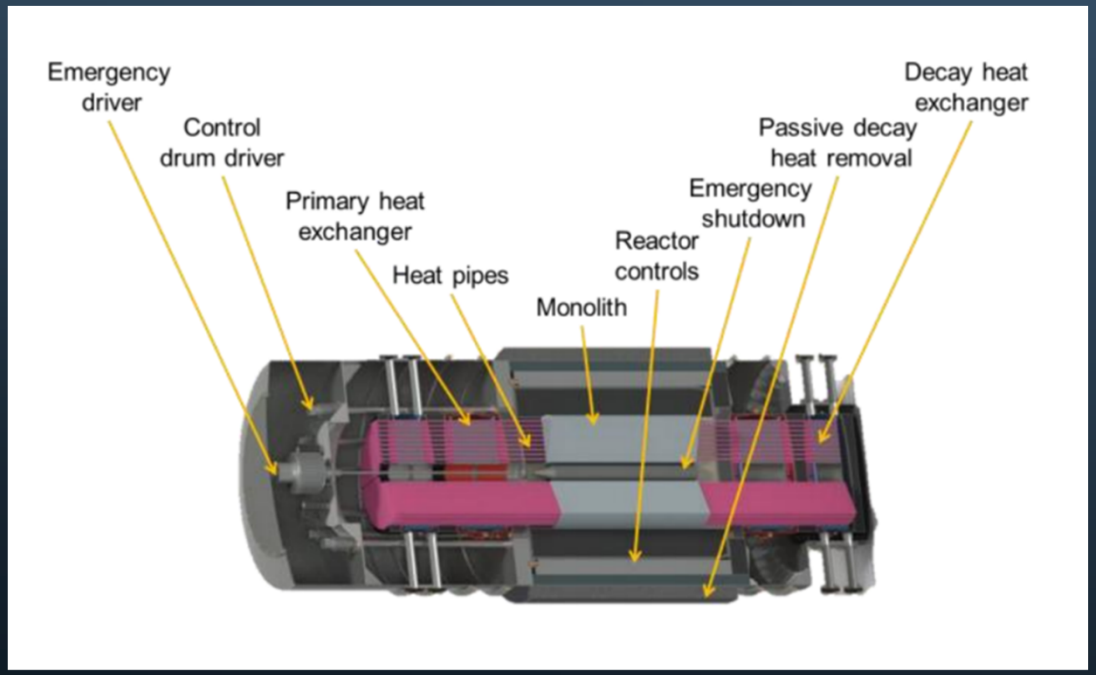
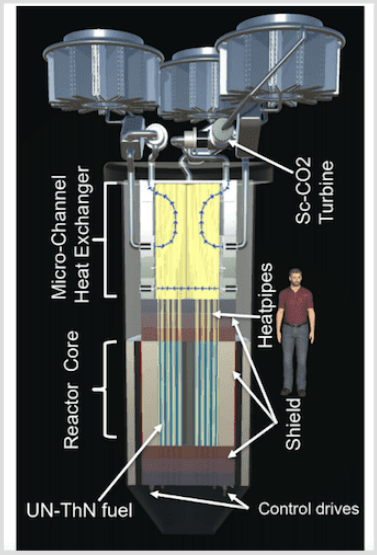
David Medich, Ph.D., CHP
Associate Professor,
Director of WPI NSE Program

U.S. Nuclear Regulatory Commission
34th ANNUAL REGULATORY INFORMATION CONFERENCE
RIC VIRTUAL 2022

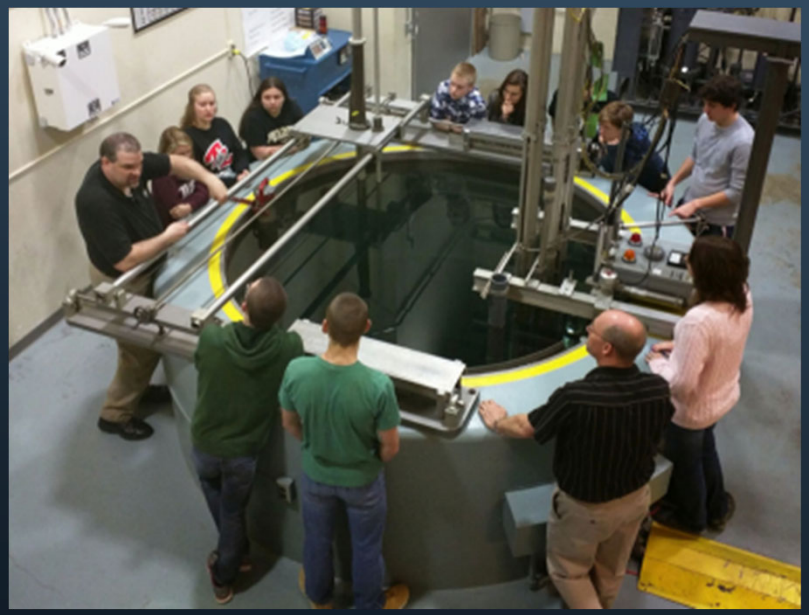
Evaluating Nuclear Microreactors as a Hybrid Next-Generation Source for University Research and Energy





Nuclear Research Reactors

Nuclear research reactors, also known as "non-power" reactors, are used for nuclear training and development programs and to advance research and knowledge in a broad range of fields.



https://engineering.purdue.edu/NE/research/facilities/reactor_html

Personal picture of the UMLRR Core
(Please note that I believe Cherenkov makes everything look cool)

University Research Reactor Background

- U.S. University Research Reactors (URRs) operate between ~0 – 10 MW_{th}
- URRs were developed primarily to study reactor operations and provide greater insight into nuclear physics and engineering
- URRs also a great source for neutrons as a research tool in fields such as physics, chemistry, biology, mechanical engineering, electrical engineering, medicine, agriculture, forensics, and geology.
  - But… *Many of these fields need high neutron intensities* (*about 5MW_{th} or more equivalent*)…

https://www.uml.edu/Engineering/Chemical/Programs/Nuclear/default.aspx

Limits of URRs

The U.S. has built 59 Research Reactors – of which, only 25 remain in operation. Why?

