PLANNING EXERCISE FOR THE RESOLUTION OF HIGH LEVEL WASTE TANK SAFETY ISSUES

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ABSTRACT

Several conditions have been found to exist within high level radioactive waste storage tanks at the Hanford site which could lead to uncontrolled exothermic reactions and/or to the release of tank contents into the environment. These conditions have led to the establishment of four priority 1 safety issues for the Hanford tanks.

Resolution of these safety issues will require the coordinated efforts of professionals in chemical, nuclear, operations, safety, and other technical areas. A coordinated and integrated approach is necessary in order to achieve resolution in the shortest possible time, while ensuring that the steps taken do not complicate the later jobs of vitrification and ultimate disposal. This paper describes the purpose, process, and results of an effort to develop a suggested approach.

INTRODUCTION

Summary of Priority 1 Waste Tank Safety Issues

- Ferrocyanide: It is estimated that 24 storage tanks contain at least 465 pounds of ferrocyanide precipitates each, along with sodium nitrates and nitrites. In the presence of oxidizers such as nitrates and nitrites, ferrocyanide can be shown to explode by heating to high temperatures above 280°C (temperature measurements in the tanks have not exceeded 129°C) or by an electrical spark of sufficient energy.
- Hydrogen: Twenty-three tanks are known or believed to have the potential to produce, retain, and periodically release gas mixtures containing hydrogen from the waste into the tank dome space. The resulting concentrations may exceed the lower flammability limit for hydrogen.
- Organics: Concentrations of organics, in combination with nitrates and nitrites, may be sufficient in some tanks as to pose the possibility of uncontrolled exothermic reactions given a sufficiently energetic initiating event. Unacceptably high concentrations of organics are suspected in eight storage tanks.
- High Heat: Since 1971, water has been added to one tank in order to maintain the tank temperature within established limits by means of evaporative cooling. Without this, the resultant increase in tank temperature would likely have caused structural problems, with resultant radioactive releases to the environment.

Terms and Concepts

Several terms which may not be familiar to the reader will be used throughout this paper. These are:

- Watch List: The list of the waste tanks which are associated with any of the four priority 1 safety issues. Special operating procedures and restrictions have been implemented for watch list tanks. Tanks would be removed from the watch list only when the hazard is demonstrated to be minimal, either by thorough analysis of the hazard or by correction of the condition(s) creating the hazard.
- Remediation: The elimination or substantial reduction of a hazard by removal of the mechanism(s) or condition(s) through which an unacceptable event can occur. Remediation is directed at the cause of a safety hazard rather than its symptoms. For the hydrogen safety issue, successful remediation might eliminate the generation of all hydrogen gas other than that generated through radiolysis.
- Mitigation: The reduction of a hazard by minimizing the condition(s) which can lead to an unacceptable event. Mitigation is directed toward treating the symptoms of a safety hazard rather than its cause. For the hydrogen safety issue, mitigation might increase the frequency of gas releases to the point where concentrations of hydrogen do not approach the lower flammability limit.
- Resolution: For the purposes of this paper, a safety issue is defined to be resolved for a specific tank when the tank either may be removed from the watch list or requires only increased monitoring, rather than mitigative or remediative measures, to assure continued safe operation.

Figure 1 summarizes the concept for the resolution of priority 1 safety issues (or just "safety issues"). For each tank, three resolution processes are possible depending upon the results from the evaluation of the tank. These are:

- The hazards and associated risks are determined to be minimal or non-existent. The tank may be removed from the watch list with no further action required.
- The risk is significant and the hazards will have to be remediated or mitigated in order to eliminate or control them.
- A degree of risk is present, but it is not significant. While remediation or mitigation is not required, neither is the tank entirely free from concerns related to that safety issue. Increased monitoring can assure that the tank remains within defined safety limits that are appropriate.

Ultimately, there are only two final disposition states, on the right of the diagram, for each waste tank: either it is removed from the watch list or it will be monitored more closely until pretreatment begins. The former final state will likely be associated with the "hazard eliminated" condition and the latter with the "hazard controlled" condition.

