stale reactor
2.3.4 Determine servicability of fresh R410				
	Plan 2.3.4: If C2H2 analyzer is in doubt, do 1. When C2H2 in outlet is <= 1ppm and if reactor bed temps are >=30C, do 2. Then do 3. If temps take off rapidly, do 4, else do 5 while reactor effluent is on spec. As needed to manage both reactors (esp. stale one) do 6. When inlet MOV is fully open and CO is 5-10ppm and inlet temp is 40-42C for both reactors, do 7.			C2H2 analyzer status and readout. Test results and/or C2H2 ppm in outlet (vs threshold 1ppm). Reactor temps (current and historical trend and vs. threshold of 30C). Reactor effluent vs. spec. Inlet MOV status and control. CO ppm vs. range 5-10ppm. Inlet temps (vs. range 40-42). Current implementation uses a combined analyzer for both reactors. Reactor status is assessed by a mismatch between the status of the C2H2 inlet valve but normal temps. H2 unbelievably high.
	1. Chk C2H2 at reactor outlet	pot	OO	Not done now.
	2. Slowly open inlet MOV further	seq	BO	Location, control and status of MOV.
	3. Monitor temp increase across fresh bed			temp profile across bed, looking to push reaction further down in bed, and for overall delta temp increases across bed to level of the old bed. Looking for bed temps ~40-42C. What row the high temperature is on is important. If it's high on the first row, that means you've got a very reactive bed (and probably too much H2). If it's high on the last row, that's not so bad.
	4. Do EM.3	pot		
	5. Continue to open inlet MOV gradually	cont, para		location, status and control over MOV. History of status (position)?
	6. Control feed inputs			
	7. Wait for reactors to stabilize.			C2H2 should be on spec (less than 5 ppm), delta temps should be 20C or less, and overall temps are out of trip risk range (<= 80C)-- and these values are not changing over some period of 15+ minutes.

Task	Plan	Timing	Actors	IRs
2.3.4.1 Chk C2H2 at reactor outlet				
	Plan 2.3.4.1: Do 1-3 in order			This wouldn't be done nowadays. If it needed to be done, they'd call in the lab.
	1. Prepare 1:1 solution of hydroxylamine hydrochloride & cupric ammonia sulphate	seq	OO	
	2. Bubble small amount of gas flow through solution		OO	
	3. Chk for pink discoloration in precipitate (= C2H2 present)		OO	Precipitation color match?
2.3.4.6 Control feed inputs				
	Plan 2.3.4.6: some combination of 1-3. 3 is generally prefered, 1 is more drastic, 2 is generally only used in case of furnace trip during swing.			Monitoring temps, pressures and flows in stale reactor is critical. Large adjustments to feed inputs could put old reactor off spec. Thus, monitor C2H2 output levels throughout.
	1. Reduce inlet feed temps			Heat exchange rates at E410 and E411. Control over these rates at TV410 (and ST1052?). Cutting heat is more drastic; losing delta temp in bed will cause C2H2 to go off spec more quickly. Inlet temp should normally be 40-42C for a fresh reactor.
	2. Increase inlet feed CO concentration			generally not important during swing, generally not used, but in case of furnace trip during swing, then very important. Location, control and commanded and actual flows of CO (vs. 'normal'?). DMDS stream at FV135 is only control for an indirect effect. CO concentration should normally be 5-10 ppm for a fresh reactor

Task	Plan	Timing	Actors	IRs
	3. Reduce inlet feed H2 flow			H2 gives quicker response, better for runaway suppression; location, control and commanded and actual flows of H2 (vs. 'normal'?). H2 can be adjusted primarily at TV440 and FV413, but also at a number of check valves, manual lockout valves and the SDV413 cluster. H2 to C2H2 ratio should normally be 1.2-1.6 for a fresh reactor.
2.3.4.6.1 Reduce inlet feed temps				
	Plan 2.3.4.6.1: As for plan 4.1.3.4			
2.3.5 Isolate stale R410				
	Plan 2.3.5: Do 1 and 2 until fully closed. Then do 3. When fresh reactor is stable and on spec, do 4 and 5.			especially if done in parallel with 2.3.4, it is critical to make right move on right MOV. Use stickies to indicate?
	1. Slowly close 16" process inlet MOV for stale reactor	cont & parallel	BO	Location, status and control of 16" process inlet MOV (MV410 or 411). History trend of status?
	2. Control feed inputs		BO	
	3. Tag process inlet MOV	seq	OO	master card procedure, but not a BO job
	4. Close 16" process outlet block valve		BO	
	5. Tag outlet MOV		OO	
2.3.5.2 Control feed inputs				
	Plan 2.3.5.2: as for 2.3.4.6			
2.3.5.4 Close 16" process outlet block valve				
	Plan 2.3.5.4: Do 1, then do 2 as soon as possible			
	1. Ensure Fresh Reactor is stable and on spec and can be kept so			Fresh reactor temps and pressures (with history and target data).
	2. Close 16" outlet block valve on stale reactor			Location, status and control of 16" process outlet block valve (VM 6/7 or VM8/9)

Task	Plan	Timing	Actors	IRs
2.3.6 Depressure Stale reactor and prepare for regen				
	Plan 2.3.6: Do 1. When stale reactor is fully depressured, do 2-6 in order.			Generally hold off about 2 hours after putting fresh reactor on line before doing this. Elapsed time, fresh reactor temps, pressures, and C2H2 out quantities with target values and history trends). Also, stale reactor temps should be monitored throughout. Expect only downward trends. Any increase, especially a large one, might mean leakage in the MOV. A trip of stale reactor can trip fresh one too.
	1. Depressure stale reactor to flare through 3" dry flare line	seq	BO?	location, status and control of flare line (PV410 A/B?), flow through line, pressure in reactor
	2. Close process inlet downstream blk vlv and tag		OO	VM4/5
	3. Close process outlet upstream blk vlv and tag		OO	VM6/8 or VM 7/9?
	4. Bleed block valves		OO	
	5. Purge stale reactor with N2		??	Monitoring and controlling the flow of N2 is part of the regen process we decided not to model.
	6. Leave reactor with 100 kPa N2 pad		??	Monitoring and controlling the flow of N2 is part of the regen process we decided not to model.
2.3.6.5 Purge reactor with N2				
	Plan 2.3.6.5: Do 1. Then do 2 three times			
	1. Do 30 min flow purge	seq rpt		N2 equipment is part of regen process. Not modelled.
	2. Do pressure purge			N2 equipment is part of regen process. Not modelled.
2.4 Swing H2 Feed				
	Plan 2.4: (Procedure 410.11) Do 1-3 in any order, then Do 4 or 5 as needed.			
	1. Ensure E2 aware of swing	any	BO	
	2. Ensure Cold Service Valve Safety Ops		FO	field check and communications
	3. Review Procedure			

Task	Plan	Timing	Actors	IRs
	4. Swing H2 from E1 to E2	xor		
	5. Swing H2 from E2 to E1			
2.4.1 Ensure E2 aware of swing				
	Plan 2.4.1: Do 1 and 2 in order			
	1. Contact E2 Finishing Control	seq	BO	Commo channel: phone (speed dial), email, radio, etc. May be some advance discussion; will be followed-up at time of swing.
	2. Obtain E2 H2 Content Info		BO	May be available via data highway (TDC) - confirm. JoAnne developing calculation to make E1 H2 concentration (mol%) reading available when E2 H2 is being used. PID 440-0355.
2.4.3 Review Procedure				
	Plan 2.4.3: Do 1, 2 if desired, then do 4 in order, Do 3 at any time.			
	1. Obtain Procedure	opt seq		Procedure R410.11. Location: Hard: Operations room binder. Most up-to-date on LAN.
	2. Review Procedure with OO, any trainees		BO	[Procedure review] is primarily for new operators. May just take place over radio (dedicated channel for E1) because OO only has to manipulate 1 valve.
	3. Establish coordination with OO	any	BO	radio chanel
	4. Plan H2 adjustments (with E2 H2 info)	seq	OO	Prediction of H2 molar ratio for E1 with corresponding flow rate target and controller setting. Will need E1 and E2 H2 data, current temp profile, +??
2.4.4 Swing H2 from E1 to E2				
	Plan 2.4.4: Do 1-2 in order, do 3&4 continuously			
	1. Open block valve from E2 to E1	seq	OO	location, status and flow through VH3 and VH4 (should be open) and VH2 (should be closed)
	2. Close blk vlv from E1 to R410 feed		OO	location, status and flow through TV440?

Task	Plan	Timing	Actors	IRs
	3. Monitor H2 flow and temp	cont	BO	H2 flow, temperature and concentration. Secondarily, E410 temp and steam flow (heat exchange), and R410 bed temps (with deltas and history).
	4. Adj H2 flow as needed		BO	status, control and target (Input planned number obtained in 2.4.3.4.) for H2 flow. H2 temp, bed temps and their history. C2H2 out
2.4.5 Swing H2 from E2 to E1				
	Plan 2.4.5: as for 2.4.4 but with appropriate changes (cf. 1.6.2)			
2.5 React to Furnace Swing				
	Plan 2.5:Do 1 and 2 continuously. If no C2H2 increase and CO increase < 100 ppm, do nothing. If CO increase is ~200 ppm or greater, do 3 and 4. If CO remains high or if there is a C2H2 increase, do 5.			notification of furnace swing is needed to start this. Also, timer of event would be helpful. H2S and CO2 are also important because they affect caustic tower operations, but no immediate impact on AHR.
	1. Monitor CO at K201		BO	K201 is the first CO monitor after the furnaces. You expect an increase here-- which will affect the AHR in about 30 minutes-- but size of delta tells you what to do. Thus, CO ppm at K201 vs target (300 ppm) and history and trend and rate of change.
	2. Monitor CO2 and H2S for caustic towers		not AHR	
	3. Increase heat of feed input		BO	*causes increased C2H2 conversion. Inversion of 4.1.3.4*
	4. Add DMDS		BO	to reduce CO production
	5. Add H2		BO	*increases C2H2 conversion. Inversion of 2.3.4.6.3*
2.5.4 Add DMDS				
	Plan 2.5.4: Do 1, then do 2. If cracking unit can't do 2, then do 3.			CO output (at K201) throughout, trend and target.
	1. Estimate desired quantity			DMDS flow, Feed flow, current delta CO flow from target (300 ppm)

Task	Plan	Timing	Actors	IRs
	2. Ask Cracking to add to the swung furnace			commo, report of feasibility (or indicators of DMDS flow, CO performance with trends and targets)
	3. Add DMDS from panel			position, status and flow through FV135
3. Shut Down				
	Plan 3:When shutting down the whole plant, do 1, then do 2.			
	1. Warm up	seq		
	2. Hydrocarbon free			
3.1 Warm up (Procedure 0.FINMSC.4)				
	Plan 3.1: (Procedure 0.FINMSC.4) Do 1 -3 in parallel (and parts of 2 continuously throughout 3.1). Then do 4 and 5 in order.			
	1. Establish pre-reqs	para cont		
	2. Establish safety precautions			
	3. Obtain references			
	4. Pre-warm up meeting	seq		
	5. Perform warm up			
3.1.1 Establish pre-reqs				
	Plan 3.1.1: Do 6 one week before warm up. Do 5 the weekend before the warm up. Do 1 and 2 in order. Then do 3,4,7-10 in any order. Do 7 continuously throughout plan 3.1			
	1. Review procedure	seq	BO, Oos	procedure 0.FINMSC.4
	2. Do check sheets			
	3. Ensure in and out of T-210s regenerated and ready	any	coord, BO	preplanned. Coord with OO and maint to ensure.
	4. Ensure offline R-410 regenerated and ready for startup		coord, BO	preplanned. Coord with OO and maint to ensure.
	5. Ensure Offline T-411 ready	wknd	coord, BO	preplanned. Coord with OO and maint to ensure. OO checks block valves and reports.
	6. Ensure P-601 serviced and operable	1 wk	coord, BO	preplanned. Coord with OO and maint to ensure.
	7. Ensure tower pressures lowered to maintain specs	any cont	coord, BO	preplanned. Coord with OO and tower ops to ensure. Tower pressures (T-320, T-330, T-350, T-365, T-370, T-420, T-430) or notification

Task	Plan	Timing	Actors	IRs
	8. Ensure leak response crew available.	any	coord, BO	communication, radio
	9. Notify affected units			
	10. Review reactor runaway procedure.		BO, OO	Procedure EM.3
3.1.1.2 Do Check sheets				
	Plan 3.1.1.2: do 1 then 2.			
	1. Complete check sheet items	seq	coord, BO, OO	
	2. Attach check sheets		coord	
3.1.1.9. Notify affected units				
	Plan 3.1.1.9: Do 1 and 2 in any order			
	1. Notify pipeline	any	BO or Coord	phone, email, radio; address; . . .
	2. Notify waterblock		BO or Coord	phone, email, radio; address; . . .
3.1.2 Establish safety precautions				
	Plan 3.1.2: Do 0-4 in any order. Then do 5-11 continuously throughout Plan 3.1			
	0. Review safety precautions	any	coord, BO, OO	safety precautions (checklists?)
	1. Review emergency procedures		coord, BO, OO	emergency procedures (EM.3 and any others??)
	2. Define emergency chain of command		coord	Manpower lists?
	3. Perform emergency communications tests			
	4. Notify LP of plant activities and potentials		BO	phone?
	5. Wear protective clothing	cont	OO	location and procedures for protective clothing
	6. Watch for falling ice		OO	location of ice??
	7. Monitor for leaks'			
	8. Note minimum pressure tower specs for flare		BO	min pressure specs for towers to flare, current pressures and trends (see 3.1.1.7)
	9. Monitor for pipe shoes off supports		OO	location and appearance of pipe shoes
	10. Drain liquids to flare instead of OW when possible		OO	
	11. Ensure E-205 outlet temp >=20C		BO	E205 outlet temp and trend (or reports)

Task	Plan	Timing	Actors	IRs
3.1.2.0. Review safety precautions				
	Plan 3.1.2.0: Do 1-10 in any order			
	1. Man down	any	BO, OO	Man down procedure
	2. Fire		BO, OO	Fire procedure
	3. Explosion		BO, OO	Explosion procedure
	4. Leaks		BO, OO	Leaks procedure
	5. 222		BO, OO	222 procedure
	6. Gaitronics		BO, OO	Gaitronics procedure
	7. Alarms		BO, OO	Alarms procedure
	8. Reactor runaway		BO, OO	Reactor runaway procedure
	9. Deluges		BO, OO	Deluges procedure
	10. Safety showers and eyewash stations		BO, OO	Safety showers and eyewash stations procedure
3.1.2.3. Perform emergency communications tests				
	Plan 3.1.2.3: Do 1-3 in any order			
	1. Test emergency alarm	any	BO	emergency alarm, outside feedback
	2. Test Gaitronics		BO	Gaitronics controls, outside feedback
	3. Test 222		BO and OO and staff	222 phone line commo from various outside points
3.1.2.7. Monitor for leaks'				
	Plan 3.1.2.7: Do 1 and 2 continuously			
	1. Monitor for Flange leaks	cont	OO	
	2. Monitor for Packing leaks		OO	
3.1.3 Obtain references				
	Plan3.1.3: Do 1-4 in any order			
	1. Obtain P&ID RD-A-440	any		P&ID RD-A-440
	2. Obtain training manuals 1&2			training manuals 1&2
	3. Obtain emergency procedures			emergency procedures (see 3.1.2.0 above)
	4. Obtain procedures for chemical wash on K-201 A/B/C			procedures for chemical wash on K-201 A/B/C
3.1.4 Pre warmup meeting				
	Plan 3.1.4: Do 1-3 in any order			
	1. Review questions		BO, OO, coord	questions
	2. Resolve problems		BO, OO, Coord	problems

Task	**Plan**	**Timing**	**Actors**	**IRs**
	3. Designate responsibilities		coord	roles, duty roster, manpower list
3.1.5 Perform warm up				
	Plan 3.1.5: Do only as a part of an overall plant warmup (0.FINMSC.4) When T-320/330 liquid free and warmup is complete, do 1 & 2 in order. Then do 3 for 15 minutes. When T320/330 level is <20%, do 4. Then do 5&6 in order. When at 5 ppm C2H2, do 7. When T-350 to T-430 are warmed up and liquid free, do 8. Then do 9. As a part of the overall depressuring sequence after E-353 is depressured, do 10.			Liquid status and temp of T320 and T-330 (or report). Timer. Level status of T-320, T-330. Concentration of C2H2. Liquid status and temp of T-350 to T-430. Pressure of E353. (or reports).
	1. Trip H2	seq	BO	Position, flow and control of H2 flow (FV413 or SDV 413A-C-- probably the latter).
	2. Block in H2		OO	position and flow of SDV413 A-C?
	3. Sweep reactor with C2 feed		BO	timed flow with C2 feed and no H2. Hence, H2 flow status, C2 feed flow status and control and elapsed time. Watching delta bed temps and C2H2 out vs. targets.
	4. Bypass reactor			
	5. Depressure reactor with 4" from inlet		OO	reactor pressure, flow through 4" (position and flow through VM2 or VM3??)
	6. Perform N2 Purge			
	7. Monitor T370 O/H			
	8. Block in E412			
	9. Warm up E411			
	10. Depressure PV-412 to flare			
3.1.5.4. Bypass reactor				
	Plan 3.1.5.4: Do 1-3 in order			
	1. Open bypass valves		OO	control, location and status of bypass valve (VM1)
	2. Close inlet MOV		BO (or OO?)	control, position and flow through MV410 or 411, bed temps, delta temps, bed pressure, c2H2 out

Task	Plan	Timing	Actors	IRs
	3. Close outlet valves		OO	control, position and flow through VM6/7 or VM8/9
3.1.5.6. Perform N2 Purge				
	Plan 3.1.5.6: Do 1 three times. Then do 2 and 3 in order			Monitoring and controlling the flow of N2 is part of the regen process we decided not to model.
	1. Pressure Purge	rpt seq		reactor pressure, flow through MV410 or MV411 and VM6/7 or VM8/9.
	2. Create N2 blanket			reactor pressure.
	3. Seal reactor			reactor pressure, flow through MV410 or MV411 and VM6/7 or VM8/9.
3.1.5.7 Monitor T-370 O/H			not AHR	
	Plan 3.1.5.7: Do 1-3 in order			
	1. Dump V-371 to 20% level into D-375	seq		
	2. Close LV-373			
	3. Block in LV-373			
3.1.5.8. Block in E412				
	Plan 3.1.5.8: Do 1-3 in order			
	1. Block in E412 cooling water valves	seq	OO	position, flow and control for VW1 and VW2 for water flow. I'll bet they're only concerned with VM10 and 12.
	2. Blow out E412 with N2		OO	N2 source and control
	3. Vent E412		OO	position, flow and control of VM11??
3.1.5.9. Warm up E411				
	Plan 3.1.5.9: do 1 and 2 in parallel.			
	1. Set TIC-410 to 75C		BO	status, location and control of TIC-410, heat exchange, steam flow.
	2. Monitor E411 temp		BO	E411 temps, timer?
3.1.5.10. Depressure PV-412 to flare				
	Plan 3.1.5.10: same as 4.1.4.4?? 2.3.6??		BO	Position, flow and control of PV412. R410 pressures, delta temps, and history.
3.2 Hydrocarbon Free AHR				
	Plan 3.2			This is probably part of (or at least related to) regen.

Task	Plan	Timing	Actors	IRs
4. Fault Management				
	Plan 4:When reactor is in normal service and plant is online and a high (~90C) or rapidly increasing reactor temp is observed, do 1. If temps in a reactor under N2 pad begin to rise, do 2. If K201 trips, do 3. If K601 trips, do 4. If K651 trips, do 5. If reactor offspec (as for 1, but rising less rapidly), do 6. If loss of turbos, do 7. If loss of DMDS, do 8. If loss of cooling water, do 9.			Standing monitor of reactor temps (and temp history trend) for both in service and N2-padded reactors. Also monitor for trips in K201, K601, K651. Monitored or reported conditions for: turbos (H2 flow), DMDS (furnaces), cooling water.
	1. Manage Reactor Temp Runaway	pot		
	2. React to temp rise in padded reactor			
	3. Respond to K201 trip			
	4. Respond to K601 trip			
	5. Respond to K651 trip			
	6. Reactor offspec			
	7. Loss of Turbos			
	8. Loss of DMDS			
	9. Loss of cooling water			
4.1 Manage Reactor Temp Runaway				
	Plan 4.1: Do 1 and 2 in any order. If reactor temps reach 100C, do 3. If reactor temps reach 200C, do 4. If reactor temps reach 250C, do 5. If reactor temps reach 300C, do 6. If reactor temps return to <=55C, do 7.			reactor temps (multiple levels), history trends, thresholds at 100, 200, 250, 300 and 55
	1. Ensure Pre Reqs	any		
	2. Perform Safety Precautions			
	3. Do Mild runaway steps	seq		
	4. Do Moderate runaway steps	pot		
	5. Do Severe runaway steps			
	6. Do Critical runaway steps			
	7. Do Return to normal temps steps			

Task	Plan	Timing	Actors	IRs
4.1.1 Ensure Pre-Reqs				
	Plan 4.1.1: Do 1-5 in any order			most of these are informal and generally true. In the heat of the moment, they might not be checked, but it'd be nice to be informed if they weren't true.
	1. Ensure reactor inlet MOV in remote position	any	FO	not important, can be checked later with travel feedback on MOV move.
	2. Ensure trip alarms activated by PLC when inlet MOV opened.		BO	Status of temperature trip alarms. 'motherhood'-- it should have been activated after last swing.
	3. Ensure HS-416A activated by PLC when inlet MOV opened		BO	Status of HS-416A trip logic. also motherhood. This controls H2 trip logic.
	4. Ensure FLS-411 (low feed flow) not bypassed (HS-416B)		FO?	shouldn't be bypassed normally
	5. Ensure firewater monitor aimed at on-line reactor midpoint and on power cone setting		FO	normally in that position
4.1.2 Perform safety precautions				
	Plan 4.1.2: Do 1-3 in any order			
	1. Remove all personnel from reactor area	any	OO	radio, gaitronics and face to face commo.
	2. Maintain liquid seal on T-330		not AHR	liquid level in T330 and trends over time with threshold-- or notifcation. Currently alarmed with lite box annunciation.
	3. Maintain liquid seal on T-320		not AHR	liquid level in T320 and trends over time with threshold-- or notifcation. Currently alarmed with lite box annunciation.
4.1.3 Do Mild runaway steps				
	Plan 4.1.3: If autotrip has not occurred by 110C, do 1. Then do 2 if no liquid level is evident in T-320 bottoms and do 3 if no liquid in T-330 bottoms. Then do 4 and 5 in order. If reactor temp continues to increase (on any thermocouple) above 110C, do 6.			autotrip status (a litebox indicator). reactor temps, trends and thresholds. Liquid levels in T320 and T330 bottoms
	1. Manually trip H2 to R410	pot	BO	hand knob control, status of control, flow of H2 (through FV413 or SDVs)

Task	Plan	Timing	Actors	IRs
	2. Close FV-320	pot	not AHR	H2 flow even with H2 tripped might be an indicator of loss of liquid level in these columns
	3. Close FV-33001		not AHR	
	4. Reduce reactor inlet feed temp	seq	BO	
	5. Flare reactor effluent			
	6. Flare more at PV-412	pot		
4.1.3.4 Reduce reactor inlet feed temp				
	Plan 4.1.3.4: Do 1 and 2 in parallel.			
	1. Close TV-410	para	BO	location, status and flow through TV-410 (steam flow).
	2. Observe inlet temps		BO	C2 feed inlet temps, history trends vs 'normal'
4.1.3.5 Flare reactor effluent				
	Plan 4.1.3.5: Do 1. Then, if possible, do 2.			
	1. Open PV-412	seq	BO	
	2. Close C2 Drier outlets	pot	not AHR	
4.1.3.5.1 Open PV-412				
	Plan 4.1.3.5.1 Do 1-4 in any order (but rapidly). Then do 5. If successful, do 6 continuously.			
	1. Manually open PC-412	seq	BO	go to manual control to break cascade, control and status of PV-412; put to 60% and return to pressure control
	2. Issue board command to close HV-41001		BO	control and status and flow of HV-41001
	3. Put PV412 back on pressure control		BO	control, status and flow through PV412
	4. Issue Board command to close PC-412A		BO	control and status of PV-412A
	5. Issue board command to close FC-364		not AHR	
	6. Observe R410 pressure for decrease.	seq	BO	temp more important than pressure; both absolute and gradient. Trend vs. previous values, expectation is steady or decline.
	7. Maintain T-350 pressure by adjusting PC-412	pot	BO	not really needed if step 3 is done.

