A UNIQUE SOLUTION TO NUCLEAR REACTOR PARAMETER CENTRALIZATION:

STREAMLINING THE SEARCH AND ANALYSIS OF PROLIFERATION ASSISTING REACTORS

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ABSTRACT

To improve current methods of nuclear reactor parameter analysis research a new system of citation and information centralization is proposed. The tool would include long-form summaries of nuclear reactors, a holistic database of nuclear reactor characteristics, associated scoring / filtering tools, and the ability of users to compile and update reactor-specific citations in an open-sourced platform. The alterations and additions to the database would be confined within the Department of Energy, Department of Defense, or partner laboratories. Moreover, the proposal of this inter-agency database would serve to minimize the time needed to summarize and analyze potential proliferation assisting reactors, particularly when source information is limited. The Nuclear Reactor Directory Project would be an open-source inter-agency tool capable of minimizing preliminary research time while remaining accountable to the broader expert community.

INTRODUCTION

The current state of nuclear reactor research is decentralized. This fact is particularly true for generation IV and Chinese-developed reactors. Varying formats for parameter communication combined with infrequent updates from parent developers often makes current methods of information collection and analysis tedious and inaccurate. However, projects like The International Atomic Energy Agency's (IAEA) Advanced Reactors Information System (ARIS) and Power Reactor Information System (PRIS) or The World Nuclear Association's (WNA) Reactor Database attempt to resolve some of these issues.[1, 2, 3]

The most recent of these databases comes in the form of the IAEA's ARIS database. With the stated mission of "foster[ing] information exchange and collaborative research in the area of advanced nuclear reactor technologies." It provides users with an executive summary database of advanced reactors and a corresponding overview from historical IAEA reports. While capable of summarizing reactors in both long-form IAEA reports and in shorter in-page database rows, ARIS is unable to provide users with external citations which, in cases where reactors are under development, can be critical in the search for current reactor specifications. Moreover, ARIS is susceptible to irregular publication and information reporting due to the internal publication requirements needed for citation referencing. That is, reactors categorized as "Under Design" by ARIS, like ABWR-II, VBER-300, and all VVER reactors, can remain untouched in technical and parameter reporting for more than a decade because of the IAEA's limited publications.[1]

In their 2023 report, Ana Getaldić and Dr. Marija Surić Mihić summarize the primary function of the IAEA's database features and capabilities with an emphasis on nuclear and radiological data.[3] The summary report broadly serves to reinforce the authority and accuracy of the IAEA's databases, it also demonstrates the IAEA's limited tools for researchers looking to find technical design or parameter information of reactors that are not generation-IV or research focused. As such, the IAEA is unable to provide users with the web-page-to-user export features needed for multi-platform user analysis research. More specifically, users are unable to download design specifications in formats other than in the Portable Document Format (PDF).

PRIS and WNA's reactor database pose their own limitations. The central focus of these databases is on the summarization and categorization of power plants– not the nuclear reactors themselves. These databases largely focus on providing national governments and international agencies with the information needed to readily understand the features and capabilities of different power plants. Outside of peripheral information relating to the reactors employed by a given power plant, the two databases are limited in their descriptions and technical reports of the reactors themselves. Both databases provide little information regarding reactor specifications outside of its use at a given plant- their focus is power plant analysis, not reactors themselves.[4] A database for nuclear power plants cannot replace a centralize and comprehensive database of nuclear reactors.

Long term, the establishment of a new form of parameter centralization could also serve as a preliminary step in identifying civilian-counter proliferation gap in development. This gap, as outlined by Dr. Man-Sung Yim and Jun Li, can be found in the inhibiting effect nuclear weapons programs have on the development of domestic nuclear energy programs. Understanding the limitations and challenges of individual reactors, according to their country of implementation, would enable counter-proliferation researchers to better identify the national energy programs that are inadvertently limited by weapons development. Both identifying what reactors are being utilized and how those reactors are advancing within national energy programs will promote a more holistic analysis of a given reactor. If proliferation assisting reactors are to be found and studied by researchers and, eventually, the impacted public at large, then a larger emphasis is need on the formatting, accessibility, and resourcing of nuclear reactor parameter information.[5]

Current reactor information systems are limited in four primary ways:

1) Updating reactor parameters irregularly.

2) Providing citations external to the parent organization.