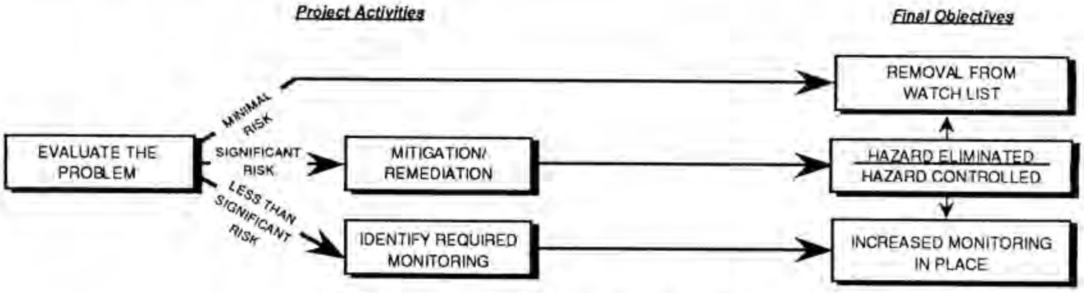

Fig. 1. Summary planning methodology.

There is no assurance that the characteristics which cause a waste tank to be placed on a watch list are indicative of the presence of a safety hazard in that tank. One of the objectives of the safety issue resolution logic is to identify such tanks and remove them from the watch lists. The summary logic above may imply that waste tanks are only *removed* from safety lists. This is not true. As a result of the evaluations carried out, other tanks may be *added* to existing watch lists for identified safety issues and new watch lists may be constituted for newly discovered safety issues.

Assumptions and Constraints

The logic for safety issue resolution was developed based upon the assumptions and constraints listed below:

- Each high level waste tank associated with a safety issue must be individually evaluated as to the types of hazards and the level of risk and individually treated as necessary. None of the safety issues identified to date may be resolved globally.
- No final conclusions on hazards or risks for an individual tank may be developed nor remedial actions identified without taking valid and representative samples of actual waste from that tank.
- Any logic for safety issue resolution will have to include sufficient characterization of the hazard so as to preclude selecting a treatment which either creates a new hazard or aggravates an existing hazard.
- Safety issue resolution measures will be selected so as not only to eliminate or control safety hazards but also to reduce the complexity of the ensuing waste treatment activities.

SAFETY ISSUE RESOLUTION LOGIC

The planning process to develop this logic was a structured one which served to focus the planning efforts on the specific problem to be addressed. This structured approach, it is felt, was necessary to assure the recognition and integration of all of the required activities. The structure of the planning process was "top down". That is, the ultimate objectives of the work were identified first, then the logic was constructed so as to achieve those objectives in the most direct and efficient manner.

The safety issue resolution process conceptualized in Fig. 1 has been translated into the network logic shown in Fig. 2. Network diagrams show the precedence relationships among the tasks. In such presentations, higher level work breakdown structure (WBS) elements are displayed as larger boxes encompassing the lower level WBS elements within smaller boxes. Constraints on the size of this diagram have precluded inclusion of the more detailed (lower WBS levels) steps. These are included in the blow-ups of portions of the network which accompany the discussions of these steps.

The network logic is divided into three major activities: evaluation of the problem, mitigation or remediation of the problem, and the implementation of enhanced tank monitoring. This section addresses the details of each of these three major project activities.

Major Activity 1 - Evaluate the Problem

The judgement on the presence of an unacceptable hazard in a particular tank is based upon:

- a definition and analysis of the mechanism(s) potentially creating the hazards,
- an understanding of the particular conditions (and, to the extent possible, levels of measurable parameters) which would enable those mechanisms to operate, and
- the measurement of the important parameters within the tank to determine the risks associated with each of the hazards identified.

This is the starting point for the resolution of the safety issue.

This first major project activity begins with the definition of hypotheses concerning the hazardous mechanisms and includes refinement of these hypotheses through the analysis of actual samples of tank contents. The evaluation of the hypotheses and their possible refinement is not a one-time event but will take place with the retrieval and analysis of samples from each waste tank.

Task 1.1 - Establish Preliminary Hypothesis

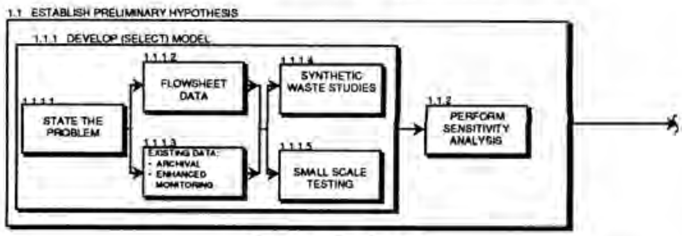

Fig. 3. Task 1.1.

