Safety Culture and the Accident at Three Mile Island

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Abstract:
Prior to the accident at Three Mile Island, little attention was being paid to the human role in the safe operation of civilian nuclear power plants. The investigation of the TMI accident showed that its root causes were primarily human-related. The Kemeny Report on the TMI accident does not use the term "safety culture"; however, it fully identifies all relevant aspects of safety culture.
It was only after the accident at Chernobyl that the term "safety culture" came into widespread use. However, it should be noted that, during the years after TMI and before Chernobyl, already major changes had been instituted concerning human factors and human reliability in the civilian nuclear energy programs of many countries. Greater credit should be given to the remarkable insights developed by the Kemeny Commission as contained in the Kemeny Report.

1. Introduction

Until the accident at Three Mile Island (TMI), little attention was being paid to the important role of human factors and human reliability in the operation of nuclear power plants. The prevailing opinion (mindset) at that time was that the many safety systems were capable of terminating and stabilizing any and all safety-related operational events in a timely and safe way. The human role was largely ignored and, if considered at all, the operators were assumed to only undertake actions favorable to safety. This mindset is the probable cause that, at that time, human errors (of commission and omission) were given little or no attention.

The Reactor Safety Study (WASH-1400, usually referred to as the Rasmussen Report [1]) which was the first probabilistic safety assessment of civilian nuclear plants, should have been a warning. However, the insights gained in this study that human factors play an important role in safety did not penetrate into the nuclear establishment until after the accident at TMI. This situation was in large measure a consequence of the reticence of the U.S. Nuclear Regulatory Commission (NRC) to give credence to the results of the Rasmussen study. In fact, at that time, a letter was issued by the chairman of the NRC warning all NRC employees to refrain from using probabilistic safety considerations in reaching licensing decisions.

During the investigation into the root causes of the TMI accident it was found that, while some design deficiencies and system malfunctions were contributory, the main causes were human-related. The well-known Kemeny Report [2] presents the results of one of the main investigations into the TMI accident. It does not use the term "safety culture"; however, it fully identifies all relevant aspects of safety culture, including the important role of the mentality (culture) existing in organizations from the highest level of management down to the individual workers. Subsequent probabilistic safety assessment studies confirmed these findings and concluded that human factors constitute the main contributor to the overall risk of nuclear power plants of the current generation. The realization of this fact has become the driving force in the search for innovative reactor designs that are more forgiving of human errors and component/system failures.

It was only after the accident at Chernobyl that the term "safety culture" came into widespread use. However, much had already happened during the years after TMI and before Chernobyl: Major changes had been instituted in many countries based on the findings gained from TMI concerning the important role of human factors and human reliability in the safe operation of nuclear power plants.

This paper intends to show that important advances had been made in the area of human factors and human reliability as a consequence of TMI; specifically, attention will be focused on the important contributions made by the Kemeny Commission in this respect. To that end, the paper briefly discusses the sequence of events that resulted in the TMI accident, identifying some of the main design deficiencies, mechanical failures and human-factor deficiencies that were the cause. It then reviews the Kemeny Report and highlights its major findings, showing that the basis for safety culture had already been laid before the accident at Chernobyl occurred. In this connection, it is important to note that the Kemeny Report attributes serious shortcomings to all parties involved, including design/construction organizations, operating organizations and regulatory organizations.

3. **Brief Description of the TMI Accident**

The accident at Three Mile Island started on March 28, 1979, at about 4:00 AM and evolved over about six days until April 2, 1979. It took place near Middletown, Pennsylvania, USA. Two weeks after the accident, the President of the United States - Jimmy Carter - established a Presidential Commission under the chairmanship of John G. Kemeny with the task to conduct a comprehensive investigation into the accident. This investigation was to include (a) a technical assessment of the events and their causes, (b) an analysis of the role of the managing utility, (c) an assessment of the U.S. Nuclear Regulatory Commission's emergency preparedness and response capability as well as its licensing, inspection, operation and enforcement procedures.

In order to identify some of the human-related aspects of the TMI accident, a brief summary of some of the main points of the sequence of events is presented in the following:

(1) A plant malfunction caused the pumps of the main feed water system to be tripped automatically at a time when TMI unit #2 was operating at 97% of nominal power;

(2) As a consequence, the steam generators (being of the once-through type and having a small feed water inventory) started to boil dry, resulting in increased pressure of the primary cooling system;

(3) In response to this increased primary pressure, the pilot-operated relieve valve (PORV) of the pressurizer opened (as required by design), allowing release of primary coolant into the quench tank;

(4) Because the primary coolant pressure continued to rise, the automatic protection system of Unit #2 tripped the reactor 8 seconds after the first feed water pump had tripped, thus terminating the nuclear fission chain reaction;

(5) Three pumps of the emergency feed water system started automatically as required by design. However, no feed water was delivered to the steam generators, because the block valves on the two emergency feed water lines had inadvertently been left closed (*human error*). Furthermore, the operators did not notice for some 8 minutes that these valves were closed (*human error*);

(6) The primary pressure decreased (because of the reduced reactor power level and the loss of primary coolant to the quench tank) to the point at which the PORV should have closed automatically. However, the PORV remained mechanically stuck open.
(7) The operators assumed that the PORV had closed because the status lights on the control board erroneously indicated so (*design deficiency*). As a consequence, the PORV remained open for 2 hours and 22 minutes, resulting in a loss-of-coolant accident draining the primary system;
(8) As a consequence of the loss of primary coolant, the primary coolant pressure decreased to the point where the emergency core cooling system (ECCS) started automatically;
(9) The liquid level in the pressurizer increased because saturation temperature had been reached in the core, resulting in a steam bubble at the core outlet.
(10) The ECCS was shut down by the operators because they had been trained to do so when the liquid level in the pressurizer became too high (*training deficiency*).
(11) The operators had not been adequately trained to recognize the prevalent plant conditions. Under most operating conditions, if the liquid level of the pressurizer is too high, the primary system could "go solid", thus incurring a risk of over-pressurization. However, in this case, there was a large steam bubble at the top of the core, so that there was no danger of the primary system "going solid".
(12) The continued loss of primary coolant through the open PORV and the shutting down of the ECCS resulted in uncovering of the fuel assemblies, and eventually in the melting of approximately 50% of the core.

