

Computer Simulation Helps Design New Technique for Nuclear Waste Disposal

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Computer simulation is playing a critical role in designing accelerator-driven transmutation of waste (ATW) systems that may help solve the problem of disposing of nuclear waste. ATW systems are designed to destroy long-lived fission products, reducing the time required for the waste to decay naturally from 10,000 to less than 1,000 years. One of the key components in the ATW concept is a target that is bombarded with protons from a linear accelerator, which in turn produces neutrons that sustain the transmutation of the waste to a stable or less radioactive material. A huge amount of heat is generated during this process, called spallation, which can be removed with a liquid lead-bismuth eutectic (LBE). One of the greatest design challenges in developing a working ATW system is designing the target and its operating conditions to maintain the proper temperature. Researchers at Los Alamos National Laboratory are using finite element analysis based computational fluid dynamics software to analyze target designs produced by engineers at the Institute of Physics and Power Engineering (IPPE) and the Experiment and Design Organization-"Gidropress" (EDO-GP) in Russia. The results have been used to significantly improve succeeding design iterations.

Nuclear waste from commercial power plants contains large quantities of plutonium, other fissionable actinides and long-lived fission products that are potential proliferation concerns and create

challenges for long-term storage. The current United States policy is to store unprocessed spent fuel in a geological repository. Long-term uncertainties are hampering the acceptability and eventual licensing of such a repository and driving up its cost. The greatest concerns are the potential for radiation release and exposure from the spent fuel for tens of thousands of years and the possible diversion and use of the actinides contained in the waste for weapons construction. In the ATW concept, spent fuel would be shipped to a site where the plutonium, transuranics, and selected long-lived fission products would be destroyed by fission or transmutation using an accelerator-driven subcritical burner cooled potentially by liquid LBE and limited pyrotechnical treatment of the spent fuel and residual waste. This approach contrasts with the present-day reprocessing practices in Europe and Japan in which high-purity plutonium is produced and used in the fabrication of fresh mixed oxide fuel that is shipped off-site for use in light water reactors.

Description of the ATW process

An ATW facility consists of three major elements: a high-power proton linear accelerator, a pyrochemical spent fuel treatment system and a liquid lead-bismuth eutectic target producing the high intensity neutron source, and the surrounding subcritical blanket containing the transmutation assemblies. Since significant neutron multiplication and heat

production occurs from the fissioning of the actinides contained in the surrounding transmutation assemblies, adequate means for heat removal must be present. ATW takes advantage of the exceptional properties of liquid LBE, both as a nuclear coolant and as a spallation neutron source. Spallation neutron sources exploit the thermal excitation of heavy nuclei with energetic (GeV) protons and the subsequent decay of these nuclei by evaporation of mainly neutrons with energies of a few MeV. Only a small fraction of the proton's kinetic energy is dissipated into thermal excitation energy while a larger fraction is carried off during the initial intra-nuclear cascade by energetic -- hundreds of MeV -- particles (mainly nucleons). These pre-equilibrium particles, in turn, initiate in a thick target secondary reactions (through an inter-nuclear cascade) producing additional neutrons.

Because of its subcritical mode of operation, ATW is ideally suited as an incinerator of nuclear waste material that is not well characterized, that transmutes poorly or not at all in reactors, that has potentially unstable and hazardous reactivity responses and cannot be isolated and placed in reactors.

The International Science and Technology Center (ISTC) has funded the IPPE and the EDO-GP to design and manufacture a pilot target (Target Circuit One - TC1) that incorporates Russian LBE technology into the ATW concept. The ISTC is an intergovernmental organization dedicated to the nonproliferation of weapons and technologies of mass destruction. The ISTC achieves its objective by funding peaceful scientific and technical research by former weapons scientists in Russia and Commonwealth of Independent States (CIS) countries. Since 1994, the ISTC has provided \$267 million to hundreds of projects employing over 30,000 scientists and technical team members at nearly 400 institutes.

Target description

The target is going to be tested in the 800 MeV, 1.25 mA proton beam at the Los Alamos National Laboratory (LANL) located in Los Alamos, New Mexico, in two years. These target experiments will

provide valuable information on the performance of LBE as both a spallation target and coolant. They will also help to design target/blanket systems for future ATW facilities. As a part of the preparation for the beam-on test, researchers at LANL have carried out a thermal hydraulic analysis for the TC1 target that works as follows. The proton beam from an accelerator is injected into the target through a steel window. Liquid LBE flows in from an outer annulus channel, sweeps over the target window, and flows out through an inner channel. A diffuser plate is placed near the window to enhance flow around the window center, where the heat deposition from the proton beam is the greatest. The heat deposition in the target comes from the results of IPPE's neutronics calculations.

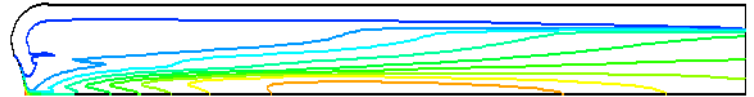


Figure 1 : Calculated temperature distribution in LANL/IPPE/EDO-GP 1MW LBE spallation target. The numerical simulation is carried out using FIDAP.