The initial set of hypotheses is based upon existing information concerning tank contents. A candidate model is developed (Task 1.1.1) which replicates the situation in the tank, consistent with the tank contents as estimated from flowsheet data and, if available, archived tank samples or sample analyses. A part of this model development process is the conduct

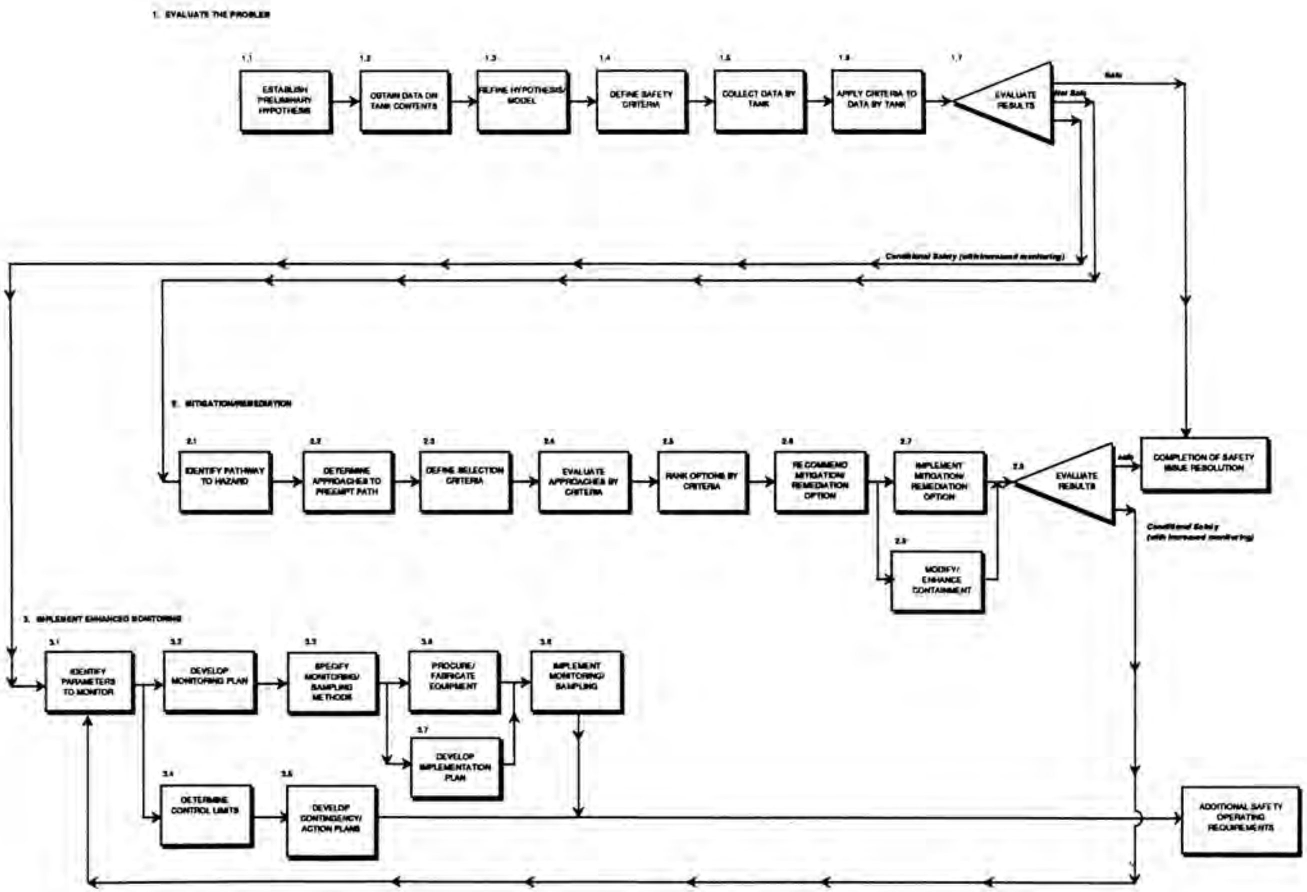

Fig. 2. Safety issue resolution network logic.

of studies on synthetic (non-radioactive) wastes and small scale testing to either verify or improve the model. Once the candidate model has been developed, sensitivity analyses are *performed* on it (Task 1.1.2) to assess how sensitive the validity of the model and the output of the model are to changes in any of the parameters, including tank contents.

