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TCF Base Technology-Specific Final Report:
Used (Spent) Nuclear Fuel Management and Analysis Tool
Milestone: M2OT-21PN0207047
PNNL-40137

TCF-21-24808

Oak Ridge National Laboratory and Pacific Northwest National Laboratory

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Used (Spent) Nuclear Fuel Management and Analysis Tool
TCF-21-24808

PROJECT INFORMATION

TCF Tracking Number: TCF-21-24808-1 (Oak Ridge National Laboratory [ORNL])/ TCF-21-24808-2 (Pacific Northwest National Laboratory [PNNL])
Project Start Date: 12/31/2021 Project End Date: 10/31/2026
Point(s) of Contact at U.S. Department of Energy (DOE): Narvaez, Jorge Luis
Prime Lab: UT-Battelle, LLC/ ORNL
Principal Investigator name(s): Georgeta Radulescu (ORNL) and Justin Clarity (PNNL)

Project Partner(s): Please include any partner lab(s), cost-share partner(s), etc. that participated on the project.

Partner	Agreement Type	Point of Contact
Battelle Memorial Institute/PNNL	Partner DOE national laboratory, party to the Cooperative Research and Development Agreement (CRADA)	Justin Clarity, justin.clarity@pnnl.gov
Electric Power Research Institute (EPRI)	CRADA	Hatice Akkurt, hakkurt@epri.com

FUNDING TABLE

Year or Budget Period	Federal Funding for ORNL		EPRI Cost-Share	
	ORNL Planned/Actual	PNNL Planned/Actual	Planned	Actual
PY1	$50,000/$50,000	$250,000/$250,000	$385,000	$385,000
PY2	$150,000/$150,000	$220,000/$220,000	$385,000	$385,000
PY3	$50,000/$50,000	$200,000/$200,000	$150,000	$150,000
Total	**$250,000/ $250,000**	**$670,000/ $670,000**	**$920,000**	**$920,000**

TYPE OF COST-SHARE *(select all that apply)*
☐ Cash
☒ In-Kind

SOURCE OF TCF BASE FUNDING *(select all that apply to indicate which DOE Program(s)/Program Office(s) funded this project.)*

☐	**Office of Cybersecurity, Energy Security, and Emergency Response (CESER)**
☐	**Office of Fossil Energy and Carbon Management (FECM)**
☒	**Office of Nuclear Energy (NE)**
☐	**Office of Electricity (OE)**
☐	**Office of Clean Energy Demonstration (OCED)**
Office of Energy Efficiency and Renewable Energy (EERE)	
☐	Advanced Manufacturing Office (not for projects funded in FY24 and after) (AMO)
☐	Advanced Materials and Manufacturing Technologies Office (AMMTO)
☐	Bioenergy Technologies Office (BETO)
☐	Building Technologies Office (BTO)
☐	Hydrogen and Fuel Cell Technologies Office (previously Fuel Cell Technologies) (HFTO)
☐	EERE Grid Integration Program (EGI)
☐	Geothermal Technologies Office (GTO)
☐	Industrial Efficiency and Decarbonization Office (IEDO)
☐	Solar Energy Technologies Office (SETO)
☐	Vehicle Technologies Office (VTO)
☐	Water Power Technologies Office (WPTO)
☐	Wind Energy Technologies Office (WETO)

PROJECT SCOPE AND OBJECTIVE

STANDARDS (Storage, Transportation and Disposal Analysis Resource and Data System), formerly known as Used Nuclear Fuel-Storage, Transportation & Disposal Analysis Resource and Data System (UNF-ST&DARDS), provides a comprehensive domestic used nuclear fuel (UNF) system database integrated with nuclear analysis capabilities for storage, transportation, and disposal systems based on the actual characteristics of the as-loaded UNF (e.g., fuel assembly burnup, enrichment, decay time). This project, which had the objective to enhance STANDARDS for use by the nuclear industry, was performed under multi-laboratory Cooperative Research and Development Agreement (CRADA) No. NFE-21-08883 (PNNL CRADA 556) among UT-Battelle, LLC/(Oak Ridge National Laboratory [ORNL]), Battelle Memorial Institute/(Pacific Northwest National Laboratory [PNNL]), and Electric Power Research Institute (EPRI).

