

THE POTENTIAL NON-ELECTRIC APPLICATIONS OF CIVILIAN NUCLEAR ENERGY

HEARING BEFORE THE COMMITTEE ON ENERGY AND NATURAL RESOURCES UNITED STATES SENATE ONE HUNDRED SEVENTEENTH CONGRESS FIRST SESSION

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THE POTENTIAL NON-ELECTRIC APPLICATIONS OF CIVILIAN NUCLEAR ENERGY

THURSDAY, NOVEMBER 4, 2021

U.S. SENATE,
COMMITTEE ON ENERGY AND NATURAL RESOURCES,
Washington, DC.

The Committee met, pursuant to notice, at 10:03 a.m. in Room SD-366, Dirksen Senate Office Building, Hon. Joe Manchin III, Chairman of the Committee, presiding.

OPENING STATEMENT OF HON. JOE MANCHIN III, U.S. SENATOR FROM WEST VIRGINIA

The CHAIRMAN. The Committee will come to order.

Normally, when we talk about nuclear energy, we are talking about electricity generation, but today we will be discussing the non-electric applications of nuclear energy and systems integration. It is the technology set that will truly transform how we think about and use energy. I want to thank our witnesses, who will provide us with insights on how we can best deploy these technologies over the next decade. Earlier this year, we had a hearing that focused on the importance of maintaining our current nuclear fleet and developing advanced reactors. That hearing set the stage nicely for this one, as developing additional value streams for nuclear technologies will help their competitiveness in electricity markets. In addition, being pioneers in this endeavor will allow the U.S. a competitive edge in the international market. Reducing emissions in the industrial sector has been identified as a significant challenge that we must tackle in order to meet our climate goals. The U.S. has had success in lowering emissions in the electricity and transportation sectors due to advances spearheaded by the Department of Energy (DOE) in energy efficiency, renewables, batteries, and electric vehicles.

But as we have progressed in these sectors, emissions from the industrial sector have increased by about 69 percent since 1990. The industrial sector also represents a significant portion of global emissions, accounting for approximately 28 percent of total greenhouse gas emissions. As developing economies begin to shift to more energy-intensive industries, the U.S. must be on the cutting edge in developing the technologies required to decarbonize industry. This shift is an enormous opportunity to deploy new technologies domestically and abroad to promote job growth here in the U.S. as the demand for nuclear technologies that reduce emissions

and deliver industrial products, such as hydrogen, chemical feedstock, district heating, water purification, and building materials increases.

Last year we enacted the Nuclear Integrated Energy Systems Research, Development, Demonstration, and Commercial Application Program as a part of the Energy Act of 2020 and we are fortunate to have Dr. Shannon Bragg-Sitton, who is leading this crucial endeavor, with us today. The Department of Energy and the national laboratories are developing energy systems designed to be jointly operated with nuclear energy to reduce emissions in both the electric and non-electric sectors while maximizing energy production and efficiencies. In short, this program will help commercialize technologies to reduce emissions for water purification, heat for industrial processes, microgrids, district heating, and other various applications, all through the use of nuclear energy. The Department of Energy is leading a tri-lab consortium, including Idaho National Laboratory (INL), the National Renewable Energy Laboratory (NREL), and National Energy Technology Laboratory (NETL) in Morgantown, West Virginia, to pioneer the technologies to transform how we use energy.

As we begin this transition, it is my hope that we can commercially deploy these types of technologies in my State of West Virginia. However, West Virginia has had a ban on the construction of nuclear power plants for over two decades. This is something that I would like to see changed, and I have spoken to all of my friends in the legislature and I think they understand the need and the urgency also. I believe advanced nuclear reactors hold enormous potential to provide opportunities to communities across the country with zero-emission baseload power. I am very excited to get the utility perspective today from Dr. Paul Chodak on how we can best deploy the next generation of nuclear.

With that, I am going turn to my friend, Ranking Member Barrasso, for his opening statement.

**OPENING STATEMENT OF HON. JOHN BARRASSO,
U.S. SENATOR FROM WYOMING**

Senator BARRASSO. Well, thanks so much, Mr. Chairman, for holding this very important hearing today.

Nuclear technology is fundamental to meeting America's energy, environmental, and national security needs. Nuclear energy is necessary for reliable, affordable, and resilient electric service. Now, more than ever, we need to be looking for opportunities to expand the use of nuclear energy. The U.S. currently has 93 operating commercial reactors in 28 states. These reactors provide 20 percent of our electricity. They provide the majority of our carbon-free energy. These reactors could safely remain online for decades.

Yet many of our nuclear reactors are facing political and economic pressures to shut down. Since 2013, 12 reactors have shut down. This trend needs to stop. Earlier this year, this Committee took an important step by advancing the Nuclear Credit Program. But that program will only provide a temporary fix. Reckless federal and state policies are pushing excess amounts of wind and solar energy onto the grid. The result is an oversupply of electric capacity that forces nuclear reactors off the grid. In some parts of

the country, these policies have caused wholesale electricity prices to drop below zero. Nuclear operators have been left with no choice but to consider ways to reduce costs, to increase revenues, or to shut down.

Today, we are discussing potential expanded revenue streams. Some nuclear operators are pursuing non-electric applications and other specialized uses. Several nuclear operators are making or considering investments in hydrogen and ammonia production. Others are looking at powering Bitcoin mining data centers. Nuclear operators are also considering the production of medical isotopes—elements used in the diagnosis and treatment of diseases like cancer. Each of these innovative applications presents an opportunity to retain our existing nuclear power plants.

