From: Alex Murray
To: Amy Cubbage; Donald Carlson; Howard Faulkner; Stuart Rubin; Undine Shoop
Date: Tue, Jul 31, 2001 2:24 PM
Subject: Draft Summary of trip to Germany

FYI,

NMSS requires that I send out a short summary of an overseas trip soon after returning to the NRC (it is understood the Trip Report will follow several weeks later). I have put together the attached, short summary for this purpose - and I may try to shorten it further. Please let me know if the attached is consistent with your observations by 9 a.m. Wednesday.

Thanx in advance - and I hope to soon figure out what time zone I am in!

Alex.

CC: Bill Gleaves; Eric Leeds; Joseph Giitter; Sharon Steele; Vanice Perin

I-5

Highlights of the Trip to GRS and FZJ (Julich), Germany, July 20-27, 2001

I participated with an NRC team on a four-day visit to organizations and facilities with experience in high temperature reactors (HTRs) similar to the proposed Pebble Bed Modular Reactor (PBMR). The team consisted of Don Carlson, Amy Cubbage, Howard Faulkner, Stuart Rosen, Undine Shoop, and myself. Vanice Perrin was an observer. The representatives of the German organizations were gracious hosts. A short summary of the visit follows, and a more comprehensive trip report will be prepared by the team over the next few weeks.

A joint government/industry effort developed the gas cooled reactors in Germany over the time period 1960-1990. The objective was a high quality product that could be sold by German companies as a competitor to other reactor designs and vendors. The program was technically successful and demonstrated many subtle and intricate aspects of gas reactor technology, including test loops, a research/test reactor (the AVR), and a prototype (the THTR). Changes in government and industry policies in the late 1980s/early 1990s and the success of the light water reactors (LWRs) resulted in decreasing funding and the redirection of the program to decommissioning and waste management.

The German program developed several high temperature designs. Most of these have steam generators. The HTR-M (High Temperature Reactor - Module) forms the basis for the PBMR. The HTR-M is a design based upon the AVR and THTR approach and experience, and has a nominal electrical output of 100 MW and a nominal thermal output of around 200 MW. The core power density is about one-third of a normal LWR. It includes a helium primary circuit with a secondary steam cycle via helium/water steam generators. One or two steam generators would be in the circuit. Nominal helium coolant temperatures would range from 250 to 750 C across the reactor core. A prestressed concrete pressure vessel, wrapped with steel plates and cables, would be used to surround the core. The fuel would consist of the 60 cm "pebbles," containing 10,000-15,000 fuel particles ("kernels"), each coated in multiple layers, and encased in graphite. The principal coating for fission product retention is silicon carbide. Nominal enrichment levels are in the 8-10% range. The core itself would be a moving bed of the fuel pebbles, without incore instrumentation and guide tubes for control rods. The pebbles would be removed from the bottom of the core by gravity, examined (for radioactivity/burnup and integrity), and recycled to the top of the core using pressurized helium via numerous fluted (slotted) fuel tubes. The fuel pebbles are fungible and not individually marked like LWR fuel. Reactivity is controlled by half-height control rods in the primary graphite reflector. Side systems would purify the helium by filters and molecular sieves. Several areas of the plant would require exhaust via HEPA filters for airborne control of graphite fines.

The fuel proceeds in pebble flow through the core. Observations at AVR and THTR noticed some tendencies for the pebbles in the center to move much faster than those at the periphery, resulting in reactivity differences and gas temperature variations of 100-200 C. This had to be addressed empirically by redistributing a greater fraction of the pebbles to the periphery. A core with a higher aspect ratio and internal redistributors might alleviate this phenomena. From the meetings, the researchers recommended determining the pebble flow characteristics as part of a start-up phase.

The design objective is a "catastrophe-free" approach to nuclear safety. The HTR-M plant would be designed with a "diving bell" approach for addressing accidents. In the design, the steam generators are located at an elevation below the core (the rationale being water cannot flow uphill into the core and react during an event). During an accident situation, the control rods are inserted, and the core is isolated (by valves, collapsible penetrations, or nitrogen blanketing) to prevent air and water ingress into the core. A "chimney effect" from a failure in the pressure vessel needs to be avoided as it would lead to excessive graphite corrosion. Due to the elevation, higher coolant temperatures, and an intact vessel, the helium would be trapped and cover the graphite core and fuel pebbles. Subsequent core cooling would be passive, with a peak fuel temperature of about 1,600 C for about 2% of the fuel pebbles, at around 20 or so hours into the event. Excess pressure would be periodically relieved by relief valves, occasional parting of the steel plates around the pressure vessel, or a combination of the two. It was not clear how temperature affected the concrete pressure vessel. Recriticality could occur after several days but at a low power level (0.5-1%), and, thus, some external measures (e.g., adding boron carbide or other neutron poisons) would need to be taken before that time to avoid the criticality. Note that in the NRC regulatory context, several of these features (the shutdown system , the vessel, the isolation features, etc.) would likely be considered active and be assigned a safety significance, requiring management measures and QA/QC programs to ensure their operability.

German industry applied for a license to build a prototype of the HTR-M. After approximately one year, the consortium subsequently withdrew the license application for economic reasons (primarily to focus on LWRs). The regulatory authorities decided to complete the review for archival purposes, and ultimately concluded that the design would have received a license to start construction. A strong confinement or containment would be needed to address external events, such as seismic events, crashes, and explosions. Safety analyses were primarily deterministic - the reactor vessel was assigned a failure rate of 1E-8/yr based upon the German approach and, thus, its failure was considered incredible. However, statistics were used for fuel quality and temperature.

