

I'm Phil Sharpe. I lead a research program at Idaho National Laboratory (INL). INL and our fellow Department of Energy laboratories are developing advanced nuclear energy technologies. I'm here with a team of scientists involved in this effort. AMA!

INL<sub>AMA</sub><sup>1</sup>*andr/ScienceAMAs*<sup>1</sup>

<sup>1</sup>Affiliation not available

April 17, 2023

### Abstract

Hi Reddit! My name is Phil Sharpe and I am here today with a few of my colleagues from Idaho National Laboratory (INL) and the Gateway for Accelerated Innovation in Nuclear (GAIN). This is Nuclear Science Week, so we thought it would be great to start a conversation about the future of advanced nuclear energy, including reactor designs, fuel types, industry engagement, and some of the ideal uses for advanced nuclear systems. Commercial nuclear power currently provides nearly 60 percent of the U.S. emission-free power, according to the Nuclear Energy Institute. INL is the U.S. Department of Energy's lead nuclear energy laboratory. INL experts are developing, testing and demonstrating new fuels and materials, reactor systems, advanced nuclear energy system applications, plant monitoring and safety systems, and waste management options. The scientists participating in today's AMA: Phil Sharpe, Ph.D., director of Nuclear Systems Design & Analysis Rita Baranwal, Ph.D., director of the Gateway for Accelerated Innovation in Nuclear (GAIN) Hans Gougar, Ph.D., director of the Advanced Reactor Technology Technical Development Office at INL George Griffith, Ph.D., INL Manager for Small Modular Reactor Deployment Brenden Heidrich, Ph.D., Chief Irradiation Scientist, the Nuclear Science User Facilities (NSUF) Some fodder for discussion: \* The Potential for Disruptive Innovations in Nuclear Power - <http://pubs.cnl.ca/doi/full/10.12943/ANR.2014.00033> \* What Will Advanced Nuclear Power Plants Cost? - [https://www.eenews.net/assets/2017/07/25/document\\_gw\\_07.pdf](https://www.eenews.net/assets/2017/07/25/document_gw_07.pdf) \* Advanced Test Reactor Options Study - [https://art.inl.gov/INL%20ART%20TDO%20Documents/Advanced%20Demonstration%20and%20Test%20%20Reactor%20Options%20Study/ADOptions\\_Study\\_Rev3.pdf](https://art.inl.gov/INL%20ART%20TDO%20Documents/Advanced%20Demonstration%20and%20Test%20%20Reactor%20Options%20Study/ADOptions_Study_Rev3.pdf) \* Global Nexus Initiative Reports on nuclear energy – <http://globalnexusinitiative.org/category/results/reports/> We'll be back at 11 a.m. EST (9 a.m. MST) to answer your questions, ask us anything!

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INL\_AMA [R/SCIENCE](#)

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Hans Gougar, Ph.D., director of the Advanced Reactor Technology Technical Development Office at INL

George Griffith, Ph.D., INL Manager for Small Modular Reactor Deployment

Brenden Heidrich, Ph.D., Chief Irradiation Scientist, the Nuclear Science User Facilities (NSUF)

Some fodder for discussion:

• The Potential for Disruptive Innovations in Nuclear Power - <http://pubs.cnl.ca/doi/full/10.12943/ANR.2014.00033>

• What Will Advanced Nuclear Power Plants Cost? - [https://www.eenews.net/assets/2017/07/25/document\\_gw\\_07.pdf](https://www.eenews.net/assets/2017/07/25/document_gw_07.pdf)

• Advanced Test Reactor Options Study -

[https://art.inl.gov/INL%20ART%20TDO%20Documents/Advanced%20Demonstration%20and%20Test%20%20Reactor%20Options%20Study/ADTR\\_Options\\_Study\\_Re](https://art.inl.gov/INL%20ART%20TDO%20Documents/Advanced%20Demonstration%20and%20Test%20%20Reactor%20Options%20Study/ADTR_Options_Study_Re)

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Hi there! Super interesting AMA.

So, I studied nuclear reactors (quickly) at the university around 2007. There were lots of theories about "burner" reactors, where you irradiated nuclear waste with an accelerator and then extracted the energy from the induced decay heat. This way you could both safely dispose of long-lived isotopes and gets tons of cheap, emission free energy.