Innovation will be the key to reestablishing America's leadership in nuclear energy. Over the next decade we expect advanced nuclear reactors to be in operation. Advanced reactors will be smaller, safer, and more efficient. They will also generate less nuclear waste. Some may even run on previously used nuclear fuel. My home State of Wyoming will host TerraPower's Sodium reactor, which will be the first of its kind anywhere in the world. It is designed to generate and store electricity. Like existing reactors, advanced nuclear technologies will enable new market opportunities beyond the electricity sector. Unlike existing reactors, which require modifications to enable these applications, advanced reactors are specifically designed for multiple purposes.

The heat from advanced nuclear reactors can drive a variety of industrial processes, and can improve the efficiency and economics of chemical hydrogen and medical isotope production. Nuclear heat can contribute to enhanced oil recovery. This heat can also clean up wastewater and turn salt water from our oceans into fresh water. In addition, small advanced reactors are well-suited for specialized electricity generation. The Department of Defense is considering transportable microreactors for powering remote bases. These same reactors could also provide needed power for disaster recovery. Microreactors will even power missions in space.

We must ensure American technologies are leading this global expansion of nuclear energy. Today we are going to hear about exciting new applications for nuclear energy. These new applications can help make nuclear energy profitable. They will also create new markets around the world for American-made nuclear technologies. So thanks so much, Mr. Chairman, for holding this important hearing. I look forward to hearing from our panel of experts and look forward to the testimony.

The CHAIRMAN. Thank you, Senator Barrasso.

Now let me welcome our highly qualified panel of witnesses for their opening statements. We are going to start with Dr. Shannon Bragg-Sitton. She is Division Director of the Integrated Energy and Storage System, Idaho National Lab. Thank you for being here.

STATEMENT OF DR. SHANNON BRAGG-SITTON, DIVISION DIRECTOR FOR INTEGRATED ENERGY AND STORAGE SYSTEMS, IDAHO NATIONAL LABORATORY

Dr. BRAGG-SITTON. Good morning. I want to thank Chairman Manchin and Ranking Member Barrasso for scheduling this important hearing and for the opportunity today to participate. As you said, my name is Shannon Bragg-Sitton, and I am the Director of the Integrated Energy and Storage Systems Division at Idaho National Laboratory. INL is the nation's center for nuclear energy research and development, and INL works with industry to develop and deploy advanced reactors that will power American prosperity into the future. We also lead DOE's Light Water Reactor Sustainability (LWRS) Program, which is working to extend the operating lifetime of our high-performing nuclear fleet. A key focus for both of these programs is extending the use of nuclear energy beyond electricity generation.

Integrated energy systems refer to power plants that are able to leverage multiple energy sources to meet a variety of energy demands. These systems provide us with many benefits. They provide the ability to couple diverse energy sources such as nuclear, renewable, and fossil with carbon capture, allowing us to leverage the benefits of each resource. This provides us with more efficient energy use, which helps the environment while keeping consumer costs down. And they also increase revenues for plant owners by providing multiple product streams and they offer the potential for cleaner, lower-cost, and more efficient transportation and industrial applications. These integrated systems will help us to stabilize the grid through their flexible operation. It is exciting to be examining their non-grid applications, which could include water desalination, production of clean hydrogen, production of heat and hydrogen to support industrial processes, such as steel manufacturing or to produce synthetic fuels for transportation or ammonia-based fertilizers for the agricultural sector.

This isn't just theoretical. We are partnering with the private sector to demonstrate how existing nuclear plants can use their excess heat and electricity when it is not needed by the grid in order to produce hydrogen. Today, hydrogen is primarily produced by breaking down methane, which also produces carbon dioxide, and if we instead use non-emitting nuclear energy to produce hydrogen from water, we can realize enormous emissions savings across multiple industries. And these projects are an important part of DOE's Earthshot Initiative, which aims to reduce the cost of clean hydrogen to decarbonize industrial applications as well as to realize a net-zero economy by 2050. So we are partnering with a tri-utility consortium that will first demonstrate clean hydrogen production using water electrolysis at the Energy Harbor Davis-Besse plant in Ohio. That will be followed by higher temperature steam electrolysis demonstrated at an Xcel nuclear plant in Minnesota. And in the third phase, we will demonstrate larger-scale hydrogen production at the Palo Verde Generating Station in Arizona in partnership with Arizona Public Service.

Additionally, INL, Argonne National Laboratory, and the National Renewable Energy Laboratory are partnered with Exelon generation, which is also demonstrating hydrogen production at

their Nine Mile Point plant in New York. These projects will produce hydrogen in the next year. These efforts will enhance grid stability and will create an additional revenue stream for these nuclear plants. This is becoming more important as the financial pressures on our existing fleet are increasing as evidenced by recent plant closures. Because traditional nuclear plants operate 24/7, they are impacted by negative power prices, which occur when generation appears simultaneously with reduced electricity demand, and these situations are becoming more prevalent as we have more deployment of variable renewables. Hydrogen production will enable these plants to become more profitable as they continue to produce more than half of our nation's carbon-free electricity and contribute roughly \$600 billion annually to our economy.

Finally, I want to emphasize that integrated systems research is not just about the current fleet. Advanced reactors that are in development today and planned for deployment within the next decade are designed to operate at higher temperatures, run more efficiently, and provide greater flexibility. Working in concert with renewables, these advanced reactors can power microgrids in isolated communities, supply heat and electricity to remote mining applications, produce synthetic fuels, and much more. These advanced reactors could even be sited at retiring coal plants to ensure that reliable, affordable electricity remains available for these communities. All of this is vital to our nation's economy and environment as we develop technologies that will create clean energy jobs, reduce land use and the impact on air and water, promote energy independence, and increase our nation's economic competitiveness.