3) Creating systems capable of quantitatively comparing reactor characteristics and developments.

4) Exporting reactor parameter characteristics to user in multiple formats.

The proposed solution of this paper aims to resolve these issues through an expert driven open-sourced database of nuclear parameters. Obtaining and analyzing information on the reactors of national nuclear programs should not be limited by a given country's willingness to participate as is the case of the IAEA's Country Nuclear Power Profiles (CNPP) program – a complete understanding of all potential proliferation supporting reactors is necessary for comprehensive proliferation research.[6]

DIRECTORY ATTRIBUTES & FEATURES

Reactor-Specific Summaries

The Nuclear Reactor Directory Project (NRDP) is comprised of two primary user interfaces: (1) reactor-specific summaries and (2) the over-arching database and directory. The dual platform enables analysis of both specific reactors and broader trends within reactor sub-groups. The NRDP provides a framework for experts to understand and summarize the analysis of peer researchers and and conduct comparitive analysis of nuclear reactors.

A proposed outlook for a reactor-specific summary page, like those created by the IAEA, would primarily provide the user with an executive overview of the reactor, a reference of primary citations, varying export formats, and relevant technical diagrams in one location. With the ability to download all information stated on the page, users would be able to conduct independent analysis without the need for the web page.

Moreover, reactor summary pages serve as the primary point for information validation. Summary information with accompanying citations enables users to directly validate information from primary sources. When information is inaccurate or out-of-date, primary source

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Reactor	Plant or SMNR	Generation	Operational Status	Type	Primary Coolant	Primary Moderator	Primary Company/Group	Country	Thermodynamic Cycle	Decade of First Use	Operational Life	Thermal Output (MWt)
EGP-6	SMNR	X	operational	RBMK	light water	graphite	Institute of Physics and Power Engineering	Russia	TBD	1970	50	29
KLT-40S	SMNR	X	operational	PWR	light water	light water	OKBM Afrikantov	Russia	Rankine	2010	37.5	300
RITM-200	SMNR	X	operational	PWR	light water	light water	OKBM Afrikantov	Russia	Rankine	2010	40	175
TMSR-LF1	SMNR	X	in-construction	MSR	molten salt	graphite	China National Nuclear Coporation	China	TBD	2020	20	10
BREAST-OD-300	SMNR	X	in-construction	LFR	lead	X	Atomenergoprom	Russia	Rankine	2020	30	700
CAREM	SMNR	X	in-construction	PWR	light water	light water	CNEA	Argentina	TBD	2020	60	100
ACP100	SMNR	X	in-construction	PWR	light water	light water	China National Nuclear Coporation	China	TBD	2020	60	385
MMR	SMNR	X	licensing	MSR	molten salt	graphite	Ultra Safe Nuclear Corp.	Canada	TBD	2020	20	15
BWRX-300	SMNR	X	licensing	ABWR	light water	light water	GE Hitachi Nuclear Energy	U.S.	TBD	2020	60	900
NuScale	SMNR	X	licensing	PWR	light water	light water	NuScale Power Inc.	U.S.	Rankine	2020	60	160

Figure 1: Partial example from current prototype of NRDP summary database. This primary page is designed to be capable of exporting summary Data Frames of reactor parameters, conducting preliminary filtering, and enabling users to complete direct searches of the database for reactors or their composing characteristics. All reactors shown in the database are correspondingly hyperlinked to reactor-specific informational pages.

alterations by any user with access is possible with an accompanied citation reference. The utility of the database, then, is directly the result of its open-sourced structure.

Database Features & Scoring Analysis

The second main feature, the over-arching database, allows users to find reactors with shared characteristics and quantitatively compare listed parameters based on individualized needs. Similar, to the reactor-specific pages, export file variety would remain central to the page. The ability to filter the database for reactors with similar characteristics means that export files can be easily limited to only the information necessary to the user. As seen in Figure 1, reactor summary rows will correspondingly be linked to reactor-specific page which can also be found through a directory search engine.

Built into the database page is a comparative analysis tool that aims to quantify how “similar” a reactor is with an external set of user desired specifications – it is a method for finding the reactor(s) best suited for the needs of the user.