Task 1.2 - Obtain Data on Tank Contents

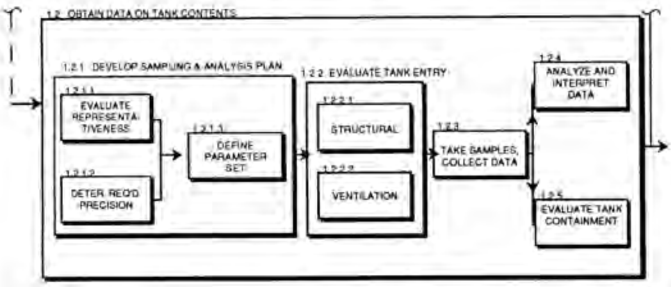

Fig. 4. Task 1.2.

Once the important parameters are defined, at least on an initial basis, a sampling and analysis plan may be developed (Task 1.2.1) to measure those parameters within each tank. The outputs of the sensitivity analyses in Task 1.1 are used in determining the precision with which each of the parameters must be measured as well as the need for the representativeness of the sample. Once these are determined, then the parameters to be measured during the sampling activity are defined.

At this point, entry into the tank to obtain the required samples is evaluated from a safety standpoint (Task 1.2.2). This evaluation includes considerations on the adequacy of the structural integrity of the tank, as well as the possibility of problems based upon the presumed contents. In tasks 1.2.3 through 1.2.5, samples are collected, analyzed, and interpreted.

Task 1.3 - Refine Hypothesis/Model

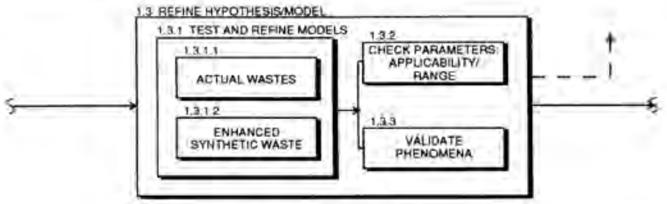

Fig. 5. Task 1.3.

The results of the sampling process on each tank provide validation of the hypothesis. The mechanisms postulated can now be validated and the applicability and range of the theoretically important parameters can be assessed. In some cases, further work on the hypotheses and on the sampling and analysis plans, along with additional sampling, will be indicated. In such instances, Tasks 1.1 through 1.3 become iterative.

Tasks 1.4 through 1.6

These tasks are diagrammed in Fig. 6. Once there is sufficient confidence in the validity of the model, it may be used to define the criteria for safe operation of a tank (Task 1.4). These criteria may be a range of acceptable values for each of a specified set of parameters or they may be defined

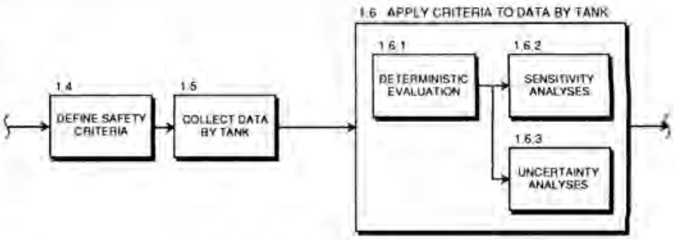

Fig. 6. Task 1.4 to 1.6.

in terms of interrelationships among parameter values. Data are collected for each tank, usually requiring samples to be taken, which will allow the evaluation of a tank's safety status against the criteria which have been developed. In Task 1.6, these criteria are applied to the collected data in deterministic evaluations, supplemented by probabilistic evaluations and sensitivity analyses.