If the TMI operating staff had refrained from shutting down the ECCS (*error of commission*), the automatic safety systems would have prevented core damage by establishing a feed-and-bleed mode of operation and the accident could have been terminated without major consequences. However, the operating staff is not to be blamed for their actions because, at that time, the action of shutting down the ECCS for high pressurizer level was in full compliance with the (then) existing operating instructions. Similarly, if the operators had stopped the loss of primary coolant in the early part of the accident sequence by closing the pressurizer block valve (*error of omission*), the accident would have remained a minor incident.

We shall not follow here in detail the entire further evolution of the accident. Suffice it to say that the accident resulted in melting of the core for about 50% and that many lessons were learned, in particular in the area of human factors.

4. **Discussion**

This paper will draw mainly from the Kemeny Report, highlighting by direct quotations the important insights that were gained by the Kemeny Commission from its TMI investigation.. Some of these main findings and recommendations are as follows:

Findings:

"To prevent nuclear accidents as serious as TMI, *fundamental changes will be necessary in the organization and practices* of the Nuclear Regulatory Commission and the nuclear industry";

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"Equipment can and should be improved to add further safety to nuclear power plants. But as the evidence accumulated, it became clear that *the fundamental problems are people-related problems* and not equipment problems";

"When we say that the basic problems are people-related, we do not mean to limit this term to shortcomings of individual human beings....We mean more generally that our investigation has revealed *problems with the "system" that manufactures, operates and regulates nuclear power plants*. There are structural problems in the various organizations, there are deficiencies in various processes, and there is a lack of communication among key individuals and groups".

The (TMI) equipment was sufficiently good that, except for human failures, the major accident at TMI would have been a minor incident. But, *wherever we looked, we found problems with the human beings who operate the plant, with the management that runs the key organization, and with the agency that is charged with assuring the safety of nuclear power plants.*

"....*we are convinced that regulations alone cannot assure safety.* Indeed, once regulations become as voluminous and complex as those regulations now in place, they can serve as a negative factor in nuclear safety....This Commission believes that *it is an absorbing concern with safety that will bring about safety* -- not just the meeting of narrowly prescribed and complex regulations".

"....we find that *the approach to nuclear safety had a major flaw*....Some potentially serious scenarios, such as the break of a huge pipe....were studied extensively and diligently....the attitude developed that *we need not worry about the analysis of 'less important' accidents* if such large-break accidents could be controlled. Large-break accidents require extremely fast action that therefore must be automatically performed by equipment. Lesser accidents may develop much more slowly and their control may be dependent on actions of human beings. *This was the tragedy of TMI*, where the equipment failures in the accident were significantly less dramatic than those that had been thoroughly analyzed, but *where the results confused those who managed the accident*".

"The most serious 'mindset' is the preoccupation....with the safety of equipment, resulting in the *down-playing of the importance of the human element* in nuclear energy generation. We are tempted to say that *what the NRC and the industry have failed to recognize sufficiently is that the human beings....constitute an important safety system*"

"*The control room*, through which the operation of the TMI-2 plant is carried out, *is lacking in many ways*. The control panel is huge, with hundreds of alarms, and there are some key indicators placed in locations where the operators cannot see them"

"The WASH-1400 Reactor Safety Study (the Rasmussen Report) analyzed events, equipment failures and human errors that could happen during reactor accidents, including those

associated with the TMI accident. However, *NRC has not made systematic use of WASH-1400 in its design review analyses*"

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Recommendations:

The nuclear industry must dramatically change its attitude towards safety and regulations:

- The industry should establish a program that specifies appropriate safety standards including those for management, quality assurance and operating procedures and practices;
- There must be a *systematic gathering, review and analysis of operating experience* at all nuclear power plants coupled with an industry-wide international communications network to facilitate the speedy flow of information to affected parties;

Although the Commission considers the responsibility for safety to be with the total organization of the plant, *we recommend that each nuclear power plant have a separate group that reports to high-level management;*

Clearly defined roles and responsibilities for operating procedures and practices must be established to ensure accountability and smooth communication;

Since, under our recommendations, *accountability for operations during an emergency would rest on the licensee, the licensee must prepare clear procedures* defining management roles and responsibilities in the event of a crisis;

5. **Conclusions**

Although the importance of the human role in the safe operation of nuclear power plants had already been established in 1975 by the Rasmussen study, this insight did not penetrate into the nuclear establishment until after the accident at Three Mile Island.
The investigation of the Kemeny Commission into the TMI accident firmly established that the root causes of the accident were primarily human-related. The Kemeny Report does not use the term "safety culture"; however, it fully identifies all relevant aspects of safety culture, well before the Chernobyl accident subsequent to which the term safety culture came into widespread use.
Greater credit should be given to the groundbreaking work performed by the Kemeny Commission in the area of safety culture and to the remarkable insights that are contained in the Kemeny Report which established the concept of "safety culture" well before it became part of the accepted terminology.

6. **References**

[1] Reactor Safety Study: An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants, WASH-1400 (NUREG-76/014), by Norman Rasmussen, Saul Levine, et al., October 1975

[2] Report of the President's Commission on the Accident at Three Mile Island, by John G. Kemeny et al., October 1979 (Pergamon Press)