As a physicist without any engineering background it seems a way too simple solution not to work. But obviously it's not, as it's not a solution being considered some decades after being first proposed. What do we miss? Is there some limit we can't overcome?

[lucax85](#)

Thanks for the question, and you have touched upon one of the many avenues for which nuclear science can be applied. Indeed there are nuclear reactors designed to "burn" or transmute much of the long-lived byproducts from operating nuclear reactors, as well as what are called "driven" systems using accelerators. Systems have been built and tested that prove the concept and even, to a degree, demonstrate how the systems can be scaled up to production. In principle, the technology is shown to work without any real show-stoppers.

So why have such systems not been deployed and utilized at a wider scale? As with many things, economics and politics... At present in the US, we execute a once-through fuel cycle, where nuclear fuel is utilized to extract energy in a nuclear reactor, then we store the leftover material for eventual

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disposal underground. Currently the cost and availability of uranium have not exceeded that needed to deploy burners and an extension of the technology for breeding fuel. Part of the political arguments concern potential proliferation of the nuclear material. All in all, the burner technology, while achievable, has not found the need for deployment as yet. Perhaps at some point in the future, a more direct need could arise.

--Phil Sharpe

Hi, and thank you for doing this very interesting AMA!

What are the most exciting projects you're working on, according to you?

Do you think we're close from having nuclear fusion as a widespread energy source? In your opinion, will it come from inertial confinement fusion or magnetic confinement fusion?

[Hafornin](#)

Thanks for the interest in advanced reactors! I am very fortunate to be able to work on several reactor concepts, aiming to help develop some to success and deploying for clean essentially unlimited energy. With your question on fusion, I'll discuss more in that area.

Fusion nuclear energy has an advantage over fission nuclear energy in essence because the fuel and the fission products do not produce decay heat- which sticks around even after the fission reactor is shutdown or turned off. And the fuel for fusion reactors come essentially from sea water (via deuterium - a form of hydrogen- and lithium, used to make the other fuel, tritium -another form of hydrogen). The main problem with fusion, though, is the ability to conveniently and easily get the nuclei of the fuel to, well, fuse. As you've noted, 2 predominate mechanisms are used. Magnetic confinement uses the fuel atoms in a plasma state (4th state of matter) which can literally be squished by the magnetic fields applied by very large superconducting electromagnets. The other method, inertial confinement fusion, relies on rapidly firing laser (or particle beams) pulses to heat tiny pea-size targets of frozen deuterium and tritium, which is heated and then squished together for the fusion reaction. Both approaches require different but extensive equipment to cause the fuel to fuse.

Both approaches, however, share a common issue. When the fuels are squished together, they tend not to go in the direction you want- in what scientists call fluid instabilities. One could argue that overcoming these instabilities is a critical aspect to the possible success of fusion, and different approaches are needed for the two main concepts.

As to which may be ultimately successful? Could be either, or both, depending on how the instabilities are solved. Of course there are many other complicating factors, which is why research continues.

--Phil Sharpe

Hi and thanks for joining us today!

So I try to have some kind of germane question for AMAs unfortunately advanced nuclear physics is way outside of my wheelhouse.

However, I was wondering if you knew about ORAU and could maybe explain how DoE sites generate money to fund fellowships for thousands of new scientists in every field, every year?

[PHealthy](#)

ORAU is a clearinghouse for scholarships and fellowships from a variety of sources, including the Department of Energy, Office of Nuclear Energy (DOE-NE). DOE-NE funds students through fellowships and scholarships via the Nuclear Energy University Programs (NEUP) Program (NEUP.INL.gov). Funding for this program comes from Congress on an annual basis as part of the DOE Budget. DOE-NE/NEUP also funds research and development grants to universities that fund graduate students indirectly. If you want to make sure that you get emails on the program, set up an account at NEUP.INL.gov. - Brenden Heidrich

Thanks for the AMA! What would you say is the biggest obstacle in having widespread nuclear energy production?

[useful person](#)

The primary barrier is, quite simply, cost. Nuclear plants, as we build them today are very complex machines built to exacting (Nuclear Quality Assurance) standards, the toughest in the energy field.