Task 1.7 - Evaluate Results

The disposition appropriate for each tank is determined and is rigorously justified and documented. Possible dispositions are:

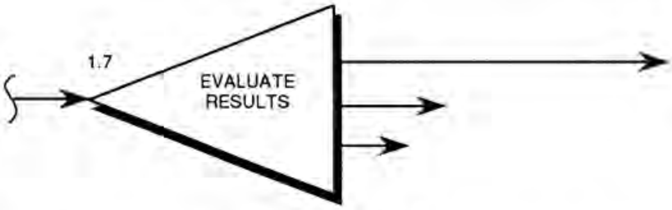

Fig. 7. Task 1.7.

- it may be removed from the watch list with no further actions required because the risk is found to be minimal: it is "inherently safe" (e.g., there is not enough fuel in the tank to support an exothermic reaction) or it is "passively safe" (e.g., enough fuel is present but so are sufficient diluents to preclude any significant reaction),
- it may require mitigative or remediative actions because the risk is not acceptable, or
- because the risk is real but below limits for requiring corrective action, key tank parameters may need to be monitored more closely until the tank either enters one of the above two disposition states or its contents are disposed of.

Major Activity 2 - Mitigation/Remediation

Task 2.1 - Identify Pathway to Hazard

A common approach to identifying pathways to hazards makes use of the fault tree and event tree theories used in nuclear and industrial safety work. In these theories, the events which lead up to an accident are considered as a sequence, and the removal of events or combinations of events which result in failure will either eliminate the accident or reduce its consequences to an acceptable level. The first step in the mitigation/remediation efforts, therefore, is the identification of the events (or pathways) leading to an undesirable situation. When applicable, the various pathways suggested

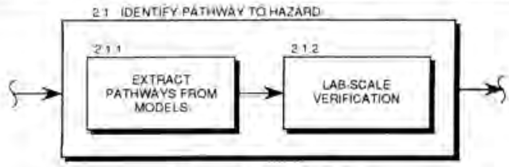

Fig. 8. Task 2.1.

are evaluated in the lab and those which cannot be verified as valid are discarded.

Task 2.2 - Determine Approaches to Preempt Path

Techniques are sought to disrupt the process leading to an accident by eliminating either a key event or a combination of events along the path. A number of techniques are likely to

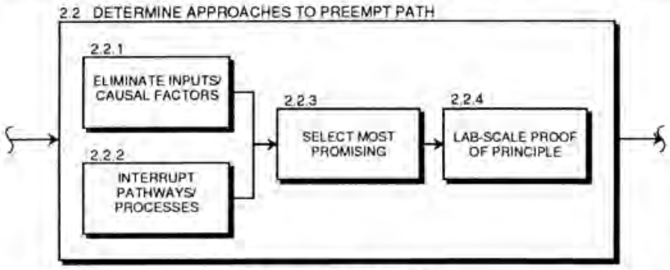

Fig. 9. Task 2.2.

be suggested. The most promising of these will be verified as to their effectiveness in laboratory scale tests.

Tasks 2.3 through 2.6

Several approaches may be generated which show promise in addressing the identified tank problems. Following laboratory tests validating the principles involved, one or more approaches are selected for further development based upon their performance against certain selection criteria. The more important criteria would include the safety of the method, the effects the approach might have upon the final treatment of the waste, the rapidity with which the approach could be implemented, and its potential for success. Other criteria could relate to environmental impacts and risks, availability of the required technology, acceptability to oversight

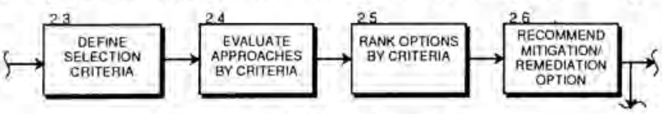

Fig. 10. Task 2.3 through 2.6.

groups and the public, costs, and associated paperwork and regulatory requirements.

Evaluation of the competing approaches against the selection criteria is a pencil and paper effort, with no laboratory or modelling input required. This should be a group process, with expertise available for every dimension on which the approaches are being evaluated (e.g., technical feasibility and efficacy, cost, public acceptability). Generally, one promising approach to mitigation or remediation will go forward to pilot testing and preparation for implementation. In certain cases, though, the urgency of the situation will require that several approaches go forward in parallel in order to minimize the time required for resolution of the safety issue.