So thank you again for the opportunity to testify here today. I look forward to answering any questions you may have.

[The prepared statement of Dr. Bragg-Sitton follows:]

Non-Electric Applications of Nuclear Energy

Shannon Bragg-Sitton, Ph.D.

Director, Integrated Energy and Storage Systems Division
Energy & Environment Science & Technology Directorate
Idaho National Laboratory

Good morning. I want to thank Chairman Manchin and Ranking Member Barrasso for scheduling this important hearing and the opportunity to participate.

My name is Shannon Bragg-Sitton, and I am the Director of the Integrated Energy and Storage Systems Division at Idaho National Laboratory. INL is the nation's center for nuclear energy research and development.

The Biden administration has committed to full decarbonization of the U.S. electricity grid by 2035 and economy-wide net zero emissions by 2050. These aggressive goals demand immediate action if we are to be successful, and they require us to think more holistically about our clean energy options. A variety of low- or zero-carbon technologies can be employed in various combinations to meet energy demand, particularly in the electricity sector.

Renewable energy technologies are being deployed in significant numbers around the world in response to the desire to reduce emissions, coupled with decreasing costs for these technologies. Despite this growth, data compiled in the May 2019 International Energy Agency (IEA) *Nuclear Power in a Clean Energy System* report¹ indicates that the fraction of clean energy contributions to electricity generation has not changed over the last 20 years. This unexpected trend results from the premature shutdown of large-scale, non-emitting generators, such as nuclear power plants, in some regions in response to the pressures created by historically low-cost renewable generation sources, alongside the low cost and high availability of natural gas. These combined factors have driven down the price of electricity and decreased the minimum baseload generation required to meet load at certain times of the day or year.

Many nuclear plants have responded to increasing volatility in net electricity demand by operating flexibly, reducing power output to reduce the financial impact to the plant from very low or negative market prices. This practice preserves the contribution of nuclear energy to grid stability and reduces economic losses associated with negatively priced electricity sales, but it does not reduce plant operating costs. Nuclear energy is a proven, low-emission option that can provide consistent, dispatchable power to meet electricity demands while also providing high-quality heat that can meet energy demands beyond the electricity sector. Energy system design should seek to maximize these assets. Several recent studies indicate that without

¹ International Energy Agency, *Nuclear Power in a Clean Energy System*, May 2019, <https://www.iea.org/reports/nuclear-power-in-a-clean-energy-system>.

contributions from nuclear, the cost of achieving deep decarbonization targets increases significantly.²

As the nation's nuclear laboratory, INL works with industry to develop and deploy the non-emitting, advanced nuclear reactors that will power American prosperity into the future. INL also leads DOE's Light Water Reactor Sustainability program, which is working to extend the operating lifetime of America's high-performing nuclear fleet. A major emphasis for both currently operating plants and new, advanced nuclear plants is expanding nuclear energy's use beyond electricity generation.

Integrated energy systems refer to power plants that can leverage multiple energy sources to meet a variety of energy demands.³ These systems can provide many benefits, including:

- The ability to couple diverse energy sources, such as nuclear, renewable, and fossil with carbon capture, allowing us to leverage the benefits of each source.
- More efficient energy use, which helps the environment while keeping consumer costs down.
- Increased revenues for plant owners by providing multiple product streams.
- Potential for cleaner, lower cost, and more efficient transportation and industrial applications.

Integrated systems will enhance power grid reliability and resilience, and they will help stabilize the grid through their increasingly flexible operation.

Traditionally, electricity generation and management, and then meeting energy demands for industry and transportation, are considered independently. As we seek to achieve net-zero carbon emissions, we need to pause and reassess our energy demands. When we consider overall energy use, only one-third is in the form of electricity. Additional energy demands are in the form of heat or steam for industrial processes, as well as transportation. These sectors are much harder to abate, and electrification may not be the best option. The primary output from a nuclear plant is heat, and we should leverage that heat effectively as we seek to decarbonize industry and the primarily fossil-fuel dependent transportation sector. The non-grid applications of non-emitting nuclear energy are vast, including, but not limited to:

- Seawater or brackish water desalination;
- Clean hydrogen production via water and steam electrolysis;
- Synthetic fuel production for transportation systems;

² For example, Massachusetts Institute of Technology, *The Future of Nuclear Energy in a Carbon-Constrained World*, 2018, <https://energy.mit.edu/wp-content/uploads/2018/09/The-Future-of-Nuclear-Energy-in-a-Carbon-Constrained-World.pdf>.

³ Integrated Energy Systems Program, DOE Office of Nuclear Energy, program website, <https://ies.inl.gov/SitePages/Home.aspx>.

- Production of heat and hydrogen for industrial processes, such as steel manufacturing; and
- Fertilizer production for the agricultural sector.

This is not just theoretical. We are currently partnering with the private sector on important projects to demonstrate how existing nuclear power plants can use excess heat and electricity that aren't needed by the grid to produce hydrogen without emissions.

Today, hydrogen is produced by breaking down methane, which produces CO₂. Using non-emitting nuclear energy to produce hydrogen from water could result in enormous emissions savings across multiple industries.

These demonstration projects are important contributors to DOE's Earthshot Initiative, which aims to significantly reduce the cost of clean hydrogen over the next decade, decarbonize the industrial sector, and realize a net-zero economy by 2050.