- U.S. University Research Reactors (URR) are based on 1950's / 1960's designs,
- All URRs started operating in period between 1955 to 1975*
  - the first New England URR was at WPI (10 kW_{th}) in 1959
  - The last were UML (1MW_{th}) and University of Utah (100 kW_{th}) in 1975
  - Of US URRs, only two (MURR and MIT) can meet all current research needs!
- This limits scientific research! (e.g., SANS and root imaging)

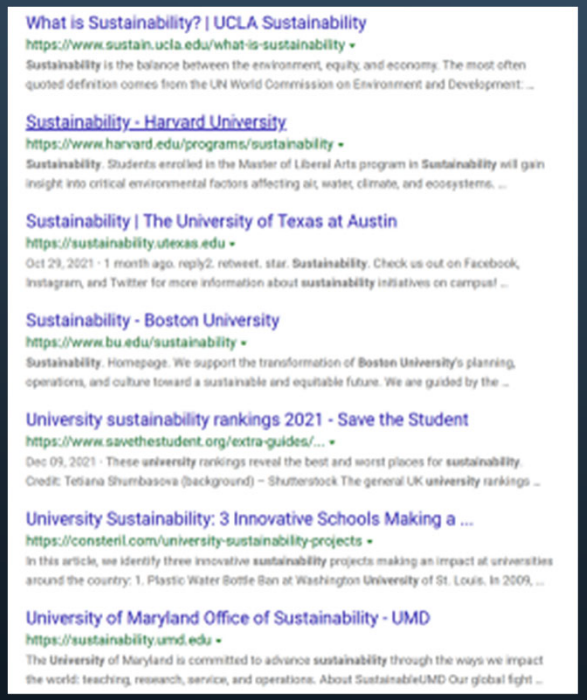
So, our Fleet of Research Reactors are about 50-65 years old and may be underpowered!

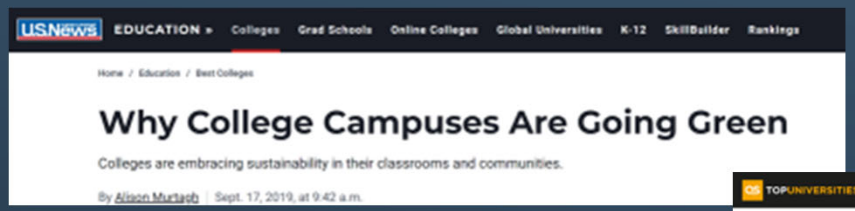
*https://en.wikipedia.org/wiki/List_of_nuclear_research_reactors#United_States

University Sustainability Push

Concurrent with the need for high intensity neutron sources, universities are strongly pushing to become more sustainable and reduce carbon emissions

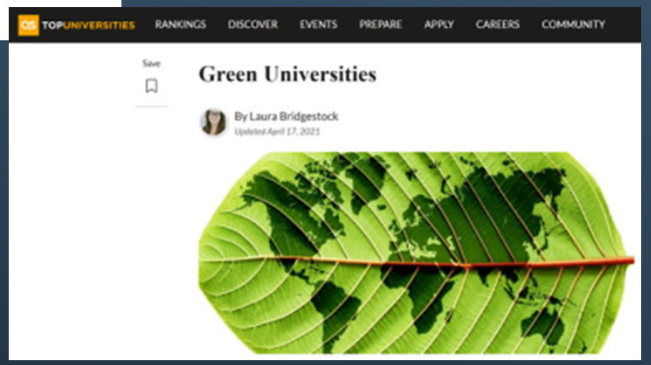
https://www.bing.com/search?q=university+sustainability&first=6&FORM=PERE



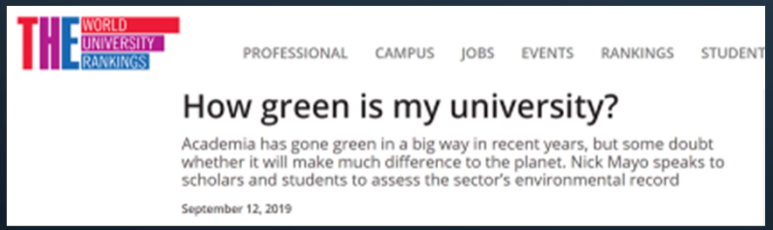


https://www.usnews.com/education/best-colleges/articles/2019-09-17/why-college-campuses-are-going-green

https://universitybusiness.com/colleges-achieve-carbon-neutral-net-zero-sustainability/



https://www.topuniversities.com/student-info/choosing-university/green-universities



https://www.timeshighereducation.com/features/how-green-my-university

Which Brings Us to Nuclear Microreactors

Nuclear Microreactors are a type of G*eneration IV (some can be Gen III+) nuclear reactor currently being developed.* And they are SMALL…*

Generation IV Requirements**:

A Gen IV Reactor Must Demonstrate one or more of the following:

- increased efficiency,
- generation and capture of process heat for other thermal applications,
- increased safety and waste reduction.