Engineers began by simulating the company's and competitors' existing elbow designs. The simulation results included diagrams of flow through the elbow that showed pressure at each point. These diagrams showed that pressure loss and turbulence in the elbow was clearly concentrated in the inside corner region. Existing designs at this time all had a sharp inside corner in order to minimize molding expense. But the analysis results showed that after passing this corner, water was directed immediately to the opposite outside wall of the elbow where it was congested, creating a high-pressure zone. Conversely, there was very little flow or pressure on the half of the pipe nearest the inside wall. In effect, water was flowing only in the outside half of the pipe, reducing its effective diameter by 50% and greatly increasing pressure loss.

LANL researchers used FIDAP computational fluid dynamics (CFD) software from Fluent Inc., Lebanon, New Hampshire, to perform the analysis. The finite element method is ideal for generating the complex and irregular geometries required to model ATW targets. FIDAP has been validated by LANL researchers and found to provide accurate predictions

of target thermal hydraulics. A CFD analysis provides fluid velocity, pressure, and temperature values throughout the region of interest for problems with complex geometries and boundary conditions. As part of the analysis, a researcher may change the geometry of the system or the boundary conditions such as inlet velocity and flow rate and view the effect on fluid flow patterns or temperature distributions. CFD can also provide detailed parametric studies that can significantly reduce the amount of experimentation necessary to develop a prototype device and thus reduce design cycle times and costs.

Simulation scenarios

LANL researchers simulated two scenarios, one for nominal beam power of 1 MW with an inlet temperature of 242C and the other for 80% of the nominal power with an inlet temperature of 235C. The flow rate of liquid LBE is fixed at 14.2 m3/h. To date, they have carried out simulations with a 2D axisymmetric model. Studies with a 3D model are underway. The results from the 2D simulations show that the coolant flows through the target smoothly without any recirculation zones. This is important because recirculation may lead to undesired temperature buildup. Because of the diffuser plate,

of coolant plays a key role in cooling the center of the target window, where the energy deposition from the proton beam is the highest.

The calculated temperature ranges from 242 C to 462 C. The highest temperature occurs outside the center of the target window. This temperature range is within the working range for both the LBE coolant and the construction materials. The average temperature at the outlet is 360 C. This temperature increase between the inlet and outlet is consistent with the total energy deposition in the target. There is a 30 to 40 C temperature drop through the window near the window center. The temperature variation in the target window is negligible 5 cm away from the centerline. The temperature in the diffuser plate varies from 250 C to 280 C. This variation is relatively small compared to that in the window. The temperature distribution in the target with 80% nominal power is similar to that with nominal beam condition. The highest temperature still occurs outside the center of the window but is reduced to 412 C. The temperature drop in the window reduces to 25 C.

LANL researchers have carried out a series of analyses on the designs produced by the Russian scientists. Each time the Russians develop a new design iteration they send it to LANL where it is analyzed from a thermal hydraulic standpoint. The results are sent back to Russia and used to improve the existing design. In the last several years, the ATW design has been dramatically improved through this process. Analysis results show that the latest designs are suitable for beam-on testing. The diffuser plate successfully enhances the coolant flow around the window center but still avoids generating recirculation zones downstream. The temperature range is within the proper operation range for both the LBE coolant and the structural materials. LANL researchers are proceeding

ATW Consists of Three Major Functional Blocks

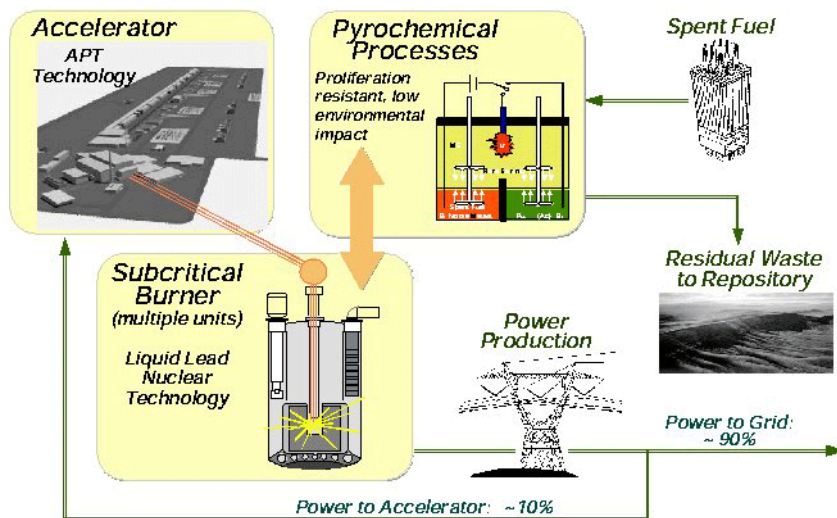


Figure 2 : The conceptual ATW facility. The target is the heart of the subcritical system. This is only a "conceptual" picture and many things are yet to be worked out.

the majority of coolant is forced to sweep over the window center and pass through the center hole of the diffuser plate at high speed (2.0 m/s). This swift flow

with additional work that needs to be carried out prior to testing including development of 3D models and analysis of accident scenarios.