



FASt TEST Reactor (FASTER) design overview

F. Heidet^{a,*}, C. Grandy^a, T. Sumner^a, H. Belch^a, A. Brunett^a, R. Hill^a, E. Hoffman^a, E. Jin^a, W. Mohamed^a, A. Moisseytsev^a, S. Passerini^a, J. Sienicki^a, R. Vilim^a, S. Hayes^b

^a Argonne National Laboratory, United States

^b Idaho National Laboratory, United States

ARTICLE INFO

Keywords:

Fast reactor
Test reactor
Reactor design
Advanced reactor

1. Introduction

One of the observations of the Advanced Demonstration and Test Reactor (ADTR) planning study (Pettiet al, 2017a; Pettiet al, 2017b), chartered in 2015 by the U.S. Department of Energy as part of the Advanced Reactor Technology campaign, is that current material test reactors are limited to water-cooled conditions. Such reactors are operating near full capacity with damage rates up to 10 dpa/yr. Irradiation capabilities for non-water based reactor technologies are largely lacking worldwide, especially for fast spectrum systems, which require significantly higher flux levels than currently available.

As part of the ADTR study, reactor point designs were developed in order to inform the study and assess performance that could be expected from various types of reactors with respect to four different strategic objectives. One of these strategic objectives was to provide an irradiation test reactor to support development and qualification of fuels, materials, and other important components (e.g., control rods, instrumentation) of both thermal and fast neutron-based advanced reactor systems. The FASt TEST Reactor (FASTER) concept was developed targeting this strategic objective.

The FASTER plant is a pool-type sodium-cooled fast spectrum test reactor that provides high levels of fast and thermal neutron flux for scientific research and development. It mostly relies on previously demonstrated Sodium-cooled Fast Reactor (SFR) technologies, and with power level of 300 MW_{th} it would be able to offer the highest levels of both fast and thermal neutron fluxes available in the world, in a single reactor. The reactor plant has a superheated steam power conversion system, which can provide electrical power to a local grid allowing for recovery of operating costs for the reactor plant. In addition, the

FASTER plant could be used for isotope production or as a heat source, if desired.

The design philosophy and target objectives driving the design of FASTER are discussed in this paper. Details about the ADTR study and its objectives are summarized in Section 2 in order to place FASTER in the context of this study. The approach and objectives driving the design of FASTER are presented in Section 3. An overview of the FASTER concept and of its performance is provided in Section 4. This is supplemented by two companion papers. The first companion paper (Kim and Hofman, 2003) offers an in-depth view of the FASTER core design and of the performance achieved, while the second companion paper (Hofman et al., 1997) discusses the safety analysis performed for FASTER. The contents of the current paper are summarized in Section 5.

2. Advanced Demonstration and Test Reactor study

The ADTR planning study (Pettiet al, 2017a; Pettiet al, 2017b) was performed in 2015/2016 as part of the Advanced Reactor Technology campaign of the U.S. DOE Office of Nuclear Energy. Argonne National Laboratory, Idaho National Laboratory, and Oak Ridge National Laboratory worked collectively on this study, with input from university and industry stakeholders to help guide the study and ensure its relevancy.

The purpose of this planning study was to provide transparent and defensible technology options for a test and/or demonstration reactor (s) to be built to support public policy, innovation and long term commercialization within the context of the DOE's broader commitment to pursuing an “all of the above” clean energy strategy and associated

* Corresponding author.

E-mail address: fheidet@anl.gov (F. Heidet).

<https://doi.org/10.1016/j.pnucene.2018.06.008>

Received 27 February 2018; Received in revised form 1 June 2018; Accepted 12 June 2018

0149-1970/ © 2018 Elsevier Ltd. All rights reserved.

time lines. This planning study included identification of the key features and timing needed for advanced test or demonstration reactors to support research, development, and technology demonstration leading to the commercialization of power plants built upon these advanced reactor platforms.

Advanced reactor technologies have favorable features (e.g., high thermal efficiency, inherent safety) that promote improved performance, have the potential to expand the energy applications, enhance their competitiveness, and improve the sustainability of nuclear energy. They provide the opportunity to extend the impact of nuclear power beyond the traditional electricity market. For the ADTR study, a series of four strategic objectives that span the range of key advanced reactor nuclear energy missions and needs were established: the first three were focused on potential demonstration reactor options (“process heat applications”, “resource utilization and waste reduction”, and “demonstration of a less-mature reactor technology”) and the fourth on irradiation test reactors options. This fourth strategic objective is the one relevant to the FASTER concept.

Goals, criteria, and metrics were established as part of the ADTR study to assess the point design options developed as part of the study against the strategic objectives. Expert judgment was used to elicit goals, criteria, and metrics from a large group of scientists and engineers from the nuclear community spanning industry, national laboratories, and universities. Different teams comprised of industry and national laboratory partners developed point designs within a standardized framework as part of the study.

The assessment for the “process heat” objective identified two discriminators between point designs: suitability and prototypicality for a variety of high temperature applications and commercially relevant scale of the demonstration. The higher maturity options were favored, with the most promising option being the High Temperature Gas-cooled Reactor because of its high outlet temperature ($> 700\text{ }^{\circ}\text{C}$), flexibility for energy applications and its state of development.