Task	Plan	Timing	Actors	IRs
4.1.3.6 Flare more at PV-412				
	Plan 4.1.3.6: as for plan 4.1.3.5, but step 4.1.3.5.1.7 can be relaxed		BO	as for 4.1.3.5, pressures vs. normal (normal is 2500 kPa ,could go to 1000 kPa). Amount to flare is based on pressure, speed of temp rise, and plant feed rates.
4.1.4 Do Moderate Runaway Steps				
	Plan 4.1.4: Do 1-4 in order			
	1. Sound plant alert	seq	BO (atually, emerg. Coord)	control and status of plant alert broadcast; yell across room to tell cracking to call alert
	2. False load K201		not AHR	
	3. Close reactor inlet MOV (MS410 or MS411)			
	4. Depressure R-410 to flare (PC-412)			
4.1.4.3 Close reactor inlet MOV (MS-410 or MS-411)	*Plan 4.1.4.3 Do 1 and 2 in parallel.*			
	1. close inlet MOV	para	BO	control and status and flow through inlet MOV
	2. Observe MOV status change		BO	status delta for MOV, timer?
4.1.4.4 Depressure R-410 to flare (via PC-412)				
	Plan 4.1.4.4 As for 4.1.3.5		BO	set-point change (0%) or put in manual (more likely); monitor changes in reactor pressure and temperature
4.1.5 Do Severe Runaway Steps				
	Plan 4.1.5: Do 1 and 2 in order			both reactor deluge and firewater monitor can trip themselves, but operator can and should usually anticipate.
	1. Dump reactor deluge	seq	BO, OO	panel, back-panel (cracking side), deluge control shack (OO); deluge activation will give alarm at DCS
	2. Turn on firewater monitor		OO	
4.1.6 Do Critical Runaway steps	*Plan 4.1.6: Do 1 and 2 in order*			

Task	Plan	Timing		Actors	IRs
	1. Sound plant evacuate	seq		BO (emerg coord).	control and status of plant evac alarm
	2. Perform Evac procedures			emerg coord	location and status of people on unit
4.1.7 Do return to normal temps steps					
	Plan 4.1.7: If preparing for shutdown, do 1. Else, do 2 and 3 in order				
	1. Continue shutdown procedure	pot			as for plan 3
	2. Follow Procedure 410.03 from 6.5.2 on	pot	seq		as for plan 2.3.6
	3. Bring fresh reactor online				as for plan 2.3
4.2 React to temp rise in padded reactor					
	Plan 4.2: (procedure 0.FINMSC.3) When temps begin to rise in a padded reactor, do 1. Do 2 and 3 continuously. Do 4. If reactor temps continue to rise, do 5. If temps rise to 80C, do 6. If temps rise to 200C, do 7. If temps rise to 300C, do 8.				temperatures in padded reactor (current and historical trend). Also, temps vs. thresholds. Reactor pressures vs. historical trends and benchmarks.
	1. Obtain references	seq			
	2. Monitor reactor temps		cont		temperatures in padded reactor (current and historical trend). Also, temps vs. thresholds. Rising reactor temps are the primary concern in this procedure. They are probable evidence of an unexpected inflow of O2, but diagnosing the source of O2 is not the point of this procedure, and the procdure is generally relevant regardless of the source of heat rise.
	3. Ensure no O2 entering reactor		pot	OO	
	4. Repressure reactor with N2				part of regen plan and equipment. Reactor pressures will still be needed.
	5. Vent reactor				
	6. React to Moderate reactor runaway				

Task	Plan	Timing	Actors	IRs
	7. React to Serious reactor runaway	pot		
	8. React to Critical reactor runaway.			
4.2.1. Obtain references				
	Plan 4.2.1: Do 1 and 2 in any order			
	1. Obtain Training Manuals 1 & 2	any		Training manuals 1&2
	2. Obtain Reactor runaway procedure EM.3			Reactor runaway procedure EM.3
4.2.5. Vent reactor				
	Plan 4.2.5: Do 1 and 2 in order			
	1. Leave N2 open	any	not AHR	N2 system is not part of AHR we have studied. Part of regen.
	2. Open reactor vent to disperse O2 to atmosphere.		FO?	location, control, position and flow through reactor vent (VM2/3?)
4.2.6. React to Moderate reactor runaway				
	Plan 4.2.6: Do 1-3 in order. Do 4 at any time.			
	1. Call out on call personnel	seq	emerg. Coord.?	duty roster, manpower list, commo
	2. Line up fire water monitor to reactor		FO	as for Plan 4.1.1.5?
	3. Check fire water monitor for leaks		FO	
	4. Ensure H2 is isolated	any	FO/BO	As for Plan 4.1.3.1-- position, control and flow through FV413 and SDV valves
4.2.7. React to Serious reactor runaway				
	Plan 4.2.7: Do 1. Then do 2 & 3 simultaneously			
	1. Sound alert	seq	emerg. Coord.	control and status of alert broadcast
	2. Cool reactor with fire monitor	para	BO/FO	control, status and flow of firewater monitor fire water; temperature, trend and delta trend of hot reactor
	3. Continue to purge with N2 to atmosphere		BO	As for 4.2.5
4.2.8. React to Critical reactor runaway.				
	Plan 4.2.8: Do 1 and 2 in order			
	1. Sound plant evacuate	seq	emerg. Coord.	control and status of alert broadcast

Task	Plan	Timing		Actors	IRs
	2. Have all personnel report to control room	seq		emerg. Coord.	commo, rosters, position sheets
4.3 Respond to K201 trip					
	Plan 4.3: Do only in the context of an overall response to a K201 trip (Procedure 0.F.R.021). Do 1 if possible. If trip is (will be??) > 4 hours, do 2-4 in order. Do 5 throughout as needed. Then do 6-9 in order. If depressuring occurs, do 10. If longer term shutdown, do 11.				K201 trip status. Predicted (actual elapsed) duration of trip. Depressuring status (and history).
	1. Switch to E2 H2	pot			
	. . .				
	2. Reduce furnace feed to 60-80 Mgs/hr.	pot	seq		no real AHR actions. Monitor status and communicate it to K-201 operator. Monitor feed rate and pressure and adjust CO and heat accordingly.
	3. Stop feed forward from reactor				position, flow and control of HV-41001. Flow through.
	4. Ensure PC-412 on auto				position and control over PV-412 control scheme
	5. Adjust PC-412 as needed to maintain pressure	cont			position, flow and control of PV-412; pressure in other vessels (??-- pressure into AHR or into R410 would do).
	6. Trip H2 to reactor	seq			
	. . .				
	7. Shut down all regens and reductions				
	8. Monitor 350 and 4160 steam temps				unclear that this affects AHR. steam temps
	9. Log all closed field block valves for startup				
	10. Blow cooling water out of E412	pot		OO	
	11. Do long term shutdown actions				
4.3.1. Switch to E2 H2					
	Plan 4.3.1: As for 2.4				
. . .					
4.3.6. Trip H2 to reactor					
	Plan 4.3.6: Do 1 and 2 in order				
	1. Issue board command	seq		BO	position, flow and control over SDV valves?

Task	Plan	Timing	Actors	IRs
	2. Manually block in H2 in field	seq	OO	
4.3.6.2 Manually block in H2 in field				
	Plan 4.3.6.2: As for 4.2.6.4/4.1.3.1??		OO	
. . .				
4.3.7. Shut down all regens and reductions				
	Plan 4.3.7: Do for active reactor and for reactor undergoing regen (if any)			reactor status; regen status
	1. Isolate R-410	seq		
4.3.7.1 Isolate R-410				
	Plan 4.3.7.1 As for 3.1.5			
4.3.9. Log all closed field block valves for startup				
	Plan 4.3.9: Do 1-3 in any order			
	1. Log HV-41001		shift super	log book and control to input to it.
	2. Log H2 inlet		shift super	log book and control to input to it.
	3. Log R-410 valves		shift super	log book and control to input to it.
4.3.11. Do long term shutdown actions				
	Plan 4.3.11: Do 1-3 in order			
	1. Pull feed from furnaces	seq	not AHR	
	. . .			
	2. Depressure R-410			*Plan 4.3.11.2: As for 3.1.5 and 2.3.6*
	3. Create N2 cap on R-410			*Plan 4.3.11.3: As for 3.1.5.6.2 and 2.3.6.6*
4.4 Resond to K601 trip				
	Plan 4.4: Procedure 1.F.R.022. Do 1-3 in parallel. Then do 4			K601 trip status, predicted or actual duration (fact that quick restart isn't going to be attempted).
	1. Ensure pre-reqs	para		
	2. Take safety precautions			
	3. Obtain references			
	4. Do Response actions	seq		
4.4.1 Ensure pre-reqs				
	Plan 4.4.1 Do 1. If QuickStart is rejected or has failed, do 2 and 3 in parallel			
	1. Verify K-601 trip	seq		For AHR operatior, this is just a notification

Task	Plan	Timing	Actors	IRs
	2. Review procedure with team	pot		Procedure 1.F.R.022
	3. Assign/review roles and responsibilities			manpower sheets, rotation.
4.4.2 Take safety precautions				
	Plan 4.4.2: Do 1 and 2 continuously throughout plan 4.4.			
	1. Do NOT attempt to restart K601 until step 4.4.6 has been completed for > 2 hrs.	cont		elapsed timer, K201 trip status
	2. Maintain all vessels and exchanges at operating pressures			operating pressures for all vessels and exchanges, current pressures for all vessels and exchanges vs. target.
4.4.2.2 Maintain all vessels and exchages at operating pressures				
	Plan 4.4.2.2. Do 1-4 continuously during shutdown.			
	1. Maintain pressure of R410 A/B		BO	pressure and flow control of R410A/B (position, flow and control of PV410A/B, VM1 & PV412)
	2. Maintain pressure of E413s		BO	pressure and flow control of E413s (position, flow and control of VM1 and ST1199 for steam; position, flow and control of PV441, TV440 and FV413 for feed).
	3. Maintain pressure of E411		BO	pressure and flow control of E411 (position, flow and control of TV410 for steam--nothing? For feed?)
	4. Maintain pressure of E410		BO	pressure and flow control of E410 (position, flow and control of HV41001 for outgoing feed, PV412 for incoming?)
4.4.3 Obtain references				
	Plan 4.4.3: Do 1-3 in any order			
	1. Obtain P&Ids	any		P&Ids
	2. Obtain Training manuals			Training manuals
	3. Obtain procedure 1.G.R.011			Procedure 1.C.R. 011. I doubt this is an AHR info requirement for this task.

Task	Plan	Timing	Actors	IRs
4.4.4 Do Response Actions				
	Plan 4.4.4: Do 1 ASAP. Then do 2-6 in order. If shutdown is for > 4 hrs, do 7.			shutdown timer and/or prediction
	1. Perform immediate response actions	seq		
	2. Isolate T365 and T370			
	3. Trip turbos and K-651		not AHR	
	4. Pull out of P/L		not AHR	
	5. Isolate T-420, T-430 and T-350		not AHR	
	6. Trip K201 and isolate unit			
	7. Do long term shutdown actions	pot		*As for 4.3.11*
4.4.4.1 Perform immediate response actions				
	Plan 4.4.4.1: Do 1-3 in order			
	1. Verify K-601 trip	seq	BO	K601 trip status and timer. just notification to the AHR operator.
	2. Cut cracking rates to 100 Mgs/hr		not AHR	cracking rates and time (will affect AHR in ~2 hrs)
	3. Cut cracking rates to 80 Mg/hr		not AHR	cracking rates and time (will affect AHR in ~2 hrs)
4.4.4.2 Isolate T356 and T370				
	Plan 4.4.42: Do 1-3 in order, do 4 continuously.			timing and coordination of actions with other operators and units.
	1. Close HV-41001	seq	BO	control and status of "HV-41001 and flow of C2 feed out of E410 before and after the valve.
	2. Ensure PC-412 is on auto		BO	control and status of PC-412
	3. Trip H2 to reactor		BO	*Plan 4.4.4.2.3: As for 3.1.5.1 & 2 and 4.1.3.1*
	4. Adjust PC-412 to maintain pressure	cont	BO	position, flow, and control of PV-412, pressure in R410 A/B with delta over time and target values
4.4.4.6 Trip K-201 and isolate unit				
	Plan 4.4.4.6: Do 1. Do 2 continuously. Do 3&4 in any order. Do 5 if depressurization occurs.			timing and coordination of actions with other operators and units.
	1. Shut down all regens and reductions	seq		
	2. Maintain 350 and 4160 steam temps	cont		
	. . .			

3. Log all closed field block valves	any	FO	
4. Block in all unnecessary flaring		FO?	radio coordination with BO to determine necessary??
5. Blow cooling water out of E412	pot		
. . .			
4.4.4.6.1 Shut down all regens and reductions			
Plan 4.4.4.6.1: Isolate R-410 (as for 3.1.5). (Other steps are related to regen procedure).			record of all ongoing regens and reductions and their equipment status
4.4.4.6.2 Maintain 350 and 4160 steam temps			
Plan 4.4.4.6.2: Do 1. Do 2 as needed			
1. Monitor steam temps	seq	not AHR?	350 and 4160 steam temps, (and pressures?)
2. Adjust heating of 350/4160 in east highline	pot	not AHR	
4.4.4.6.5 Blow cooling water out of E412		FO	
Plan 4.4.4.6.5: As for 4.3.10			
4.5 Respond to K-651 trip			
Plan 4.5: (Procedure 1.F.R.023) Do1-2 in parallel. Do 3 if desired. Then do 4.			timing and coordination of actions with other operators and units.
1. Ensure pre-reqs	seq		
2. Take safety precautions			
3. Obtain refs	pot		Process manuals; P&Ids 440-0651, 440-0652, 440-0653; SYS 300.0 P300.05; SYS300.0 P-300.03
4. Do Response actions	seq		
4.5.1 Ensure pre-reqs			
Plan 4.5.1: Do 1 and 2 in any order			
1. Verify K651 trip	any		K651 status. Notification to AHR op.
2. Evaluate time available			reports from K651 op on estimated time to restart. Not critical to AHR, though responses will be different.
4.5.2 Take safety precautions			
Plan 4.5.2: Do 1 and 2 in any order			

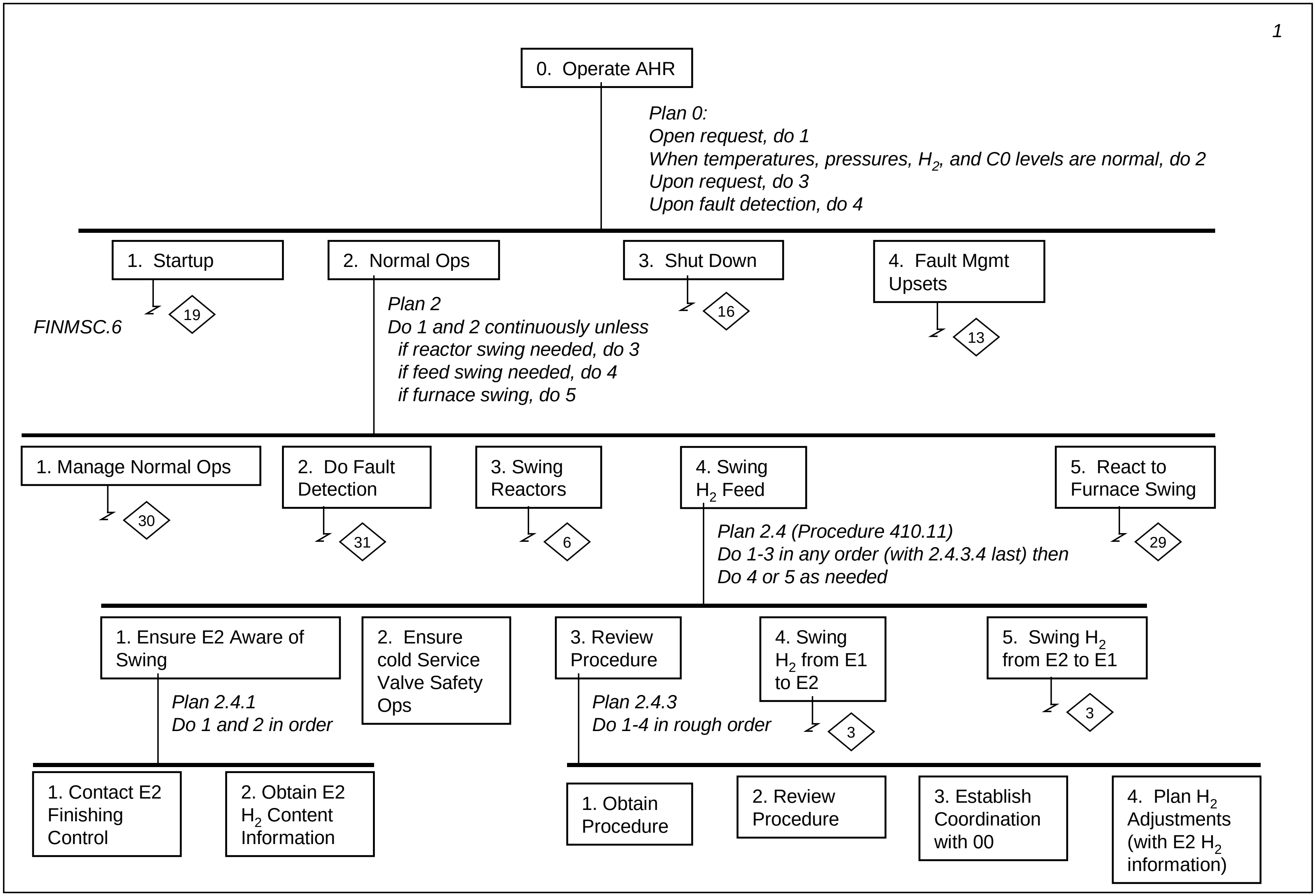
Task	Plan	Timing	Actors	IRs
	1. Prevent reactor reducing or cooling down with off gas	any	not AHR?	status of offgas use. Not much AHR operation here--more regen? AHR op should monitor Reactor temps, delta temps and C2H2 out for AHR runaway conditions.
	2. Verify mechanical integrity of machine for restart		FO	
4.5.4 Do response actions				
	Plan 4.5.4: Do 1 immediately. Then do 2-4 in order.			timing and coordination of actions with other operators and units.
	1. Do immediate actions	seq		
	2. Ready machine for restart		not AHR	these are mostly not AHR tasks
	3. Bring up to speed		not AHR	these are mostly not AHR tasks
	4. Monitor machine		not AHR	these are mostly not AHR tasks
4.5.4.1 Do immediate actions				
	Plan 4.5.4.1: Do 1 and 2 in parallel. Then do 3. If trip will last > 5 min, do 4. Do 5 in any case.			Elapsed/expected duration of trip
	1. Perform inside checks	para	not AHR	
	2. Perform outside checks		not AHR	
	3. Increase H2 to R410	seq	BO	
	4. Do K201 trip	pot		as for 4.3
	5. Isolate regens on driers and reactor	seq		as for 4.4.4.6.1 (including Isolate Reactor: plan 3.1.5)
4.5.4.1.3 Increase H2 to R410				
	Plan 4.5.4.1.3: Do 1 if E1 can't reliably meet increased H2 needs. Else do 2 and 3 in order and 4 at any time.			status of E1 H2 production, turbo capacity and cracking capacity-- or reported H2 capacity to AHR op.
	1. Swing to E2 H2	pot		
	2. False load turbos	pot seq	not AHR	turbo status, H2 capacity
	3. Increase H2 ratio by 25%		BO	status and control of H2 flow rate and mole % ratio, position, flow and control of TV440, FV413 and SDV valves; temperature, temp control and flow through E413s
	4. Inform E2 HOG	any		phone. Seems to be coordination action done whether or not using E2 H2.

4.5.4.1.3.1 Swing to E2 H2					
	Plan 4.5.4.1.3.1: As for 2.4				
4.6. Reactor offspec					
	Plan 4.6: (Procedure FR 027) Do 1. If small excursion, do 2 til back on spec. If large, do 3 then 4 until back on spec.				C2H2 out
	1. Determine degree of excursion				C2H2 out + trend and target. H2 in and out (trend vs. target). CO in (trend and target). Supporting information from upstream units
	2. Adjust reaction				As for Plan 2.1.5
	3. Cut feed				Commo with cracking; feed rate (trend) time expected before effects hit AHR.
	4. Flare				As for Plan 3.1.5.3.10
4.7. Loss of Turbos					
	Plan 4.7 (Procedure FR 024 and 025). Do 1 or 2.				
	1. Swing to E2 H2				As for plan 2.4
	2. Add H2				As for plan 2.1.5.3
4.8. Loss of DMDS	*Plan 4.8 (procedure 101.21) If E2H2 available, do 1, then do 3 and 4 continuously. If E2H2 unavailable, do 2, 5, and 6 in parallel. Do 3 and 4 continuously. Do 7 if CO and CO2 remain too high. If unable to regain DMDS flow after 1 hr, do 9; Else do 8 until back on spec.*				
	1. Go to E2H2	pot			*as for 2.4*
	2. Minimize CO in feed		para	cracking	*coord. With cracking op*
	3. Watch for runaway conditions		cont		*as for EM.3 (plan 4.1)*
	4. Watch for C2H2 breakout conditions				C2H2 in output, trend and target.
	5. Increase H2 to reactor	pot	para		as for 2.1.5.3
	6. Raise reactor inlet temp				as for 2.1.5.4
	7. Cut ethane feed		seq	cracking	coord with cracking op
	8. Flare offspec product				as for 3.1.5.3.10
	9. Shut down				as for plan 3

Task	Plan	Timing	Actors	IRs
4.9. Loss of cooling water				
	Plan 4.9: Do 1-3 in order. Do 4 continuously throughout.			
	1. Go to Flare			As for 3.1.5.3.10
	2. Cut feed			As for 4.6.3
	3. Do controlled shutdown			As for Plan 3
	4. Watch for runaway conditions.			as for 4.1

10. Appendix B

This section contains graphical presentations of the hierarchical task analysis presented in Appendix A.