The discussions provided limited information on the proposed PBMR. From a technical perspective, the German researchers noted that there was a less of a temperature gradient across the PBMR core, with coolant temperatures only varying by 200 C or so (i.e., more of the core was hotter). They also thought the helium turbine might require more maintenance than anticipated. Programmatically, the Julich Research Center has provided copies of all HTR documentation and has a task-order arrangement with Eskom. The researchers thought the level of effort was too low and should be significantly increased (the implied numbers were 1-3 FTEs now versus 10-20 thought to be needed). Interactions with PBMR Pty and Exelon were more limited, although Corbin McNeil of Exelon had visited the Julich Research Center two weeks earlier.

Testing at Julich has shown that significant graphite corrosion (i.e., burning) can occur in the presence of air and water. Researchers have successfully coated pebbles and larger graphite surfaces with silicon carbide to reduce this corrosion. Some concerns were expressed by the fuel researchers about the durability of these coatings at the macroscopic scale due to abrasion and thermal cycling.

The principal metallic materials are mild carbon steels and cast iron. Very few higher alloys would be used, perhaps for the steam generator tubes. This is surprising as such steels are ferritic and more prone to helium diffusion effects. Extensive testing was performed at Julich to understand the impact of helium upon the steels, bearings, and other components due to the lack of formation of any surface oxide films. Without the proper design, some steel joints were found to fuse due to the helium. It was not clear why more higher and/or austinitic alloys were not used for better temperature performance and improved properties in a helium environment.

The German firm Nukem provided the fuel for the German reactors. This fuel is identical to that proposed for the PBMR. Fuel particles, or kernels, would be prepared by a modification of the ammonium diuranate (ADU) process that used vibrating nozzles to generate the initial spherical droplets. Some furans may be used. Upon hardening and sintering, these become the fuel particles. A fluidized bed coater applied the various coating layers to these kernels via chemical vapor deposition processes. The first coating consists of soft graphite deposited from ethylene. This coating serves to accommodate the irradiation-induced swelling of the fuel (including recoil) and retains most of the fission product gases. The second coating consists of dense, pyrolytic carbon deposited from propylene. This coating retains most of the fission products and protects (seals) the fuel from hydrogen chloride generated during the formation of the silicon carbide (HCl would have a deleterious effect upon silicon carbide by the formation of volatile metal chlorides). The third coating is silicon carbide, generated from the deposition of methyl silicon chloride; this seals against all fission products. A fourth, outer coating of pyrolytic carbon protects the silicon carbide. Only silver and cesium isotopes have any appreciable diffusion through the silicon carbide, and higher temperatures are usually required (above the 1,500-1,600 C range). The coatings substantially lose their effectiveness above 2,000 C with the breakdown of the silicon carbide layer. One coater can process one kilogram (U) of fuel and apply all four coatings in 8-10 hours. The pebbles are made by mixing the kernels with a pitch/graphite blend, pressing, and firing. An outer, fuel free coat of graphite is similarly applied.

Fuel quality is primarily verified by destructive analyses on selected samples from batches. Experience has developed a set of procedures and processes requiring verbatim compliance for generating the fuel with known quality; typical failure numbers of 1E-4 to 1E-5 were cited for defective pebbles, with one or two defective particles per pebbles. It is not clear how defective pebbles would be found and removed from the HTR-M. It was repeated several times that there is insufficient time for the PBMR programs to develop new procedures and techniques for fuel fabrication.

Spent fuel is placed into casks by gravity, under an air atmosphere. There is no mechanism for close packing the pebbles. Each cask holds about 1,900 pebbles with a heat load of approximately 60 watts (after a minimum of ten years of decay). The casks use mechanical seals.

Mail Envelope Properties (3B66F7D4.4A8 : 14 : 19085)

Subject: Draft Summary of trip to Germany
Creation Date: Tue, Jul 31, 2001 2:24 PM
From: Alex Murray

Created By: AXM2@nrc.gov

Recipients
nrc.gov
owf1_po.OWFN_DO
EJL CC (Eric Leeds)
HJF (Howard Faulkner)

nrc.gov
owf2_po.OWFN_DO
AEC (Amy Cubbage)

nrc.gov
owf4_po.OWFN_DO
USS (Undine Shoop)

nrc.gov
twf4_po.TWFN_DO
BCG CC (Bill Gleaves)
JGG CC (Joseph Giitter)
SAS CC (Sharon Steele)
VAP CC (Vanice Perin)

nrc.gov
twf5_po.TWFN_DO
DEC1 (Donald Carlson)
SDR1 (Stuart Rubin)

Post Office	Route
owf1_po.OWFN_DO	nrc.gov
owf2_po.OWFN_DO	nrc.gov
owf4_po.OWFN_DO	nrc.gov
twf4_po.TWFN_DO	nrc.gov
twf5_po.TWFN_DO	nrc.gov

Files	Size	Date & Time
lt073001pbmr.wpd	14124	Tuesday, July 31, 2001 2:16 PM
MESSAGE	1085	Tuesday, July 31, 2001 2:24 PM

Options

Expiration Date:	None
Priority:	Standard
Reply Requested:	No
Return Notification:	None
Concealed Subject:	No
Security:	Standard