THE *NUCLEAR NEWS* INTERVIEW

Larry Townsend: Barge transporting of modular reactors

When the time comes for Generation IV plants to be built, how will the modular parts be delivered to their desired plant locations?

Generation IV nuclear plants are to be modular, have increased safety margins, be suitable for local electrical grid requirements, be competitive in the marketplace, have applications beyond power generation, and be relatively affordable to build.

The first part of that collection of assets—modularity—comes with an attachment—transportability—i.e., how does a modular part, big in size and weighing many tons, get to a plant site?

The Department of Energy decided to study that question and received assistance from university researchers who investigated transport issues for different types of next-generation designs.

Larry Townsend, professor in the Nuclear Engineering Department at the University of Tennessee (UT), investigated the transport of light-water designs, while UT's Larry Miller handled the liquid-metal concept and Andy Kadak, Professor of the Practice, Nuclear Engineering, at the Massachusetts Institute of Technology (MIT), researched the gas reactor concept.

Townsend talked about reactor modularity and transportation issues with Rick Michal, *NN* Senior Editor.

Townsend: The modular reactor building "would cover . . . the barge and weigh nearly 5000 metric tons."

How did your transportation study get started?

The project was started in August 2000 as part of the Department of Energy's Nuclear Energy Research Initiative (NERI) program that granted funds to the University of Tennessee and others to study transportation methods for next-generation reactors. In fact, the title of the grant was "Design and Layout Concepts for Compact Factory-Produced Transportable Generation IV Reactor Systems."

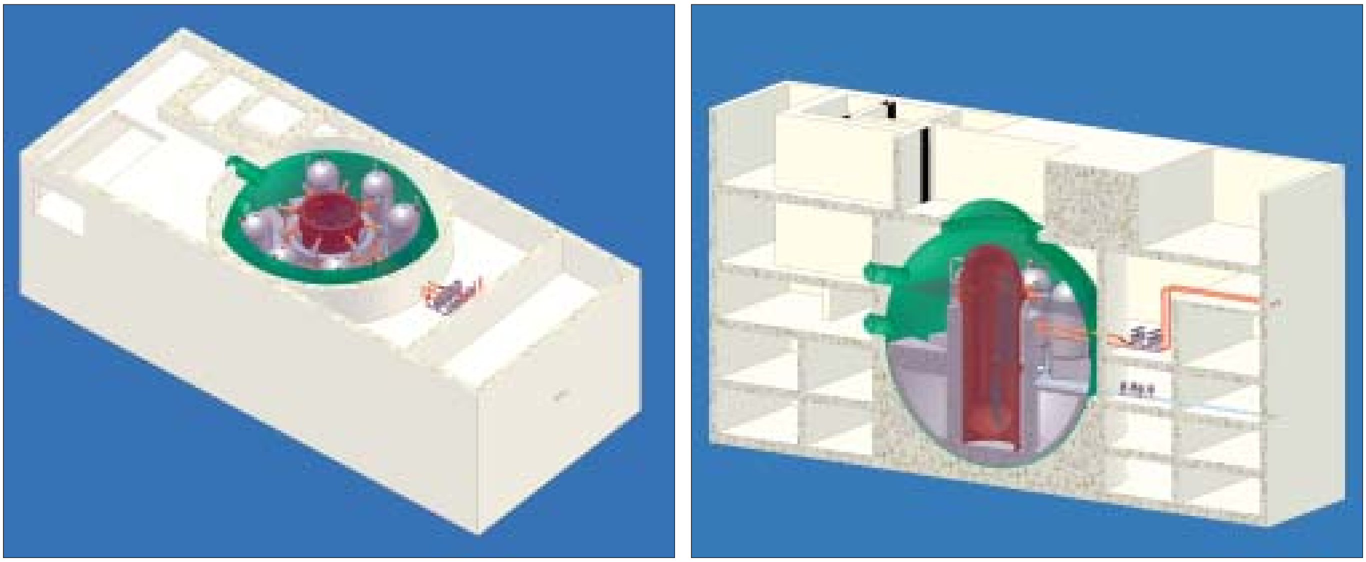
What the project intended to do was develop modular transportable concepts for liquid metal, light water, and gas reactors. The project had three different groups: Larry Miller, a professor in the Nuclear Engineering Department here at the University of Tennessee, handled the liquid metal concept, I did the light water, and Andy Kadak at MIT handled the gas reactor concept.