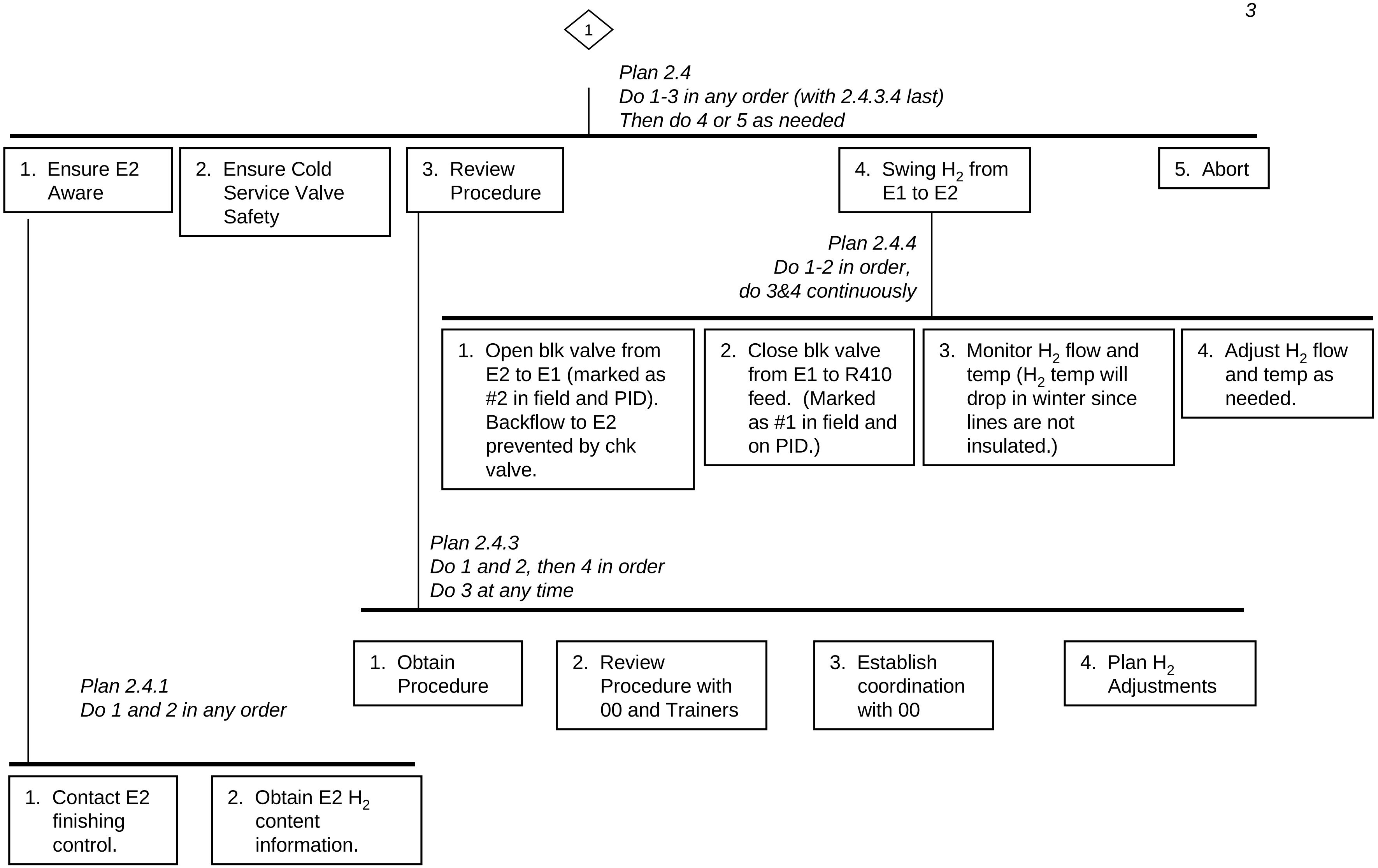
Plan 0:
Open request, do 1
When temperatures, pressures, H_2, and C0 levels are normal, do 2
Upon request, do 3
Upon fault detection, do 4

Plan 2
Do 1 and 2 continuously unless
if reactor swing needed, do 3
if feed swing needed, do 4
if furnace swing, do 5

Plan 2.4 (Procedure 410.11)
Do 1-3 in any order (with 2.4.3.4 last) then
Do 4 or 5 as needed

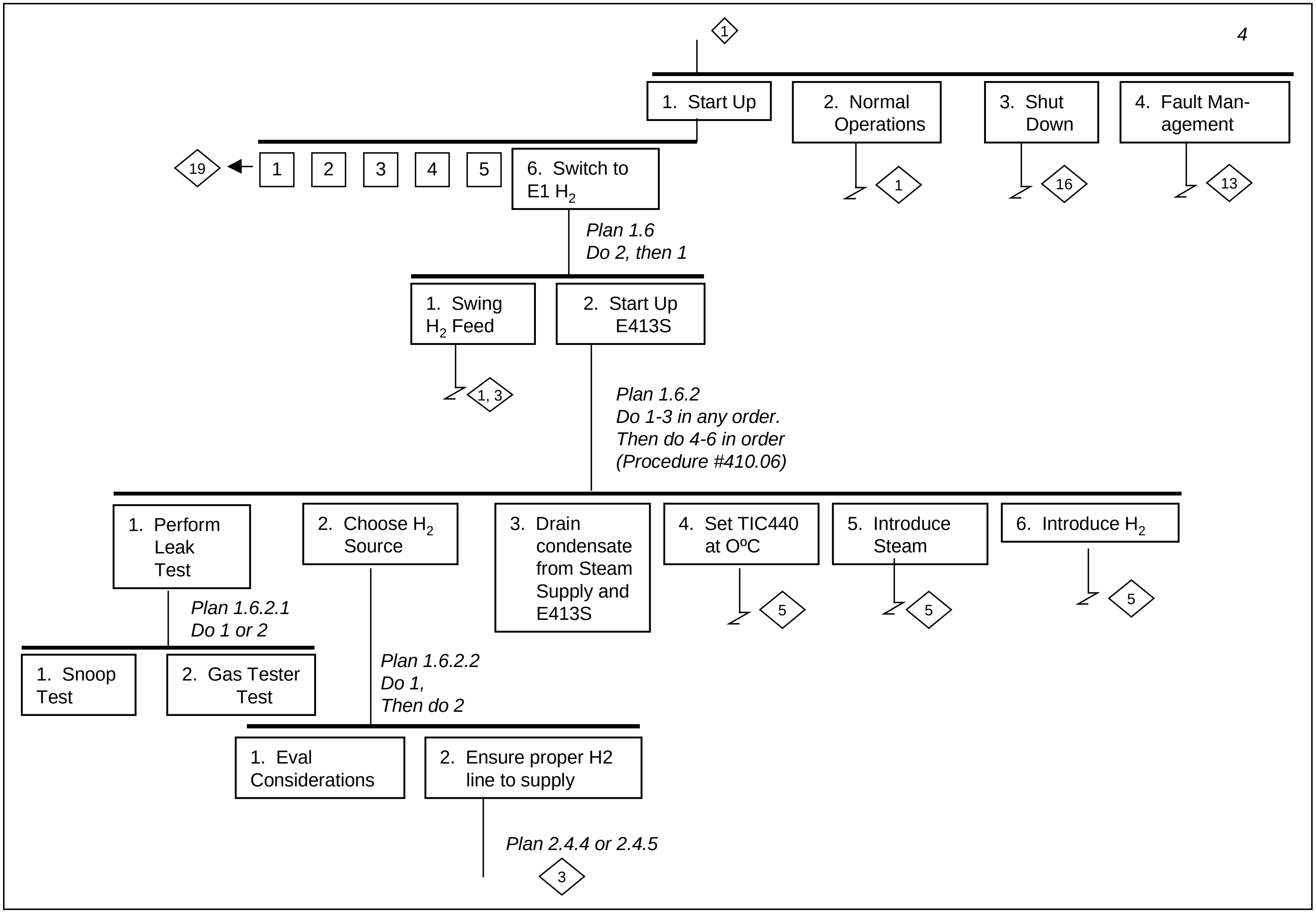
Plan 2.4.1
Do 1 and 2 in order

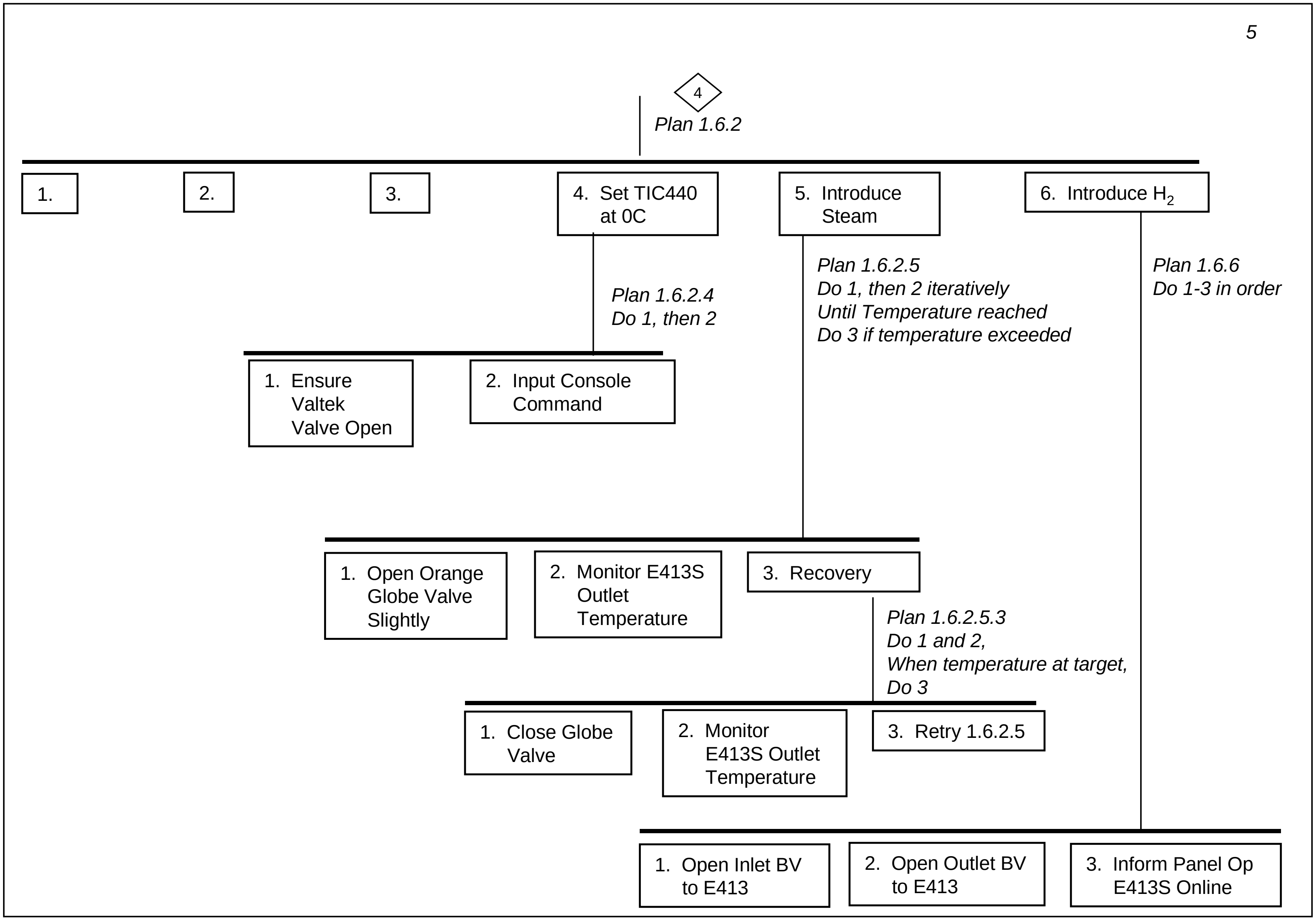
Plan 2.4.3
Do 1-4 in rough order

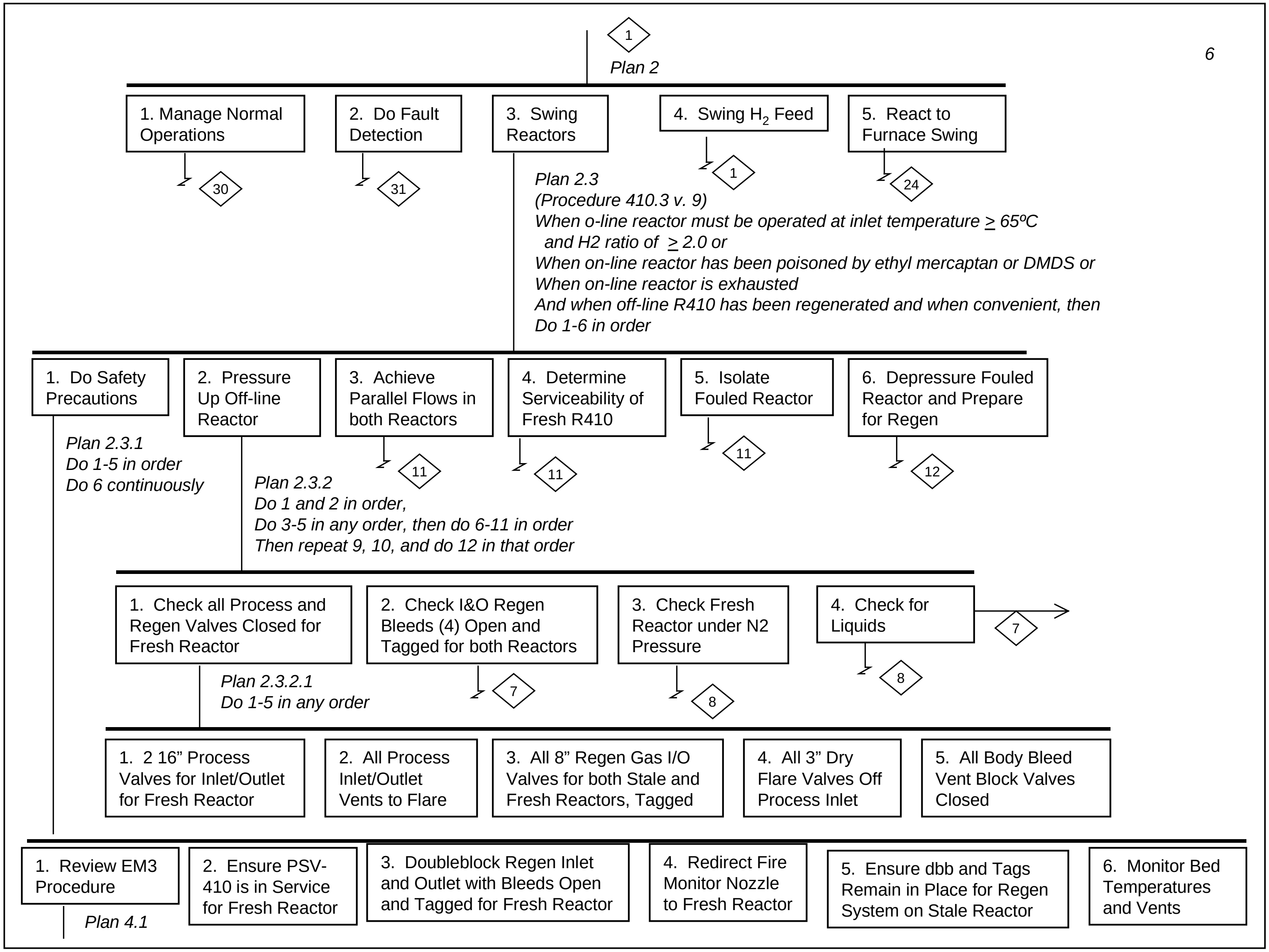


Plan 2.4
Do 1-3 in any order (with 2.4.3.4 last)
Then do 4 or 5 as needed

1. Ensure E2 Aware
   - *Plan 2.4.1*
     Do 1 and 2 in any order
   1. Contact E2 finishing control.
   2. Obtain E2 H_2 content information.
2. Ensure Cold Service Valve Safety
3. Review Procedure
   - *Plan 2.4.3*
     Do 1 and 2, then 4 in order
     Do 3 at any time
   1. Obtain Procedure
   2. Review Procedure with 00 and Trainers
   3. Establish coordination with 00
   4. Plan H_2 Adjustments
4. Swing H_2 from E1 to E2
   - *Plan 2.4.4*
     Do 1-2 in order,
     do 3&4 continuously
   1. Open blk valve from E2 to E1 (marked as #2 in field and PID). Backflow to E2 prevented by chk valve.
   2. Close blk valve from E1 to R410 feed. (Marked as #1 in field and on PID.)
   3. Monitor H_2 flow and temp (H_2 temp will drop in winter since lines are not insulated.)
   4. Adjust H_2 flow and temp as needed.
5. Abort


1
4
1. Start Up
2. Normal Operations
3. Shut Down
4. Fault Management
19
1
2
3
4
5
6. Switch to E1 H_2
1
16
13
Plan 1.6
Do 2, then 1
1. Swing H_2 Feed
2. Start Up E413S
1, 3
Plan 1.6.2
Do 1-3 in any order.
Then do 4-6 in order
(Procedure #410.06)
1. Perform Leak Test
2. Choose H_2 Source
3. Drain condensate from Steam Supply and E413S
4. Set TIC440 at OºC
5. Introduce Steam
6. Introduce H_2
5
5
5
Plan 1.6.2.1
Do 1 or 2
1. Snoop Test
2. Gas Tester Test
Plan 1.6.2.2
Do 1,
Then do 2
1. Eval Considerations
2. Ensure proper H2 line to supply
Plan 2.4.4 or 2.4.5
3


5
4
Plan 1.6.2
1.
2.
3.
4. Set TIC440 at 0C
5. Introduce Steam
6. Introduce H_2
Plan 1.6.2.4
Do 1, then 2
Plan 1.6.2.5
Do 1, then 2 iteratively
Until Temperature reached
Do 3 if temperature exceeded
Plan 1.6.6
Do 1-3 in order
1. Ensure Valtek Valve Open
2. Input Console Command
1. Open Orange Globe Valve Slightly
2. Monitor E413S Outlet Temperature
3. Recovery
Plan 1.6.2.5.3
Do 1 and 2,
When temperature at target,
Do 3
1. Close Globe Valve
2. Monitor E413S Outlet Temperature
3. Retry 1.6.2.5
1. Open Inlet BV to E413
2. Open Outlet BV to E413
3. Inform Panel Op E413S Online



Plan 2

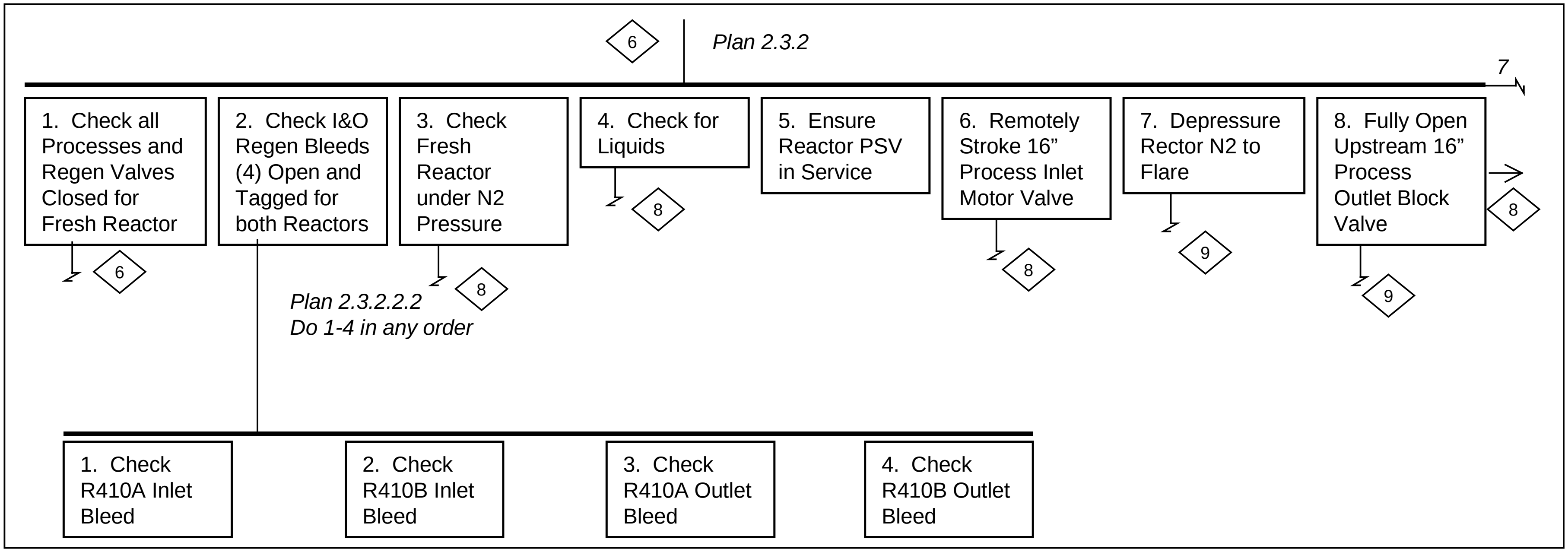
Plan 2.3
(Procedure 410.3 v. 9)
When o-line reactor must be operated at inlet temperature ≥ 65ºC
and H2 ratio of ≥ 2.0 or
When on-line reactor has been poisoned by ethyl mercaptan or DMDS or
When on-line reactor is exhausted
And when off-line R410 has been regenerated and when convenient, then
Do 1-6 in order

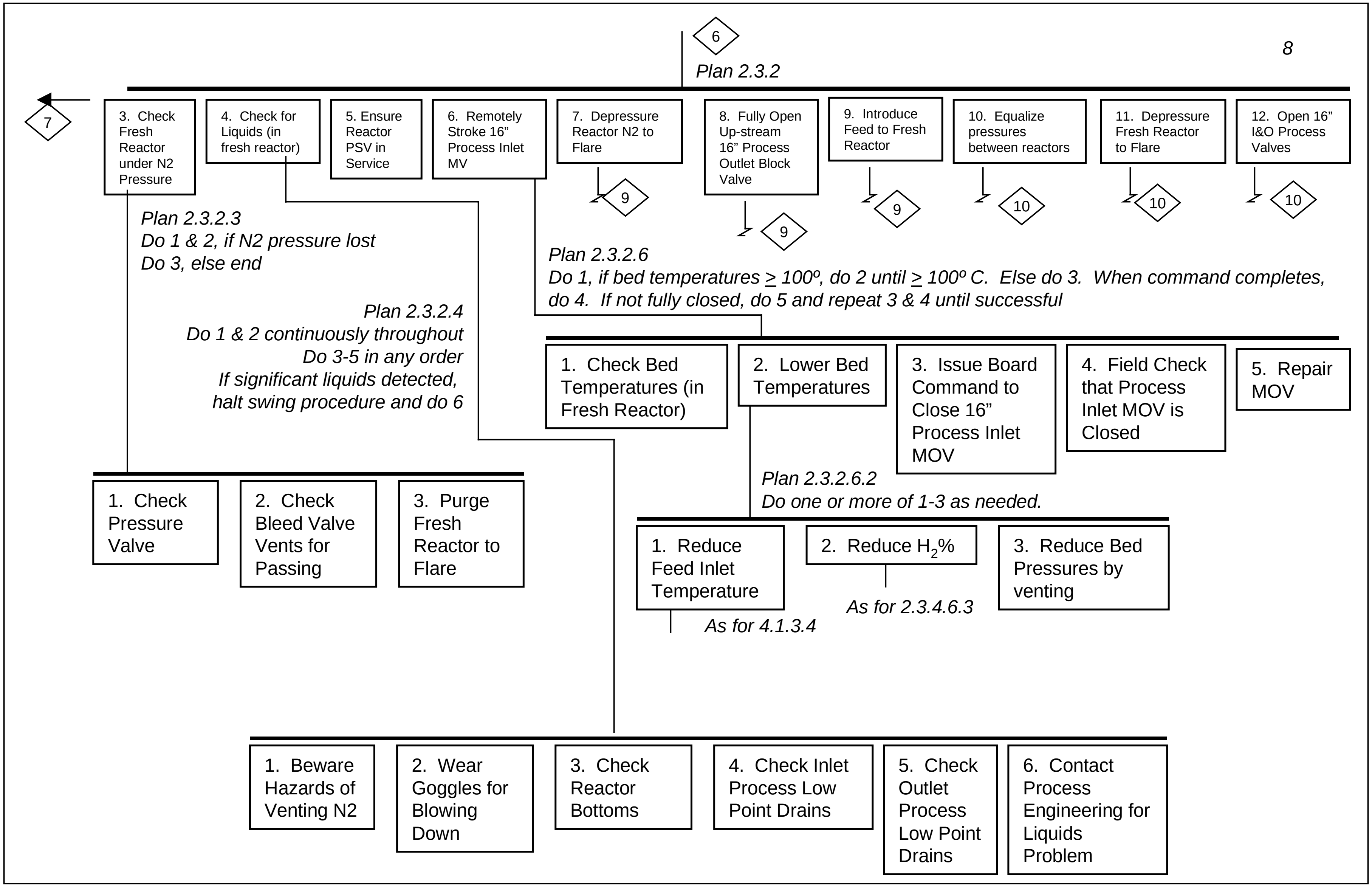
Plan 2.3.1
Do 1-5 in order
Do 6 continuously

Plan 2.3.2
Do 1 and 2 in order,
Do 3-5 in any order, then do 6-11 in order
Then repeat 9, 10, and do 12 in that order

Plan 2.3.2.1
Do 1-5 in any order

Plan 4.1


6
Plan 2.3.2
7
1. Check all Processes and Regen Valves Closed for Fresh Reactor
6
2. Check I&O Regen Bleeds (4) Open and Tagged for both Reactors
3. Check Fresh Reactor under N2 Pressure
8
4. Check for Liquids
8
5. Ensure Reactor PSV in Service
6. Remotely Stroke 16” Process Inlet Motor Valve
8
7. Depressure Rector N2 to Flare
9
8. Fully Open Upstream 16” Process Outlet Block Valve
8
9
Plan 2.3.2.2.2
Do 1-4 in any order
1. Check R410A Inlet Bleed
2. Check R410B Inlet Bleed
3. Check R410A Outlet Bleed
4. Check R410B Outlet Bleed