Today's nuclear plants employ multiple and redundant safety systems to prevent core damage. A plant is built from large amounts of concrete, steel and miles of cables and piping; a massive design engineering feat. Every detail of proposed design is scrutinized by the regulator during an intense and lengthy (~50 month) review process. Once a design is approved is granted, modifications to the design must be approved by the regulator through a rigorous review process.

Construction of the plant takes years and billions of dollars. While under construction, the utility or construction firm is paying interest on the loans which is exacerbated by delays. Once built, any proposed improvements or backfits to the plant are also subjected to this review process. Operation and maintenance of current designs can be expensive, requiring more than a comparatively-sized fossil plant. The saving grace of nuclear is the low cost of fuel and the high reliability and availability (>90%) of the plants, as well as the plant lifetime that can stretch to 60 to 80 years or more if properly maintained.

Unlike cellphones or automobiles in which thousands or even millions of units may be built every year, only about 100 plants have been built in the US over the past 50 years. This provides little opportunity for companies to experiment with design and process improvements that would lower the unit cost. Building new advanced reactors will allow us to take full advantage of new developments in all of the challenging areas noted above. --Hans Gougar

Hi there! I've got a question regarding reactors for 99Mo production.

Currently the Whole world nuclear medicine supply comes from just 4 reactors, and 60% of it just from one Canadian reactor. All these reactors use HEU, which isn't politically correct anymore apparently. Also, these reactors are like 70 years old, and when the duct tapes fails in a single reactor the medical community goes in panic mode. Just the Canadian reactor provides isotopes for some 20M exams a year.

So... are there any new designs being considered to produce 99Mo? Are designs based on LEU being finalized? I remember lots and lots of announcements in decades, but nothing ever was built, and we're still left with a ridiculously unreliable chain of production

[lucax85](#)

There are low-enriched uranium (LEU) solutions being developed by several organizations in the US and globally, as well as non-uranium accelerators which are being developed to address the global Mo-99 shortage.---RB See this link for more information: <http://www.world-nuclear-news.org/C-US-firms-target-revival-in-domestic-Mo-99-production-01051501.html> --Rita Baranwal

What is the next big thing in nuclear fuels and material science research? In other words, do we know what we should be working on, and are people or programs working to close that gap?

[dainw](#)

Advanced nuclear reactors will rely on advanced materials to support them. The Nuclear Science User Facilities (NSUF) provides access to national laboratory resources to support materials and fuels research at no cost to the researcher. We review every proposal that comes in against the work that has been done and against the needs of the DOE-NE reactor and fuels development programs. NSUF has started a comprehensive program to track the materials and fuels research that has been done and identify gaps in the knowledge that can be filled by new research projects. In addition, we are looking forward to emerging technologies, such as advanced manufacturing (3D printing, etc.) so that we can get projects started to have materials and capabilities available for the researchers when they are ready. – Brenden Heidrich

Another area for the next big thing in nuclear fuels and materials centers around the concept of "Accident Tolerant Fuels." We are involved with several partners including nuclear fuel vendors to develop fuel and cladding materials that enhance current plant safety during possible events where injecting cooling water is delayed. Such an event is called a Station Blackout, where offsite and on-site (via Emergency Diesel Generators) power is not available for the pumps injecting cooling water after plant shutdown. Such Accident Tolerant Fuels leverage different materials that hold up well at high temperatures, reduce reactions producing combustible hydrogen gas, and are now within the reaches of modern manufacturing technologies. These Accident Tolerant Fuels also may improve normal plant operations by relaxing some constraints on equipment controlled by the fuel and cladding currently used. For example, longer testing intervals for those Emergency Diesel Generators means less wear and tear on the equipment, and hence improved reliability when they are truly needed. Development of these Accident Tolerant Fuel options is a big thing the the current operating fleet of nuclear reactors, and could see deployment in a relatively short time! --Phil Sharpe

How far has nuclear safety come from the days of Chernobyl and Three Mile Island?

Also what safety lessons were learned from the Fukushima incident? Considering all that, what is the likelihood of danger for a community living close to a nuclear plant today and the comparison of danger to living near more conventional methods of power generation?