The idea was to come up with a reactor design that was modular, transportable, and compact, and then decide on a transportation method that could deliver the modular parts to whatever site was picked for a new reactor.

For the particular design I worked on—the light-water reactor—early on we decided to use Westinghouse's IRIS reactor as the baseline concept. Rather than design our own reactor, we took Westinghouse's design to see what could be done with it in terms of addressing issues regarding modularity and transportability.

How did you decide that barge transport was the best method for your design?

Initially, we considered transport by barge, truck, or rail. But for the IRIS reactor, because of the large size of the reactor vessel itself, it quickly became clear that we were limited to barge transport. So, we decided to focus strictly on barge transport. The other two groups—the liquid-metal and gas reactors—focused on truck and rail transport.



Isometric and side cutaway views of the primary reactor building barge (Source: Westinghouse Electric Co.)

Were the reactor groups working in tandem on the project?

Each group worked as a separate unit, but the studies themselves were similar and information was exchanged among the groups several times each month through teleconferences. For Kadak and MIT, most of their effort was focused on transportation by truck. They did, however, look at transporting their components by air in large cargo planes. In the case of Miller's liquid-metal group, most of their effort was spent studying rail transport.

It's important to note that Kadak's MIT gas-reactor group was designing its reactor system from scratch, so much of their focus was on the reactor design itself, with only an eye toward transportability. In the case of Miller's liquid-metal group, much of their effort too was on designing a reactor system and a primary system.

Were there any assumptions in place as you began the project?

Yes, there were. Basically, the DOE told us that if a test reactor were built using a Generation IV design, it likely would be at a DOE site. That site obviously had to be on a river system if the reactor were going to be transported by barge. Early on, the DOE suggested we look at what it would take to get a reactor to DOE sites in Paducah, Ky., and Portsmouth, Ohio.

One preliminary barge design we worked on had both the primary and the secondary sides of the plant on one barge. The problem there was with barge instability. For instance, if all the weight were at one end of the barge, it obviously wouldn't be level. In fact, depending on how the components were arranged, the barge's bow or stern would actually drag on the bottom of the river. But if the weights of the components were evenly distributed on the barge, there would be clearance.

It's important to remember that the components on the primary side weigh more than the secondary side, so balancing the barge was a challenge. At that point, we decided that the primary components would go on one barge and the secondary components on another.

Was there a standard size for the barge?

The initial size of the barge was assumed to be 600 ft in length by 110 ft in width, but we reduced it because we realized we'd need a smaller barge to navigate the Tennessee River, which had smaller size restrictions. Ultimately, the barge dimensions selected were about 98 ft wide by about 230 ft long. This size permitted barge transport from the mouth of the Mississippi River to Chattanooga, Tennessee.

What were the dimensions of the primary and secondary components that could be shipped on a barge?

The primary-side barge would carry the building that houses the reactor, the containment structure, fuel handling equipment and facilities, a shield that surrounds the containment structure, and typical auxiliary building features (see illustrations above). So, in effect, the entire reactor building would fit on one barge. This building would cover the entire surface area of the barge and weigh nearly 5000 metric tons. The fully loaded barge draft—meaning the clearance from the boat's underside to the river bed—was 7.8 ft.

The secondary-side barge contained power conversion equipment and other support and auxiliary equipment, including the turbo-generator unit, six feedwater heaters, two reheater stages, a condenser, and associated major piping runs (see illustrations on page 22). The total weight of this fully loaded barge was estimated at about 2400 metric tons. The barge draft was 3.7 ft. Within the base design, the feedwater heaters were each about 20–33 ft long and about 4–10 ft in diameter. The reheater stages were approximately 10 ft long and 3 ft in diameter. The condenser was about 30 ft long with a diameter of about 26 ft.

