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The Status of the US High-Temperature Gas Reactors

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ABSTRACT

In 2005, the US passed the *Energy Policy Act of 2005* mandating the construction and operation of a high-temperature gas reactor (HTGR) by 2021. This law was passed after a multiyear study by national experts on what future nuclear technologies should be developed. As a result of the Act, the US Congress chose to develop the so-called Next-Generation Nuclear Plant, which was to be an HTGR designed to produce process heat for hydrogen production. Despite high hopes and expectations, the current status is that high temperature reactors have been relegated to completing research programs on advanced fuels, graphite and materials with no plans to build a demonstration plant as required by the US Congress in 2005. There are many reasons behind this diminution of HTGR development, including but not limited to insufficient government funding requirements for research, unrealistically high temperature requirements for the reactor, the delay in the need for a "hydrogen" economy, competition from light water small modular light water reactors, little utility interest in new technologies, very low natural gas prices in the US, and a challenging licensing process in the US for non-water reactors.

1. Introduction

In December 2002, the US Department of Energy (DOE) published *A Technology Roadmap for Generation IV Nuclear Energy Systems* [1], which outlined many future nuclear power energy options. This study was part of a Generation IV International Forum in which nations selected technologies that they would like to develop as part of an international effort. The United States chose high-temperature helium-cooled gas reactors for process heat applications and electricity production. Because of this decision, the US Congress passed the *Energy Policy Act of 2005* (Public Law No. 109–58) [2] to create funding for a project entitled the Next-Generation Nuclear Plant (NGNP), mandating that this plant becomes operational by September 30, 2021. The Idaho National Laboratory was designated as the lead national laboratory to coordinate the research and development (R&D) of high-temperature gas reactor (HTGR) technology. The nuclear industry both in the US and South Africa participated in the R&D, in a shared technology development program.

The program made excellent initial progress, with two alternative HTGRs under development and consideration. The two candidate technologies were the pebble-bed modular reactor (PBMR), being developed in South Africa with Westinghouse, and the prismatic design, being developed by General Atomics and AREVA. The industry formed the NGNP Industry Alliance [3], which consists of industry partners interested in seeing the deployment of HTGRs. In addition to the vendors, these partners include Dow Chemical and Conoco Philips, potential users of NGNP technology. During this period, 33 industry partners joined the NGNP Industry Alliance.

Over the past decade, more than $1 billion USD [3] was spent by the industry in developing the technology, while more than $500 million USD [3] was spent by the US DOE in support of research and technology development. The DOE funding was spent on fuel development, graphite qualification, and materials research, performed by the Idaho National Laboratory and the Oak Ridge National Laboratory. The industry work was largely focused on conceptual designs of the nuclear plant and process heat production facilities.

Although both the pebble-bed and prismatic reactors were under consideration for the NGNP, the Westinghouse PBMR project in South Africa was withdrawn and the DOE chose the prismatic

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design as the reference plant for the NGNP.

In 2011, upon the recommendation of his Nuclear Energy Advisory Council [4], the Secretary of Energy, Steven Chu, decided to reduce the scope of the NGNP project down to an R&D program, forgoing all design activities and thus ensuring that the congressionally mandated operational date of 2021 could not be met. One of the major reasons for reducing the scope of the project was an inability to reach an agreement with the industry in terms of a funding formula to support continued work. As detailed in a letter to the Secretary [5], the industry provided a funding formula that focused on industrial-type investments—namely, support construction, rather than on the basic research needed to justify designs. Table 1 [5] provides detailed funding recommendations that include considerable private sector investment once the design was ready to be built and licensed.

The DOE or government share totaled $1925 million USD, compared with the private sector share of $3621 million USD. The government was unable to agree with this funding formula. The NGNP Industry Alliance proposed a phased partnership commensurate with business risk in that the government would fund the R&D in Phase 1; Phase 2 which addressed preliminary design and licensing activities would be split 80% government and 20% industry; and the final construction Phase 3 would be 100% industry financed. This lack of agreement essentially doomed the project in terms of plant construction. At the time, the industry alliance consisted of 33 companies that were interested in moving the NGNP forward; however, no single company wanted to commit to building the plant without the necessary research and licensing agreements in place, due to the high risks in government funding and Nuclear Regulatory Commission (NRC) approval. The alliance is still actively engaged in supporting the development of HTGRs in the US.

