An Expert System to Estimate Time, Rate and Magnitude of Release of Important Radioactive Isotopes, Given a Loss of Containment Integrity

Kil-Yoo Kim, David Okrent
University of California, Los Angeles, CA USA

ABSTRACT

A prototype expert system is developed to provide information to emergency planners on the time, rate, and magnitude of release of important radioactive isotopes, given a loss of integrity. Basic to the method is the anticipated availability of instruments to measure concentration of significant individual radioisotopes in containment about once a minute. The escape of radioisotopes is assumed to be proportional to that of non-condensable gases, which are monitored and/or predicted in part. If such a system can be executed practically, it would provide actual release information not available with monitoring systems currently deployed.

1. INTRODUCTION

In the unlikely event that an accident involving large scale core melt occurred in a light-water-cooled, nuclear power reactor, various preparations have been made to gather information to help guide any offsite evacuation steps, should they be necessary. These include measurement of radioactivity exterior to the reactor plant, as well as a group of measurements inside the containment. However, the existing measurement capability is inadequate to give quantitative information on the rate of escape of radioactive material, isotope by isotope, should a significant loss of containment integrity occur. Such information, together with continuing meteorological data, could place evacuation or sheltering measures on a much more certain foundation than is possible with the radioactivity measurements now provided.

This study is intended to explore the practicality of devising a simple expert system, which, together with the relevant instrumentation, could provide detailed information on rate of escape of radioactive isotopes from containment, at least approximately. A pressurized water reactor (PWR) with a large dry containment is used as the model for study.

2. INSTRUMENTATION

The expert system assumes the availability of the following parameters on an essentially continuous basis (all triply redundant):

- containment atmospheric temperature (five locations)
- containment pressure (five locations)
- containment sump level
- water level above containment floor

- refueling water storage tank level
- containment sump temperature
- hydrogen concentration
- carbon dioxide concentration

It is also assumed that the concentrations of the following isotopes can be obtained frequently (say, every minute) at several sampling stations in the containment:

xenon 133, xenon 135, krypton 85, krypton 85m, iodine 131, iodine 133, cesium 134, cesium 137, rubidium 88 and strontium 90.

Tellurium is also of potential importance but may be more difficult to measure; hence the tellurium is assumed to be proportional to the cesium in the current version of the code. Other radioisotopes could be added to the list as appropriate.

Discussions with manufacturers of such sampling and measuring equipment indicate that sampling of the listed isotopes about every fifteen minutes is currently within the state of the art, and that with the appropriate emphasis, one might approach a sampling rate of once a minute (Archibald, 1988).

3. PHYSICAL APPROACH TO ESTIMATING RELEASE RATE

It is assumed that the fission products in the containment atmosphere at any time are well mixed with the nitrogen and oxygen gas (and hydrogen and carbon dioxide, if any) and the steam, which, prior to occurrence of a loss of containment integrity, is ordinarily saturated and in equilibrium with the water in the sump or on the containment floor. Containment and sump water temperature are assumed to be the same, prior to an event involving significant leakage rates. Containment spray actuation or a hydrogen burn are detected and treated as such.

3.1 Magnitude of Release

The leakage rate determination involves the calculation of gas loss during the leakage period by direct observation of containment pressure and temperature.

The leakage rate computation is based on the ideal gas law in the form

$$P_{\text{gas}} V = W_{\text{gas}} R T_c \quad (1)$$

where

P_{gas} = absolute partial pressures of gases except H_2O inside containment
 $= P_{\text{total}} - P_{\text{H}_2\text{O}}$

P_{total} = total pressure inside containment

$P_{\text{H}_2\text{O}}$ = partial pressure of H_2O vapor

V = net free internal volume of containment

W_{gas} = mass of gases except H_2O inside containment

T_c = temperature inside containment

R = gas constant

Leak fraction defined in the expert system is,

$$\begin{aligned}\text{leak fraction} &= \frac{\text{gas mass at state 1} - \text{gas mass at state 2}}{\text{gas mass at state 1}} \\ &= \frac{W_{\text{gas},1} - W_{\text{gas},2}}{W_{\text{gas},1}}\end{aligned}$$

where 1 minute is usually taken as the time interval between state 1 and state 2.

A_i , the released amount of radionuclide i during state 1 to state 2, equals leak fraction $\times$ concentration of radionuclide i , and the rate per minute is derived directly.

During most accidents, the containment atmosphere usually contains saturated steam. Therefore, during the depressurization of containment due to containment failure, it is assumed that P_{H_2O} is obtained by the following rules.