Plan 2.3.2

Plan 2.3.2.3
Do 1 & 2, if N2 pressure lost
Do 3, else end

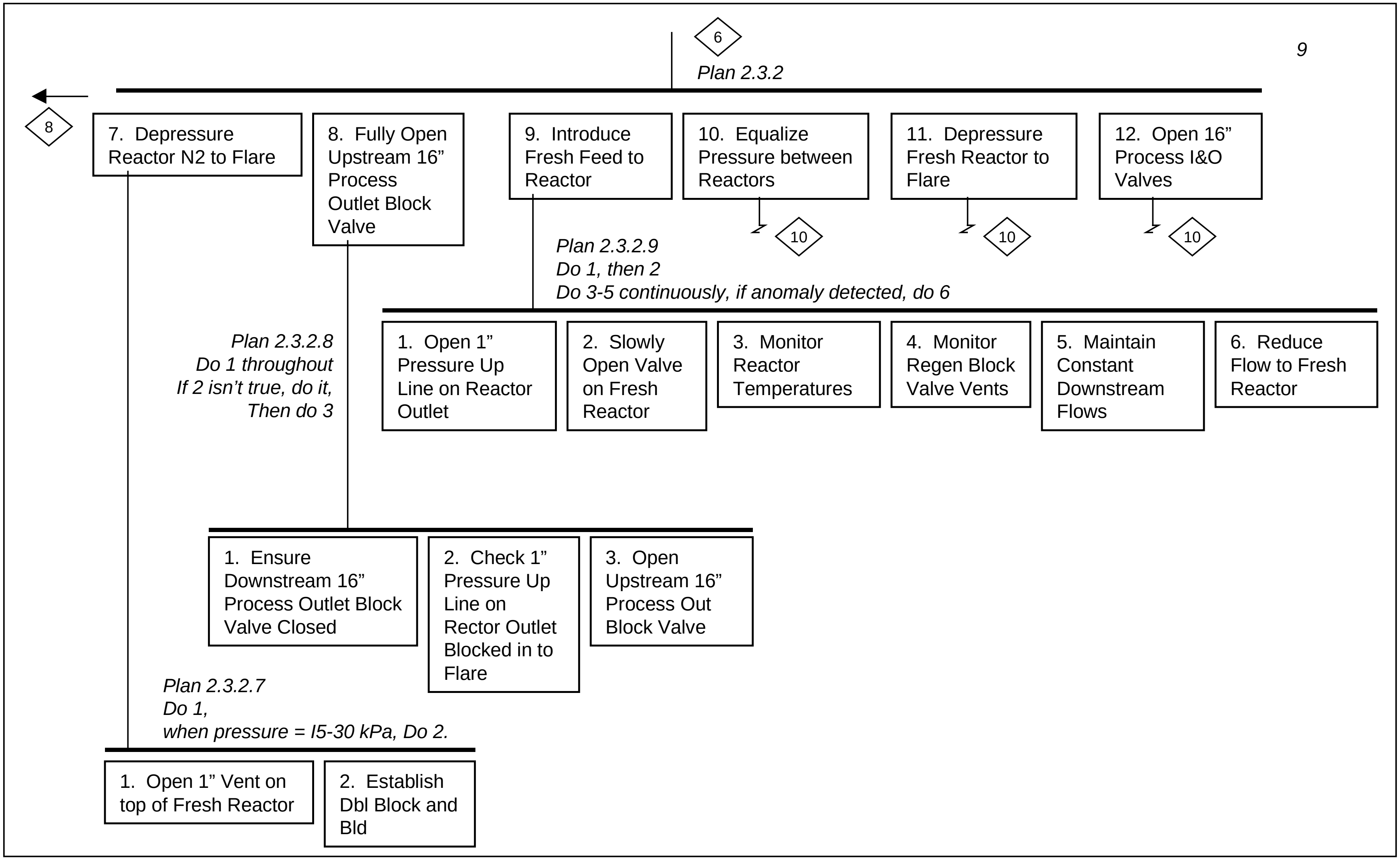
Plan 2.3.2.6
Do 1, if bed temperatures ≥ 100º, do 2 until ≥ 100º C. Else do 3. When command completes, do 4. If not fully closed, do 5 and repeat 3 & 4 until successful

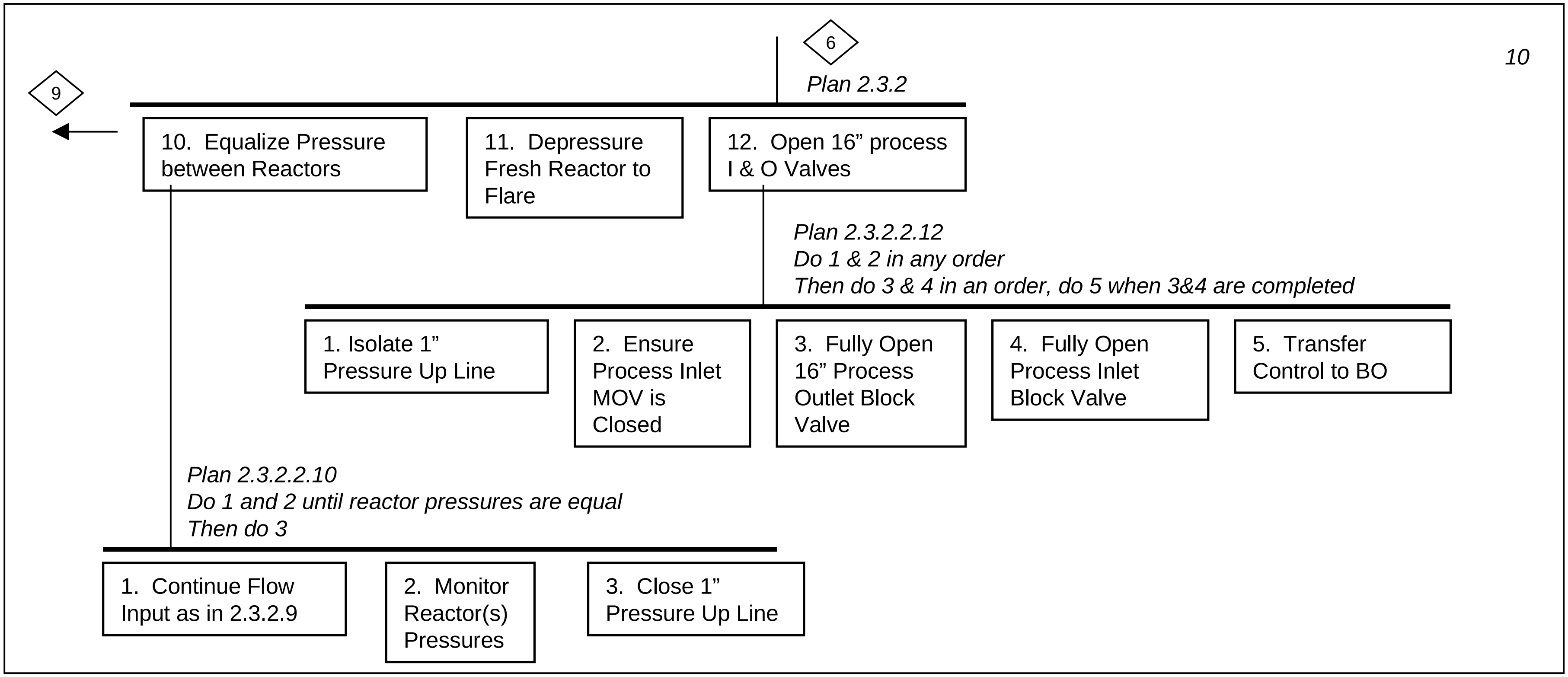
Plan 2.3.2.4
Do 1 & 2 continuously throughout
Do 3-5 in any order
If significant liquids detected, halt swing procedure and do 6

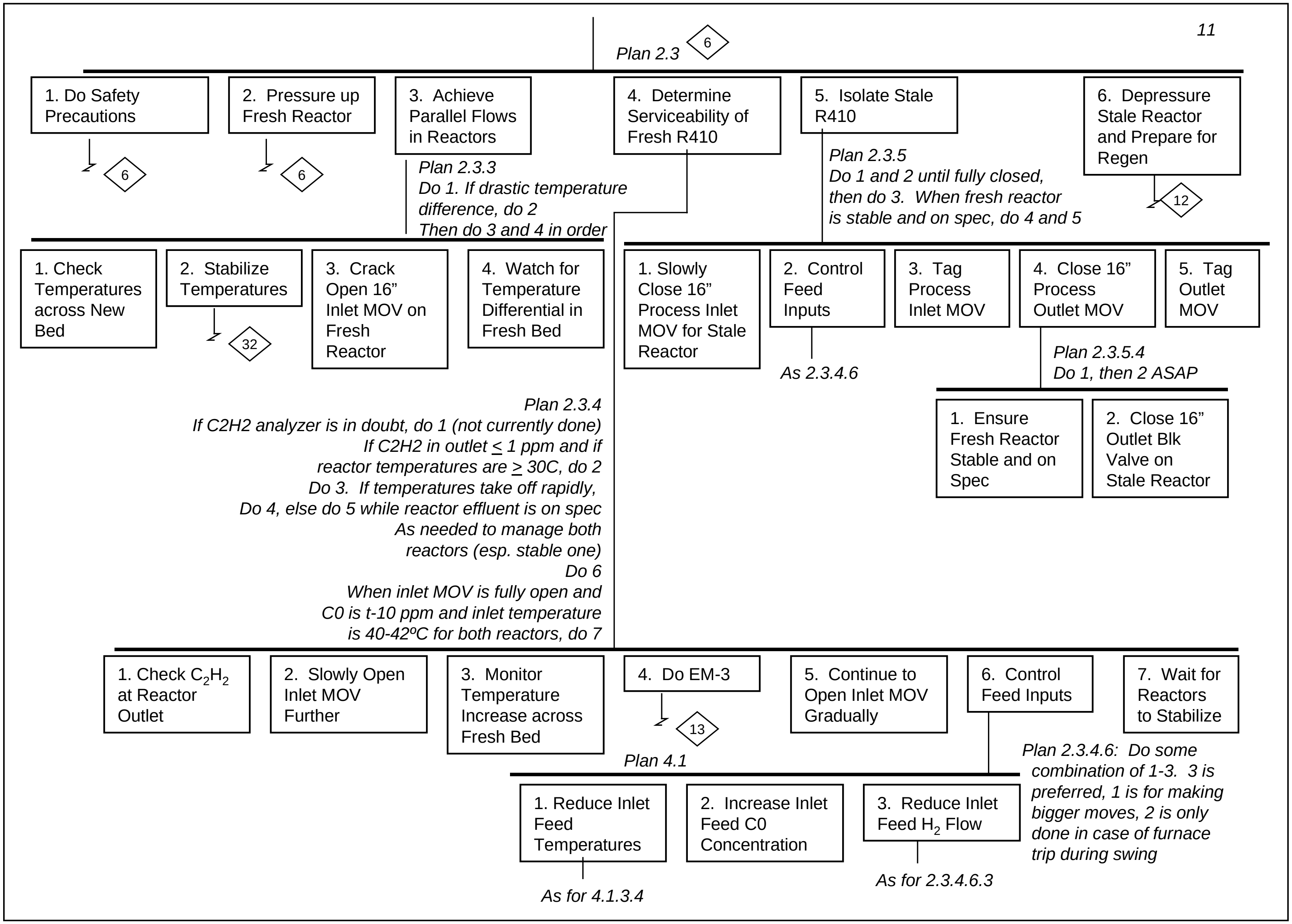
Plan 2.3.2.6.2
Do one or more of 1-3 as needed.

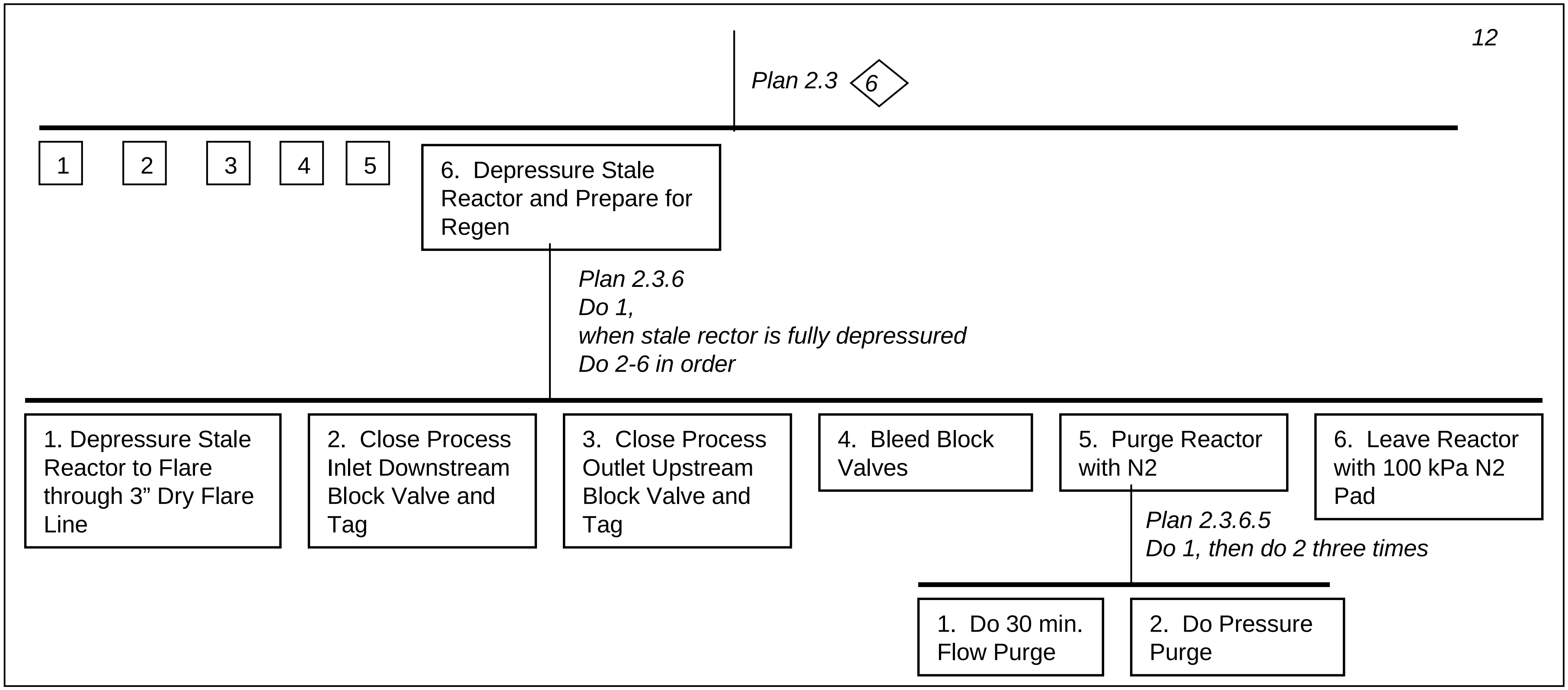
As for 4.1.3.4

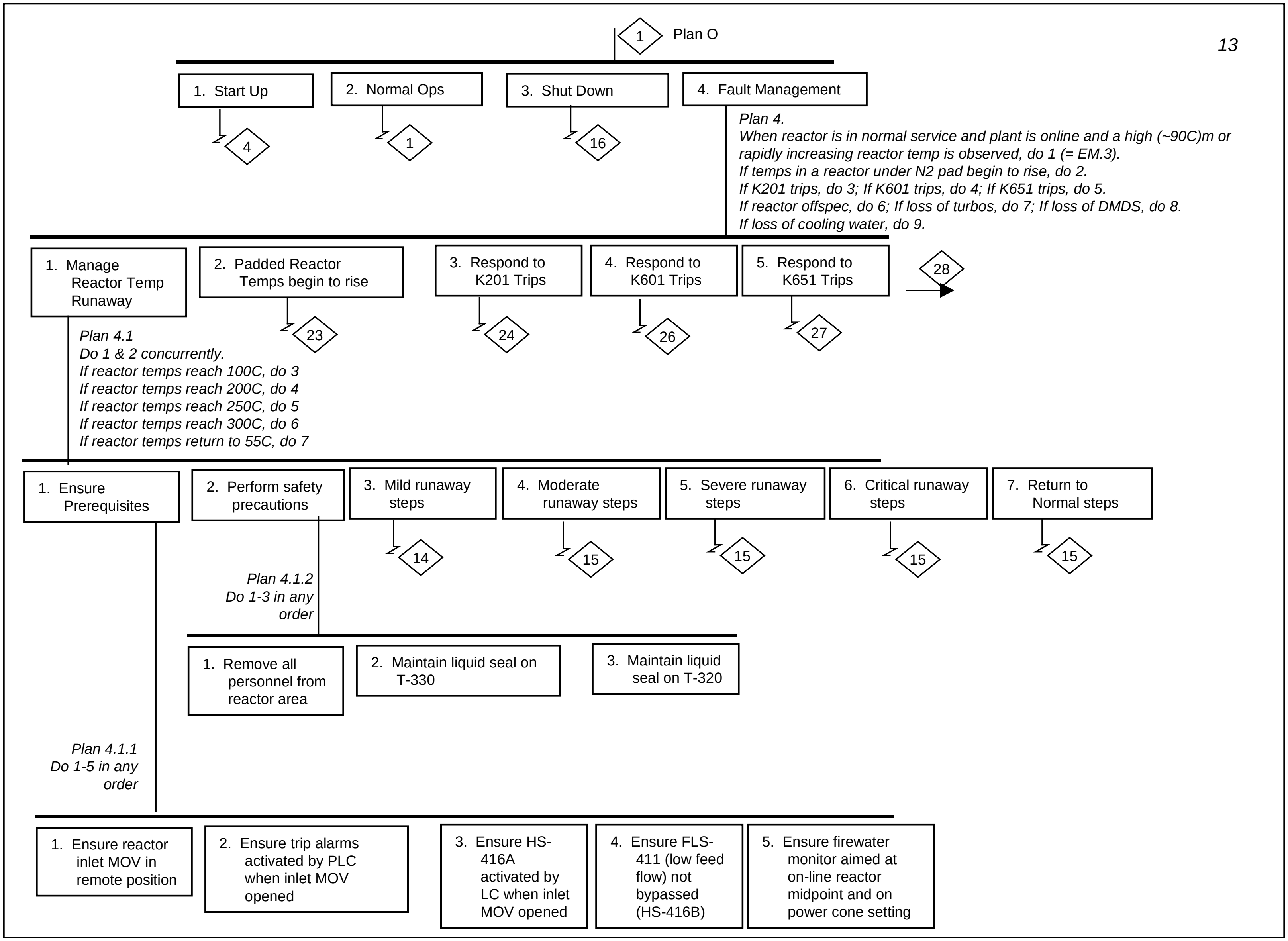
As for 2.3.4.6.3


6
Plan 2.3.2
9
8
7. Depressure Reactor N2 to Flare
8. Fully Open Upstream 16” Process Outlet Block Valve
9. Introduce Fresh Feed to Reactor
10. Equalize Pressure between Reactors
11. Depressure Fresh Reactor to Flare
12. Open 16” Process I&O Valves
10
10
10
Plan 2.3.2.9
Do 1, then 2
Do 3-5 continuously, if anomaly detected, do 6
1. Open 1” Pressure Up Line on Reactor Outlet
2. Slowly Open Valve on Fresh Reactor
3. Monitor Reactor Temperatures
4. Monitor Regen Block Valve Vents
5. Maintain Constant Downstream Flows
6. Reduce Flow to Fresh Reactor
Plan 2.3.2.8
Do 1 throughout
If 2 isn’t true, do it,
Then do 3
1. Ensure Downstream 16” Process Outlet Block Valve Closed
2. Check 1” Pressure Up Line on Rector Outlet Blocked in to Flare
3. Open Upstream 16” Process Out Block Valve
Plan 2.3.2.7
Do 1,
when pressure = I5-30 kPa, Do 2.
1. Open 1” Vent on top of Fresh Reactor
2. Establish Dbl Block and Bld


10
6
Plan 2.3.2
9
10. Equalize Pressure between Reactors
11. Depressure Fresh Reactor to Flare
12. Open 16” process I & O Valves
Plan 2.3.2.2.12
Do 1 & 2 in any order
Then do 3 & 4 in an order, do 5 when 3&4 are completed
1. Isolate 1” Pressure Up Line
2. Ensure Process Inlet MOV is Closed
3. Fully Open 16” Process Outlet Block Valve
4. Fully Open Process Inlet Block Valve
5. Transfer Control to BO
Plan 2.3.2.2.10
Do 1 and 2 until reactor pressures are equal
Then do 3
1. Continue Flow Input as in 2.3.2.9
2. Monitor Reactor(s) Pressures
3. Close 1” Pressure Up Line


11
Plan 2.3
6
1. Do Safety Precautions
6
2. Pressure up Fresh Reactor
6
3. Achieve Parallel Flows in Reactors
4. Determine Serviceability of Fresh R410
5. Isolate Stale R410
6. Depressure Stale Reactor and Prepare for Regen
12
Plan 2.3.3
Do 1. If drastic temperature difference, do 2
Then do 3 and 4 in order
Plan 2.3.5
Do 1 and 2 until fully closed, then do 3. When fresh reactor is stable and on spec, do 4 and 5
1. Check Temperatures across New Bed
2. Stabilize Temperatures
32
3. Crack Open 16” Inlet MOV on Fresh Reactor
4. Watch for Temperature Differential in Fresh Bed
1. Slowly Close 16” Process Inlet MOV for Stale Reactor
2. Control Feed Inputs
As 2.3.4.6
3. Tag Process Inlet MOV
4. Close 16” Process Outlet MOV
5. Tag Outlet MOV
Plan 2.3.5.4
Do 1, then 2 ASAP
1. Ensure Fresh Reactor Stable and on Spec
2. Close 16” Outlet Blk Valve on Stale Reactor
Plan 2.3.4
If C2H2 analyzer is in doubt, do 1 (not currently done)
If C2H2 in outlet ≤ 1 ppm and if reactor temperatures are ≥ 30C, do 2
Do 3. If temperatures take off rapidly, Do 4, else do 5 while reactor effluent is on spec
As needed to manage both reactors (esp. stable one)
Do 6
When inlet MOV is fully open and C0 is t-10 ppm and inlet temperature is 40-42ºC for both reactors, do 7
1. Check C_2H_2 at Reactor Outlet
2. Slowly Open Inlet MOV Further
3. Monitor Temperature Increase across Fresh Bed
4. Do EM-3
13
5. Continue to Open Inlet MOV Gradually
6. Control Feed Inputs
7. Wait for Reactors to Stabilize
Plan 4.1
Plan 2.3.4.6: Do some combination of 1-3. 3 is preferred, 1 is for making bigger moves, 2 is only done in case of furnace trip during swing
1. Reduce Inlet Feed Temperatures
As for 4.1.3.4
2. Increase Inlet Feed C0 Concentration
3. Reduce Inlet Feed H_2 Flow
As for 2.3.4.6.3


12
Plan 2.3
6
1
2
3
4
5
6. Depressure Stale Reactor and Prepare for Regen
Plan 2.3.6
Do 1,
when stale rector is fully depressured
Do 2-6 in order
1. Depressure Stale Reactor to Flare through 3” Dry Flare Line
2. Close Process Inlet Downstream Block Valve and Tag
3. Close Process Outlet Upstream Block Valve and Tag
4. Bleed Block Valves
5. Purge Reactor with N2
6. Leave Reactor with 100 kPa N2 Pad
Plan 2.3.6.5
Do 1, then do 2 three times
1. Do 30 min. Flow Purge
2. Do Pressure Purge

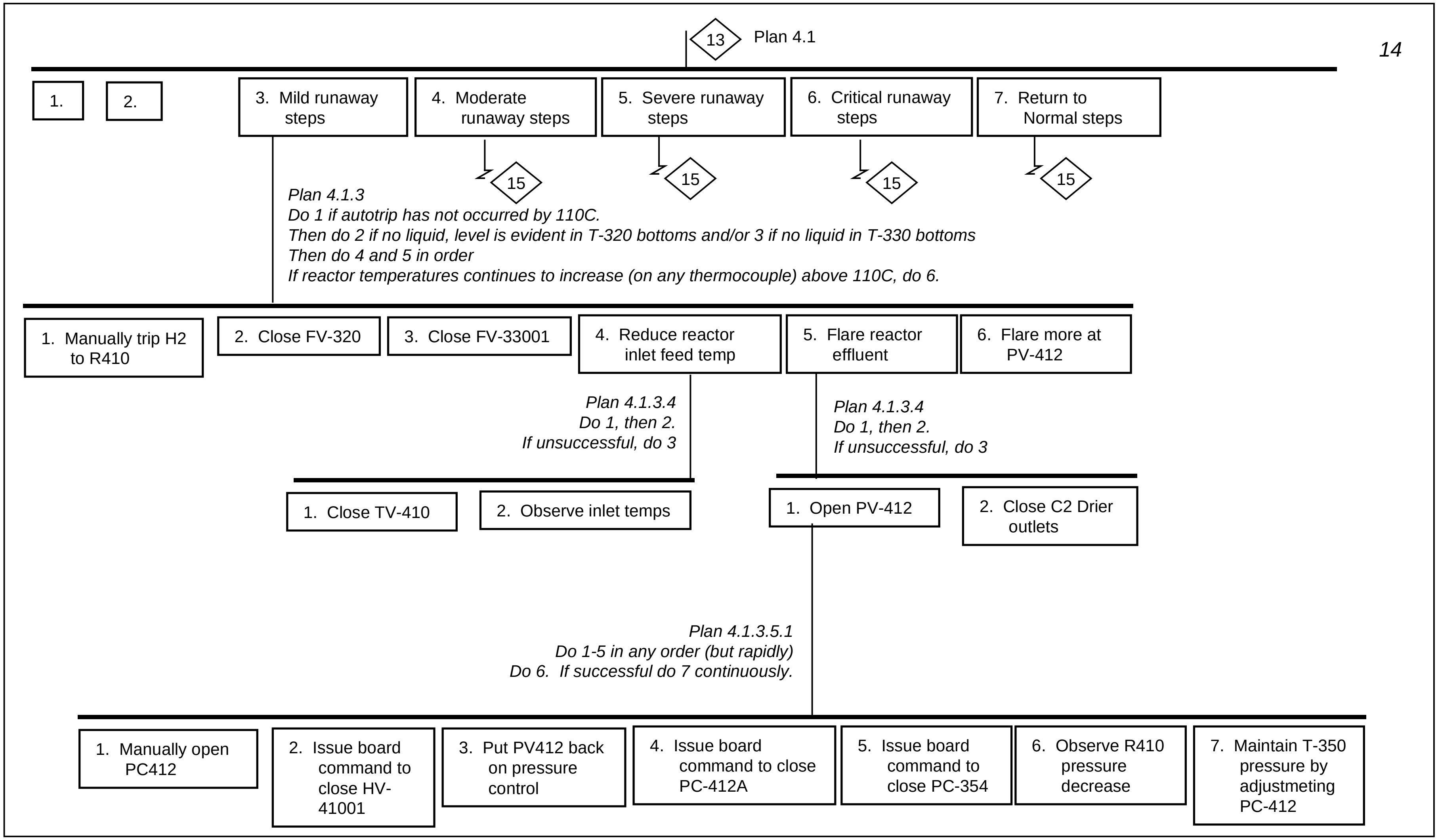


Plan 4.
When reactor is in normal service and plant is online and a high (~90C)m or rapidly increasing reactor temp is observed, do 1 (= EM.3).
If temps in a reactor under N2 pad begin to rise, do 2.
If K201 trips, do 3; If K601 trips, do 4; If K651 trips, do 5.
If reactor offspec, do 6; If loss of turbos, do 7; If loss of DMDS, do 8.
If loss of cooling water, do 9.