[peregrin5](#)

A very good, and important, question. Thanks for asking about nuclear safety and how the evolution given the accidents you mentioned. Part of the answer lies in advances toward the design of nuclear reactors and the equipment in place to keep the reactor safe. While Chernobyl, Three Mile Island, and even Fukushima are reactors of older designs, new and modern reactors incorporate features of "passive safety," meaning that active, powered systems are not needed. Good examples include the AP-1000 from Westinghouse, the ESBW from General Electric, the EPR from Areva - all of which are sized on energy output comparable to today's nuclear plants. Other designs include small modular reactors, such as the NuScale design currently under review by the US Nuclear Regulatory Commission, have smaller energy output and application of passive safety features. Several other designs are being developed that also reduce the different safety hazards of water cooled plants, and include designs using liquid metal, liquid salt, and even pressurized gas! So, part of the lessons learned from these incidents can be characterized as design evolution to make the next generation of plants safer.

But what about the nuclear plants that are still operating, providing abundant reliable and clean energy for our use today? Following the Three Mile Island incident, the US Nuclear Regulatory Commission, along the entire US fleet of nuclear reactor owners and operators, instituted many changes with extensive review and analysis aimed to enhance the nuclear plant's safety. Operator training, equipment upgrades and maintenance schedules, statistical-based analyses to understand consequences and mitigation of severe but very unlikely events were all part of the improvements.

When a severe and unlikely event did happen at Fukushima, the US nuclear reactor fleet made several additional enhancements to prepare response to external hazards, such as floods, hurricanes, tornados, even an airplane strike (terrorist threats are also extensively considered). Staging added mobile equipment nearby, and procedures anticipating how to use the equipment, is a key element of the response to Fukushima, and generally focusing on assuring electrical power is available to the extensive safety equipment already in place at the plants.

Overall all, nuclear plants are today very safe and prepared for events with reasonable chance of occurring. Compared to other types of power generation, in my opinion they are all generally safe and suitable for folks to live nearby, assuming compliance with the rules in place to keep those nearby folks safe (for example, control of ash ponds for coal plants). On a relative scale, power generation plants are generally safe.

--Phil Sharpe

Hi and thank you for doing this AMA.

Are there any projects for production scale thorium based reactors in the works or coming online? Do you think there is a viable future in our lifetimes for thorium based reactors? My understanding is that thorium is extremely abundant and that thorium reactors produce waste that decays much faster than uranium or plutonium. If that is truly the case, what are the obstacles to bringing this technology online?

[ndbarbre](#)

Interest and research in thorium (as an alternative to uranium) in power reactors goes back many decades. Indeed, commercial power reactors operated with thorium in Germany and the USA. Interest revived in the past decade, particularly by companies proposing molten salt reactor concepts. Thorium is at least as abundant as uranium in the earth's crust and thus has the potential to extend nuclear fuel supplies for centuries. The major obstacle to the use of thorium is that it, unlike uranium, it has no fissile isotopes. It is not 'fuel' per se in that it cannot easily be fissioned. Instead, the isotope Th-232 is converted to fissile U-233 when an atom of it captures a stray neutron. Thus, to 'burn' thorium in a reactor, one must load the core with enough fissile material (U-235 or Pu-239) to sustain the chain reaction and generate enough excess neutrons in the process to convert Th-232 into U-233. The U-233 can be extracted (recycled) from the core through a chemical separations process and re-inserted into the core as fuel. Like U-235 and Pu-239, U-233 can be used for both nuclear fuel and nuclear weapons. This conversion process already occurs in reactors fueled with uranium; non-fissile U-238 absorbs a neutron and is converted into Pu-239. The Pu-239 can then be extracted from the fuel rods to make new fuel elements. This involves removing the fuel rods and shipping them to a recycling plant