One method for quantitative comparative analysis of nuclear reactors parameters comes from weighting desired user specifications. To do this we categorized reactor parameters as describing either qualitative or quantitative characteristics. Qualitative characteristics, generally, include those specifications that do not exist on an explicit numerical spectrum – a reactor either uses molten salt or it does not, the coolant is either heavy water or it is not. These binary categorizations, while not directly capable of capturing potential relationships between qualitative characteristics, enables our system to easily integrate all forms of categorical parameters into a system of numerical analysis. Quantitative characteristics include all parameters that can be described by continuous numerical values – that is characteristics like “reactor generation” of “3” would not be considered quantitative.

To compare these characteristics the users are first asked to select the set of characteristics they wish to analyze, assign a proportional weight to each characteristic (W), and input the desired value they find ideal. All characteristic weights are normalized to find a scaling score factor (W_i) - this is accomplished by dividing individual characteristics weights by the sum of all characteristic weights (W_n).

$$W_i = \frac{W}{W_n} \quad (1)$$

The normalized score is then assigned to each characteristic regardless of qualitative or quantitative categorization. Once complete, each parameter of every reactor is compared with those specified by the user. For those categorized as qualitative a simple binary analysis is conducted where the same characteristic is given a percent deviation score (d) of 0 while those with parameters different from those desired by the user are given a score of 1.

For quantitative characteristics, the absolute difference between the user-desired parameter (v_d) and the value from a reactor of interest (v_r) is found. The difference is then divided by the user-desired parameter to determine the absolute percent deviation (d).

$$d = \frac{|v_d - v_r|}{v_d} \quad (2)$$

Once the difference values are found from a given reactor, the values are then used to assign a similarity sub-score (S) out of 100 to each reactor characteristic.

$$S = (1 - d) \cdot W_i \cdot 100 \quad (3)$$

The summation of all sub-scores (S_i) are used to assign each reactor a total score for comparison (S_n).

$$S_n = \sum_{i=1}^{n} S_i \quad (4)$$

Reactor scores are then ranked and presented to the user. Parameter sub-scores for each analyzed characteristic are correspondingly listed for all reactors.

Currently, a desktop-based Graphical User Interface (GUI) version of the analysis methods described has been prototyped. Input and output interfaces for the prototype can be found in Appendix A and Appendix B respectively. Providing users with the underlying python code and alternative interface could provide users with increased flexibility during research.

FUTURE WORK & LIMITATIONS

The current focus of future work aims to increase partnerships with existing laboratories and research institutions within the counter-proliferation and nuclear engineering fields to improve web-design, expand features, and generate new tools.

Institutional support and ownership would also enable the project to develop with a governing body of proliferation expertise and discretion. Agencies like the National Nuclear Security Administration (NNSA) have, in many cases, the reach to promote the platform and the technical expertise needed to resolve issues of reactor information exchange from both intellectual property and national security perspectives. Systems of accountability for information exchange will need to be established before the project can be implemented. Who should be empowered to make reactor specific edits and what information is available to various groups of researchers is not within our current capacity – higher governing bodies are needed.

A final challenge is acceptance and use. Currently, 40 reactors and their corresponding parameters have been catalogued. The success of NRDP is heavily dependent on the ability of the directory to gain wider adoption. Broader use of the NRDP is dependent on user time investment which, indirectly, is the result of user perceived utility. Further research into a larger baseline of reactor information, in addition to the 40 reactors, could serve to create the foundation of utility desired by initial users. Likewise, the refinement of the desktop analysis tool could serve to meet researchers in a setting preferable for their needs.

CONCLUSION

The creation of a central platform for nuclear reactor research could serve to reduce redundancies and improve short comings in current methods of reactor parameter research. Enabling partner laboratories with shared research aims to readily exchange information collection reduces total time spend on preliminary information centralization and could serve as a common space for increasing inter-laboratory research opportunities.