Plan 4.1
Do 1 & 2 concurrently.
If reactor temps reach 100C, do 3
If reactor temps reach 200C, do 4
If reactor temps reach 250C, do 5
If reactor temps reach 300C, do 6
If reactor temps return to 55C, do 7

Plan 4.1.2
Do 1-3 in any order

Plan 4.1.1
Do 1-5 in any order

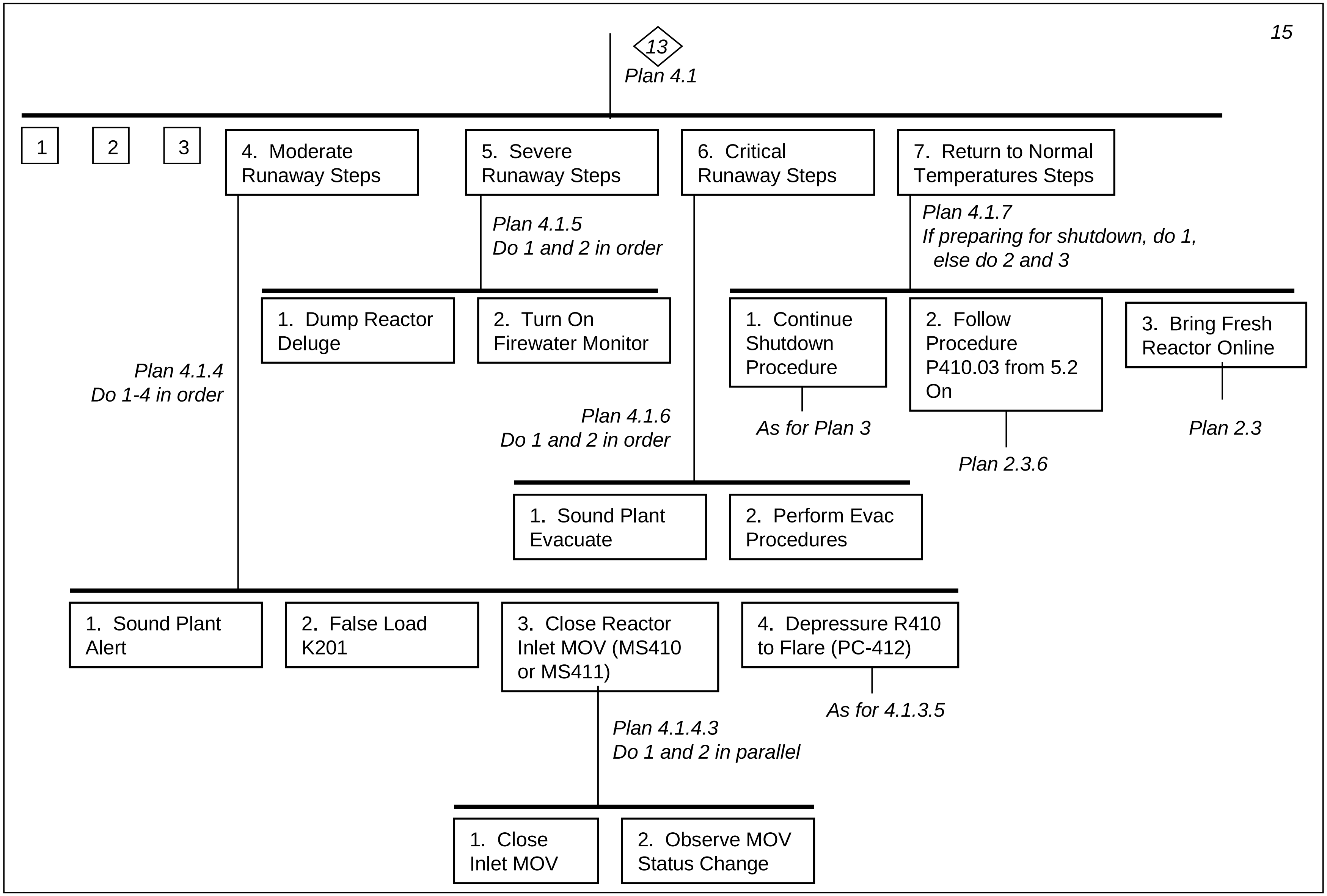


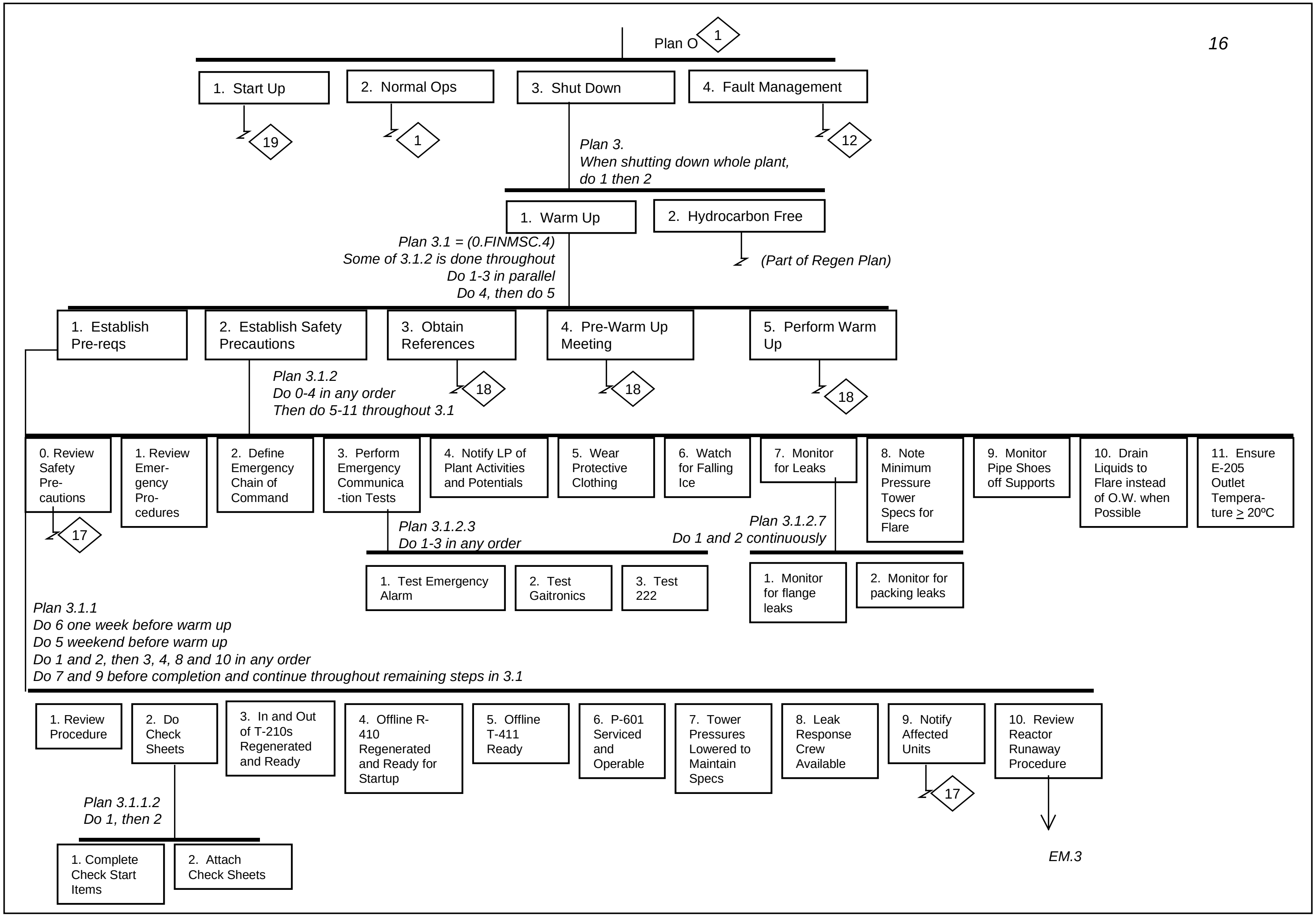
Plan 4.1.3
Do 1 if autotrip has not occurred by 110C.
Then do 2 if no liquid, level is evident in T-320 bottoms and/or 3 if no liquid in T-330 bottoms
Then do 4 and 5 in order
If reactor temperatures continues to increase (on any thermocouple) above 110C, do 6.

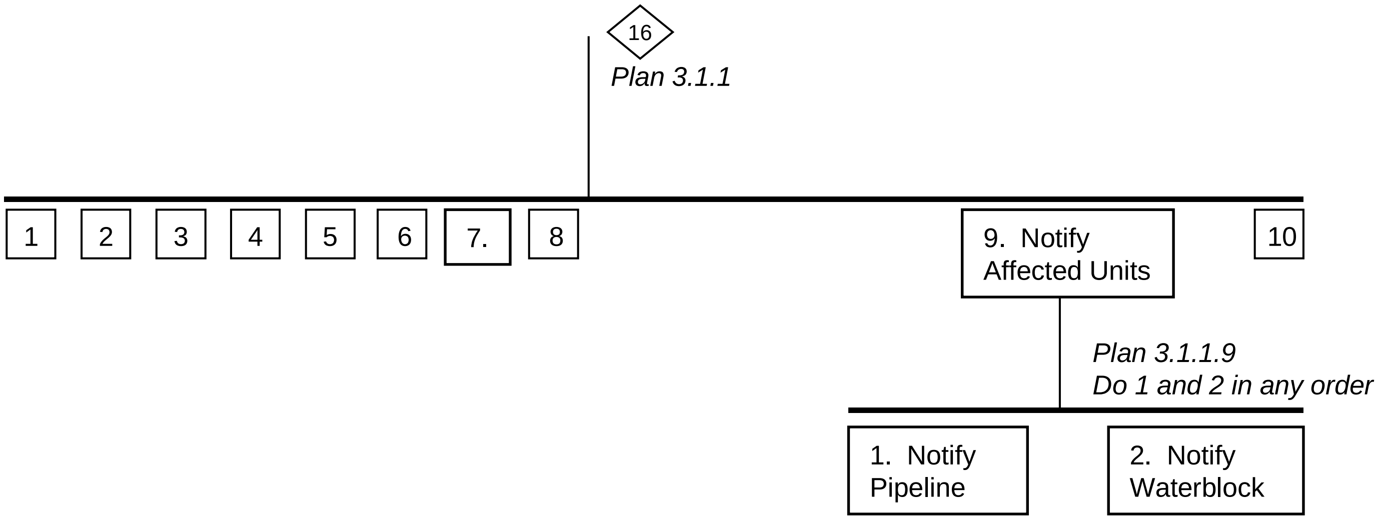
Plan 4.1.3.4
Do 1, then 2.
If unsuccessful, do 3

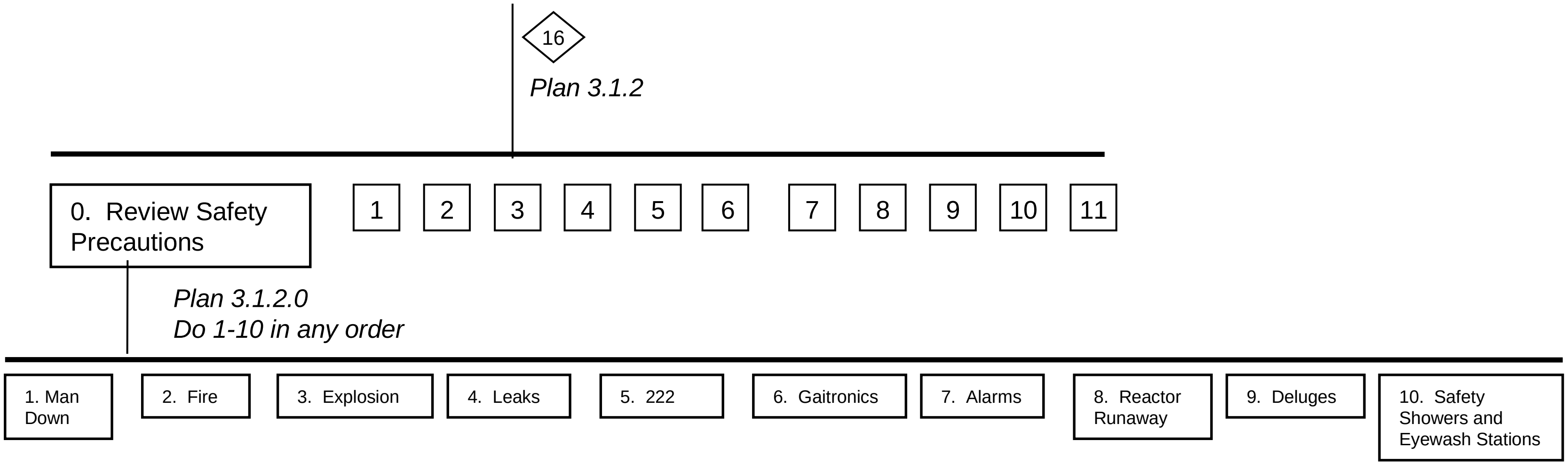
Plan 4.1.3.4
Do 1, then 2.
If unsuccessful, do 3

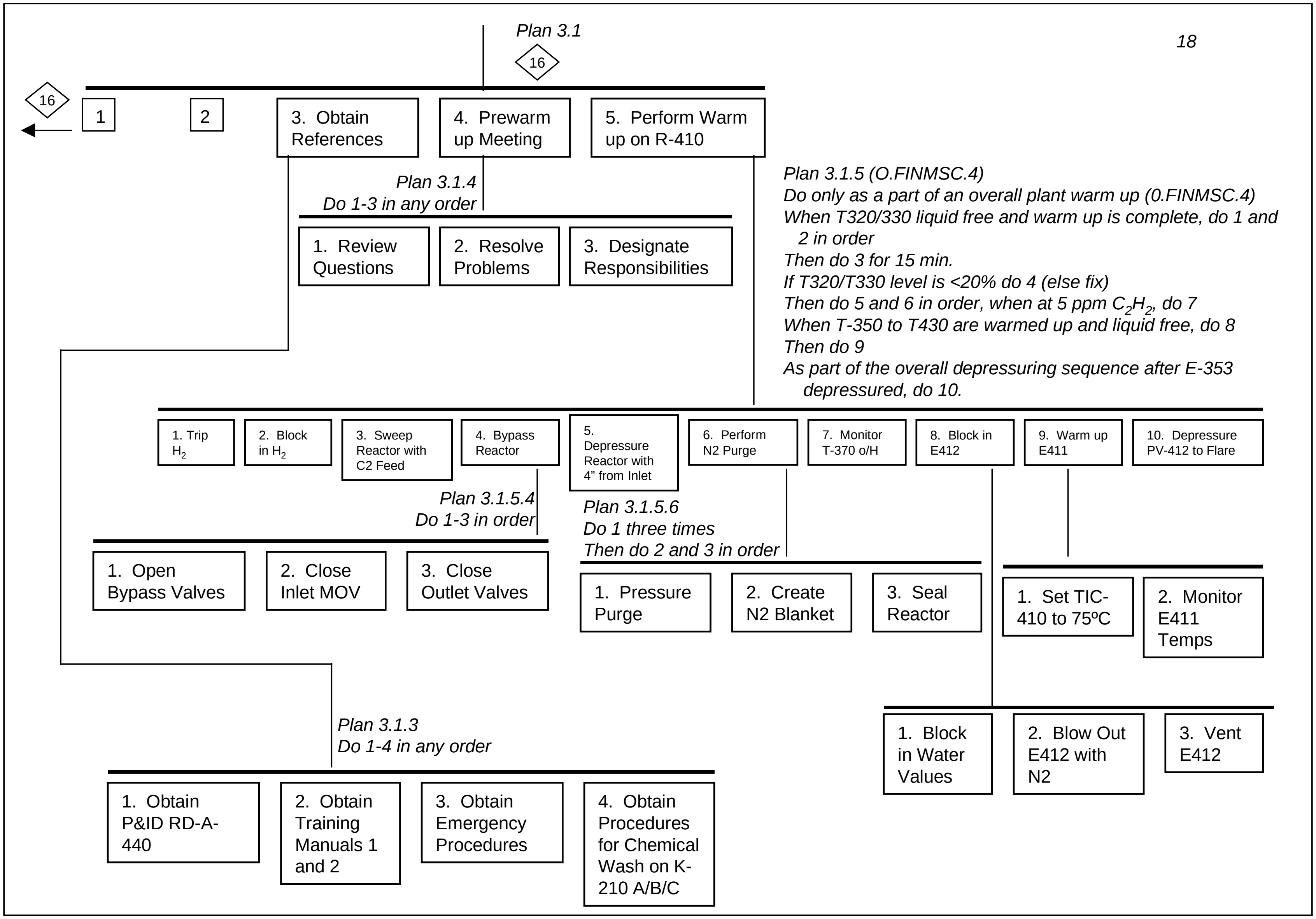
Plan 4.1.3.5.1
Do 1-5 in any order (but rapidly)
Do 6. If successful do 7 continuously.


15
13
Plan 4.1
1
2
3
4. Moderate Runaway Steps
5. Severe Runaway Steps
6. Critical Runaway Steps
7. Return to Normal Temperatures Steps
Plan 4.1.5
Do 1 and 2 in order
Plan 4.1.7
If preparing for shutdown, do 1, else do 2 and 3
1. Dump Reactor Deluge
2. Turn On Firewater Monitor
1. Continue Shutdown Procedure
2. Follow Procedure P410.03 from 5.2 On
3. Bring Fresh Reactor Online
Plan 4.1.4
Do 1-4 in order
Plan 4.1.6
Do 1 and 2 in order
As for Plan 3
Plan 2.3.6
Plan 2.3
1. Sound Plant Evacuate
2. Perform Evac Procedures
1. Sound Plant Alert
2. False Load K201
3. Close Reactor Inlet MOV (MS410 or MS411)
4. Depressure R410 to Flare (PC-412)
Plan 4.1.4.3
Do 1 and 2 in parallel
As for 4.1.3.5
1. Close Inlet MOV
2. Observe MOV Status Change


Plan O
1
16
1. Start Up
2. Normal Ops
3. Shut Down
4. Fault Management
19
1
12
Plan 3.
When shutting down whole plant,
do 1 then 2
1. Warm Up
2. Hydrocarbon Free
(Part of Regen Plan)
Plan 3.1 = (0.FINMSC.4)
Some of 3.1.2 is done throughout
Do 1-3 in parallel
Do 4, then do 5
1. Establish Pre-reqs
2. Establish Safety Precautions
3. Obtain References
4. Pre-Warm Up Meeting
5. Perform Warm Up
18
18
18
Plan 3.1.2
Do 0-4 in any order
Then do 5-11 throughout 3.1
0. Review Safety Pre-cautions
1. Review Emer-gency Pro-cedures
2. Define Emergency Chain of Command
3. Perform Emergency Communica-tion Tests
4. Notify LP of Plant Activities and Potentials
5. Wear Protective Clothing
6. Watch for Falling Ice
7. Monitor for Leaks
8. Note Minimum Pressure Tower Specs for Flare
9. Monitor Pipe Shoes off Supports
10. Drain Liquids to Flare instead of O.W. when Possible
11. Ensure E-205 Outlet Tempera-ture ≥ 20ºC
17
Plan 3.1.2.3
Do 1-3 in any order
Plan 3.1.2.7
Do 1 and 2 continuously
1. Test Emergency Alarm
2. Test Gaitronics
3. Test 222
1. Monitor for flange leaks
2. Monitor for packing leaks
Plan 3.1.1
Do 6 one week before warm up
Do 5 weekend before warm up
Do 1 and 2, then 3, 4, 8 and 10 in any order
Do 7 and 9 before completion and continue throughout remaining steps in 3.1
1. Review Procedure
2. Do Check Sheets
3. In and Out of T-210s Regenerated and Ready
4. Offline R-410 Regenerated and Ready for Startup
5. Offline T-411 Ready
6. P-601 Serviced and Operable
7. Tower Pressures Lowered to Maintain Specs
8. Leak Response Crew Available
9. Notify Affected Units
10. Review Reactor Runaway Procedure
17
EM.3
Plan 3.1.1.2
Do 1, then 2
1. Complete Check Start Items
2. Attach Check Sheets


16
Plan 3.1.1
1
2
3
4
5
6
7.
8
9. Notify Affected Units
10
Plan 3.1.1.9
Do 1 and 2 in any order
1. Notify Pipeline
2. Notify Waterblock


16
Plan 3.1.2
0. Review Safety Precautions
1
2
3
4
5
6
7
8
9
10
11
Plan 3.1.2.0
Do 1-10 in any order
1. Man Down
2. Fire
3. Explosion
4. Leaks
5. 222
6. Gaitronics
7. Alarms
8. Reactor Runaway
9. Deluges
10. Safety Showers and Eyewash Stations