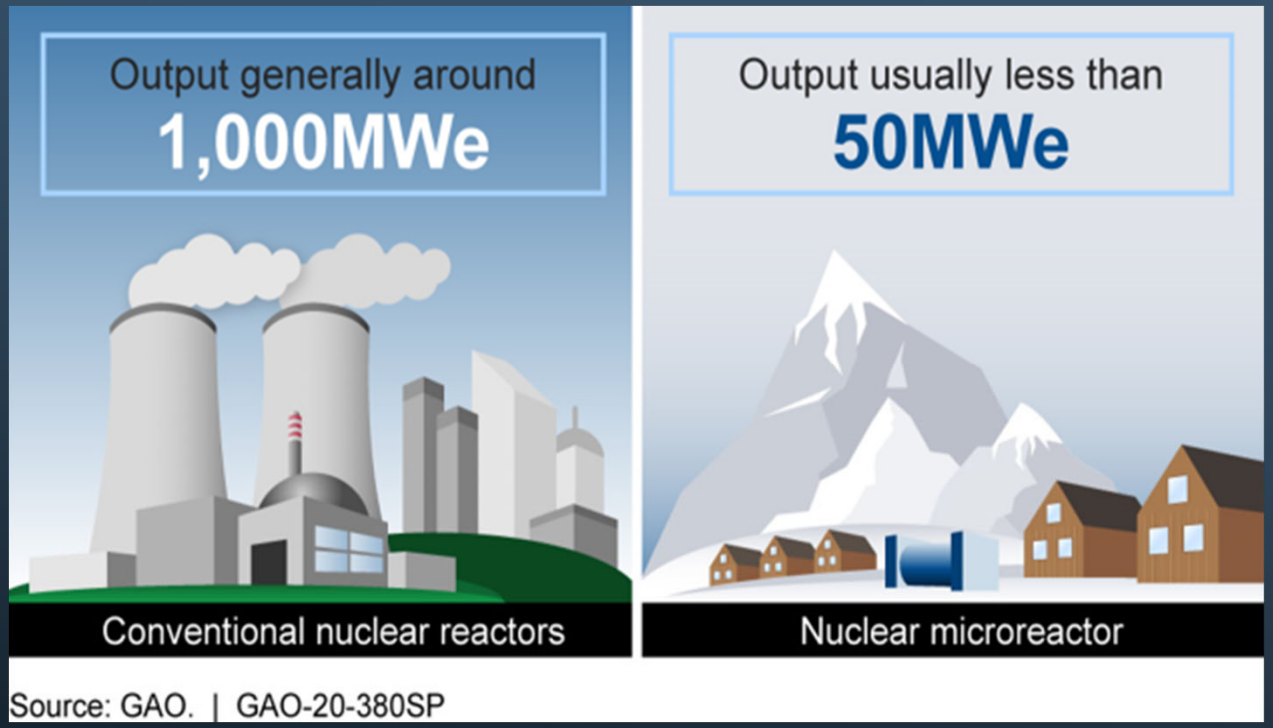
* (but not “micro” sized)

**Yıldız İlhami, Craig MacEachern, “Historic Aspects of Energy”, in Comprehensive Energy Systems, vol(1), pp24-28, 2018

What is a Microreactor?

General Features:

1. **Lower Power Output**
2. Factory Fabricated from Modular Components,
3. Transportable,
4. Self-adjusting / Passive Safety Systems.



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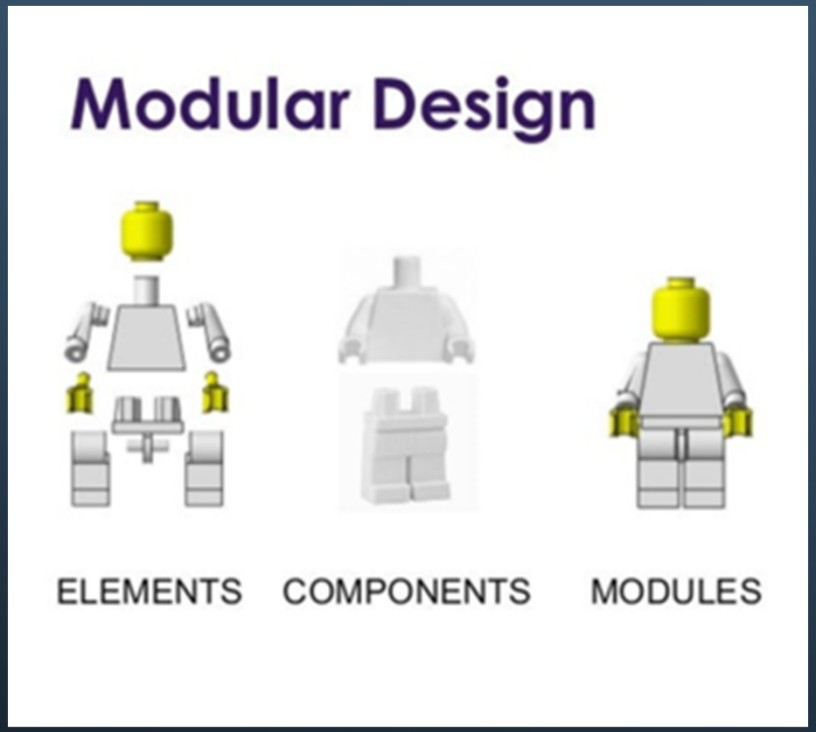

https://www.slideshare.net/Netlight/modular-design-58554891

What is a Microreactor?