where they are dissolved in acid (or molten salt) and subjected to a complex series of chemical reactions to extract the usable fuel. Fuel recycling of this nature takes place only in a few countries such as France, Russia, and Japan because the chemical separation and fabrication process is expensive (more so than simply mining and enriching uranium). It has been discouraged internationally because the same technology can also be used to produce weapons material. Liquid-fueled molten salt reactors may be more amenable to this burn & convert process if the chemical separation plant is connected to the reactor. There is no need to remove the solid fuel rods and dissolve them in acid. In the simplest case, the fuel is simply piped out of the core and into the separations facility. The separated fuel is returned to the reactor. One still must 'prime' the process by initially loading the core with fissile material (U-235). Eventually, however, the reaction can be sustained with the recycled U-233. The molten salt separation process is still in the research and development phase. It was demonstrated at Oak Ridge National Lab (the Molten Salt Reactor Experiment) but has never been deployed in an actual power plant. The commercial reactors in the US (Fort St. Vrain) and Germany (THTR) used a mixture of thorium and highly enriched uranium to sustain the reaction and convert Th-232 into U-233 but there was no recycling of the fuel. For security reasons, highly enriched uranium can no longer be used in commercial power plants so future advanced reactors must start up on low-enriched uranium or plutonium. Therefore, an advanced reactor company seeking to burn thorium will need to address the following challenges: - chemistry control of the molten salt that containing numerous actinides and fission products, possibly along with new alloys that can operate at the high temperature and radiation levels characteristic of the MSR, to prevent corrosion in vessels and pipes, - an online chemical separations process that recycles fuel at a rate that is competitive with simple uranium mining and enrichment, and - can meet international safeguards standards for protection and security of separated fissile material.

There are several advanced reactor developers who are considering thorium-based fuel for their designs, planned for demonstration in to 2025-2030 timeframe. While thorium is abundant, uranium prices currently are also currently low enough to not drive the industry towards a concept that requires recycling to achieve its business case. The barriers to bringing thorium technology online are similar to those with any new reactor technology, including cost and licensing. These obstacles can be overcome, with application of new technologies and frequent communication with regulators. --Hans Gougar and Rita Baranwal

Hello,

Does your group have any active projects or anticipate any development in the area of nuclear micro reactors?

What kind of challenges do you or would you face in developing nuclear reactor technology that is capable of fitting in the palm of your hand?

[sadicgent](#)

INL is working with the nuclear vendors on micro reactor projects. These are in the 1MW to 5MW range and use unique technology.

The smallest practical reactors are approximately the size of a trash can. Geometric considerations limit how small a nuclear reactor can be. (Enough neutrons need to stay in the core and not leak out to maintain a stable and useful power level.)

Very small power concepts often rely on isotopic decay to produce heat and then electricity. The Curiosity rover on Mars, for example, uses a type of nuclear 'battery' that simply uses the decay heat of a particular radioisotope, Pu-238 and converts it to electricity using thermocouples. -- George Griffith

With our most modern reactors, how much waste will be produced over its operational lifetime? What are some strategies for dealing with this waste?

With regards to waste, I've always had this question: Why can we not transmute the waste into some other isotope that is less stable and will decay more rapidly? Can we do this and it's just not an efficient way to deal with the waste?

Also, do you all have any thoughts on fusion technology? Is it something that is taken seriously at INL, for example?

[fireballs619](#)

Most current power reactors produce approximately 20 metric tons of used fuel per year. Although some consider this material to be waste, there is still a great deal (more than 90%) of useable power left within the used fuel that could be recycled using several existing technologies. This was done in the

early days of nuclear power when uranium supplies were thought to be far more rare than they are today. INL conducts research on refining existing technology to increase its efficiency and reduce the waste generated in the process.

Transmutation of used nuclear fuel is a strategy to change the characteristics of the waste. For example, fast-spectrum reactors can potentially burn the longest-lived isotopes left in used fuel, greatly reducing the time required for long-term storage. INL is currently involved in research into applying such a technology for existing thermal-spectrum power reactors.

Nuclear fusion reactors are a technology option also under serious investigation, with focus to overcome several of the existing technical hurdles (for example, fluid instabilities discussed in another comment above). The jury is still out on the timeframe until we have such reactors are ready, but the possible benefits of fusion could make it worthwhile.

-- Joesph L. Campbell and Phil Sharpe

Thank you for helping me understand it makes total sense. Glad the advanced research is leading to less waste "heat" and becoming more effective at the same time.