The work for this project is organized into a series of tasks aimed at improving the usability of STANDARDS by the commercial nuclear industry. Several tasks were undertaken and are briefly described below.

- Form a group of users to evaluate STANDARDS and provide recommendations for advancements of the tool. This task involved forming a user group with EPRI members to discuss potential items that could be adapted to improve the features for applications that may be unique to commercial applications of STANDARDS (CRADA Task 5). The EPRI User Group was influential in shaping many of the tasks within this project.
- Develop a core simulator interface for STANDARDS (CRADA Task 2). This task is aimed at making fuel inventory data readily accessible for commercial users. This portion of the scope was repurposed at the direction of the EPRI User Group to focus on providing an interface for importing General Counsel (GC)-859 survey data. The task was repurposed because there are many core simulators in use in the commercial nuclear industry and accommodating more than one is impractical. Conversely, all U.S. utilities must report fuel inventory data via the GC-859 survey, and the data are already available for download for all U.S. reporters and stakeholders.
- Provide an improved method of cask loading optimization. Perform a comparison of STANDARDS to EPRI's Cask Loader software and develop any enhancements (CRADA Task 1). The Fast Optimization of Cask-loading Under STANDARDS (FOCUS) tool was developed for STANDARDS out of this portion of the project.
- Develop verification and validation (V&V) for STANDARDS (Task 3). At the direction of the EPRI User Group, this task is aimed at incorporating features that provide installation testing, the validation of STANDARDS decay heat calculations using the EPRI benchmark data, and the incorporation of uncertainties in the fuel burnup and enrichment in calculations.
- Develop on-the-fly (OTF) dose methodology (CRADA Task 4). This task developed methods to perform rapid dose calculations for scenarios that would benefit the commercial nuclear industry. Previously developed for storage and transportation scenarios, these techniques were applied to a generic transfer cask to demonstrate the method.
- Update the user manual to include the features developed from this work (Task 6). The updated user manual is a separate document.
- Complete the final report (Task 7). Task 7 is satisfied with the publication of this report.

BENEFIT TO DOE MISSION

The work described in this report improved and extended the analysis capabilities of the STANDARDS UNF data and analysis tool for fuel assembly decay heat and OTF dose rate analyses. The work also delivered FOCUS, the STANDARDS loading optimization tool, which checks a cask loading against the storage and the transport certificates. The dry storage canisters stored at the reactor sites can therefore be evaluated for transportability. The GC-859 Nuclear Fuel Data Survey, administered by DOE, collects the UNF inventory data that every U.S. utility reports. The import software developed under the CRADA makes the survey data available in the Unified Database (UDB) and in STANDARDS. With these capabilities, STANDARDS is an important resource to assist in managing UNF data and performing safety analyses, as part of DOE Office of Nuclear Energy, Office of Spent Fuel and High-Level Waste Disposition UNF management activities.

GENERATED TECHNICAL DATA AND REPORTS

Release of STANDARDS 6.0.1 including data for the EPRI decay heat measurements.

Draft of the STANDARDS Version 6.0.1 User Manual, PICS:NE Milestone No. M3OT-21PN0207046. 2026. Pacific Northwest National Laboratory. Richland, WA.

Draft Report Supporting PNNL's Final Project Report Milestone, PICS NE Milestone No. M4OT-21OR020702 (ORNL/SPR-2026/4765). 2026. Oak Ridge National Laboratory. Oak Ridge, TN.

TECHNICAL METRICS

SMART Metric Name and Description	Targeted Value	Achieved Value
Demonstrate STANDARDS' automated capability for UNF assembly decay heat calculations	V&V using benchmark fuel assembly decay heat measurements documented in EPRI report no. 3002026549	Decay heat analysis V&V were automated and verified.
Improve availability of UNF data for commercial users	Allow users to import GC-859 data for users with access to the survey form.	Users are now able to download data from the GC-859 website and import it into their local version of STANDARDS.
Run dose rate calculations and generate a library that facilitates OTF dose rate analyses for a generic UNF transfer cask	Data library for OTF dose rate analyses of a UNF transfer cask	A new data library was generated for a generic UNF transfer cask. This library was implemented in STANDARDS to perform dose rate analyses for as-loaded UNF transfer casks.
Obtain industry input on STANDARDS	User group consisting of industry participants interested in using STANDARDS	A user group consisting of EPRI members was established and provided with the STANDARDS tool and training slides for the use of the tool.
Improve the cask loading optimization of STANDARDS	A loading optimization run from the STANDARDS graphical user interface, with the storage and transport certificate limits satisfied	Run loading optimization with FOCUS, with an example provided in the STANDARDS user manual.
Update the user manual for the new features	User manual and web-browser help menu updated for the new features	Draft of the STANDARDS Version 6.0.1 User Manual.