General Features:

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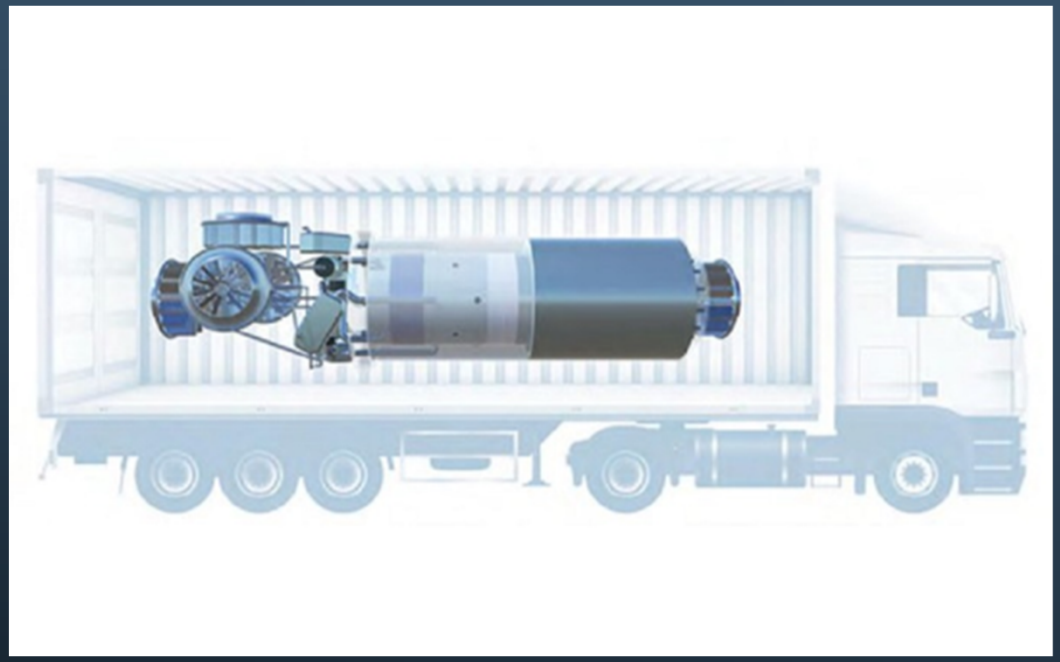
4. Self-adjusting / Passive Safety Systems.



https://inl.gov/trending-topic/microreactors/

What is a Microreactor?

General Features:

1. Lower Power Output
2. Factory Fabricated from Modular Components,
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4. **Self-adjusting / Passive Safety Systems.**

https://nenc.news/in-an-identical-simulator-pilgrim-operators-prep-for-shutdown/

A University Microreactor?

Therefore, a research/power microreactor can be advantageous because:

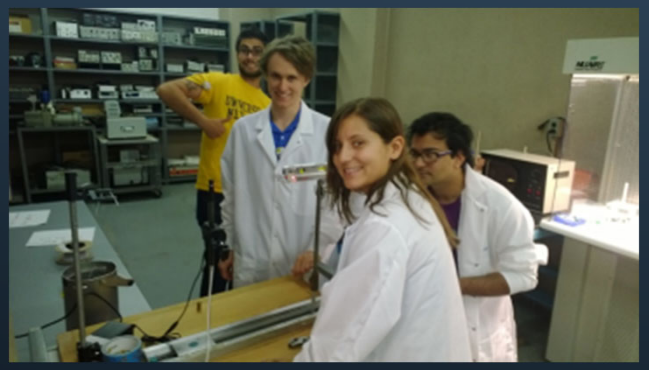
a) They will operate at an equivalent thermal power to high-demand URRs

b) They can meet most university power needs and have a *huge impact* on university carbon-reduction goals,

c) They can be stationed at a university fairly easily and economically,

d) They can be an excellent way to promote public support for next gen reactors given their enhanced safety and the safe operating history of current URRs...

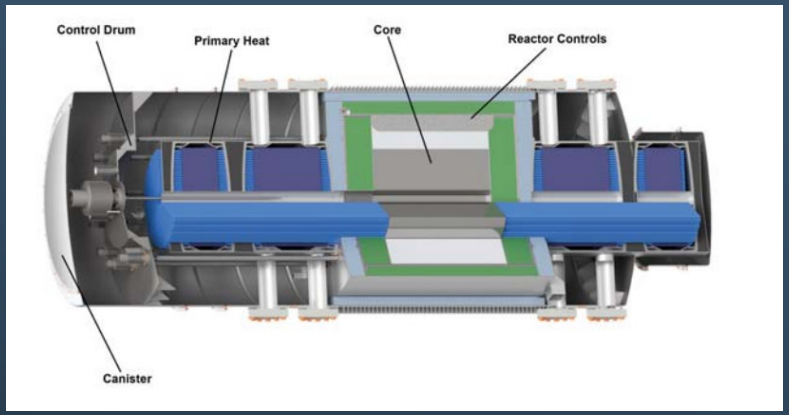
a + b + c + d = Happy Graduate Students



Westinghouse eVinci Microreactor

We are using Westinghouse's eVinci Microreactor* as the basis for our research:

a. It is a VHTR (designs finalized fall of 2021)
b. Uses solid core and advanced heat-pipe technology
c. Power output: up to 5MWe
d. 40-year design life with 3+ year refueling interval
e. Target less than 30 days onsite installation
f. Designed to operate Autonomously
g. Also provides heated water for building heating and superheated water for desalinization and hydrogen generation.