The assessment for the resource utilization and waste reduction objective identified two discriminators between point designs: suitability and the prototypicality for demonstrating high natural resource utilization and commercially relevant scale of the demonstration. The higher maturity options were favored, with the most promising option for resource utilization and waste reduction being the Sodium-cooled Fast Reactor because of its ability to efficiently convert uranium and utilize recycled fuel and its state of development.

The ability of engineering demonstration reactors to advance the Technology Readiness Level (TRL) of a less mature reactor technology was assessed. Both the Fluoride-cooled High-temperature Reactor (FHR) and Lead-cooled Fast Reactor (LFR) are low maturity technologies that require significant research, development and demonstration in order to advance their TRL towards eventual commercialization. Significant discriminators between the FHR and LFR point designs related to readiness for an engineering demonstration were not identified in the assessment. The FHR and LFR point designs, as engineering demonstration reactors, scored essentially the same in their ability to increase the technology readiness of these less mature technologies.

The ADTR study identified that mature technologies are required for reliable operations of an irradiation test reactor. Thus, only SFR and a HTGR were examined to determine their ability to provide neutron irradiation services to support nuclear fuels and materials testing for advanced reactor systems. The assessment for the irradiation test reactor objective identified two discriminators between point designs: fast flux levels and irradiation volumes. Overall, the SFR irradiation test reactor design is the preferred option because it can provide very high fast neutron flux as well as high-thermal neutron flux in moderated zones to meet many of the needs of both the fast and thermal reactor developers. The HTGR provide significantly lower fast and thermal fluxes, but the large size could accommodate testing of a wide array of fuels and materials at a very large scale, including half-scale LWR fuel assemblies. Both systems can incorporate multiple test loops to test

fuels and materials under different coolant conditions.

3. Design philosophy for FASTER

The FASTER plant has been designed with extended testing capabilities in mind, while trying to keep it as simple as possible to make it attractive and cost efficient. The main function of the reactor is to provide neutrons for irradiation testing and thus the key design philosophy of FASTER was to require a minimal amount of research and technology development. No significant technology innovations were adopted for the FASTER plant to maintain a high technology readiness level. The FASTER plant will rely upon the liquid metal base technology developed in the U.S. for Experimental Breeder Reactor II (EBR-II), Fast Flux Test Facility (FFTF), Clinch River Breeder Reactor (CRBR), and the Advanced Liquid Metal Reactor (ALMR) program with a special emphasis on the irradiation testing capabilities developed for EBR-II and FFTF. This ensured that FASTER would retain the highest TRL level for a SFR and could be operational as soon as possible. The FASTER core design is not based on any previously existing fast reactor, but it uses materials and dimensions consistent with the U.S. base SFR technology program. The main objective of the FASTER design efforts was to achieve a very high fast flux as well as a significant thermal flux while offering a large number of test locations.

The FASTER concept was designed to achieve the various goals, criteria and metrics defined by the ADTR study. Within the scope of the project, only a point design was needed to inform the study. This means that the FASTER design is not entirely optimized, and that not all aspects and details of the reactor concept have been studied in-depth. However, the concept was brought to a point where the performance claimed, plant details and safety analysis were credible enough to be considered representative of what a SFR could achieve with respect to the irradiation test reactor mission. The list of metrics targeted from the ADTR study is provided in [Table 1](#). The bins used for each metrics are also provided in this table. Weight, scores, and other such details used by the ADTR study are not provided here but can be obtained from ([Pettiet al, 2017a](#)) and ([Pettiet al, 2017b](#)). The FASTER point design scored the highest score on 10 of these metrics, and scored the medium score on the remaining three metrics (project cost, project schedule, and annual operating costs).

In order to maximize the flux levels obtained from FASTER, ternary metallic fuel, U-Pu-Zr, was selected with HT-9 stainless steel for cladding and structural material. Although there is no mandated limit on the weight fraction of plutonium that can be used in the fuel, it was decided to limit it to 20 wt% based on the availability of irradiation data. Currently, no fuel is qualified in the US for use in a SFR but it is estimated that sufficient data exist for ternary metallic fuel with $\leq 20\%$ plutonium to get qualified ([Ludewig and Todosov, 2016](#)) for use in a test reactor. Another incentive for not resorting to higher plutonium weight fraction is the degradation of the fuel thermal conductivity ([Kim and Hofman, 2003](#)) as the plutonium content is increased. This is of particular importance for FASTER due to the high power density during operations.

In order to optimize the reactor performance and obtain a relatively compact core, the zirconium weight fraction in the fuel is assumed to be 6 wt% and the fuel smear density is assumed to be 85%. Using 6 wt% instead of the more traditional 10 wt% ([Hofman et al., 1997](#)) does not affect the performance characteristics of the ternary fuel ([Hofman et al, 2009](#)); additionally, irradiation tests have previously been performed for such a fuel type. The decision to use an 85% smear density, instead of the 75% typically used for metallic fuel ([Hofman et al., 1997](#)), is based on the relatively low peak burnup that will be achieved. Because of the lower fuel burnup, the internal stress applied by the fuel on the cladding as a result of irradiation swelling will be less important than typically observed in metallic fuel that reaches a high burnup. Furthermore, the fission gas plenum length relative to the active fuel length does not need to be as long as what is typically used in SFR design, as

Download English Version:

<https://daneshyari.com/en/article/8084166>

Download Persian Version:

<https://daneshyari.com/article/8084166>

[Daneshyari.com](https://daneshyari.com)