operating conditions, reveals its nonphysical character. The field is very flat except for a few cells located between pairs of blocked-off cells near the center of the core where temperatures reach inordinately high values. The temperature difference between two adjacent cells reaches more than 43°C at a location just above the center of the core, which is almost 11 times the temperature differential between the inlet and the outlet. This is clearly a numerical artifact due to the extreme coarseness of the mesh in conjunction with an inadequate level of diffusion in the flow, which is assumed to be laminar. The coarseness of the mesh does not allow any local, secondary flows to be resolved. In a cell with only two vertical faces open to flow, which happens to lie in a region of predominantly vertical velocities, the heat balance is determined by the local heat source and diffusion. If the diffusion coefficient is too small, this must result in exaggerated local temperature gradients and therefore local temperature maximums that are too high. There is little doubt that changing the mesh configuration, e.g., by doubling the number of nodes in each direction, would result in very different local maximum values. In other words, the spatial convergence of the "solution" is highly questionable and is not discussed in Ref. 1.

While the existence of high local temperature maximums between the square "tubes" is explainable and on a very coarse mesh seems inevitable, an isolated maximum of 64.1°C in a wide-open cell near the edge of the core at about the 3 o'clock position appears to have no explanation other than possibly a fluke in the heat source distribution data or a coding error.

Incidentally, the distribution and relative magnitude of the local temperature extremes in the mockup solution is very different from the full-scale solution, which does not support the claim of "thermal similarity" between the two. The mockup solution also contains an unexplainable fluke value (in this case a minimum) of 45.0, which strongly suggests a coding error.

A separate issue of importance regarding the relevance of the results to CANDU reactors is the temperature difference between the inlet and the outlet in the full-scale solutions (Figs. 9 and 12 of Ref. 1). The design moderator flow rate for CANDU-600 (not divulged in Ref. 1) is ~0.94 m^3/s. If a total heat load of 118 MW (as in Table I of Ref. 1) is assumed, the heat balance requires an inlet-outlet temperature difference of 27°C. In the solutions presented in Ref. 1, this difference varies from 4.0°C in the case with the design inlet arrangement (Fig. 9 of Ref. 1) to 4.9°C in the case with the modified inlet arrangement. This raises two questions. First, the >20% difference between the two solutions is not explained. It may signify either a failure of the numerical scheme to conserve energy or a failure of the transient calculation in at least one of the cases to approach a time-independent solution (no criterion of convergence to a steady-state solution is mentioned). Another possibility is a lack of consistency in some assumptions or input data between the two cases. The second problem with the inlet-outlet temperature difference is that it is five or six times less in both solutions than in a CANDU-600. Fath and Hussein mention that difficulties with inlet boundary conditions resulted in too high a flow rate. However, the ratio of the total heat load to the third power of the total flow rate is an important similarity criterion for this type of flow. If the flow rate is five times too large, this ratio is two orders of magnitude too small. This alone would have made the results of Fath and Hussein's computations totally irrelevant to CANDU reactors.

Obviously, any conclusions based on these irrelevant results, such as the assessment of designing details of inlet nozzle placement, bear no weight.

Jacek Szymanski
W. I. Midvidy

Ontario Hydro
Nuclear Safety Department
700 University Avenue
Toronto, Ontario M5G 1X6, Canada

July 24, 1990

REFERENCES

1. H. E. S. FATH and M. A. HUSSEIN, "Moderator Circulation in CANDU Reactors: An Alternative Approach for the Tube Matrix Simulation," *Nucl. Technol.*, **88**, 307 (1989).

RESPONSE TO "COMMENTS ON 'MODERATOR CIRCULATION IN CANDU REACTORS: AN ALTERNATIVE APPROACH FOR THE TUBE MATRIX SIMULATION' "

In response to the comments of Szymanski and Midvidy[1] concerning Ref. 2, I begin by quoting the following from Ref. 2:

> ". . . The results presented here are to be considered as an illustration of the code's capabilities and the effectiveness of the developed approach. A complete simulation can be done whenever enough computer storage is available."

Szymanski and Midvidy's careful investigation drew my attention to two important typographical errors that were used as a basis for Szymanski and Midvidy's criticism. In Fig. 9 of Ref. 2, the temperature spots near the edge of the core at about the 3 o'clock position should read 46.1°C instead of 64.1. Also, in the mockup solution of Fig. 14 of Ref. 2, the temperature spot of 45.0 should read 49°C. All of the arguments based on these typographical errors are not relevant in view of these corrections.