*https://www.westinghousenuclear.com/new-plants/evinci-micro-reactor

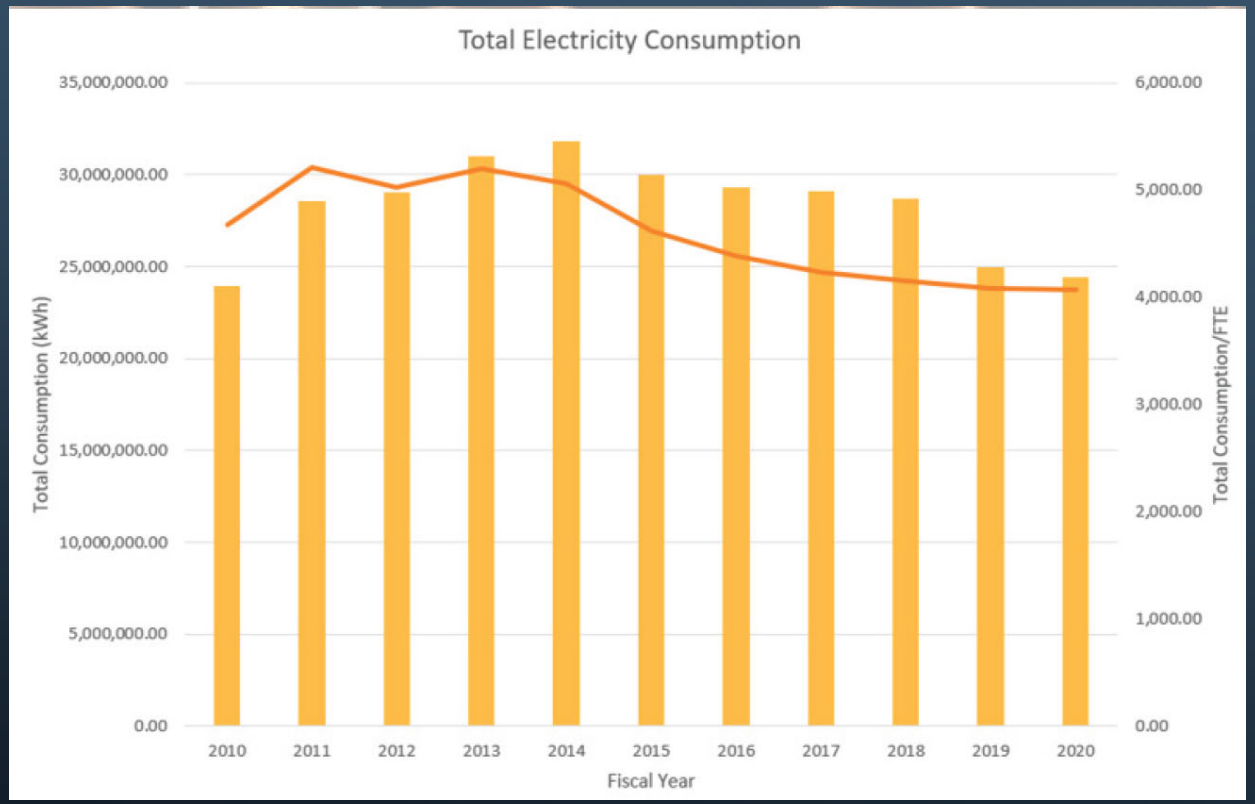
Can eVinci Meet WPI's Energy Needs

Sustainability Analysis: Energy Consumption

WPI Average Energy Use (2020): 2.8 MWe

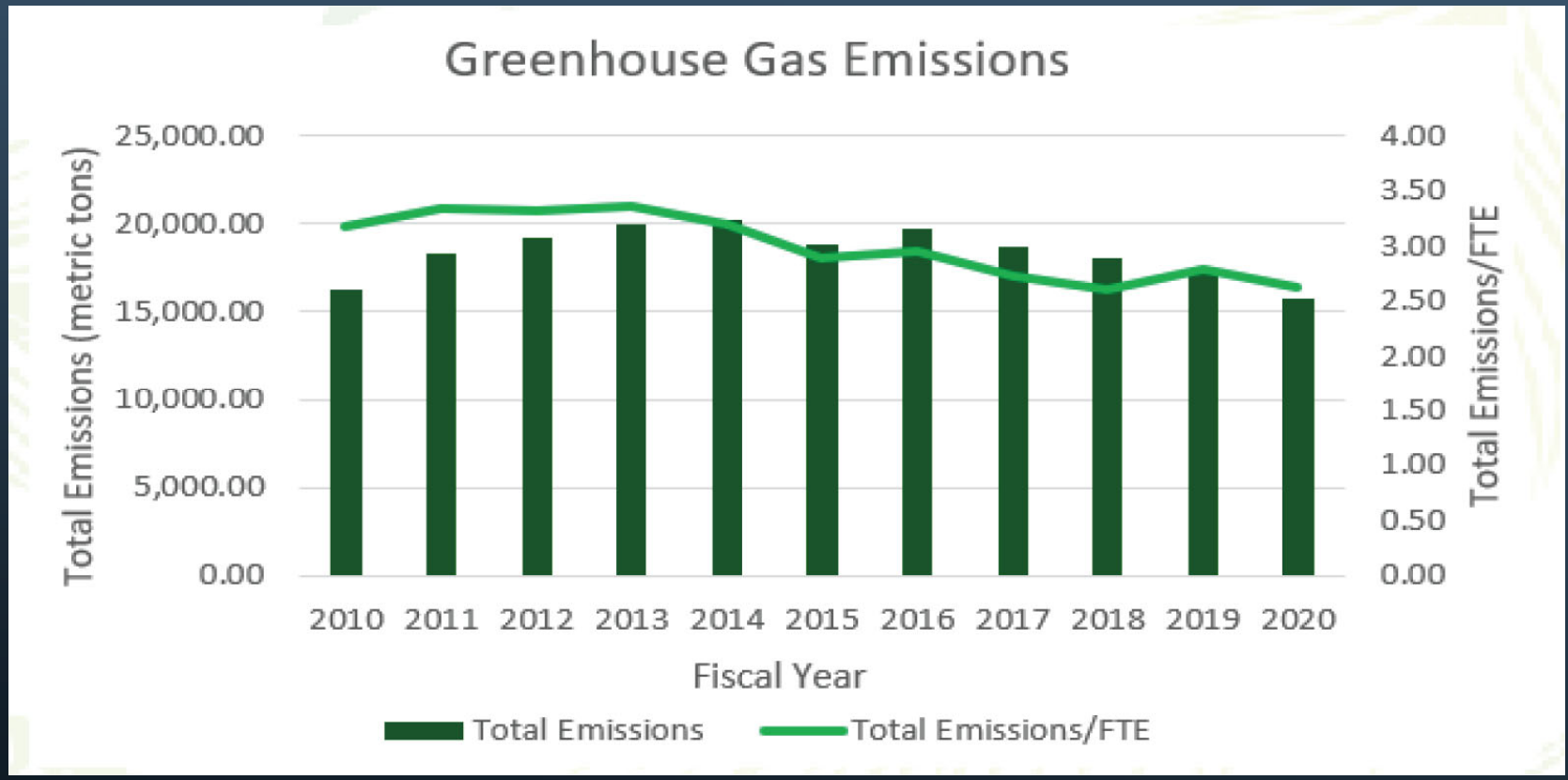
WPI Peak Energy Need (2020): 4.1 MWe

WPI Average Energy Use (2014): 3.5 MWe



Can eVinci Meet WPI's Energy Needs

Sustainability Analysis: Carbon Net-Zero Emissions



Can eVinci Meet WPI's Energy Needs

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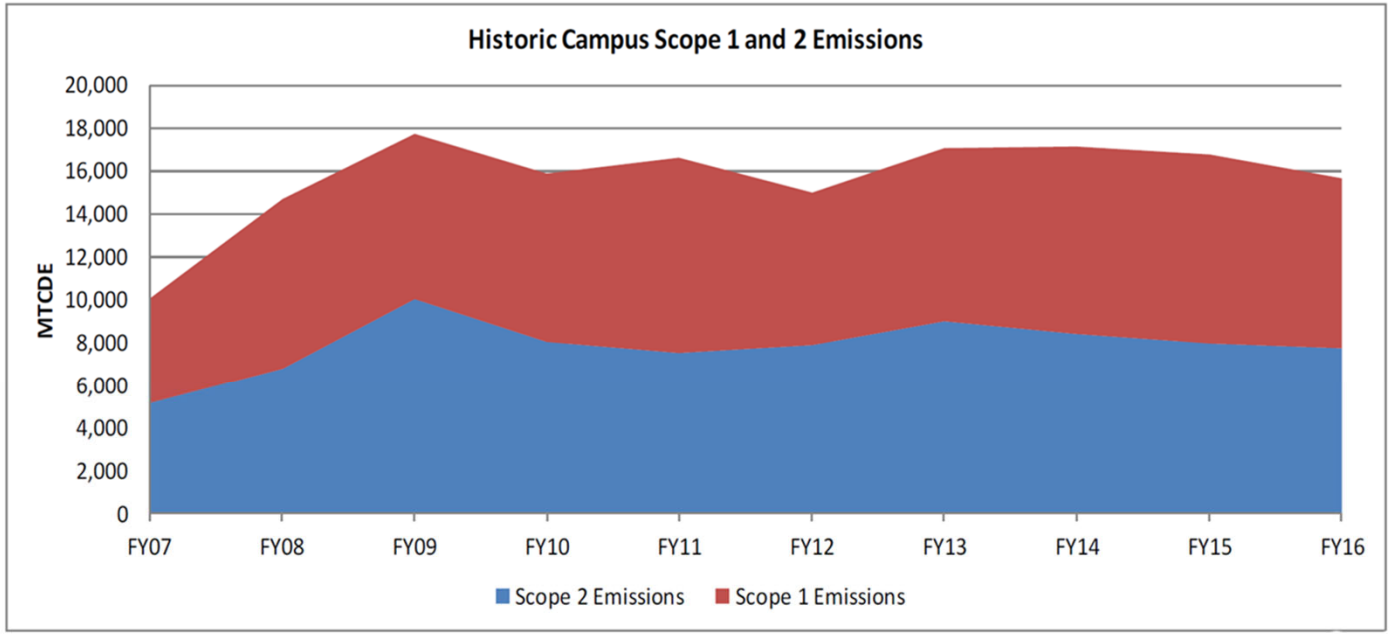
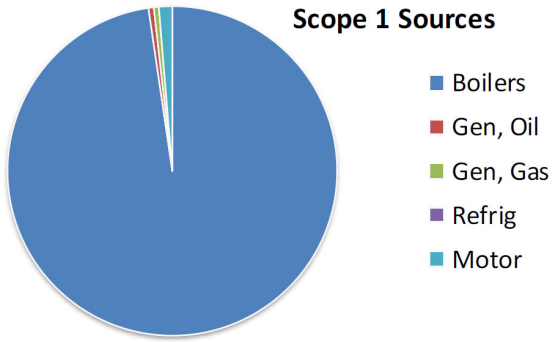




MTCDE = metric tons of carbon dioxide equivalent (from CO_2, methane, and nitrous oxide emissions)

WPI Scope 1 and Scope 2 emissions. Scope 2 is due entirely to electricity use. Scope 1 is due primarily to natural gas for building heating with contributions from campus vehicles and power equipment.

eVinci as a Research Reactor

Much of our research efforts will be to Adapt eVinci as a Research Reactor:

1. Develop MCNP model of eVinci reactor,
2. Use MCNP to determine shielding needs of this reactor model (compare against Westinghouse's Scale model to validate model),
3. Develop research facilities to go with new reactor:
   a) Thermal column: use microcollimator arrays for imaging at higher resolution/fluence rate,
   b) NAA: use fast-scattering materials to enhance ex-core neutron activation ports(?),
   c) Simulate designs for other research facilities (e.g. beamport, cold neutron source)
   d) Structural and safety analysis of adding research facilities to shielding
   e) Westinghouse wants to include a center flux-trap.