INL is partnering with a tri-utility consortium that will first demonstrate clean hydrogen production at the Energy Harbor Davis-Besse Nuclear Power Station in Ohio using water electrolysis.⁴ This work will be followed by demonstration of steam electrolysis at an Xcel Energy plant in Minnesota.⁵ The recently awarded third phase in the utility consortium will demonstrate larger-scale hydrogen production at the Palo Verde Generating Station in Arizona, in collaboration with Arizona Public Service.⁶

INL, the National Renewable Energy Laboratory, and Argonne National Laboratory are also working with Exelon Generation on a hydrogen demonstration project at its Nine Mile Point Nuclear Station in New York.⁷

And these projects will produce hydrogen within the next year. These efforts will enhance grid stability and create an additional revenue stream for nuclear plant owners and operators. This is important because the financial pressures on our existing fleet are increasing, as evidenced by recent plant closures and with more closures being scheduled for the near future.

⁴ Energy Harbor begins hydrogen fuel project at Davis-Besse, *Crain's Akron Business*, October 19, 2021, <https://www.craincleveland.com/energy-and-environment/energy-harbor-begins-hydrogen-fuel-project-davis-besse>.

⁵ Xcel Energy, INL to use nuclear energy for clean hydrogen production, *Green Car Congress*, December 13, 2020, <https://www.greencarcongress.com/2020/12/20201213-xcel.html>.

⁶ S. Patel, Power-to-Power Hydrogen Demonstration Involving Largest U.S. Nuclear Plant Gets Federal Funding, *Power*, October 14, 2021, <https://www.powermag.com/power-to-power-hydrogen-demonstration-involving-largest-u-s-nuclear-plant-gets-federal-funding/>.

⁷ Exelon to build hydrogen electrolyser at New York nuclear plant, *Power Engineering International*, August 23, 2021, <https://www.powerengineeringint.com/hydrogen/exelon-to-build-hydrogen-electrolyser-at-new-york-nuclear-plant/>.

Because traditional nuclear power plants operate 24/7, they are impacted by negative power prices, which occur when generation appears simultaneously with reduced electricity demand – something that is becoming more prevalent with increased deployment of variable renewables.

Hydrogen production will enable these plants to become more profitable as they continue to produce 20% of our nation's electricity, representing more than half of America's carbon-free electricity, while contributing roughly \$600 billion annually to our economy. The hydrogen produced will also support decarbonization of the industrial and transportation sectors, which will be critical to achieving our nation's net-zero goals.

I also want to thank this committee for your support of legislation that enables research and development of Integrated Energy Systems and hydrogen. The Energy Act that was enacted at the end of last Congress established an Integrated Energy Systems program within the U.S. Department of Energy, which will be a vital part of achieving our decarbonization goals. I appreciate the bipartisan support for collaborative efforts in this area, including Idaho National Laboratory's work with the other applied energy laboratories, such as the National Energy Technology Laboratory and the National Renewable Energy Laboratory, as well as other DOE labs.

Finally, I want to emphasize that integrated systems research is not just focused on the current fleet.

Advanced nuclear reactors in development today – and scheduled for deployment within the next decade – are designed to operate at higher temperatures, run more efficiently, and provide greater flexibility. Working in concert with renewables such as solar and wind, these advanced reactors can power microgrids in isolated communities, supply heat and electricity to remote mining operations, help produce synthetic fuels, and so much more.

All of this is vital to our nation's economy and environment as we develop technologies that create clean energy jobs, reduce land use and the impact on air and water, promote energy independence, and increase our nation's economic competitiveness. As we consider our future energy systems, we need to think more broadly and more collaboratively than our current experience about how each of these resources might support growing energy demands. Separating the electric sector from other energy demands may cause us to miss the truly elegant solution of using multiple clean generation sources collectively to support multiple demands simultaneously.

I truly believe that integrated energy systems based on clean energy options have nearly limitless potential. Through vigorous R&D, robust industry involvement, and bipartisan support at all levels of government, we can revitalize American communities, reinvigorate domestic manufacturing with clean energy, and reinvent industrial and transportation processes.

Thank you again for the opportunity to testify before the committee. I look forward to answering any questions you may have.

The CHAIRMAN. Thank you.

Next, we are going to have Dr. Paul Chodak, Executive Vice President, Generation, American Electric Power (AEP).

**STATEMENT OF DR. PAUL CHODAK III, EXECUTIVE VICE
PRESIDENT, GENERATION, AMERICAN ELECTRIC POWER**

Dr. CHODAK. Good morning Chairman Manchin, Ranking Member Barrasso, and members of the Committee. As Executive Vice President responsible for AEP's generation assets, I am privileged to be part of one of the nation's largest electricity producers, with approximately 31,000 megawatts of diverse generation capacity, including more than 5,900 megawatts of renewable energy and 2,100 megawatts of nuclear energy at our Cook Nuclear Plant on Lake Michigan. American Electric Power also plans to grow its renewable generation portfolio by approximately 16.6 gigawatts, which will put our capacity at 50 percent renewables by 2030. With our aggressive plan to invest in renewable resources, AEP is on track to achieve an 80 percent reduction in carbon dioxide emissions from 2000 levels by 2030 and has committed to achieving net zero by 2050. However, the technology to ensure that we are able to reliably and cost-effectively achieve net zero is still in development. We need a diverse mix of solutions because the best solution will likely vary by region.