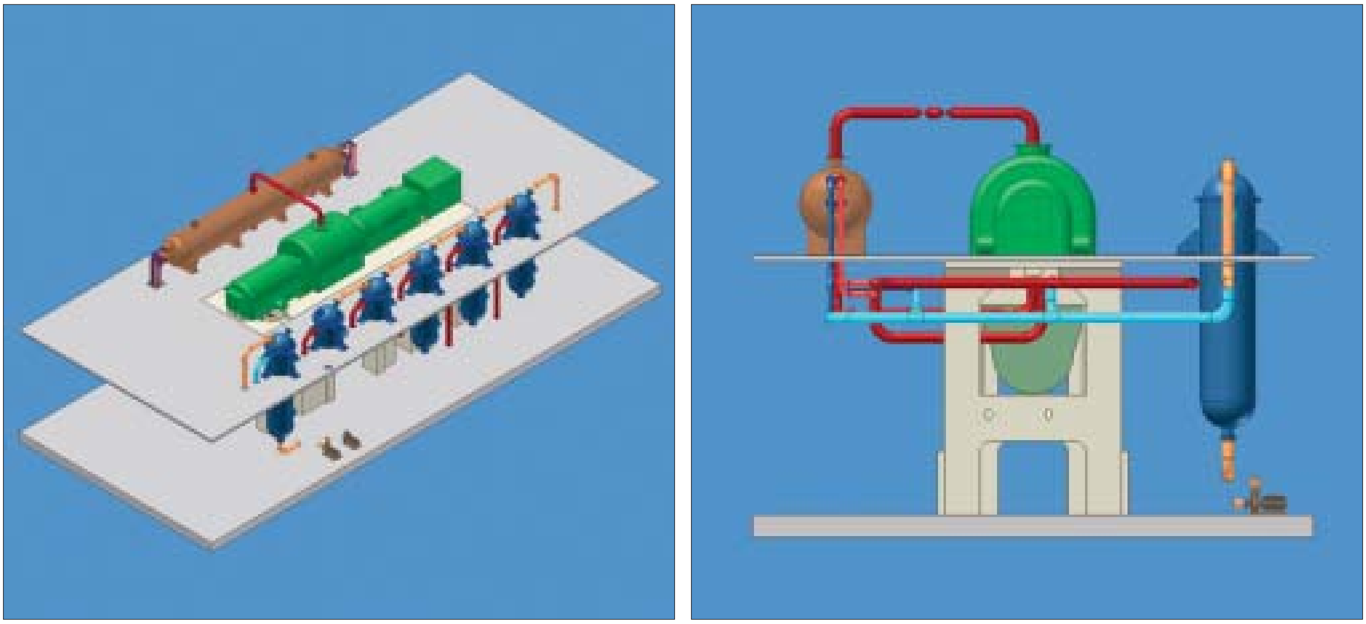
Did your study start from scratch, or did you use some sort of transportation study as a starting point?

We started from scratch. Initially, we worked with a computer code called ORCENT, obtained from Oak Ridge National Laboratory. The code can be used to design secondary systems for light-water reactors. Since Westinghouse hadn't developed a design for the secondary side of IRIS when we started this project, we input the IRIS steam generator values and some primary plant values into ORCENT in order to come up with parameters we needed for secondary component sizing and capacities. For example, we looked at turbines, various condenser designs, feedwater heaters, and reheaters.

It's important to note that the design we developed wasn't something to replace what Westinghouse itself was doing for the actual IRIS secondary side. We came up with our own design because Westinghouse's balance-of-plant design timeline wouldn't support our NERI grant timeline.

What was your plan to access the DOE sites by barge?