Preliminary Data

Too early for MCNP results, but here is some preliminarily data from a previous MQP* team (2017) for a homogeneous SMR core:

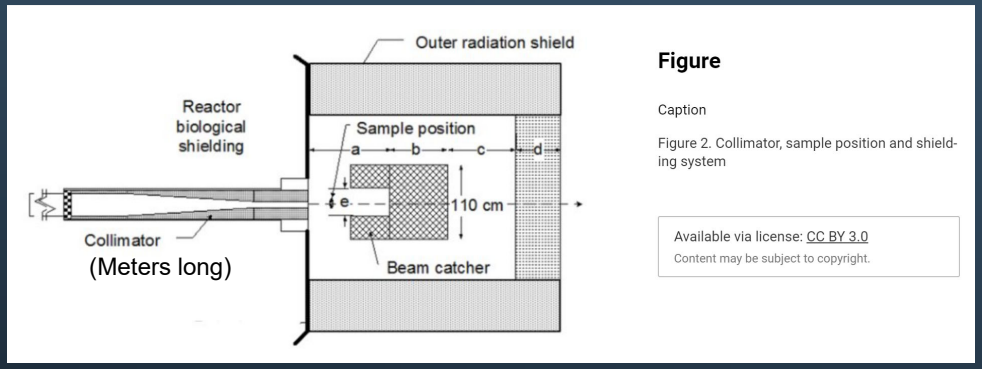
Table 6: Flux comparison

Reactor	Average Flux (n/cm^2)	Maximum Flux (n/cm^2)	Beam Area (cm^2)
UMass Lowell FNI	$1.390 * 10^{11}$	$9.200 * 10^{12}$	900
Graphite Flask	$8.877 * 10^{12}$	$1.692 * 10^{13}$	900
GOFR Design	$1.963 * 10^{13}$	$5.048 * 10^{13}$	1963

*WPI is a project-based university. Students are required to perform an IQP (junior thesis) and MQP (senior thesis / capstone) to graduate. They can also participate as freshman in our Great Problems Seminar (GPS), where they learn how to perform scholarly research and work in groups.

Current Work: Microcollimator Array

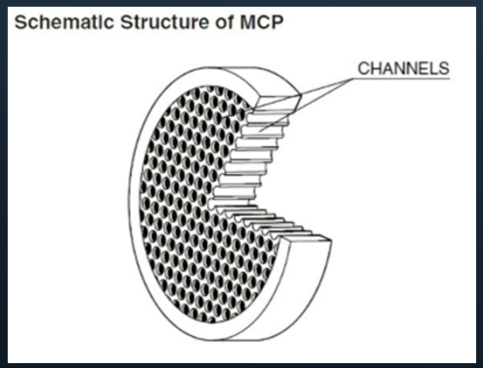
New Results: Neutron Radiography: Replacing the Single (long) Collimator Design with an Ultra-Compact Array of Microcollimators