Fossil generation with carbon capture may be the most effective solution where local geology supports CO₂ storage, while advanced nuclear generation sources can make the most sense in regions where the geology is not good for CO₂ sequestration and long-distance pipelines are impractical. As a U.S. Navy nuclear submariner and later as a Los Alamos National Lab scientist where I could prevent non-state actors from developing nuclear explosives, I had a clear mission of which I was very proud. Today, my mission is to provide our customers with safe, reliable—and when I say reliable, I mean 24 hours a day, 365 days a year, regardless of the weather—at as low a cost as possible. Our modern way of life depends on the successful execution of that mission. The United States operates the largest and highest-performing fleet of nuclear reactors in the world. The fleet already safely provides over half the carbon-free electricity consumed in the United States. Small modular reactors, or SMRs—their designs go further by incorporating decades of operating experience and technology improvements to produce even safer and inherently safe reactor designs. Several advanced reactors are currently in the design and development phase and will complement renewables by generating carbon-free electricity.

In addition, they are also capable of multiple non-electric functions such as hydrogen production. Hydrogen can be used to store large quantities of energy and to enhance grid reliability as a non-emitting transportation fuel. This is similar to the DOE demonstration projects that Dr. Bragg-Sitton talked about at the Palo Verde and Nine Mile power plants. Desalination plants will need SMRs as the world continues to stretch the supply of fresh water. Advanced nuclear plants that operate at high temperatures can also help decarbonize the industrial sector by providing electricity and hydrogen and process heat. SMRs offer resilient, reliable, and long-

term power to facilities important to national security, like military bases. I would also add that in my personal experience at Los Alamos National Lab, I saw firsthand the importance of the U.S. actively developing and deploying civilian nuclear technology, if it is to remain influential in the development of international nuclear policy.

The first SMRs are expected to be commercially viable in the 2027 to 2029 timeframe. Continued engagement between the private sector and the Federal Government is needed to advance the technology and offset the financial risk of early adoption of this technology. SMRs are very large investments that are likely to have 40-year life cycles. Consequently, they require significant regulatory and legislative support. We believe SMRs can provide an essential complement to renewable sources and can be a valuable tool to address carbon reductions and meet the growing energy needs of the U.S. economy.

Finally, AEP is very focused on the development and support of the communities we serve. The highly skilled energy workforce in our Appalachian service territory has powered America's economy for decades. Through no fault of their own, these communities are now being negatively impacted by the country's need to move toward a low-carbon economy. Nuclear generation sources bring with them large numbers of good-paying jobs. Through the co-generation of power and hydrogen, these communities can continue to meet the energy demand of our economy while making possible our nation's transition to net zero. Given the tremendous challenges ahead, we can ill-afford to forgo this great resource.

Thank you.

[The prepared statement of Dr. Chodak follows:]

**TESTIMONY OF
PAUL CHODAK III
EXECUTIVE VICE PRESIDENT, GENERATION,
AMERICAN ELECTRIC POWER
BEFORE THE
SENATE ENERGY AND NATURAL RESOURCES COMMITTEE
November 4, 2021**

American Electric Power, based in Columbus, Ohio, is powering a cleaner, brighter energy future for its customers and communities. AEP's approximately 16,800 employees operate and maintain the nation's largest electricity transmission system and more than 223,000 miles of distribution lines to safely deliver reliable and affordable power to 5.5 million regulated customers in 11 states. AEP also is one of the nation's largest electricity producers with approximately 31,000 megawatts (MW) of diverse generating capacity, including 2,100 MW of nuclear power and more than 5,900 MW of renewable energy. With regards to nuclear power, the Cook Nuclear Plant is located along Lake Michigan's eastern shoreline. With both Cook units at full power, more than 2,100 MW of electricity are generated – enough for more than 1.5 million homes. With regards to renewable energy, the company's plans include growing its renewable generation portfolio by approximately 16,600 MW to reach about 50% of total capacity by 2030. AEP is on track to achieve an 80% reduction in carbon dioxide emissions from 2000 levels by 2030 and has committed to achieve net zero by 2050. AEP is recognized consistently for its focus on sustainability, community engagement, and diversity, equity and inclusion. AEP's family of companies includes utilities AEP Ohio, AEP Texas, Appalachian Power (in Virginia and West Virginia), AEP Appalachian Power (in Tennessee), Indiana Michigan Power, Kentucky Power, Public Service Company of Oklahoma, and Southwestern Electric Power Company (in Arkansas, Louisiana, east Texas and the Texas Panhandle). AEP also owns AEP Energy, which provides innovative competitive energy solutions nationwide. For more information, visit [aep.com](https://www.aep.com).

The United States operates the largest and highest performing fleet of nuclear reactors in the world. This fleet currently supplies over half of the carbon-free electricity consumed in the United States. Our current fleet of reactors does this at very high capacity factors providing carbon-free electricity on a 24/7/365 basis, and has performed very well in extreme weather events that have occurred over the past decade. These reactors also can be applied to non-electricity generation applications such as:

- The production of clean hydrogen using excess power (Exelon Nine Mile Point).
- The production of clean hydrogen using excess power and process heat (APS Palo Verde).
- The production of medical isotopes (Bruce Plant – Canada).
- The desalination of water (see below).
- Military and national security purposes. USAF has selected Eielson Air Base in Alaska for deployment of a micro-reactor in 2027.

While the current fleet of reactors operates at the highest levels of safety, several companies have begun work on advanced reactor designs. The advanced reactors being designed incorporate decades of operating experience and technology improvement to produce even safer reactor designs.