EPRI = Electric Power Research Institute; FOCUS = Fast Optimization of Cask-loading Under STANDARDS; GC = General Counsel; OTF = on-the-fly; STANDARDS = Storage, Transportation and Disposal Analysis Resource and Data System; UNF = used nuclear fuel; V&V = verification and validation.

TECHNICAL WORK SUMMARY AND ACHIEVEMENTS

- A new tool to import GC-859 data was developed for this project. This tool will read the compressed archive files available from the GC-859 survey website to all U.S. reporting

entities and stakeholders. This tool greatly simplifies the process for making data available to authorized users.

- Under Task 1, PNNL compared the STANDARDS loading optimization with EPRI's Cask Loader software and extended the STANDARDS loading optimization to the operational stage. In the first part of Task 1, the comparison showed that the UDB data can be exported to Cask Loader. The STANDARDS OTF dose contributions can also be entered into the Cask Loader dose model. In the second part, PNNL developed FOCUS, the loading optimization for the operational stage, where every assembly is placed in a specific cell in a specific cask. A dry storage system and a transportation package each have a certificate of compliance (CoC) issued by the U.S. Nuclear Regulatory Commission. The CoC defines the approved contents and sets the loading limits. A loading is planned to meet two certificates at two dates: the storage certificate at the load date and the transport certificate at the transport date. As part of the development of FOCUS, fourteen storage and transport CoCs were evaluated for the unique structures of the loading requirements. From these fourteen CoCs, twelve unique loading requirement structures found were considered in the FOCUS interface design. The requirements in a certificate are entered once through the FOCUS graphical user interface (GUI) as a CoC set. The CoC set can then be reused for every campaign that loads that cask system. A run from the GUI uses the CoC set and the assembly data. The fuel records and the decay heat come from the UDB. The dose rates come from the STANDARDS OTF dose tables, which give each assembly's dose contribution in each dose region as a function of the burnup, enrichment, and cooling time. The run finds a cell for every assembly and evaluates every encoded CoC rule for that cell. A search based on simulated annealing then lowers the objective chosen by the user, while every limit is satisfied. A campaign with thousands of assemblies can be evaluated within minutes, so multiple loading scenarios can be evaluated in one session.

- Accurate, time-dependent analysis of UNF characteristics is the single most important type of information necessary for UNF management and decision-making. STANDARDS' features enable calculations of the UNF assembly decay heat with minimum user effort. Automated V&V for various analyses, including fuel assembly decay heat calculations, were implemented in STANDARDS. The project team has reviewed and tested the decay heat analysis pipeline and performed STANDARDS validation calculations for a suite of 270 fuel assembly decay heat benchmark measurements published by EPRI (https://www.epri.com/research/programs/061149/results/3002026549). The validation results demonstrated that the average fuel assembly decay heat calculated with the nominal reactor libraries available in STANDARDS is slightly conservative, within an approximately two standard deviation measurement uncertainty. A higher degree of conservatism, up to approximately 25 percent and 12 percent for boiling water reactor and pressurized water reactor UNF assemblies, respectively, is provided by calculations using the bounding reactor libraries available in STANDARDS. The nominal and bounding reactor

libraries are suitable for different UNF applications (e.g., transportation, long-term storage, disposal).

- OTF dose rate analyses employ a method that only requires radiation source term calculations for fuel assemblies loaded in a specific transportation/storage system. Removing the need for radiation transport calculations reduces the time required to perform dose rate calculations. Before this CRADA, STANDARDS had the capability to perform OTF dose rate analyses for selected UNF transportation and storage systems, but not for a UNF transfer cask. OTF dose rate analysis capability was developed for a generic pressurized water reactor UNF transfer cask. This new STANDARDS capability enables fast evaluations of the worker dose from transfer cask operations as a function of the as-loaded fuel assembly's enrichment, burnup, and cooling time characteristics.

