CONTAINMENT OF FAST BREEDER REACTORS-PRESENT STATUS-REMAINING PROBLEMS

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Containment comprises the engineering safeguards imparted to a reactor system over and above any provisions made for reactor control. While nuclear plants are designed for safe operation, containment is provided as additional protection to life and property. This presentation is limited to sodium cooled fast breeder reactors, which at this time constitute the bulk of world research and development effort on fast reactors. Also, there appears to be more concern about the safety of the emerging fast reactor plants than the thermal reactor plants currently in operation.

The excursion phenomenon that may need containment in a hypothetical accident could initiate at the core for a variety of reasons and usually, but not always, propagates inside the primary system, first as a shock wave, second as a sodium momentum, and third as an expanding gas bubble. Primary containment pertains to the absorption and dissipation of explosive effects in the primary system.

Secondary containment pertains to the confinement of radioactive gases and aerosols which may have escaped the primary reactor system (possibly through a plug-jump). It constitutes the second half of the safety system represented by containment.

The primary containment analyses and codes already developed and currently under development at Argonne National Laboratory combine the equations of hydrodynamics with the equations of state. They start with an energy input in the core in the form of temperatures, pressures and internal energy. This is the neutronic input leading to core disassembly. This energy is propagated through the primary system and components (blankets, reflector, grid, reactor vessel, plug, etc.) in a manner so as to provide a constant inventory of the position and deformation of these components at any one time after the start of the excursion. More specifically, the codes' output is in the form of displacements (strains), pressures, velocities, accelerations, densities, and internal energies.

Recently work has started to include in the energy input, the continuing effects of fuel-coolant interactions. The subject analyses and computer codes are two-dimensional. The next developmental step will attempt to modify these codes to provide engineering solutions for three-dimensional (asymmetric) cases.

The treatment of the primary system response terminates with the possible dislocation of the reactor plug. The subject codes ultimately will provide, along with plug displacement, an inventory of sodium spillage into secondary containment. It is important to make safeguard provisions which might permit modest plug movement coupled with effective sodium confinement into the primary system. If this is not possible, sodium spillage above the plug becomes the input for the evaluation of secondary containment.

Secondary containment must then be capable of sustaining the pressures resulting from these sodium fires at stress levels which are safe for the temperatures generated. Adequate evaluation of secondary containment will include aerosole treatment, plutonium products deposition, levels of radiation, and permissible maximum amount of secondary containment gas release over extended periods of time.

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DISCUSSION

Q W. M. VOGGENREITER, Germany

What is the lower limit in the pressure range you can calculate with your hydrodynamic computer program ?

A S. H. FISTEDIS, U. S. A.

In the REXCO-H code the reactor vessel, core barrel, and core support plate are treated as thin shells. There is no lower limit on the pressure range. However, for the core surrounding structures such as core reflector, core blanket, and shield, only the inertia and compressibility effects are included in the calculation. In other words, these structures are treated as compressible fluids. We feel this simplification is justified because: 1. in the reactor power excursion calculation, which provides input to REXCO-H, the strength of material is also not included; 2. the omission of material strength is on the conservative side.

Q J. BOWEN, U. K.

The expansion of the "bubble" is the driving source; should this be taken as adiabatic or isothermal ?

A S. H. FISTEDIS, U. S. A.

Generally, in the types of accidents studied thus far, bubble expansion can be considered adiabatic. However, there have been occasions where a p-v curve to describe the sodium vapor expansion has been based on a fuel-coolant interaction model in which heat transfer effects are included, thus resulting in a nonadiabatic process, but which is treated in the program as an adiabatic process.

Q K. GAST, Germany

Among the remaining problems, you mentioned the subassembly-to-subassembly propagation. Do you intend to use a modified version of REXCO for this problem ?

A S. H. FISTEDIS, U. S. A.

No. REXCO will be employed as the input generator for the subassembly-to-subassembly propagation problem which will be studied by a structural analysis code.

Q M. HÜBEL, Germany

Have you compared your REXCO results with piston-type calculations ? At which pressure rise times could you do the investigation with the simple piston model ?

A S. H. FISTEDIS, U. S. A.

I do not know exactly what you mean by "piston-type calculation". Almost in all text books the authors used plane piston motion to introduce the concept of shock wave into gas dynamics. The basic equations used are conservation equations of mass, momentum and energy; the same as those used in REXCO, except one-dimensional. We have used the REXCO code for 1-D calculations, the results agree with the piston-type calculation.