- If sump water level decreases during depressurization, P_{H_2O} is that pressure in equilibrium (saturated) with the sump water, because steam pressure in the atmosphere of containment corresponds (very nearly) to saturation pressure at sump water temperature.
- If sump water level does not decrease during depressurization, then P_{H_2O} is set (as an approximation) at the saturation pressure at the atmosphere temperature inside containment.

3.2. Thermodynamic Properties

The water vapor properties in the calculation of leak rate are derived by using functions obtained by fitting the steam tables (USNRC, 1984). These properties include the saturation pressure of steam, P_{sat} ; saturation steam enthalpy, h_g ; the saturation water enthalpy, h_f ; and the enthalpy of evaporation, h_{fg} .

3.3. Resuspension

Because of the large amount of water and the steam condensation process, resuspension is not likely to be a significant effect in containment, except that a sudden depressurization could cause flashing of water which contains fission products (ANS, 1984).

Since the concentration of radionuclides of interest is monitored, on line (every minute), it is assumed that any resuspension effects are covered.

3.4. Location of Leakage from Containment

The appropriate leak location may be detectable by zoned pressure measurements, but this remains to be studied more deeply. The current plan is:

- to install instruments to measure pressure and temperature in five containment zones.

4. BASIC SCHEME OF THE EXPERT SYSTEM

The proposed prototype expert system is implemented with Knowledge Engineering Environment (KEE) (Intellicorp, 1986) on a Symbolics LISP machine. The expert system is named RELEASE.

The basic scheme of the expert system is shown in Figure 1. If temperature or pressure inside containment suddenly changes, the inference process of the expert system starts to check whether containment has failed or not. If it has failed, the expert system shows the released amount of radionuclides during each time interval (and the rate of release) and the leak location.

4.1. Knowledge Representation and Inference

The proposed expert system represents knowledge with multiple paradigms such as rules and frames. The expert system monitors pressure and temperature inside containment. However, since the environment inside containment is very harsh, measuring sensors may fail. Therefore, the expert system should have some logic to detect failed sensors, and should not involve them in the calculation of amount of radionuclide release. This expert system has two inference processes; one is related to diagnosing containment failure; the other is to help find failed sensors.

4.1.1. Inference to Find Containment Failure

The characteristics of containment failure are;

- Containment pressure in any zone suddenly drops
- Containment temperature in any zone decreases.

Therefore, if there is a sudden pressure and temperature drop inside containment, the expert system's inference process starts. However, since the pressure and temperature drop are not unique characteristics occurring only in the event of containment failure, the expert system checks the possibility of the other phenomena such as the start of containment spray. Stored in the knowledge base are the following factors which increase pressure and temperature inside containment:

1. H₂ burning
2. High steam or gas generation due to the following:
 - core slump in large LOCA
 - reactor vessel failure
 - core-concrete interaction
 - debris quenching by spillover of sump water
 - accumulator water flow over molten core.

Also stored in the knowledge base are factors which decrease pressure and temperature inside containment.

1. Containment failure
2. Spray (or fan cooler) starts
3. the latter portions of transients which at the beginning initiate a pressure rise, for example, H₂ burning.

One example of the expert system's inference ability is illustrated by the following situation: If RWST level decreases, sump level increases and ECCS is off, the expert system deduces that spray has started. Thus, if there is a drop of pressure at $t = t_0$, it is not due to a containment failure, but due to spray. See (Kim, 1988) for details.

4.1.2. Failed Sensors

The expert system uses auctioneering of similar sensors or analytic reasoning to identify spurious readings.

4.1.2.1. H₂ Deflagration

Since the peak temperature and peak pressure due to hydrogen burning are related to the change in hydrogen concentration, the expert system can check approximately whether the readings of temperature, pressure, and H₂ analyzer are consistent.

4.1.2.2. Sump Level and Evaporation

The expert system can also check whether or not the sump temperature sensor or sump level sensor has failed by using an energy balance relation between sump level, sump temperature, and the energy to vaporize the loss of mass in the sump.

If the energy balance is not satisfied, the inference is made that the temperature or level sensor of the sump (or floor level water height) is out of order. An approximate value of P_{H_2O} is obtained by using the atmosphere temperature inside containment, instead of using the sump water temperature.

5. SUMMARY

A prototype expert system called RELEASE has been developed to explore the practicality of providing detailed information on the timing and rate of escape of radioactive isotopes from containment, given a large scale core melt accident and a subsequent loss of containment integrity.

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Figure 1: Basic Scheme of RELEASE