We started with the assumption that we would begin in the Gulf of Mexico, having brought the modular components in by barge, from wherever they were manufactured, to the mouth of the Mississippi River. We floated the barge up the Mississippi River to the mouth of the Ohio River, in Alexander County, Ky., and then up the Ohio River to the mouth of the Tennessee River, near Paducah, Ky. It's a 953-mile journey starting from mile marker zero at the Gulf of Mexico. Although there are many locks on the Mississippi River, there are none between the



Isometric and side views of the turbine generator building barge (Source: Westinghouse Electric Co.)

Gulf of Mexico and the mouth of the Ohio River. Generally, the locks constrain the size of the barges, but since there were no locks, there were no constraints.

Due to Congressional legislation some years ago, the Army Corps of Engineers is required to keep the Mississippi dredged to a minimum 9-ft depth at mean-low water. So, we used 9 ft as a minimum water depth. We then acquired navigation charts from the Army for the three rivers—the Mississippi, Ohio, and Tennessee—that our barges would travel. We went through them, chart by chart, looking for obstructions such as locks and dams, bridges and rail crossings, and overhanging cables and power lines, etc.

Using a spreadsheet, we recorded the obstructions from the mouth of the Mississippi all the way up to Knoxville, Tenn. Given this information, we went back and looked at the limitations. In the case of the Mississippi River, the minimal vertical clearance was 80 ft, which was an overhanging cable in Adams County, Miss. The minimal horizontal clearance was 500 ft, which was the Interstate 10 highway bridge across the

Mississippi in Baton Rouge, La.

The reason we established the spreadsheet was that if we didn't want to transport the barge as far as the limiting case—the Interstate 10 bridge, for example—we wanted to know the next limiting case. In other words, if we picked a different site farther up the river, we needed to know the most limiting lock size, overhead clearance, or channel width to be able to reach it. So, we recorded all the obstructions so that we could determine what the maximum barge size would be in order to pass through all those obstructions and get to the point of interest.

What were some of the obstructions you identified on the various routes?

The Ohio River flows into the Mississippi River at mile marker 981 on the Ohio. The Tennessee River merges with the Ohio River at mile marker 933. It's about 50 miles on the Ohio River between these two mile markers, and it turns out that there are two locks between those points. For both of the locks, the dimensions are 600 ft in length and 110 ft in width. The minimal horizontal clearance was regulated by these dimensions up to that point. The minimal water depth in the Ohio River is 9 ft. The minimal vertical clearance is 91 ft at the Irvin S. Cobb Bridge, which is near the Tennessee River at mile marker 937, at Paducah. In other words, if we started in the Gulf of Mexico, went up the Mississippi to the Ohio River, and then on to the mouth of the Tennessee River, the most limiting case for the barges in terms of height would be 91 ft, length would be 600 ft, and width would be 110 ft.

At that point, we looked at the Tennessee River system. From Knoxville to where the Tennessee empties into the Ohio River is 652 miles in length. There were nine main and four auxiliary locks on the river system, and three of those locks were comparatively small, each with a length of 360 ft and a width of 60 ft. So, if we wanted to get from Paducah into the Tennessee River system, we were going to have to reduce the barge size even further.

On the Mississippi, from the standpoint of a fixed obstruction, it was 500 ft down to 60 ft by the time we got onto the Tennessee River. The first set of locks we would run into coming from the mouth of the Tennessee River toward Knoxville would be the Chickamauga lock and dam, in Chattanooga, Tenn., at the 471-mile marker. That would be the limiting case. We could get as far as Chattanooga and then we would have to be no more than 360 ft in length and no more than 60 ft in width. The maximum vertical clearance was 50 ft, near downtown Knoxville.

How did you determine clearance under the barges?

For that, we looked at the weights of all the major components. On the primary side, we took numbers from Westinghouse for the large components—the reactor vessel shell, the internal components, the containment vessel without its head, the minimum amount of concrete and steel inside the containment vessel, and the pedestal—added up the metric tons, added in the assumed weight of the barge, which we took to be 280 metric tons for a barge of that size, and figured out what the draft was by taking the mass of the barge and dividing it by the mass of the water that would fit into the barge.