COMMERCIALIZATION ADVANCEMENTS

MARKET ADVANCEMENTS

- Improved UNF data accessibility:
  Ease of UNF data accessibility has been a consistent difficulty for users outside of the U.S. government. Previous methods of data import included adding data to a series of spreadsheets to import them for use with STANDARDS. The addition of the capability to import GC-859 data into the local version of the UDB will greatly ease this. Because the data have to be gathered and reported already, this will allow U.S. users interested in UNF analysis the ability to use it with STANDARDS.

- Improved cask loading optimization techniques:
  FOCUS, the loading optimization developed under this project with the experience gained from using Cask Loader, can plan a whole campaign in one run under the storage and transport certificates. FOCUS calculates each loading's actual dose rate at the location selected as the dose optimization target, from the STANDARDS OTF dose tables. A further FOCUS function is checking an already loaded cask against the certificates, without optimization, which can support transportability evaluations for loaded casks. FOCUS is delivered within the STANDARDS distribution.

- Improvement to the V&V basis of STANDARDS:
  While improvements to the quality assurance basis of STANDARDS were already a priority for the development team, this project afforded an opportunity to partner with EPRI to obtain data for the validation of decay heat measurement data and provide those data in a format that is readily available to STANDARDS users. STANDARDS V&V and UNF assembly decay heat validations were not available prior to the CRADA work. The validation study demonstrated that STANDARDS provides the means to perform fuel assembly decay calculations with minimum effort and offers options for calculations with various degrees of conservatism suitable for different applications (e.g., transportation, storage, and disposal). With STANDARDS, decay heat calculations can be performed for the entire inventory of nuclear fuel discharged from commercial nuclear power plants. This

advancement is aided by the improvements in UNF data availability discussed in the first bullet.

- Demonstration of the OTF dose rate method for an industry application:
  STANDARDS did not have the capability to perform OTF dose rate analyses for a UNF transfer cask. OTF dose rate analyses only require radiation source term calculations for the fuel assemblies loaded in a specific transportation/storage system, which are much faster calculations compared to explicit Monte Carlo radiation transport simulations. Removing the need for radiation transport calculations reduces the time required to perform dose rate calculations. Worker dose assessments using STANDARDS simplify the required calculations and may reduce the conservatism associated with a design-basis fuel assembly typically used in safety evaluations. These evaluations may be used to minimize worker exposure radiation by optimizing UNF loading and transfer operations at commercial nuclear power plants.

COMMERCIALIZATION ACHIEVEMENTS AND SUCCESS STORIES

A version of the STANDARDS UNF data and analysis tool was provided to the EPRI member organizations of the EPRI User Group under U.S. Government license for the purpose of the CRADA. The members are U.S. and European utilities, UNF management organizations, and a storage and transportation system vendor. The STANDARDS team gained insight into the member utilities' view of domestic and international market needs during virtual and one-on-one engagements meetings, including the EPRI Extended Storage Collaboration Workshop. The interaction and collaboration with the EPRI User group reshaped the purpose stated in the CRADA to better suit the industry needs. The User Group's recommendations redirected Task 2 to the GC-859 import, added the burnup and enrichment uncertainties to the calculations, and focused the OTF dose work on cask loading.

CONCLUSION

PATH FORWARD

STANDARDS Version 6.0.1, which will include the improvements and new capabilities developed as part of this project, will be provided to EPRI for additional evaluation. EPRI and DOE will have the opportunity to discuss licensing opportunities of the tool to EPRI members.

LESSONS LEARNED

STANDARDS contains various UNF decay heat, criticality, and shielding analysis models, including generic models and models developed with proprietary data for various UNF transportation, storage, and transfer systems. Therefore, only customized STANDARDS versions without proprietary information can be distributed to interested nuclear industry organizations.

In loading optimization with FOCUS, the requirements in a certificate are entered once as a CoC set, a structured JavaScript Object Notation (JSON) file produced from the

unstructured text of the certificate. That conversion lends itself to large language models, with every value checked by the user, for repeatability and fewer transcription errors. Further improvements can include the decay heat and dose rate of the non-fuel inserts, campaigns planned with the projected discharges in the UDB, and schedules that combine casks with different certificates.