The reactors in the current fleet are very large, typically 600-1,400 MWe, and were mostly constructed on their operating sites, resulting in lengthy and expensive construction schedules. Advanced reactors are smaller, typically 60-300 MWe, simpler, and utilize modular construction techniques. They are referred to as small modular reactors (SMRs). The size and inherent safety features of these designs eliminate the need for many systems, greatly simplifying the design and construction. In addition, modular construction techniques enable much of the construction to be completed in a factory setting resulting in reduced site fabrication activities and cost. These advanced reactors also require a smaller footprint. They can be deployed much more rapidly in “packs” or groups of reactors, which allows additional reactors to be added as the need arises. Finally, these smaller reactors employ air cooling systems and use far less water than reactors that use cooling water from a river, lake, or ocean.

Several advanced reactors are currently in the design and development phase. These reactors fall into the following general categories:

- Advanced light water reactors – These reactors are of similar design to the existing fleet of reactors. They incorporate advanced safety features, use the same fuel that our current fleet of reactors use and are of modular design. These reactors are being designed and developed by NuScale, Holtec, and GE-Hitachi, for example.
- So-called next generation reactors – These reactors utilize different cooling mediums, such as helium gas, or molten sodium. In addition, they utilize advanced fuel designs that often use high-assay low-enriched uranium (HALEU) fuel that can incorporate additional resistance to possible fuel melt events. These types of reactors are being designed and developed by TerraPower, X-energy, and Kairos, among others.

- Micro-Reactors – Very small nuclear reactors, typically 1-5 MWe. Some are miniature versions of SMRs, others will function like batteries or fuel cells. These reactors are being designed and developed by Oklo, Westinghouse, and Ultra Safe, for example.

SMRs and micro-reactors have several benefits that extend beyond bulk power production and can support the decarbonization of other segments of our economy:

- Their smaller size makes them ideal to power micro-grids that need a dedicated, reliable source of carbon-free power. Micro-grids perform a critical role as part of many power systems, and can directly contribute to other goals.
- Desalination plants will need SMRs as the world continues to stretch the supply of fresh water. The use of SMRs for desalination could be of critical importance in the future in some parts of the developing world, as access to fresh water emerges as a critical issue due to a combination of increased demand for water caused by population growth and decreased water supplies due to climate change and droughts.
- Distributed energy resources (DER) will challenge the grid of the future. SMRs and micro-reactors can load follow, can be dispatched as needed and provide uninterrupted voltage and frequency support to the power grid.
- They offer resilient, long-term power to facilities important to national security, like military bases. They can operate several years or more between refueling and maintenance outages.
- Similar to existing nuclear reactors, they can supply hydrogen without emitting carbon. SMRs can be located near hydrogen production facilities and transport hubs. This makes SMRs an ideal partner to large oil and gas companies that will transition to hydrogen production and transportation. (The Royal Dutch Shell chief scientist spoke to the NEI board of directors in October and explained that in the future, Shell will rely on SMRs and renewables to produce hydrogen as part of repurposing storage and transport infrastructure for the transport of hydrogen.)
- Advanced nuclear plants that operate at high temperatures also provide an option to assist in the decarbonization of some sectors like the steel industry, providing both electricity and process heat.
- SMRs may have a future role in the production of medical isotopes.

The Nuclear Regulatory Commission (NRC) has completed the technical review of one SMR design from NuScale and is currently reviewing a micro reactor application from Oklo. Several other vendors are expected to submit their designs for NRC review in the next few years. NRC's current regulatory framework and review processes are oriented toward light water reactors like the plants we operate today. The NRC is currently

assessing their processes to complete technical reviews and to issue licenses for non-light water reactors. Establishing an efficient and timely process for licensing advanced reactors is essential to enabling nuclear power to support decarbonization of our economy.

Individual states also have a role in the licensing of new reactors via environmental reviews, water rights and other regulatory constructs.

The first SMRs are expected to be placed in service in the 2027-2029 time frame. NuScale, TerraPower, and X-energy are working with federal and state authorities for design certification and combined operating licenses, and with government and private entities for financing.

There are several business models for the construction of SMRs. These include:

- Construction of reactor(s) at a government facility in partnership with a municipal utility and DOE (NuScale to build SMRs at Idaho National Laboratory in partnership with the Utah Associated Municipal Power System)
- Construction of reactor(s) at the sites of decommissioned fossil power plants in partnership with DOE (TerraPower and PacifiCorp to build SMR in Wyoming, NuScale has met with various utilities)
- Construction of reactor(s) in areas of need in partnership with DOE (X-energy with Energy Northwest in Washington)
- Construction of a SMR at a decommissioned nuclear reactor site (Holtec)

This is a good start but continued engagement between the private sector and federal government is needed to advance the technology and offset the financial risks to early adopters of this technology. Engagement includes:

- Investment or production tax credits to offset the first-of-a-kind expenses to be incurred for the initial facilities to be built. The ITC and PTC have worked well to encourage the adoption of wind and solar energy.
- Zero emission credits (ZEC), which have been utilized to compensate existing nuclear power plants for their carbon-free electricity in states such as Illinois, New York, Connecticut, and New Jersey.
- Continued DOE grants and funding for new reactor designs, testing, and fuel fabrication.

There are several promising small modular, or advanced, reactor designs being put forward by American companies. Across the globe other countries, most notably Russia, China, Canada, and the UK, are currently designing and deploying these advanced reactors to meet their carbon-free energy needs. Nuclear power has proven to be a large-scale source of 24 / 7 electricity production needed to complement numerous other sources of carbon-free electric generation to reliably power the U.S. and the global economy in the near-term and the long-term, while also providing critical non-electrical services including the production of clean hydrogen and desalination of fresh water.