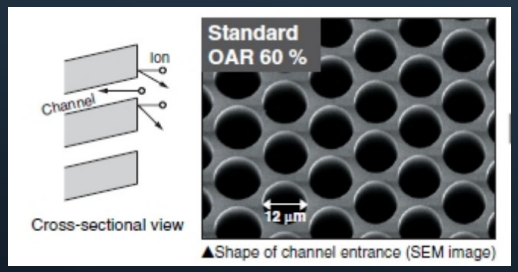


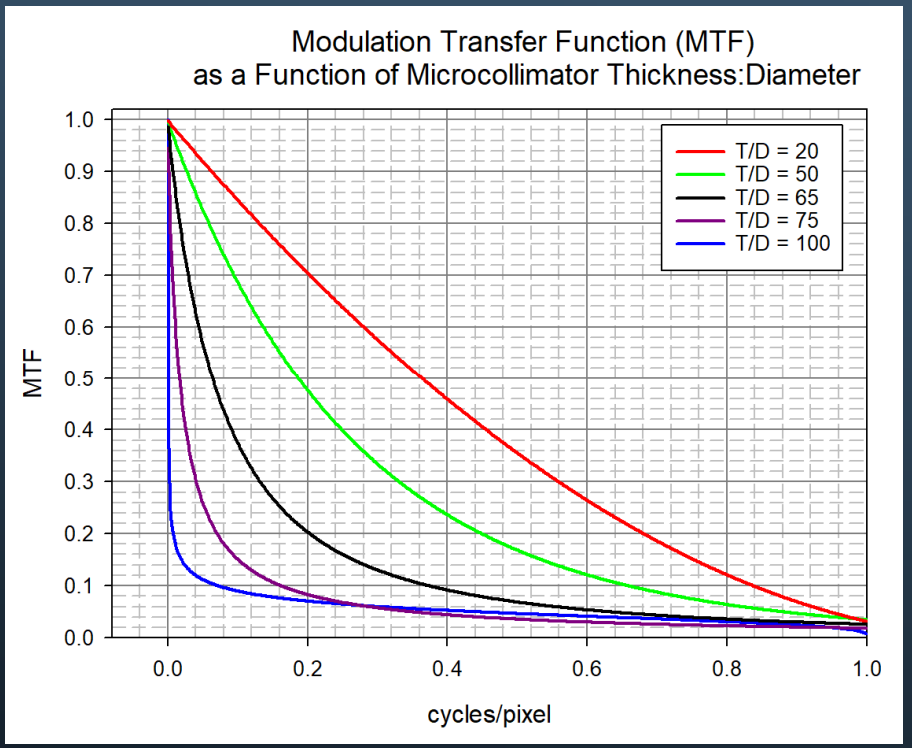
Figure

Caption

Figure 2. Collimator, sample position and shielding system







https://www.hakuto.com.tw/tw/products_d.php?p=219

Licensing Ideas

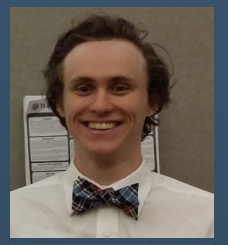
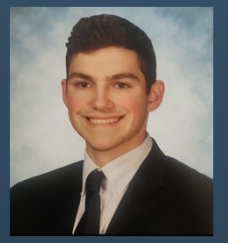
What about licensing a hybrid reactor? Although in the idea stage, we envision:

1. Initially license the reactor as a research reactor (no power),
2. Collect operations data on research reactor,
3. After a couple years and with sufficient operations data, we then could apply for a power reactor license.

https://nucleationcapital.com/nrc-approves-new-approach-to-streamline-advanced-reactor-licensing-process/

Current Student Work enabled by this NRC Award

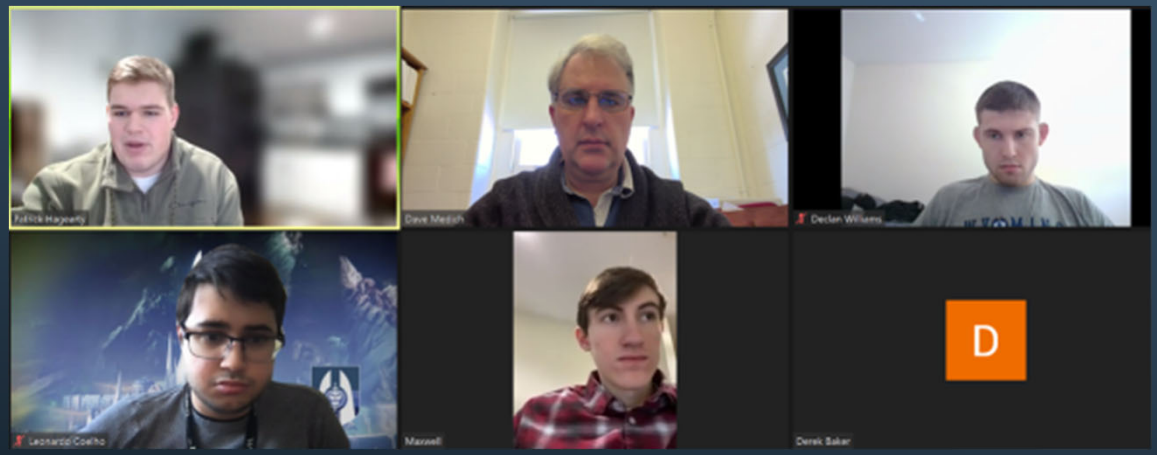
1. Norbert Hugger, Ph.D. student: "*Development of the Research Facilities to Support a Next Generation University Research Reactor*"
2. Seamus Flanagan, senior MQP: "*Modeling a Homogeneous Microreactor core in MCNP6 for First Order Fluence Rate Comparisons agains Current Research Reactors*"
3. Matthew Jalbert, Ph.D. student. "*Development of an Ultracompact Microcollimator Array For Neutron Fluence Enhancement*"
4. Brock Jolicoeur, senior: "*Microcollimator array technology: Determination of the L/D Needed to Achieve a 30um Resolution*"

Current Student Work enabled by this NRC Award

WPI 2021-2022 IQP Team: *"Exploring the feasibility of nuclear microreactors for research and energy at WPI"*

1. Derek Baker,
2. Leonardo Coelho
3. Maxwell Dargie
4. Patrick Hagearty
5. Declan Williams



Impact on Students

Previous student work *(sorry, no pictures)*:

1. WPI MQP: "*Geometry Optimized Flux Reactor (GOFR)*", 2017
   a) Sultan Jilani
   b) Ivan Melnikov
2. WPI GPS Power the World project: "*Campus Sustainability using an SMR*" (2021)
   a) Carlos Cueto
   b) Samuel Darer
   c) Jacob Ewen
   d) Gabriel Garbes
   e) Katee Harrington

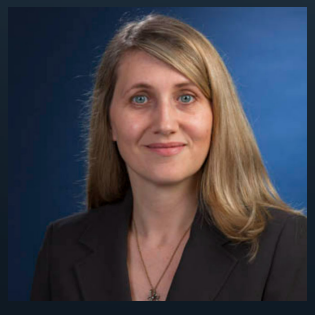
I would like to thank:

NRC Research and Development Grant Award #31310021M0046

NRC Leadership Program: Fellowship Grant Award #31310018M0034

NRC R&D Award CoPI

Derren Rosbach, Ph.D.
Associate Teaching Professor,
Worcester Polytechnic Institute



NRC Fellowship Award CoPIs

Izabela Stroe, Ph.D.
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NRC Fellowship Award CoPIs (cont)

Germano Iannacchione, Ph.D.
Professor,
Worcester Polytechnic Institute

Snehalata Kadam, Ph.D.
Associate Teaching Professor,
Worcester Polytechnic Institute

Questions?