Task 2.7 - Implement Mitigation/Remediation Option

Certain safety problems will be serious enough that the remediation activities themselves will pose unacceptable risks

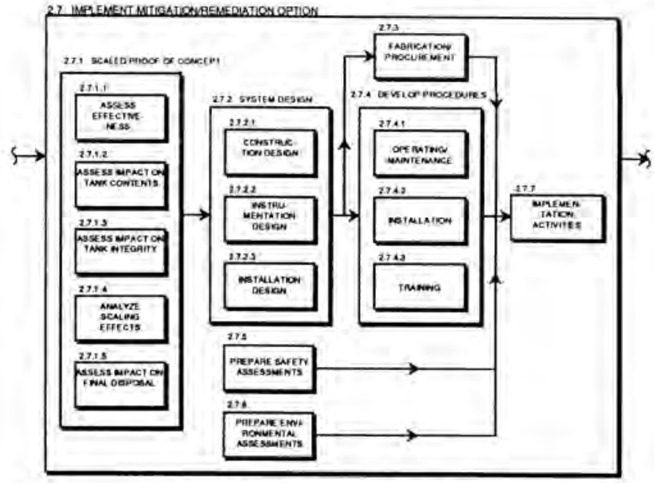

Fig. 11. Tasks 2.7.

to safety and the environment. In such instances, the hazard must be mitigated first, so that remediation may be carried out safely. The dotted line out of and back into task 2.7 on the network chart indicates that this step may be accomplished twice: once as a mitigation action and a second time as a remediation action.

The implementation begins with a scaled proof of concept (Task 2.7.1). This work demonstrates that the principles shown in the lab scale testing are also valid as the scale increases. An important part of this evaluation deals with the impact the approach will have on the integrity of the tank and on the final disposal. Failure of the approach on either of these two points would probably mean that the approach would be dropped from further consideration. Once again, it is likely that only one mitigation/remediation approach will be actively pursued at this point. However, the urgency of the problem may dictate that several approaches continue going forward in parallel in order to ensure that an effective and workable solution will be implemented in the shortest possible time.

Once through the scaled proof of concept, design starts within the construction, instrumentation, and installation areas, as appropriate (Task 2.7.2). Any necessary fabrication or materials and equipment purchases would follow the design activity, as would the development of procedures to implement this approach (Tasks 2.7.3 and 2.7.4). In parallel with these preparatory activities, safety and environmental documentation is prepared (Tasks 2.7.5 and 2.7.6) in order to secure permission to operate within the affected tank(s). After all is in readiness, the mitigation or remediation approach is implemented as a part of Task 2.7.7.

Task 2.8 - Modify/Enhance Containment

In most situations, no uncontrolled exothermic reaction within a tank would be considered acceptable, regardless of its size and regardless of its effect on tank integrity. In order to make this logic as flexible as possible, though, this task has been added to provide the option to reinforce the tank

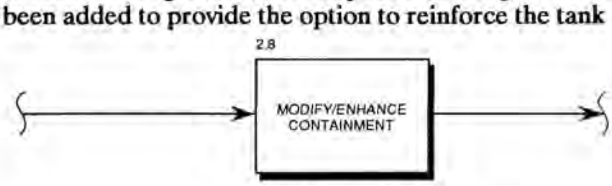

Fig. 12. Task 2.8.

structure so as to withstand the occurrence of the accident being addressed. This step would be taken in lieu of mitigating or remediating the problem so that the accident could not *occur.*

Task 2.9 - Evaluate Results

After the mitigation or remediation option selected has been implemented, tank sampling or monitoring will indicate whether or not the tank is now safe (i.e., operating within defined safety limits). If it is safe, the tank can be removed from the watch list and managed as a tank not associated with this safety issue. If, however, the hazard has not been sufficiently minimized, the tank will require enhanced monitoring to assure that it remains within acceptable operating ranges.

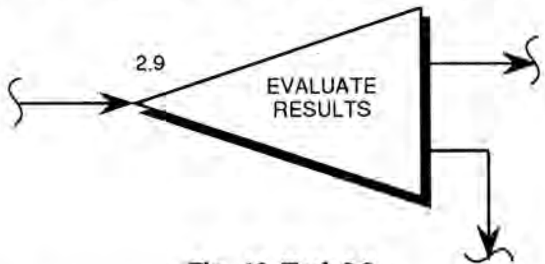

Fig. 13. Task 2.9.