The CHAIRMAN. Thank you, sir.

Next, we have Mr. Michael Guastella, Executive Director of the Council on Radionuclides and Radiopharmaceuticals.

Mr. Guastella.

STATEMENT OF MICHAEL J. GUASTELLA, EXECUTIVE DIRECTOR, COUNCIL ON RADIONUCLIDES AND RADIOPHARMACEUTICALS, INC.

Mr. GUASTELLA. Good morning Chairman Manchin, Ranking Member Barrasso, and members of the Committee. I am Michael Guastella, the Executive Director of the Council on Radionuclides and Radiopharmaceuticals (CORAR). CORAR is an association of companies that manufacture and distribute radioactive sources and medical isotopes in the United States. Thank you for the opportunity to provide the Committee with our concerns with the current supply of isotopes.

Medical isotopes are used by nuclear medicine doctors to diagnose or treat disease. Nuclear medicine has the distinct advantage of being non-invasive with few side effects. We estimate that there are 20 million nuclear medicine procedures performed annually for diseases such as cancer, heart disease, Parkinson's disease, and Alzheimer's disease. In the mid-1990's, the last U.S. commercially operated reactor that produced fission-based medical isotopes was closed and decommissioned. In addition, in the late 90's, the U.S. Government closed the Stable Isotope Production Facility at the Oak Ridge National Laboratory. These two actions left the medical and industrial communities more reliant on foreign sources. Few in the government focused on the loss of domestic medical isotope production until 9/11, when many of the isotopes coming from abroad were temporarily cut off due to the cessation of flights into the U.S.

In the years following 9/11, your Committee took up the concern over the lack of a domestic supply of medical isotopes and to remove the use of highly enriched uranium (HEU) in the production of medical isotopes, and led the effort to enact the American Medical Isotope Production Act of 2012 (AMIPA). AMIPA focused on the Department of Energy on assisting in the development of domestic medical isotope production from non-HEU sources. I am proud to be here today to say "thank you" for this Committee's acknowledgement of the isotope supply issues and your support in addressing our concerns. Also, I want to recognize past Chairman Bingaman and Ranking Member Murkowski for their leadership and efforts that resulted in the enactment of AMIPA.

Now, let me update the Committee on U.S. isotope supply, opportunities, and challenges. Of the 20 million nuclear medicine procedures performed annually in the U.S., an estimated 15 million of these procedures utilize a medical isotope that is used for diagnostic imaging procedures and is predominantly and approximately 90 percent sourced from overseas. We note that U.S. patients rely on other medical isotopes that are either sole-sourced or predominantly sourced from overseas. For example, palladium-103 is used to manufacture brachytherapy seeds, and the primary source of palladium-103 is Russia. These radioactive seeds are primarily used in early-stage prostate cancer treatment.

The DOE has also been a supportive and constructive partner through efforts of the Office of Science Isotope Program to domestically produce both the isotopes that are needed because commercial production has not yet been established or is not sufficient to meet U.S. medical and industrial needs. The DOE Isotope Program (DOE IP) accomplishes this through a network of production sites that utilize national laboratory resources. DOE especially plays a critical role in producing and distributing isotopes needed in scientific research and for initial medical clinical development, as there are not sufficient commercial incentives for production of such isotopes. CORAR and its member companies believe that where commercially feasible, medical and industrial isotopes should be produced by the private sector. Various companies are currently developing reactor and non-reactor capabilities to help scale-up domestic production of essential medical isotopes. CORAR believes that when diverse commercial production sources can meet U.S. demand, the DOE Isotope Program should exit the market for such isotopes, consistent with the mission of the DOE Isotope Program.

CORAR would recommend that the Committee continue to support the DOE's research, development, and production activities. Also, CORAR suggests that the Committee suggest an increase in DOE's industry and government cooperation through a stakeholder and an agency advisory committee to help to find the nation's isotope need and help identify opportunities to increase domestic isotope production.

I thank you for the opportunity to testify today and I welcome any questions that you might have.

[The prepared statement of Mr. Guastella follows:]



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November 2, 2021

Good morning. Chairman Manchin, Ranking member Barrasso and members of the committee. I am Michael Guastella, the Executive Director of the Council of Radiopharmaceuticals and Radiopharmaceuticals (CORAR). CORAR is an association of companies in the United States and Canada that manufacture and distribute radiopharmaceuticals, radioactive sources and medical isotopes marketed in the United States for therapeutic and diagnostic nuclear medical applications (referred to as nuclear medicine) and, in some cases, for industrial, environmental, and biomedical research and quality control.

Thank you for the opportunity to provide the committee with the perspective of medical and industrial isotope producers, processors, and distributors on the current supply of isotopes used by the industrial and medical communities.

At the outset let me provide the committee an overview on the use of isotopes and the current state of isotope supply for industrial and medical applications. In the mid-1990s the last US commercially-operated research reactor that produced fission based medical isotopes was closed and decommissioned leaving the US without a domestic source of essential medical isotopes.

Also, the US government closed the stable isotope production facility in Oak Ridge National Laboratory in the late 1990s, leaving the U.S. largely dependent on foreign sources of such isotopes which are often used as target material for the production of radioactive isotopes. Frankly few in the U.S. government focused on the loss of domestic production until 9-11 as in its immediate aftermath the supply of many radioisotopes coming from abroad was temporarily cut-off due to the cessation of flights into the U.S. The US Government recognized that essential medical procedures were being postponed with serious potential health consequences.