Q H. HOLTBECKER, JRC Ispra, Italy

Has there been any comparison made between experimental and theoretical input data ?

A S. H. FISTEDIS, U. S. A.

No.

Q H. HOLTBECKER, JRC Ispra, Italy

Can you elaborate a bit on how the core and fuel element support structures are introduced into the code ?

A S. H. FISTEDIS, U. S. A.

The core support structure was approximated by a circular plate which had a flexural rigidity as the actual core support.

Q T. MALMBERG, Germany

In one of your slides you showed various equations-of-state. Have you made calculations with the purpose of comparing these equations regarding the similarity of the geometry and the inertial and boundary condition ?

A S. H. FISTEDIS, U. S. A.

No. Various equations-of-state are for different types of excursions. For example, Eq. (a) is for a totally vaporized core, and Eq. (d) is for sodium-in type of excursion.

Q Z. ZUDANS, U. S. A.

Can you tell us more about how and in what form energy was (or is) introduced in REXCO mathematical model ?

A S. H. FISTEDIS, U. S. A.

The energy was introduced in the reactor power excursion calculation, which provides input to REXCO calculations. The input into REXCO is in the form temperatures, pressures and internal energy.

Q Z. ZUDANS, U. S. A.

What is the approximate pressure-time history introduced in the model ?

A S. H. FISTEDIS, U. S. A.

We did not use pressure-time curves in the REXCO calculations. What we have solved is an initial value problem. For a reactor of the size of FFTF, the vessel will be in dynamic equilibrium about 30-50 msec after the initiation of the excursion.

Q N. J. M. REES, U. K.

Does the REXCO code provide any feedback to the VENUS code to modify the neutronics calculations ?

A S. H. FISTEDIS, U. S. A.

At the present moment, REXCO code does not provide feedback to VENUS. However, work is in progress to link these two programs together, so that VENUS will provide a pressure boundary condition to REXCO, and in return, REXCO provides a displacement boundary condition to VENUS.

Q M. HÜBEL, Germany

In the slides you have shown, the pressure in the middle of the core starts at point zero with some k bars. Am I right in the assumption that you have studied in this example a step-wise pressure input ?

A S. H. FISTEDIS, U. S. A.

REXCO takes input from VENUS or other power excursion codes. Therefore, the zero time on the pressure-time curve shown on the slide corresponds to the time the neutronics have stopped. The problem we solved was an initial value problem.

Q J. R. FELDMEIER, U. S. A.

You stated that the experimental results in the explosive experiment cited gave results of ~ 15% below the REXCO computed results. Is there a reasonable basis for the direction of this ~ 15% difference ?

A S. H. FISTEDIS, U. S. A.

The REXCO-computed pressure exerted on the rigid tank wall was 20% higher than the experimentally recorded gage pressure. The computed value was 27,700 psi compared to a measured pressure of 23,100 psi. The most likely explanation for the discrepancy is that the measure of pressure is too low because of the slow response of the instrumentation system. The natural resonance of the gage is specified as 300 kHz, the gage output is 0.5 pC/psi, and the system frequency response is DC-20 kHz. For the very sharp rise and decay of the shock incident upon the tank wall, the peak pressure will be cut off and the recorded value will tend to be on the low side.

Q K. H. SCHALLER, France

Did you consider the effect "vessel-jump" in the comparison of calculation and post-mortem results of the SL-1 reactor accident ?

A S. H. FISTEDIS, U. S. A.

The committee which evaluated the SL-1 accident took the vessel-jump into account and offered the net slug velocity of 130 ft/sec, which we used in our REXCO calculations. In this reactor, the reactor plug was held down by the reactor vessel. Thus, upon the slug impact, the vessel acquired an upward velocity.

Q K. H. SCHALLER, France

Why did you not mention the problem of the "vessel-jump" in your list of activities to develop ?

A S. H. FISTEDIS, U. S. A.

The computer code was developed for treating FFTF type of reactors. That is, the reactor cover head is fastened to the building - not to the vessel - by holddown bolts. Thus, no SL-1 type of vessel jump can be expected. Any vessel jump that could result from the release of the longitudinal elastic stresses of the vessel can be superimposed to the slug impact for its effects on the reactor plug.

Q K. GAST, Germany

I have a question with regard to sodium spillage following the plug jump. If one takes into account not only the dynamic pressures in the first few milliseconds but also the sustained quasistatic pressure, one might expect rather large sodium spillage and, consequently, a large sodium fire and pressure built up in the containment. To prevent this, do you foresee any additional safeguards like providing an inert atmosphere above the plug for the FFTF ?