The reactor vessel shell was approximately 950 metric tons. The internal components of the reactor vessel, including the steam generators, were a little more than 500 metric tons. The containment vessel components weighed about 3200 metric tons. We ended up with a draft of 7.8 ft, which makes transport of the primary components doable. With a 9-ft depth level, it means we would have at least a foot under the bottom of the barge at mean-level water anywhere on the river systems.

On the secondary side, the weight of the unloaded barge was, again, 280 metric tons. The turbo-generator unit was about 1450 metric tons, a 6-ft water heater was 174 metric tons, a reheater was 9 metric tons, and piping was estimated at about 280 metric tons. The total came out to about 2200 metric tons. The secondary was a little bit less than half the weight of the primary. The draft on the secondary barge was only 3.5 ft, given the same width and length considerations, which gives us about a 5.5-ft clearance.

Did you consider any future obstructions on these rivers?

The only thing we could come up with involved the Chickamauga lock and dam in Chattanooga. The lock is old and falling apart. For several years now, the Army Corps of Engineers has been attempting to get funding from Congress to replace it. If the lock were replaced, the Army would replace it with a nominally standard size lock, probably 110 ft wide and 600 ft long. If that were the case, it would remove some of our restrictions. Then we could come up the Tennessee River and get as far as Lenoir City, about 20 miles from Knoxville as the crow flies.

"For this specific job, when we get the barge to the site where the new plant will be located, the component could, in principle, be put on skids and moved around."

To travel these rivers with components loaded on a barge, does a travel plan have to be filed with authorities, or do you just load and go?

Most of the time, I think that cargoes just load and go. When they come to a lock, they just wait their turn.

Was there utility participation in your project?

As we were carrying out our study, the Tennessee Valley Authority (TVA) developed some interest in looking at small, modular reactors for possible future use. Since TVA is headquartered here in Tennessee, we had some interactions with them. They asked us to expand the study to look at how the sizes of components would change if we changed various parameters. For example, if we changed the cooling inlet temperature, or the electrical efficiency of the system, how would it affect the component size? TVA also wanted us to look at barge constraints if we went anywhere within the TVA system, which includes nuclear plant sites in Alabama and Tennessee.

So, we modified the computer code in order to redesign the components. For example, in our original IRIS balance-of-plant design, the reheaters and so forth were horizontal. Westinghouse suggested we make them vertical. So, we had to reorient things, which resulted in changes in sizing of components and the system layout. In the end, we were able to tell TVA that we could send components by barge to their sites.

TVA supported the project financially until December 2003, after our NERI grant ended in August 2003.

Would the components themselves be trucked to and from the barge?

Some years ago, there was a project looking at floating nuclear plants, where the reactor itself would be located on and operated from a barge on water. There was going to be mass production associated with those floating plants, and we assumed the components would probably be trucked in, assembled, and mounted on the barge.

But, more than likely, if mass production of components were going to be done, a construction facility would likely be built on a coast somewhere. It would operate like a shipyard, where the components would be built and then put on a barge. I believe this idea was to be used by Westinghouse in the construction of offshore power plants several decades ago.

For this specific job, when we get the barge to the site where the new plant will be located, the component could, in principle, be put on skids and moved around. But our thought was that a new plant owner would probably want to build some sort of channel up to the site, so that the barge could be brought in to become the foundation of the plant. In that scenario, the barge would be floated in, the components put in place, the water pumped out of the foundation, and the plant would then go on to be completed.

What were the particulars of your NERI grant for this project?

We were funded for three years, until August 2003. The entire project was approximately \$650 000 for all three participating schools for all three years. That broke down to about \$217 000 per year, with each school getting about \$70 000 per year.

What has happened to your research?

Our study was combined with research from the liquid-metal and gas reactor studies and then submitted to the DOE last year. I am sure they are keeping it on hand for the time when new modular reactors become a reality. NN