In Szymanski and Midvidy's opinion, the introduced method is not accepted in simulating moderator flow in Canada deuterium uranium (CANDU) reactors because it ignores the effect of the drag forces due to the presence of the tube matrix and because of the crude treatment of the calandria curvilinear boundary. The claim that drag forces are not accounted for is not true. Drag forces are already included[3] in the formulation through boundary conditions and pressure variation around the immersed object. In principle, one can calculate the drag on a blocked cell from the pressure variation around this cell. In the maximum credible accident method, cell pressure is the driving force behind adjusting the divergence in the computational region. Our approximation of the smooth curvilinear calandria surface as a stepped surface is not a reason for rejecting the approach as a whole. In fact, if one has a large computer storage capacity, the consequences of the stepped boundary are highly reduced. On the other hand, Viecelli[4] proposed a method that treats the fluid boundary at an arbitrary curved wall or obstacle that can be easily applied to model the calandria curved surface as well as the calandria tubes. In other words, the method has the potential to expand to represent the actual geometrical features of both the calandria and the calandria tubes without any approximations. Based on this, I find no scientific reason to reject the method presented in Ref. 2.

The boundary conditions in Fig. 5 of Ref. 2, whose presence would show the test problem specifications, unfortunately were dropped during the last stage of preparation. The test problem is that of a flat tank of water, initially stagnant and at 20°C. The obstacle is held at a constant temperature of 40.0°C, and water enters the tank with a 0.1 m/s velocity and 60°C temperature. The fluid in front of the obstacle indeed gets heated, mainly from the obstacle itself. Of course, mixing with the hot inlet water is limited by the physical presence of the obstacle. Keeping that in mind, the predicted solution for this test problem is completely physical.

In their analysis of the Ref. 2 results, Szymanski and Midvidy claimed that the flow velocity in Fig. 3 is highest about midway between the wall and the center whereas it should have been so by the wall. This is an unacceptable interpretation of Fig. 3. In fact, the velocity is highest near the wall (velocity vectors are overlapped), and as the flow circulates, it gains its velocity again as it goes down toward the exit. This is in agreement with the experimentally measured flow pattern in Fig. 7 of Ref. 2. There is a difference, however, in the location of the main vortex, which can be attributed to the treatment of the boundary.

The spatial convergence of the solution was questioned based on the existence of hot spots in the center of the core between adjacent blocked cells. The continuity of the flow is satisfied everywhere on the numerical grid. The appearance of the hot spot in the center of the core is physical in the sense that this is the location of the highest heat load, but it could be overestimated because the mesh was not fine enough to allow for a possible dissipation of such a spot. Contrary to Ref. 1, a finer mesh is believed to give a more dependable result, which does not necessarily mean a lower temperature spot. Only a direct measurement of the temperature fields inside the calandria under normal operating conditions can provide clear evidence of whether or not such hot spots exist.

Regarding the question of whether or not the simulation conserves energy and why the inlet-outlet temperature difference T of a CANDU-600 is not predicted, we calculated T at steady state to be 4.45°C (i.e., when the flow and temperature distributions do not change, within accuracy limits, and between two consecutive cycles) based on our cell dimensions and a mass flow rate calculated using the exit cell area and velocity. The difference between the values of T predicted for the two different jet locations is due to the difference between the mesh dimensions in the x and y directions, which results in a slightly different flow rate in the two cases. In addressing the discrepancy in T between an actual reactor and the modeling results, we attribute this to the different flow rates. The main problem in using an actual flow rate lies in the treatment of the inlet jet. The current code arrangement gives a higher flow rate than the real value since the jet is modeled on a wider cell than the nozzle opening, as indicated on p. 311 of Ref. 2. Code modification to accept unequal mesh spacing will partially solve this problem, as discussed in the conclusion of Ref. 2.

Makarem A. Hussein

University of Wisconsin
Department of Nuclear Engineering and Engineering Physics
1500 Johnson Drive
Madison, Wisconsin 53706-1687

October 23, 1990

REFERENCES

1. J. SZYMANSKI and W. I. MIDVIDY, "Comments on 'Moderator Circulation in CANDU Reactors: An Alternative Approach for the Tube Matrix Simulation,'" *Nucl. Technol.*, **96**, 129 (1991).

2. H. E. S. FATH and M. A. HUSSEIN, "Moderator Circulation in CANDU Reactors: An Alternative Approach for the Tube Matrix Simulation," *Nucl. Technol.*, **88**, 307 (1989).

3. P. I. NAKAYAMA and N. C. ROMERO, *J. Compt. Phys.*, **8**, 230 (1971).

4. J. A. VIECELLI, *J. Compt. Phys.*, **4**, 543 (1969).