Plan 3.1

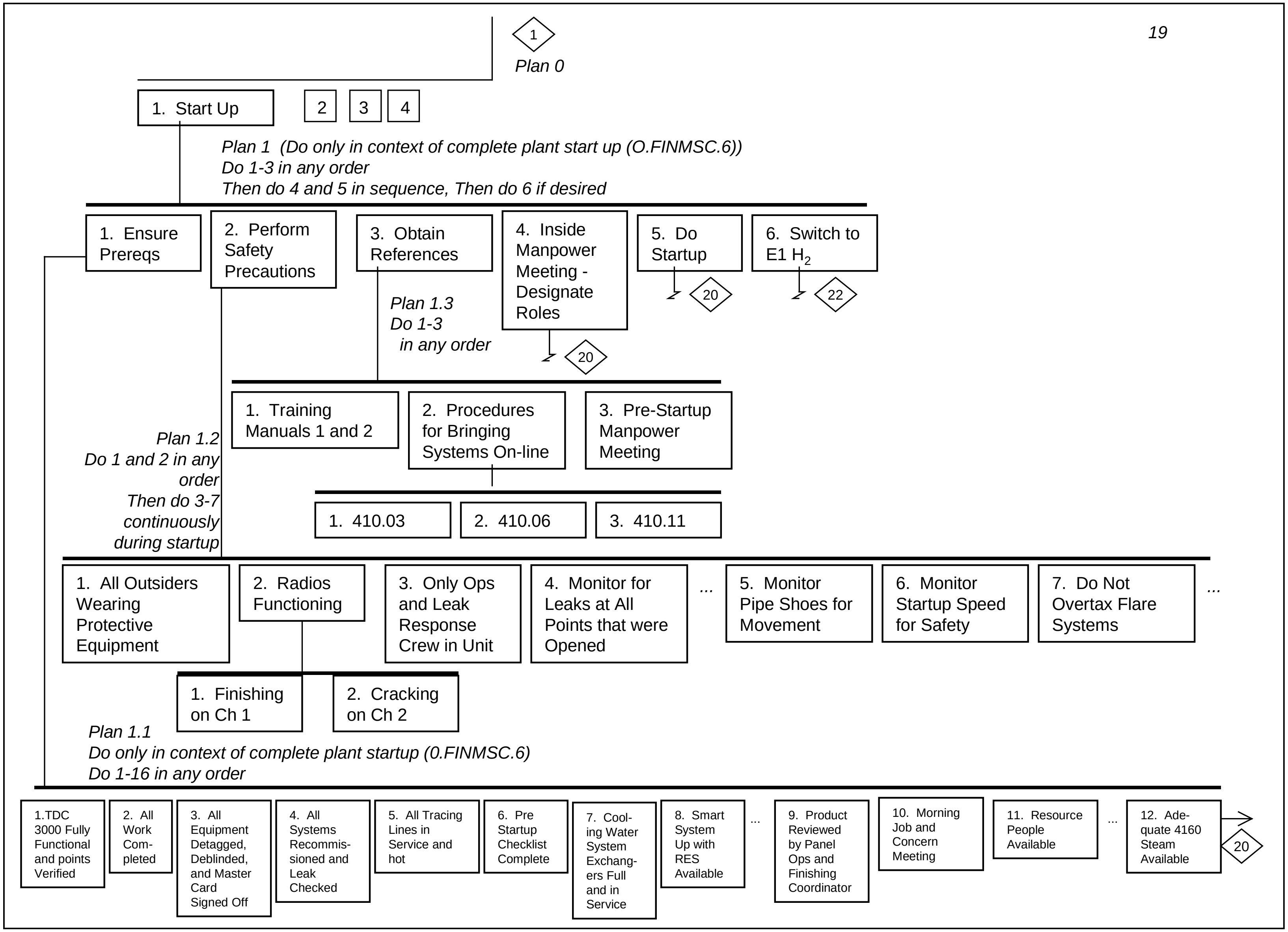
Plan 3.1.4
Do 1-3 in any order

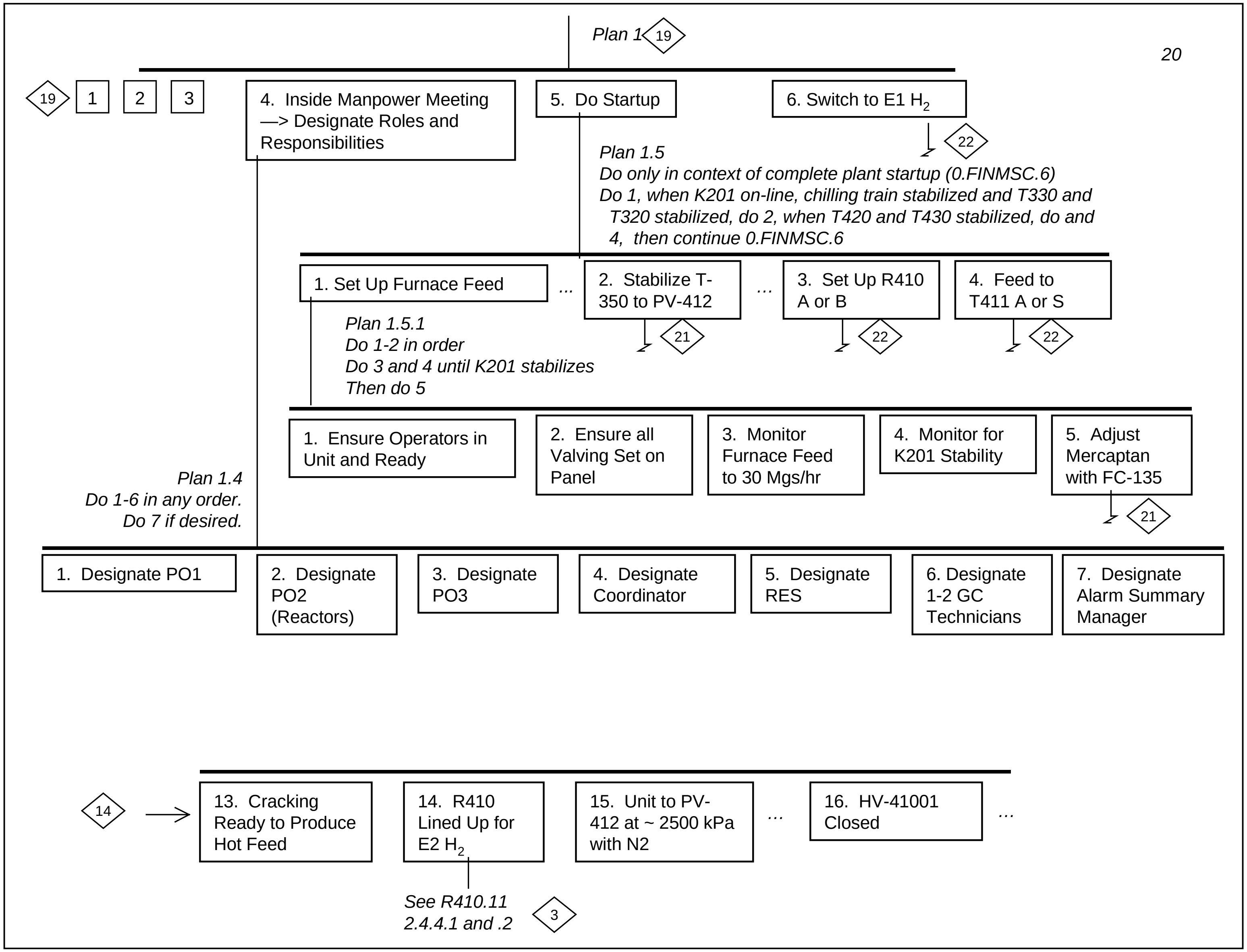
Plan 3.1.5 (O.FINMSC.4)
Do only as a part of an overall plant warm up (0.FINMSC.4)
When T320/330 liquid free and warm up is complete, do 1 and 2 in order
Then do 3 for 15 min.
If T320/T330 level is <20% do 4 (else fix)
Then do 5 and 6 in order, when at 5 ppm C_2H_2, do 7
When T-350 to T430 are warmed up and liquid free, do 8
Then do 9
As part of the overall depressuring sequence after E-353 depressured, do 10.

Plan 3.1.5.4
Do 1-3 in order

Plan 3.1.5.6
Do 1 three times
Then do 2 and 3 in order

Plan 3.1.3
Do 1-4 in any order


1
Plan 0
1. Start Up
2
3
4
Plan 1 (Do only in context of complete plant start up (O.FINMSC.6))
Do 1-3 in any order
Then do 4 and 5 in sequence, Then do 6 if desired
1. Ensure Prereqs
2. Perform Safety Precautions
3. Obtain References
4. Inside Manpower Meeting - Designate Roles
5. Do Startup
6. Switch to E1 H_2
20
22
20
Plan 1.3
Do 1-3
in any order
1. Training Manuals 1 and 2
2. Procedures for Bringing Systems On-line
3. Pre-Startup Manpower Meeting
1. 410.03
2. 410.06
3. 410.11
Plan 1.2
Do 1 and 2 in any order
Then do 3-7 continuously during startup
1. All Outsiders Wearing Protective Equipment
2. Radios Functioning
3. Only Ops and Leak Response Crew in Unit
4. Monitor for Leaks at All Points that were Opened
...
5. Monitor Pipe Shoes for Movement
6. Monitor Startup Speed for Safety
7. Do Not Overtax Flare Systems
...
1. Finishing on Ch 1
2. Cracking on Ch 2
Plan 1.1
Do only in context of complete plant startup (0.FINMSC.6)
Do 1-16 in any order
1.TDC 3000 Fully Functional and points Verified
2. All Work Com-pleted
3. All Equipment Detagged, Deblinded, and Master Card Signed Off
4. All Systems Recommis-sioned and Leak Checked
5. All Tracing Lines in Service and hot
6. Pre Startup Checklist Complete
7. Cool-ing Water System Exchang-ers Full and in Service
8. Smart System Up with RES Available
...
9. Product Reviewed by Panel Ops and Finishing Coordinator
10. Morning Job and Concern Meeting
11. Resource People Available
...
12. Ade-quate 4160 Steam Available
20



20

Plan 1 ⟨19⟩

⟨19⟩ 1 2 3

4. Inside Manpower Meeting —> Designate Roles and Responsibilities

5. Do Startup

6. Switch to E1 H_2 ⟨22⟩

Plan 1.5
Do only in context of complete plant startup (0.FINMSC.6)
Do 1, when K201 on-line, chilling train stabilized and T330 and T320 stabilized, do 2, when T420 and T430 stabilized, do and 4, then continue 0.FINMSC.6

1. Set Up Furnace Feed …

2. Stabilize T-350 to PV-412 ⟨21⟩ …

3. Set Up R410 A or B ⟨22⟩

4. Feed to T411 A or S ⟨22⟩

Plan 1.5.1
Do 1-2 in order
Do 3 and 4 until K201 stabilizes
Then do 5

1. Ensure Operators in Unit and Ready

2. Ensure all Valving Set on Panel

3. Monitor Furnace Feed to 30 Mgs/hr

4. Monitor for K201 Stability

5. Adjust Mercaptan with FC-135 ⟨21⟩

Plan 1.4
Do 1-6 in any order.
Do 7 if desired.

1. Designate PO1

2. Designate PO2 (Reactors)

3. Designate PO3

4. Designate Coordinator

5. Designate RES

6. Designate 1-2 GC Technicians

7. Designate Alarm Summary Manager

⟨14⟩ →

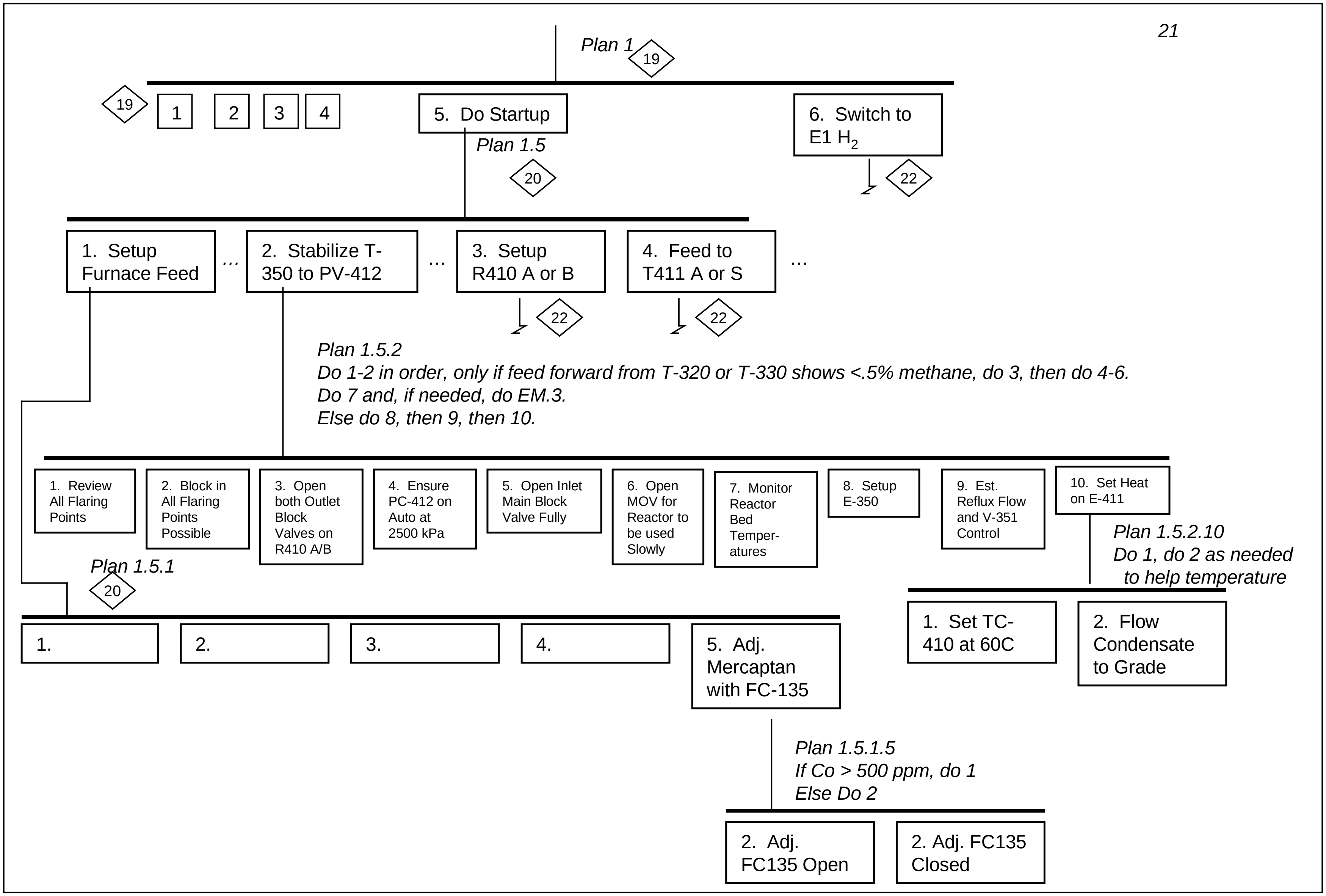
13. Cracking Ready to Produce Hot Feed

14. R410 Lined Up for E2 H_2

15. Unit to PV-412 at ~ 2500 kPa with N2 …

16. HV-41001 Closed …

See R410.11
2.4.4.1 and .2 ⟨3⟩



Plan 1

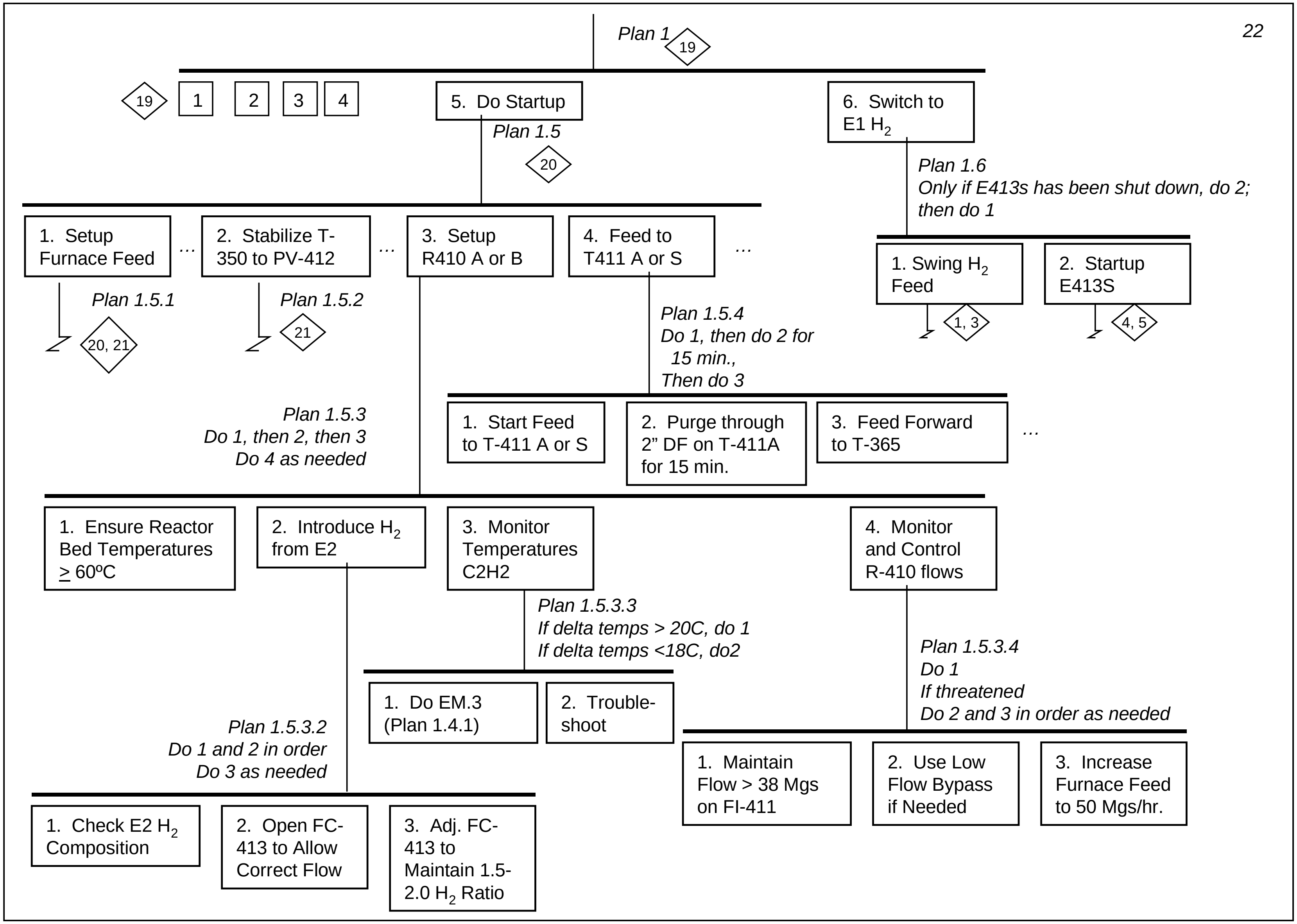
Plan 1.5

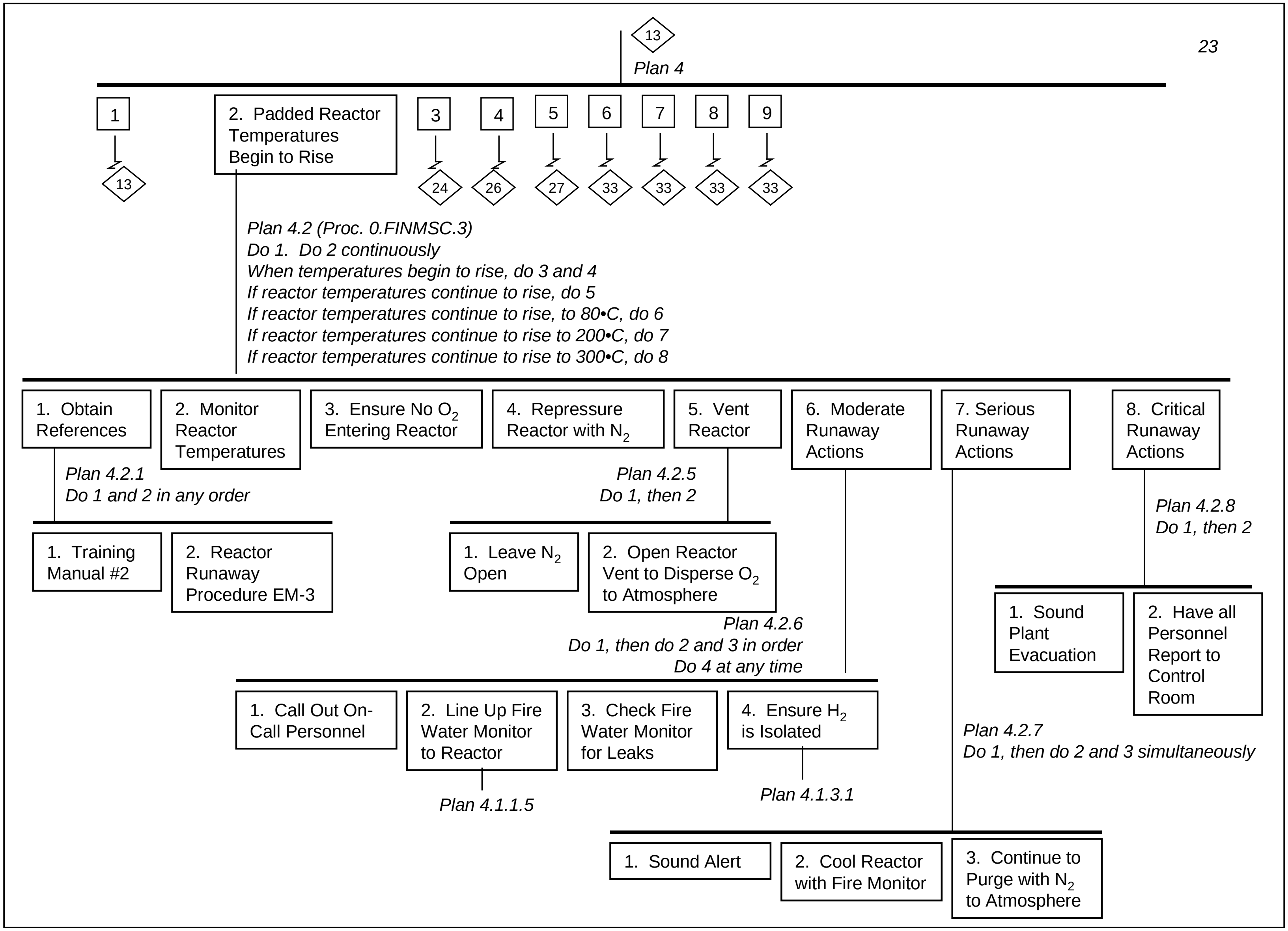
Plan 1.5.2
Do 1-2 in order, only if feed forward from T-320 or T-330 shows <.5% methane, do 3, then do 4-6.
Do 7 and, if needed, do EM.3.
Else do 8, then 9, then 10.