A S. H. FISTEDIS, U. S. A.

FFTF provides special design features, such as omega seals, which are intended to confine the sodium inside the primary system even after the reactor plug has been raised by several inches - due to the slug impact - from its original position. Every reactor will probably have similar design features. Also, it can be expected that in a hypothetical accident of this type, the residual pressure of sodium against the plug will ultimately be replaced by the expanding gas bubble of the core.

Q J. ROBEAUX, France

The French program in the field of nuclear safety has been exposed in the communication E 1/5, "Problèmes d'explosions à l'intérieur de récipients de confinement" (D. Costes et al). The physical evolution of the phenomenon and the consequences of the explosion are treated actually using a one-dimensional code. A two-dimensional hydrodynamic code is being developed and will be tested soon. Difficulties arose which give motivation to the following questions.

Which are the limits imposed on the number of different materials and the number of elements per material in order to set the limits of reasonable computation times ?

A S. H. FISTEDIS, U. S. A.

The number of different materials is limited to 20. No limit is imposed on the number of zones per material, but the total number of zones must not exceed 3,000. For the FFTF reactor, we used about 400 zones, the computation time for sodium slug to contact the top head was about 40 minutes in the IBM 360 computer.

Q J. ROBEAUX, France

In this connection, how do you control the evolution of the elements in thin structures (you remember the vessel thickness of "Phoenix" is only 15 mm) ?

A S. H. FISTEDIS, U. S. A.

REXCO-H has many options. One option is to use equations to treat thin vessels. In other words, the vessel wall is not divided into zones in the direction of wall thickness.

Q J. ROBEAUX, France

Did you consider the phenomena of cavitation in the liquids and the spallage (similar to cavitation for solids) in solids ?

A S. H. FISTEDIS, U. S. A.

The cavitation of liquids is considered in the calculations, the spallation of solids is not. This is because the pressure in the reactor excursion is not high enough to cause spallation.

Q J. ROBEAUX, France

Comparisons of computations and experiments have given, in Cadarache, good concordance. Did you already compare experiment and calculation for other type of explosives (pressure Chapman-Jouguet and delineation velocity different). Were these important differences ?

A S. H. FISTEDIS, U. S. A.

The REXCO-H code was run under several different assumed detonation conditions, and no significant differences occured in the resulting pressure distributions in the surrounding water. For example, one method was to assume the detonation wave has passed through the charge before any significant expansion of the charge has taken place. No significant changes resulted in the computed pressure distribution when compared with a second method in which the charge pressure, density, and particle velocity distributions were based upon the Taylor similarity solution. The method finally adopted was a constant burning process in which, for each time cycle of the computation, the energy of the burned portion is added to the cell energy and the resulting conditions are computed from the simultaneous equations-of-state and energy. In each of the methods, the pressure in the surrounding water quickly adjusted to very nearly the same distribution.

Q J. ROBEAUX, France

Did you perform calculations using a vapor explosion (by mixing solid particles of very high temperatures with a cold liquid) as a source ? If yes, have you compared with experiments and which was the concordance ? Which equation-of-state did you use for the vapor ?

A S. H. FISTEDIS, U. S. A.

Yes, we have in two ways. First for whole reactor containment analyses we have used such thermodynamic approaches as intimate mixing of fuel and sodium. Then by decoupling the fuel the sodium is allowed to expand from the equilibrium temperature. This model is essentially a modified Hicks-Menzies approach in which infinite heat transfer rates are assumed initially with subsequent heat transfer cut-off after the maximum temperature of the mixture has been attained. For small geometry cases, we have used a fuel-coolant interaction model. The liquid equation-of-state was based on work performed at the Bell Labs with a modification to include thermal expansion. The two-phase portion was based essentially on the work of Golden and Tokar (ANL-7323). Unfortunately, no experiments exist with which these results can be compared.

Q

J. ROBEAUX, France

Which is the precision you obtain in your energy balance ?

A

S. H. FISTEDIS, U. S. A.

REXCO performs an energy calculation at every time step. This calculation is used as a check on the accuracy of the numerical computation. Since the accuracy of the finite-difference equations depends largely on zone deformations, the deviation of energy also increases with zone distortions. For problems where zone distortions are small, the deviation of energy is about few %; for problems, where zones can be severely distorted, the deviation of energy also increases without limit. At present, we limit the deviation of energy to 10%. When the deviation of energy exceeds 10%, we stop the REXCO calculation. Zone distortions are then eliminated through a rezone process. We have a computer code which will rezone the distorted zones.