Despite the DOE's withdrawal from the commitment to build the NGNP, an enormous amount of technical work was accomplished from 2006 to the present. All publically available reports on the NGNP are found on the NGNP website [6].

2. Technical accomplishments

Highlights of these technical accomplishments are summarized below.

2.1. Advanced gas reactor (AGR) fuel

The DOE Advanced Gas Reactor (AGR) Fuel Development Program [7] is under Dr. David Petti's leadership, the Idaho National Laboratory developed an AGR fuel consisting of tristructural-isotropic (TRISO)-coated silicon carbide uranium oxycarbide fuel. The capabilities of this fuel include burnups in the range of 150–200 $GW_d \cdot (MTHM)^{-1}$ on a peak time-averaged temperature of 1250 °C, with fissions per initial metal atom (FIMAs) of 19.4% [8]. The fuel has been tested in numerous irradiations at the Idaho National Laboratory. Fig. 1 [9] summarizes the results of three AGR[†] tests.

Zero fuel failures occurred in the AGR1 irradiation. Fig. 2 [9] shows the results of the fission product releases from a test at 1600 °C for the AGR compact 6-4-3. With the exception of ^{110m}Ag, the safety performance of the uranium oxycarbide (UCO) TRISO particles is better by a factor greater than seven when compared with previously manufactured particles.

Table 1
Estimated government funding and private sector cost share [5]. Unit: million USD

Funding year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
One FOAK[a]															
DOE	$221	$244	$252	$324	$317	$173	$123	$84	$75	$26	$26	$24	$12	$12	$12
Private sector[b]			$26	$41	$37	$158	$239	$563	$730	$787	$467	$178	$57	–$36	$365
Two FOAK[a]															
DOE	$221	$244	$252	$324	$317	$207	$160	$114	$107	$30	$28	$25	$12	$12	$12
Private sector[b]			$26	$41	$37	$313	$477	$1121	$1456	$1517	$876	$295	$59	–$127	$672

[a] The acronym FOAK stands for first-of-a-kind.
[b] Not including "in kind" contributions.

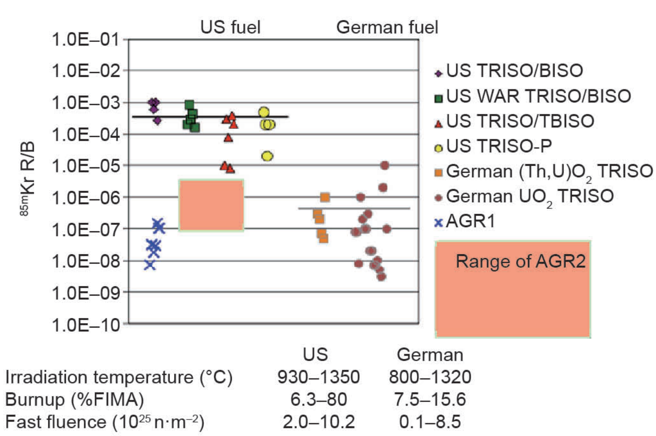

Fig. 1. End-of-life ^{85m}Kr[‡] fission gas release for AGR1 and AGR2, compared to historic German and US TRISO fuel irradiations [9].

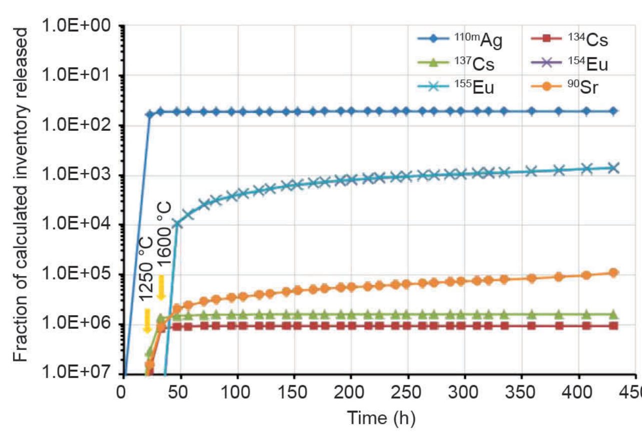

Fig. 2. Fission product releases from the heating of AGR1 compact 6-4-3 at 1600 °C [9].

[†] AGR compacts have been designated by a number to signify the type of irradiation, safety tests, post irradiation evaluations and type of tests the compacts will undergo [8].
[‡] The ^{85m}Kr R/B is a measure of the quality of the fuel relative to releasing fission products. The lower the number is, the better the fuel is.