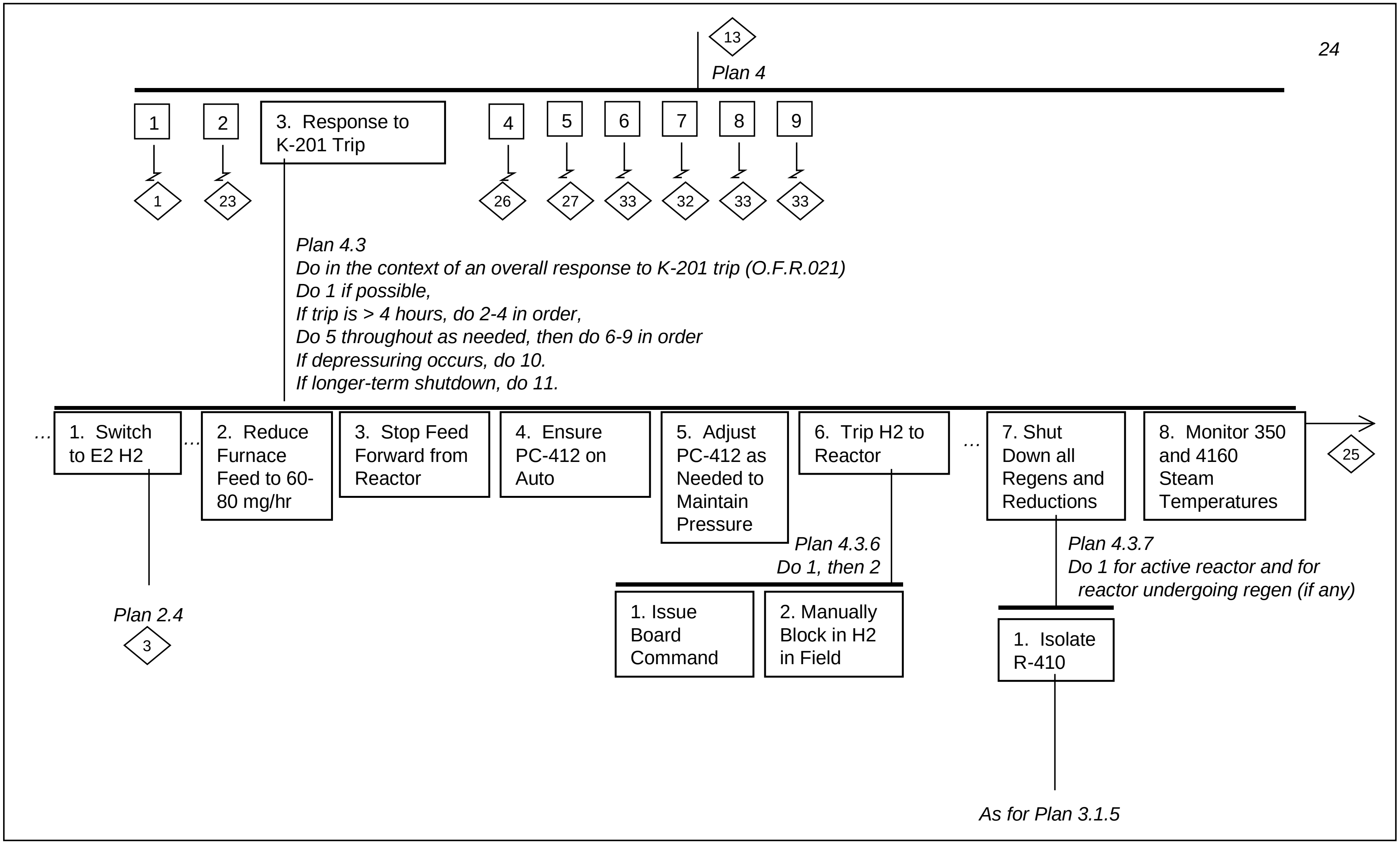
Plan 1.5.1

Plan 1.5.2.10
Do 1, do 2 as needed to help temperature

Plan 1.5.1.5
If Co > 500 ppm, do 1
Else Do 2


22
Plan 1
19
19
1
2
3
4
5. Do Startup
Plan 1.5
20
6. Switch to E1 H2
Plan 1.6
Only if E413s has been shut down, do 2;
then do 1
1. Setup Furnace Feed
…
2. Stabilize T-350 to PV-412
…
3. Setup R410 A or B
4. Feed to T411 A or S
…
Plan 1.5.1
20, 21
Plan 1.5.2
21
1. Swing H2 Feed
1, 3
2. Startup E413S
4, 5
Plan 1.5.4
Do 1, then do 2 for
15 min.,
Then do 3
Plan 1.5.3
Do 1, then 2, then 3
Do 4 as needed
1. Start Feed to T-411 A or S
2. Purge through 2" DF on T-411A for 15 min.
3. Feed Forward to T-365
…
1. Ensure Reactor Bed Temperatures ≥ 60ºC
2. Introduce H2 from E2
3. Monitor Temperatures C2H2
4. Monitor and Control R-410 flows
Plan 1.5.3.3
If delta temps > 20C, do 1
If delta temps <18C, do2
Plan 1.5.3.4
Do 1
If threatened
Do 2 and 3 in order as needed
1. Do EM.3 (Plan 1.4.1)
2. Trouble-shoot
Plan 1.5.3.2
Do 1 and 2 in order
Do 3 as needed
1. Maintain Flow > 38 Mgs on FI-411
2. Use Low Flow Bypass if Needed
3. Increase Furnace Feed to 50 Mgs/hr.
1. Check E2 H2 Composition
2. Open FC-413 to Allow Correct Flow
3. Adj. FC-413 to Maintain 1.5-2.0 H2 Ratio

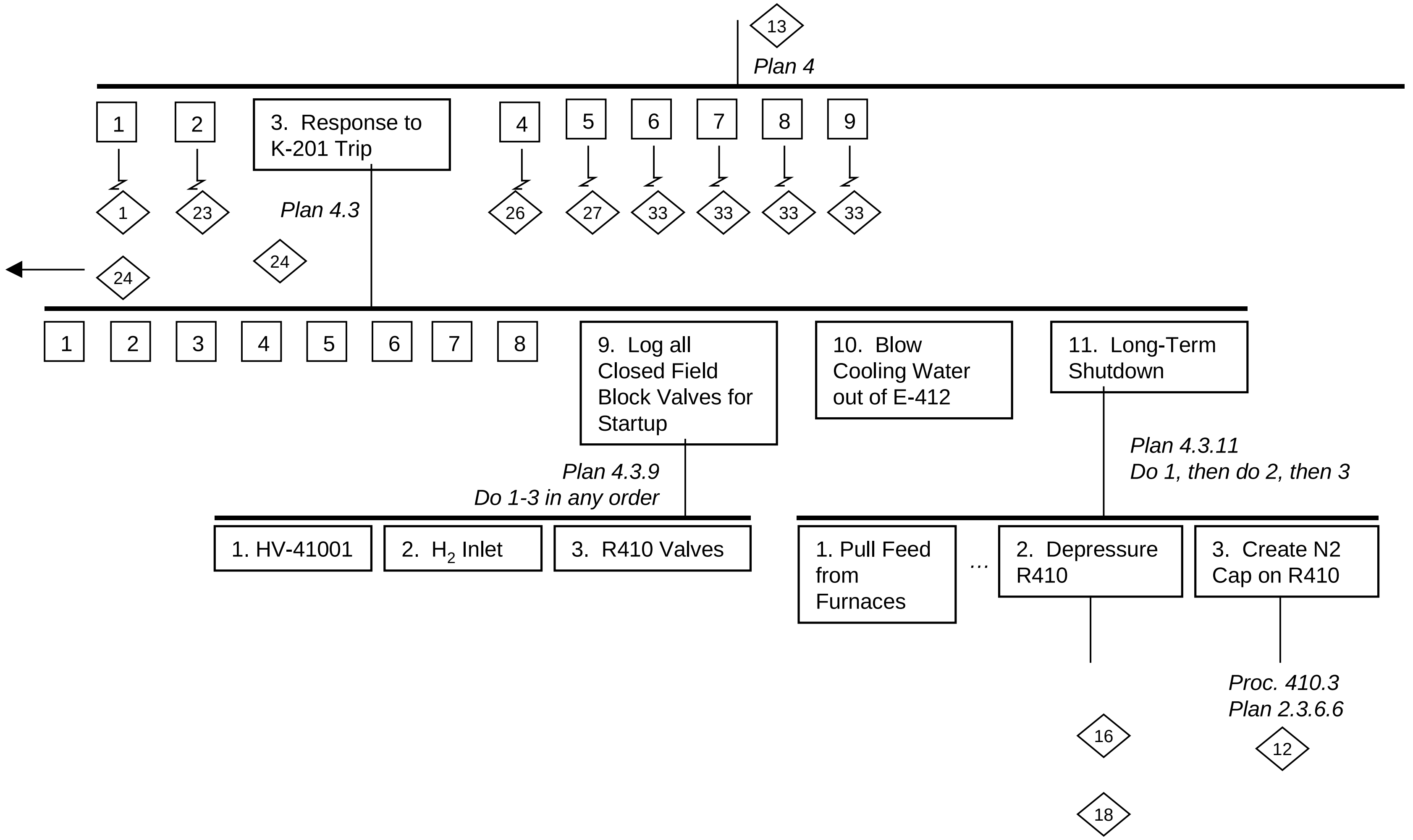

13
Plan 4
23
1
13
2. Padded Reactor Temperatures Begin to Rise
3
24
4
26
5
27
6
33
7
33
8
33
9
33
Plan 4.2 (Proc. 0.FINMSC.3)
Do 1. Do 2 continuously
When temperatures begin to rise, do 3 and 4
If reactor temperatures continue to rise, do 5
If reactor temperatures continue to rise, to 80•C, do 6
If reactor temperatures continue to rise to 200•C, do 7
If reactor temperatures continue to rise to 300•C, do 8
1. Obtain References
2. Monitor Reactor Temperatures
3. Ensure No O_2 Entering Reactor
4. Repressure Reactor with N_2
5. Vent Reactor
6. Moderate Runaway Actions
7. Serious Runaway Actions
8. Critical Runaway Actions
Plan 4.2.1
Do 1 and 2 in any order
1. Training Manual #2
2. Reactor Runaway Procedure EM-3
Plan 4.2.5
Do 1, then 2
1. Leave N_2 Open
2. Open Reactor Vent to Disperse O_2 to Atmosphere
Plan 4.2.8
Do 1, then 2
1. Sound Plant Evacuation
2. Have all Personnel Report to Control Room
Plan 4.2.6
Do 1, then do 2 and 3 in order
Do 4 at any time
1. Call Out On-Call Personnel
2. Line Up Fire Water Monitor to Reactor
3. Check Fire Water Monitor for Leaks
4. Ensure H_2 is Isolated
Plan 4.1.1.5
Plan 4.1.3.1
Plan 4.2.7
Do 1, then do 2 and 3 simultaneously
1. Sound Alert
2. Cool Reactor with Fire Monitor
3. Continue to Purge with N_2 to Atmosphere

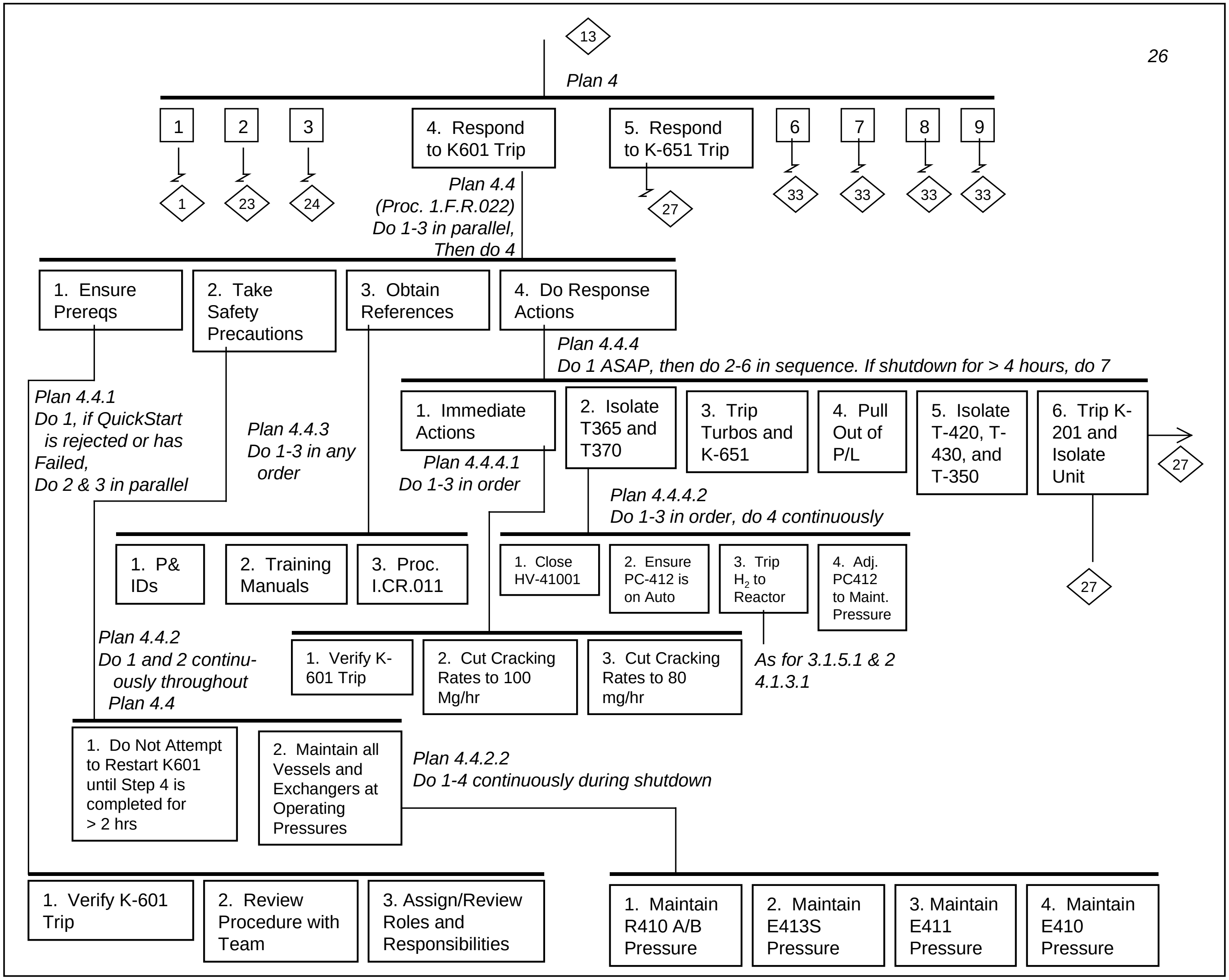


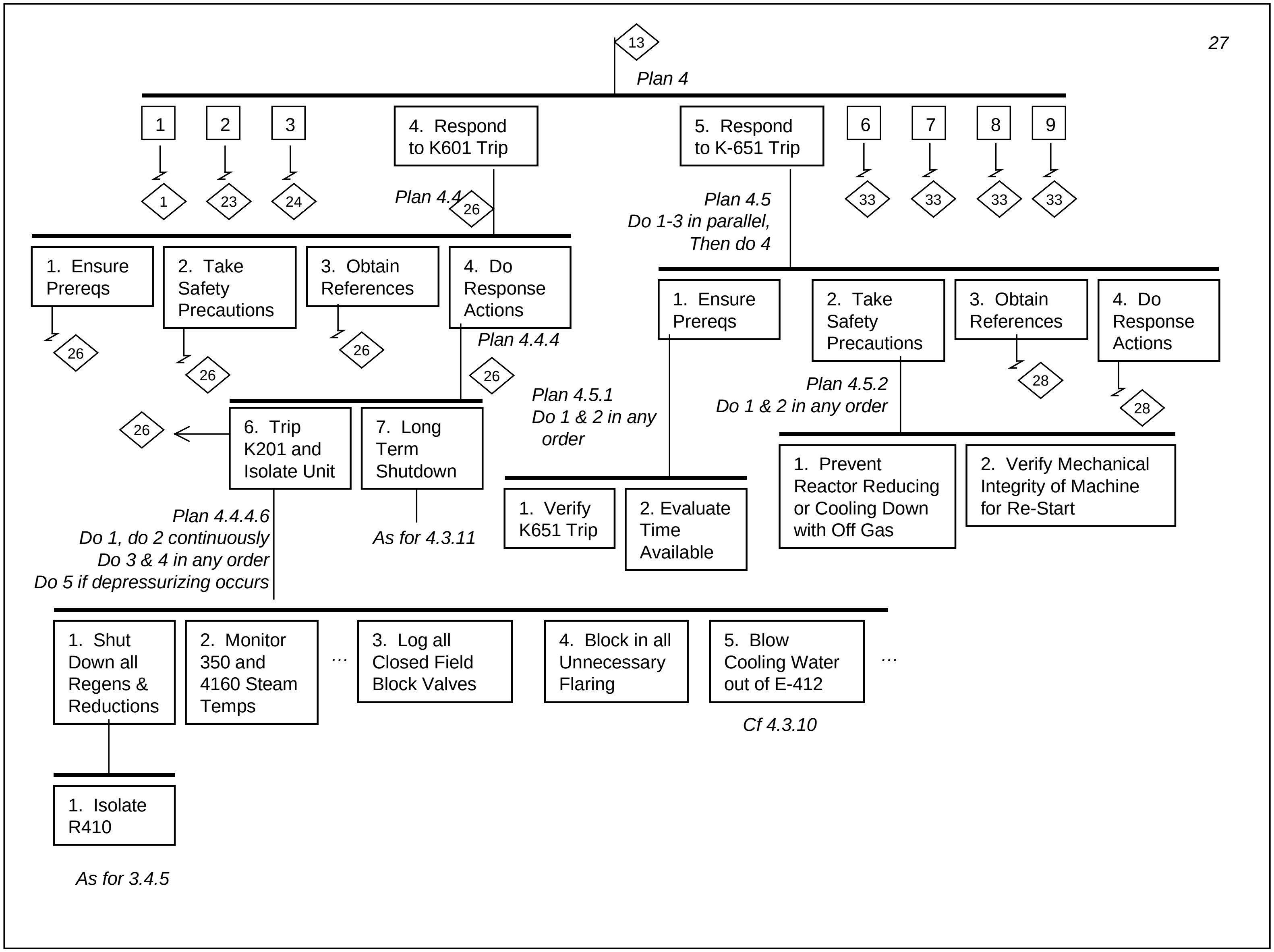
Plan 4.3
Do in the context of an overall response to K-201 trip (O.F.R.021)
Do 1 if possible,
If trip is > 4 hours, do 2-4 in order,
Do 5 throughout as needed, then do 6-9 in order
If depressuring occurs, do 10.
If longer-term shutdown, do 11.

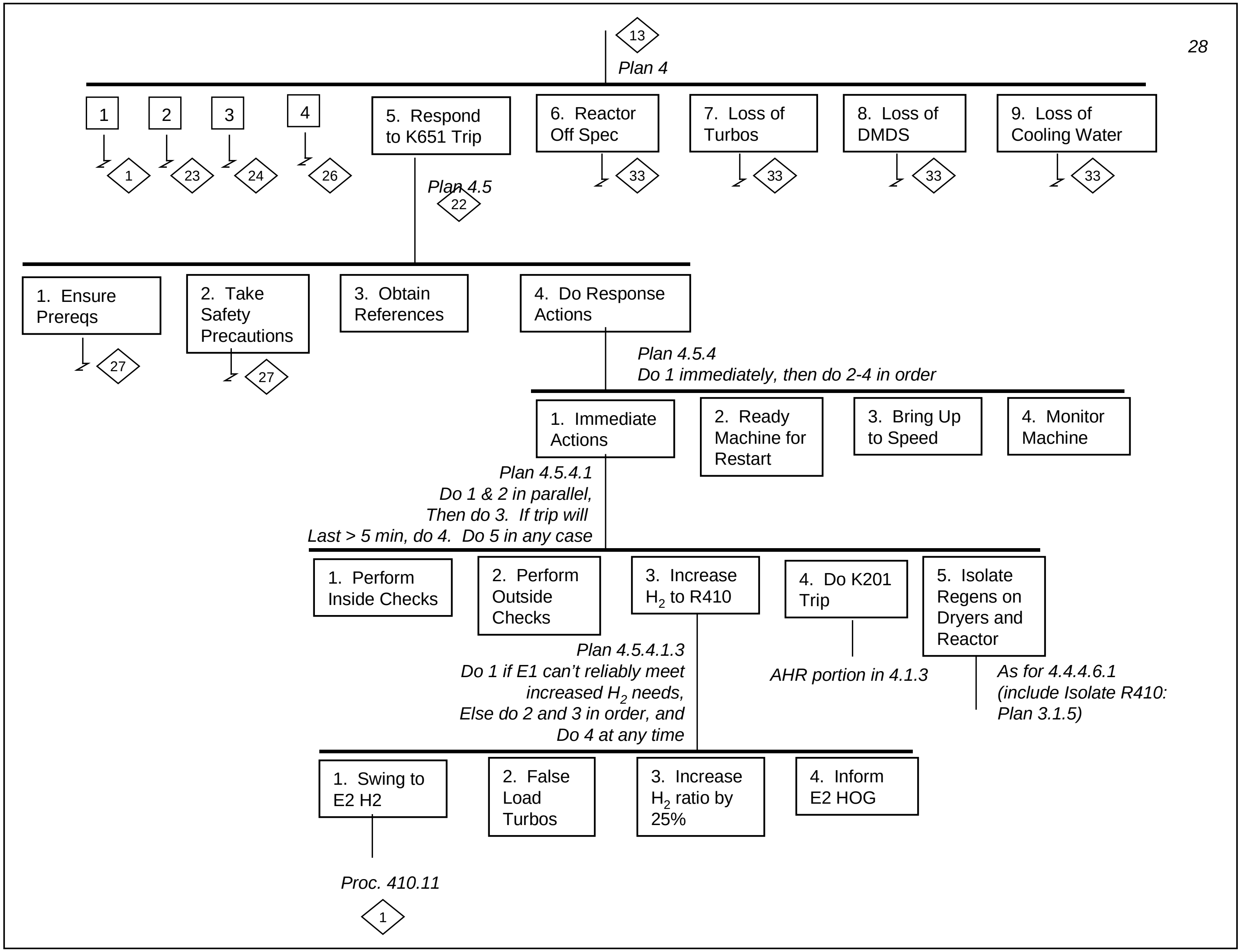
Plan 4.3.6
Do 1, then 2

Plan 4.3.7
Do 1 for active reactor and for reactor undergoing regen (if any)


13
Plan 4
1
2
3. Response to K-201 Trip
4
5
6
7
8
9
1
23
26
27
33
33
33
33
Plan 4.3
24
24
1
2
3
4
5
6
7
8
9. Log all Closed Field Block Valves for Startup
10. Blow Cooling Water out of E-412
11. Long-Term Shutdown
Plan 4.3.9
Do 1-3 in any order
1. HV-41001
2. H2 Inlet
3. R410 Valves
Plan 4.3.11
Do 1, then do 2, then 3
1. Pull Feed from Furnaces
…
2. Depressure R410
3. Create N2 Cap on R410
Proc. 410.3
Plan 2.3.6.6
16
12
18


13
26
Plan 4
1
2
3
4. Respond to K601 Trip
5. Respond to K-651 Trip
6
7
8
9
1
23
24
27
33
33
33
33
Plan 4.4 (Proc. 1.F.R.022) Do 1-3 in parallel, Then do 4
1. Ensure Prereqs
2. Take Safety Precautions
3. Obtain References
4. Do Response Actions
Plan 4.4.4 Do 1 ASAP, then do 2-6 in sequence. If shutdown for > 4 hours, do 7
Plan 4.4.1 Do 1, if QuickStart is rejected or has Failed, Do 2 & 3 in parallel
Plan 4.4.3 Do 1-3 in any order
1. Immediate Actions
2. Isolate T365 and T370
3. Trip Turbos and K-651
4. Pull Out of P/L
5. Isolate T-420, T-430, and T-350
6. Trip K-201 and Isolate Unit
27
Plan 4.4.4.1 Do 1-3 in order
Plan 4.4.4.2 Do 1-3 in order, do 4 continuously
1. P& IDs
2. Training Manuals
3. Proc. I.CR.011
1. Close HV-41001
2. Ensure PC-412 is on Auto
3. Trip H_2 to Reactor
4. Adj. PC412 to Maint. Pressure
27
Plan 4.4.2 Do 1 and 2 continuously throughout Plan 4.4
1. Verify K-601 Trip
2. Cut Cracking Rates to 100 Mg/hr
3. Cut Cracking Rates to 80 mg/hr
As for 3.1.5.1 & 2 4.1.3.1
1. Do Not Attempt to Restart K601 until Step 4 is completed for > 2 hrs
2. Maintain all Vessels and Exchangers at Operating Pressures
Plan 4.4.2.2 Do 1-4 continuously during shutdown
1. Verify K-601 Trip
2. Review Procedure with Team
3. Assign/Review Roles and Responsibilities
1. Maintain R410 A/B Pressure
2. Maintain E413S Pressure
3. Maintain E411 Pressure
4. Maintain E410 Pressure