[Swarrel](#)

Beyond electricity production is a whole world of process heat applications that previously belonged to fossil fuel plants. Non-thermal plants like wind, tidal, and solar-PV can generate clean electricity, but they cannot generate the high temperatures needed to do everything from cement plants and aluminum smelters to supporting other clean energy programs with biomass and hydrogen production and even desalinization of drinking water. There is a good breakdown at the World Nuclear Organization site: <http://www.world-nuclear.org/information-library/non-power-nuclear-applications/industry/nuclear-process-heat-for-industry.aspx> - Brenden Heidrich

I'm interested in learning more about small modular reactors. Specifically, how close are we getting to deploying this technology in the United States and what are the benefits of SMRs and potential hurdles to development and deployment?

[blue\\_tattoo](#)

There is a first of a kind project to deploy a SMR nuclear power plant here at INL. The Utah Associated Municipal Power Systems (UAMPS) is leading a project with NuScale and the DOE to deploy a SMR nuclear power plant. The plant is anticipated to start producing commercial power in 2026. NuScale is currently applying for a NRC license to allow the reactor to be operated. The site is being evaluated to receive a license to site the NuScale technology. There are multiple SMR and micro reactor concepts being developed that are planning to be available in the late 2020s to the 2030s. These reactors are introducing new technology and designs that must be fully developed and licensed. Inevitably some of these concepts will succeed and some will not. SMRs were specifically designed to address difficulties in building current gigawatt class reactors. They are literally small, allowing them to be built in a factory and be less expensive per unit to build. (Small is relative the modules are the size of airliners and require trucks with a huge number of wheels to transport.) This makes production more controlled and reliable. The SMR technology is designed to be very safe, eliminating pumps and valves as much as possible. This makes them less trouble to fabricate. The very high level of designed passive safety allows even more systems to be eliminated making operation and maintenance easier. The primary hurdle is getting to reactors that are producing power and money for their investors. Initial design and concept refinement are justifiable and relatively low cost investments. A new reactor license and detailed design is very expensive. Getting a return on the large investment can be difficult to justify requiring deep pockets and patience. The new proposed micro reactors appear to be taking the smaller simpler concept to the next level. They tend to be very small and even more passive in operation. -GWG

Is Nuclear Energies in anyway threatened by Electric Power, in the way Electric beats out Fossil Fuels?

[Swarrel](#)

In the past, most of the output from nuclear power plants has been in the form of electrical energy. Nuclear power plants are classified as "thermal" power plants, in that they change one form of energy (chemical, potential, kinetic, nuclear) into heat to generate electricity. In the past, most of this has been through the process of heating (and boiling) water to make steam to drive a turbine coupled to an electrical generator. Unfortunately, this (Rankine) cycle is limited in efficiency and results in a large

amount of "waste" heat that is rejected to the environment. It is not radioactive, but it has an effect on the environment that has to be carefully managed. This is why most nuclear power plants are near rivers, lakes, or the ocean. They reject the "waste" heat into these large bodies of water. Many of the proposed advanced reactor technologies do not use water for coolant, instead relying on gas (helium), liquid metals (sodium, lead, or some combination), or a molten salt mixture. These technologies can operate at higher temperatures than water, which can have two direct benefits. First, the power conversion cycle can operate at higher efficiency. These typically use a gas turbine rather than a steam turbine. This means less heat rejected to the environment. Second, the higher temperature allows the "waste" heat to be used to support certain industrial processes, like making hydrogen to supply fuel cells and many other options. - Brenden Heidrich

Hopefully this doesn't violate the rules of the AMA, but I was wondering if the department of energy, now headed by Rick Perry, has had any impact on your work?

[FockerCRNA](#)

Thanks for asking a very good and timely question. Administration changes always have some impact on the direction federal agencies take. Secretary Perry has publically affirmed his support for nuclear energy as source of clean, resilient, safe, and reliable source of energy. The Department of Energy—in partnership with the National Laboratories—is committed to developing advanced nuclear technology solutions and maintaining U.S. leadership in nuclear energy.

In addition, Secretary Perry recently invoked Section 403(a) of the Department of Energy Organization Act to propose that the Federal Energy Regulatory Commission consider market reforms to increase diversity and reliability of the energy supply and boost the resiliency of our electricity grid. This could help mitigate the financial challenges facing nuclear plants, particularly in deregulated markets where baseload power plants such as nuclear and coal are currently undervalued. This could also help protect the reliability of our nation's electricity supply in times of stress, including severe weather events.

-- Joesph L. Campbell and Phil Sharpe