Major Activity 3 - Implement Enhanced Monitoring

The intent of the monitoring activity is to monitor tank performance to insure that adverse conditions such as failures, malfunctions, deficiencies, deviations, defective materials, and other instances of non-conformance, are identified and managed. This approach is required where the safety problems cannot be effectively remediated or mitigated.

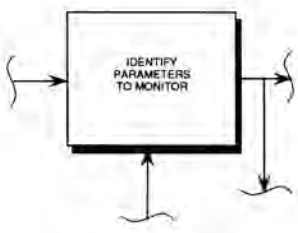

Fig. 14. Task 3.1.

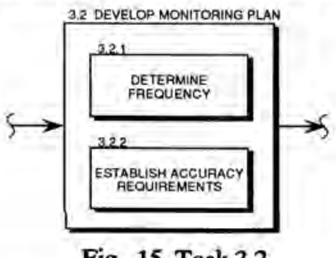

Fig. 15. Task 3.2.

Task 3.1 - Identify Parameters to Monitor

The modelling activities in Task 1.3 will have defined the tank operating characteristics which are demonstrated to be directly related to the safety status of the tank. These are the characteristics which will be tracked. In many cases, however, these characteristics are not directly observable or measurable. Therefore, surrogate parameters, which are observable and measurable and which are demonstrated to be indicative of the characteristics of interest, will be identified and monitored.

Task 3.2 - Develop Monitoring Plan

Monitoring plans are based upon the nature of the hazard and the dynamics of the contents in that particular tank as determined from the tank sampling and modelling activities. Of utmost importance in the monitoring process are accuracy and representativeness. The frequency and the accuracy of the monitoring process are specified during this step.

Task 3.3 and Tasks 3.6 through 3.8

In Task 3.3, monitoring methods are developed which will satisfy the requirements specified in the previous step. The other tasks focus on preparing for and implementing the plans for monitoring or sampling which have been developed.

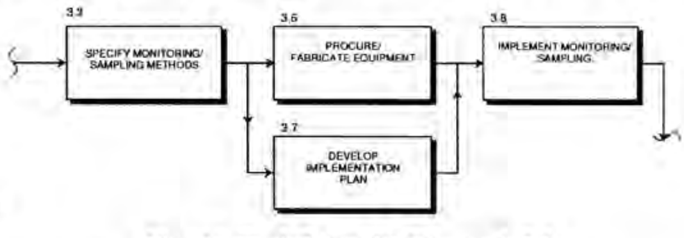

Fig. 16. Task 3.3 and 3.6 through 3.8.

Tasks 3.4 and 3.5

At the same time as the sampling and monitoring plan is being developed and implemented, control limits are specified for each parameter to be measured and contingency plans are developed which address what to do if the control limits are exceeded.

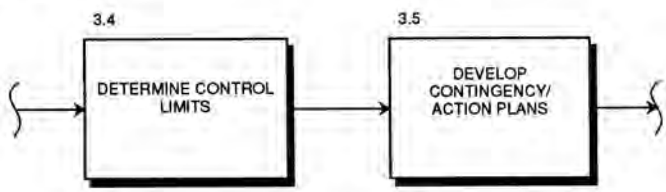

Fig. 17. Task 3.4 and 3.5.

FUTURE IMPLICATIONS OF THIS WORK

The safety issue resolution logic presented in this paper is a product of two techniques. The first is the top-down planning concept, in which the outputs or final results of an effort are identified first, then the steps necessary to those outputs or results are identified. This disciplined approach to planning helps to assure not only that all the necessary steps are identified but also that all the identified steps are necessary.

The second technique is the application of the scientific method in problem-solving:

- generation of hypotheses to explain phenomena,
- refinement and/or selection of the most valid hypotheses based upon experimentation and observation,
- development and application of corrective measures consistent with the selected hypotheses,
- and continuous feedback throughout the process to enhance understanding of the phenomena being addressed.

Environmental restoration and radioactive waste management is a complex emerging area of technology in which a number of scientific and engineering disciplines must be closely coordinated. The planning methodology which produced the problem resolution logic described here can also be used to plan effective approaches to other facets of the environmental restoration and waste management problem.