27
13
Plan 4
1
2
3
4. Respond to K601 Trip
5. Respond to K-651 Trip
6
7
8
9
1
23
24
33
33
33
33
Plan 4.4
26
1. Ensure Prereqs
2. Take Safety Precautions
3. Obtain References
4. Do Response Actions
26
26
26
Plan 4.4.4
26
26
6. Trip K201 and Isolate Unit
7. Long Term Shutdown
Plan 4.4.4.6
Do 1, do 2 continuously
Do 3 & 4 in any order
Do 5 if depressurizing occurs
As for 4.3.11
1. Shut Down all Regens & Reductions
2. Monitor 350 and 4160 Steam Temps
…
3. Log all Closed Field Block Valves
4. Block in all Unnecessary Flaring
5. Blow Cooling Water out of E-412
…
Cf 4.3.10
1. Isolate R410
As for 3.4.5
Plan 4.5
Do 1-3 in parallel,
Then do 4
1. Ensure Prereqs
2. Take Safety Precautions
3. Obtain References
4. Do Response Actions
28
28
Plan 4.5.1
Do 1 & 2 in any order
Plan 4.5.2
Do 1 & 2 in any order
1. Verify K651 Trip
2. Evaluate Time Available
1. Prevent Reactor Reducing or Cooling Down with Off Gas
2. Verify Mechanical Integrity of Machine for Re-Start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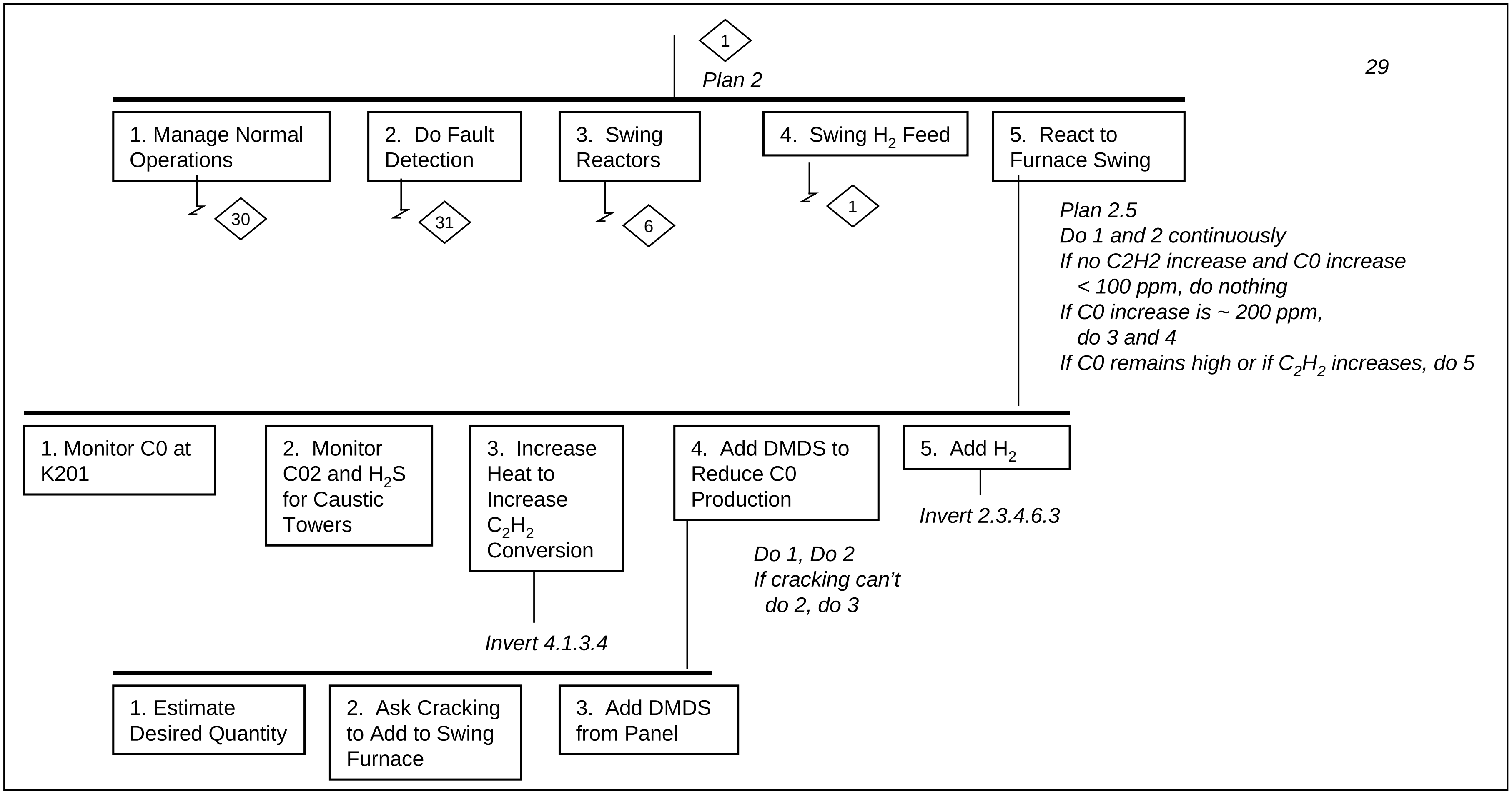
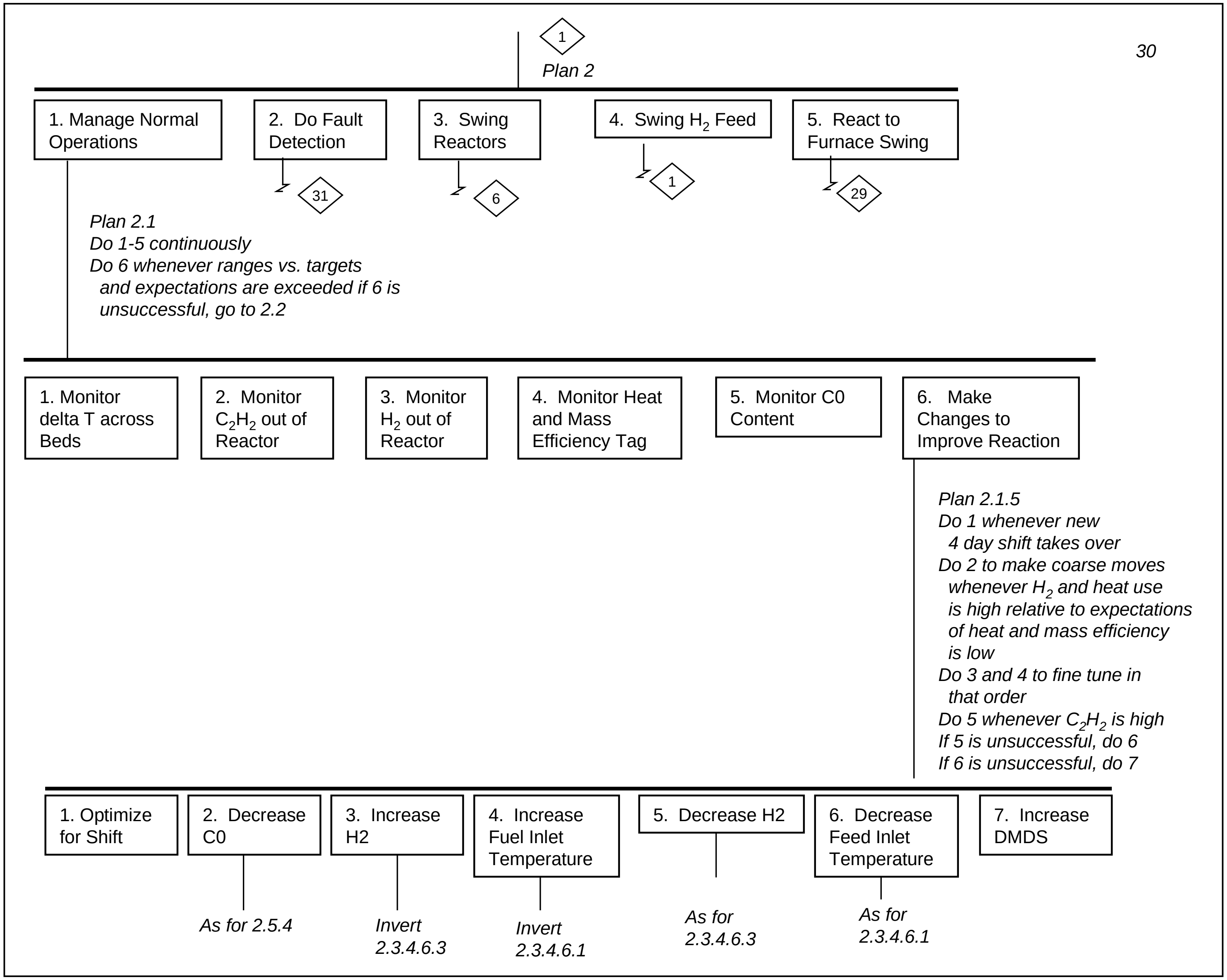
Plan 4
1
2
3
4
5. Respond to K651 Trip
6. Reactor Off Spec
7. Loss of Turbos
8. Loss of DMDS
9. Loss of Cooling Water
1
23
24
26
33
33
33
33
Plan 4.5
22
1. Ensure Prereqs
2. Take Safety Precautions
3. Obtain References
4. Do Response Actions
27
27
Plan 4.5.4
Do 1 immediately, then do 2-4 in order
1. Immediate Actions
2. Ready Machine for Restart
3. Bring Up to Speed
4. Monitor Machine
Plan 4.5.4.1
Do 1 & 2 in parallel,
Then do 3. If trip will
Last > 5 min, do 4. Do 5 in any case
1. Perform Inside Checks
2. Perform Outside Checks
3. Increase H_2 to R410
4. Do K201 Trip
5. Isolate Regens on Dryers and Reactor
Plan 4.5.4.1.3
Do 1 if E1 can't reliably meet
increased H_2 needs,
Else do 2 and 3 in order, and
Do 4 at any time
AHR portion in 4.1.3
As for 4.4.4.6.1
(include Isolate R410:
Plan 3.1.5)
1. Swing to E2 H2
2. False Load Turbos
3. Increase H_2 ratio by 25%
4. Inform E2 HOG
Proc. 410.11
1

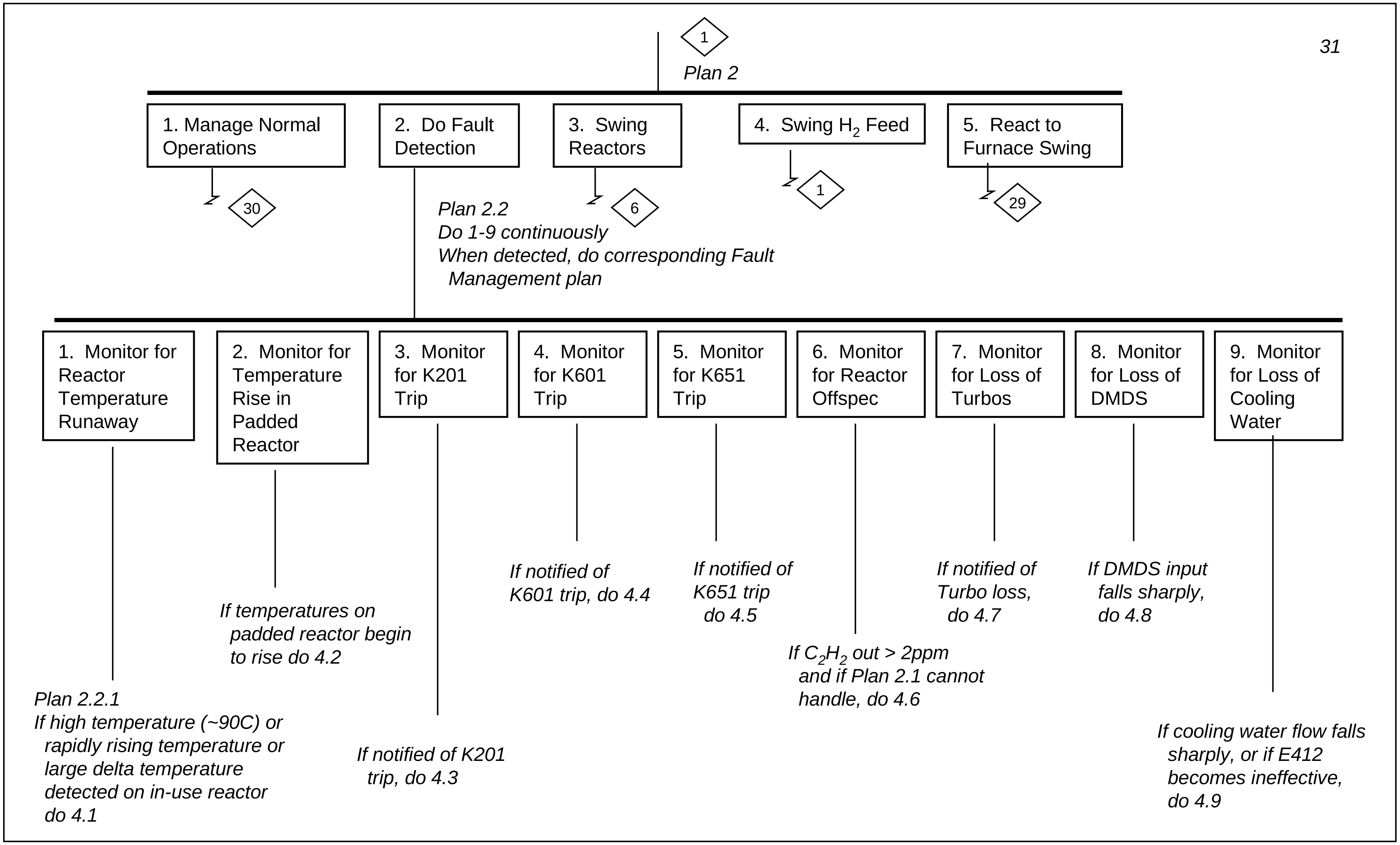

1
Plan 2
29
1. Manage Normal Operations
30
2. Do Fault Detection
31
3. Swing Reactors
6
4. Swing H_2 Feed
1
5. React to Furnace Swing
Plan 2.5
Do 1 and 2 continuously
If no C2H2 increase and C0 increase < 100 ppm, do nothing
If C0 increase is ~ 200 ppm, do 3 and 4
If C0 remains high or if C_2H_2 increases, do 5
1. Monitor C0 at K201
2. Monitor C02 and H_2S for Caustic Towers
3. Increase Heat to Increase C_2H_2 Conversion
Invert 4.1.3.4
4. Add DMDS to Reduce C0 Production
Do 1, Do 2
If cracking can't do 2, do 3
5. Add H_2
Invert 2.3.4.6.3
1. Estimate Desired Quantity
2. Ask Cracking to Add to Swing Furnace
3. Add DMDS from Panel



Plan 2

Plan 2.1
Do 1-5 continuously
Do 6 whenever ranges vs. targets and expectations are exceeded if 6 is unsuccessful, go to 2.2

Plan 2.1.5
Do 1 whenever new 4 day shift takes over
Do 2 to make coarse moves whenever H_2 and heat use is high relative to expectations of heat and mass efficiency is low
Do 3 and 4 to fine tune in that order
Do 5 whenever C_2H_2 is high
If 5 is unsuccessful, do 6
If 6 is unsuccessful, do 7



Plan 2.2
Do 1-9 continuously
When detected, do corresponding Fault Management plan

Plan 2.2.1
If high temperature (~90C) or rapidly rising temperature or large delta temperature detected on in-use reactor do 4.1

If temperatures on padded reactor begin to rise do 4.2

If notified of K201 trip, do 4.3

If notified of K601 trip, do 4.4

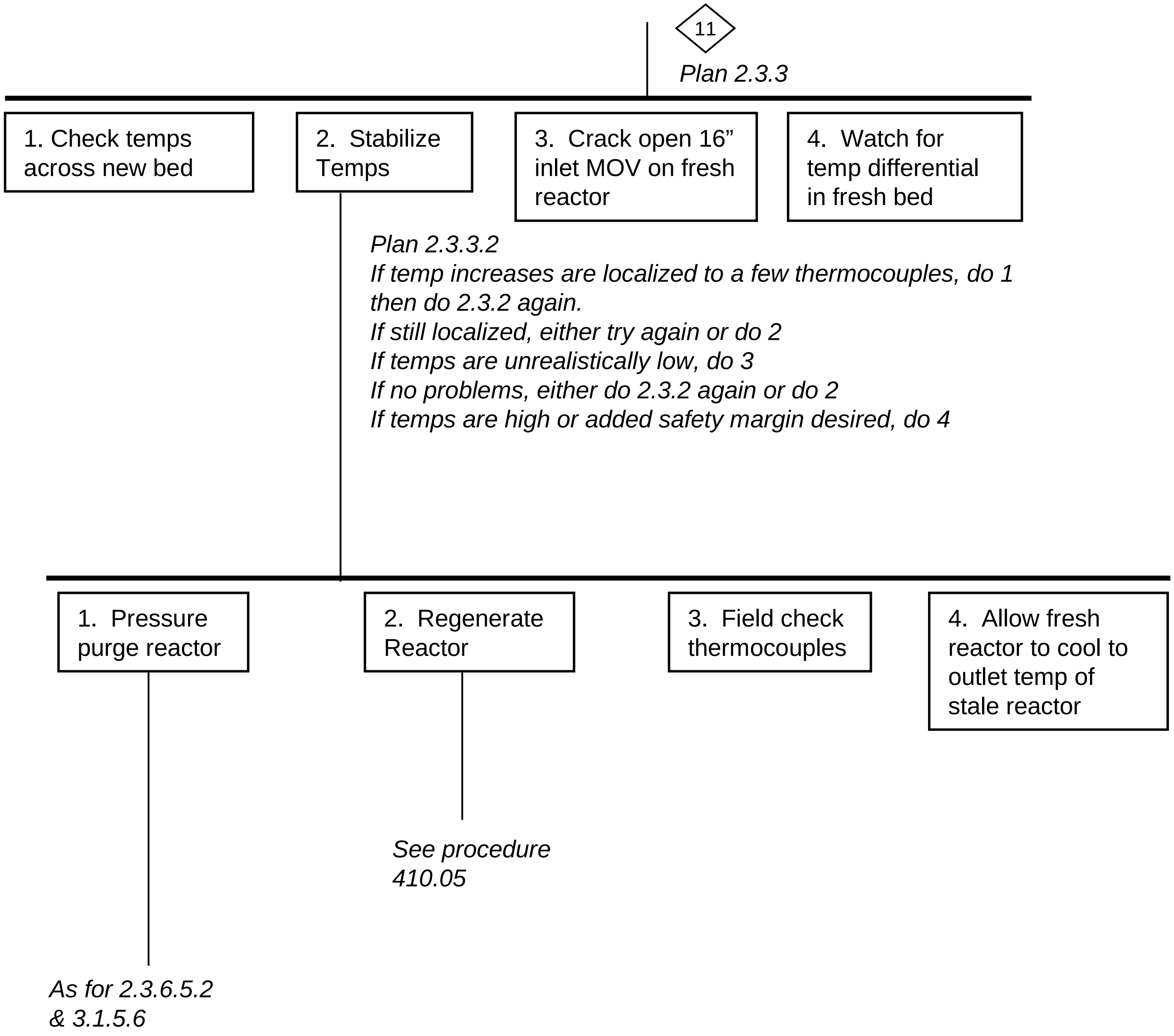
If notified of K651 trip do 4.5

If C_2H_2 out > 2ppm and if Plan 2.1 cannot handle, do 4.6

If notified of Turbo loss, do 4.7

If DMDS input falls sharply, do 4.8

If cooling water flow falls sharply, or if E412 becomes ineffective, do 4.9

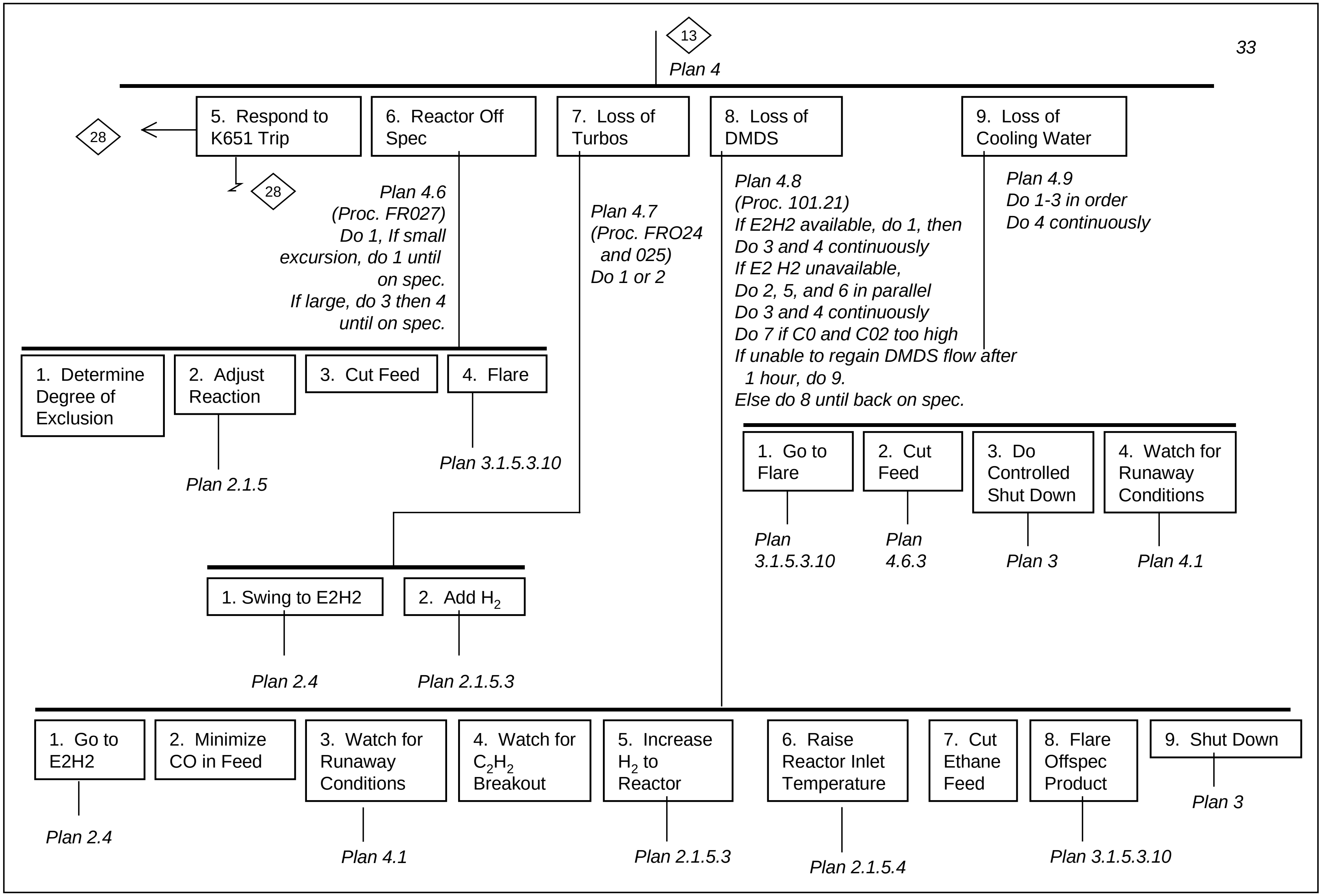


Plan 2.3.3

Plan 2.3.3.2
If temp increases are localized to a few thermocouples, do 1 then do 2.3.2 again.
If still localized, either try again or do 2
If temps are unrealistically low, do 3
If no problems, either do 2.3.2 again or do 2
If temps are high or added safety margin desired, do 4

See procedure 410.05

As for 2.3.6.5.2 & 3.1.5.6



Plan 4.6
(Proc. FR027)
Do 1, If small excursion, do 1 until on spec.
If large, do 3 then 4 until on spec.

Plan 4.7
(Proc. FRO24 and 025)
Do 1 or 2

Plan 4.8
(Proc. 101.21)
If E2H2 available, do 1, then
Do 3 and 4 continuously
If E2 H2 unavailable,
Do 2, 5, and 6 in parallel
Do 3 and 4 continuously
Do 7 if C0 and C02 too high
If unable to regain DMDS flow after 1 hour, do 9.
Else do 8 until back on spec.

Plan 4.9
Do 1-3 in order
Do 4 continuously