Research on novel or unique reactors conducted at one laboratory would no longer need to be unnecessarily repeated and the export of parameter information could be easily conducted across various formats and file types. With an orientation towards user-utility, the NRDP aims to create a standardized structure of reactor parameter information exchange while also remaining accountable to the broader technical field through open-sourced alterations. ■

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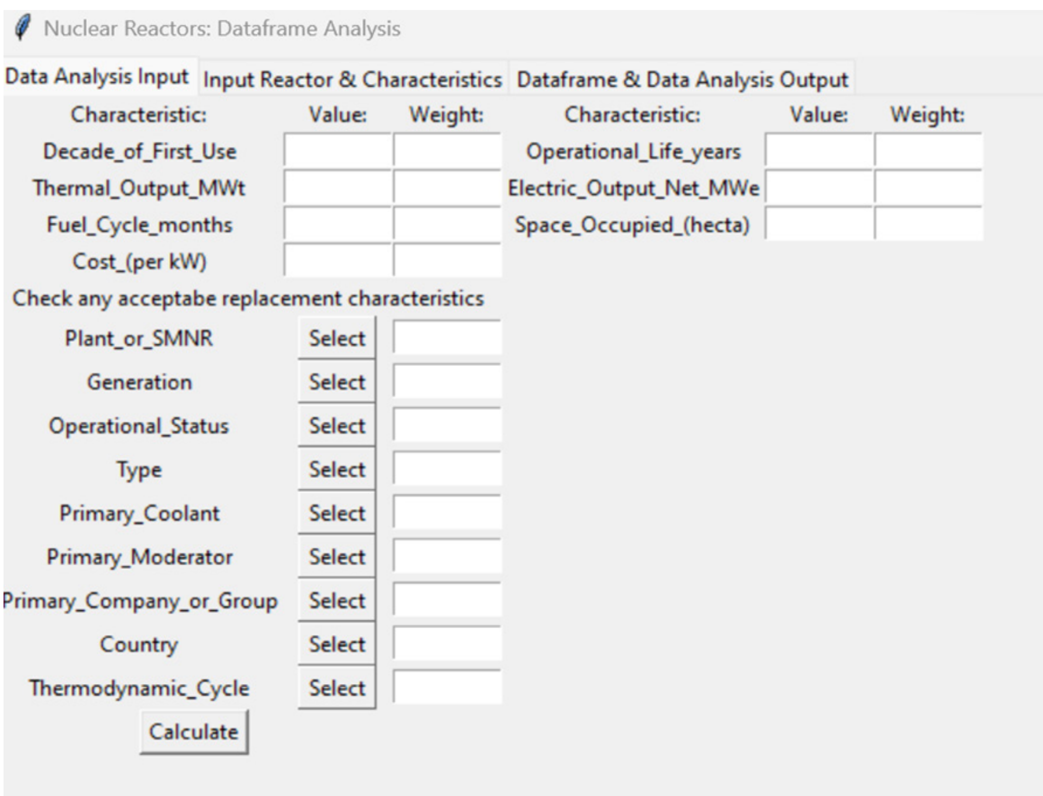
APPENDICES



Appendix A: GUI input example of qualitative and quantitative characteristics. Separate input and selection methods are shown. Relative weight input methods remain the same for both parameters categories.

Reactor		Operational_Life_years	Thermal_Output_MWt	Electric_Output_Net_MWe	Fuel_Cycle_months	Space_Occupied_(hecta)	Total Scores (w/ Weight)
EGP-6		6.25	6.25	6.25	6.25	6.25	100.0
KLT-40S		4.167	0.604	0.982	6.25	6.25	68.129
RITM-200		4.688	1.036	1.375	6.25	6.25	69.474
TMSR-LF1		0.0	0.0	0.0	6.25	6.25	49.845
BREAST-OD-300		2.083	0.259	0.229	6.25	6.25	52.417
CAREM		5.208	1.813	2.546	6.25	6.25	59.412
ACP100		5.208	0.471	0.55	6.25	6.25	56.074
MMR	•••	0.0	0.417	0.0	6.25	6.25	50.262
BWRX-300		5.208	0.201	0.229	6.25	6.25	55.484
NuScale		5.208	1.133	1.528	6.25	6.25	57.714
SMART		5.208	0.549	0.687	6.25	6.25	56.29
VBER-300		5.208	0.198	0.212	6.25	6.25	61.713
APR-1400		5.208	0.046	0.047	6.25	6.25	48.927
ACPR-100		5.208	0.062	0.065	6.25	6.25	48.961
Hualong One		5.208	0.059	0.06	6.25	6.25	48.923
ABWR-II		6.25	0.037	0.042	6.25	6.25	43.829

Appendix B: Partial example of GUI output expressing sub-scores for each reactor under every parameter and total normalized score. Comparison input reactor used was the EGP-6.

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