In the years following 9-11 your committee took up the concern over the lack of a domestic supply of medical isotopes, and in an effort to remove the use of Highly Enriched Uranium (HEU) in the production of medical isotopes, led the effort to enact the American Medical Isotope Production Act of 2012 (AMIPA). AMIPA has focused the Department of Energy on assisting in the development of a domestic medical isotope industry from non-HEU sources which led to a close relationship between several CORAR member companies and the Department of Energy as they strive to aid in the development of a domestic supply of medical isotopes and to meet the needs of our researchers and drug developers for the next generation of isotopes. These public-private relationships include several awards of Cooperative Agreements with Government cost-share by the National Nuclear Security Administration (NNSA).

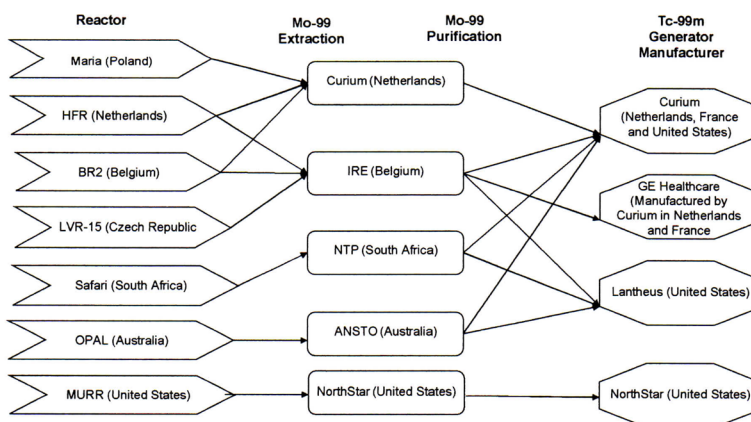
The Senate Energy Committee led on these issues, and I am proud to be here before you to say thank you for this committee's support for the medical and industrial isotope supply concerns and I want to recognize Past Chairman Bingaman and Ranking Member Lisa Murkowski for their leadership and efforts that resulted in the enactment of AMIPA.

Now let me update the committee on U.S. isotope supply opportunities and challenges.

Nuclear medicine involves the injection of radioactive materials (i.e. medical isotopes and radiopharmaceutical drugs) into a patient's body for diagnostic or therapeutic procedures. For example, Single-Photon Emission-Computed Tomography (SPECT) imaging cameras, capable of detecting and using the signals from the injected radiopharmaceutical, are used to create detailed images of patients' organs, arteries, or certain cells, as well as assessing organ function. Nuclear medicine is integral to the care of patients with cancer, heart disease and brain disorders and offers not only structural images, but allows physicians to see how the body is functioning and to measure its chemical and biological processes. There are currently twenty (20) million nuclear medicine procedures performed annually in the United States as reported by the Society of Nuclear Medicine and Molecular Imaging¹. In 2017, there were approximately 2,900 hospitals in the United States that performed diagnostic nuclear medicine procedures to diagnose and treat several million Medicare beneficiaries².

For example, the most common medical isotope used in nuclear medicine procedures in the United States is technetium-99m (Tc-99m), with a half-life of six (6) hours. Technetium-99m is derived from molybdenum-99 (Mo-99), with a half-life of 66 hours. Technetium-99m based radiopharmaceuticals are used by nuclear medicine physicians and radiologists to diagnose diseases, such as heart disease and many forms of cancer, and inform treatment plans. Of the 20 million nuclear medicine procedures performed annually in the United States, an estimated 15 million of these procedures³ utilize Tc-99m based radiopharmaceuticals. For example, over 1 million doses of Tc-99m sestamibi, needed to diagnose coronary artery disease, were dispensed to Medicare beneficiaries in CY 2017.⁴

Based on publicly available information, the majority of Mo-99 production is based overseas and handled by a series of long-established research reactors and processors in Europe, South Africa, and Australia – please see below:



¹ Society of Nuclear Medicine and Molecular Imaging, <http://www.snmmi.org>.

² Centers for Medicare and Medicaid Services Claims Data.

³ US Department of Energy, <https://www.energy.gov/nnsa/nnsa-s-molybdenum-99-program-establishing-reliable-supply-mo-99-produced-without-highly>

⁴ *Id.* at 2.

Six multi-purpose research reactors (excluding MURR⁵) and four Mo-99 processors (excluding NorthStar) supply greater than 95% of Mo-99 for patients in the United States⁶.

Although we primarily discuss Tc-99m above, we note that U.S. patients rely on other medical isotopes that are also sourced from overseas, either as the sole source provider or the predominant provider. For example, Palladium-103 (Pd-103) is used to manufacture brachytherapy permanent implant seeds and a primary source of Pd-103 is Russia. These radioactive seeds are primarily used in early stage prostate cancer treatment. An estimated 174,650 men in the United States are diagnosed annually with prostate cancer⁷ and approximately 60% of cases are diagnosed in men over 65. The average age of diagnosis is 66 and the disease rarely occurs before age 40. Restrictions on access to Pd-103 will impact the ability of oncologists to treat patients.

In addition, all of the Xenon-133 (Xe-133) is produced overseas and shipped to the United States for the diagnosis of lung disease. Also, foreign sourced Iodine-131 (I-131) used to treat thyroid disease is required to meet the domestic needs for this isotope.

In order to function accurately, each nuclear medicine camera requires a calibrating device, known as a sealed source. Sealed sources are made from isotopes such as Gadolinium-153 (Gd-153), and Cobalt-57 (Co-57). Due to the relatively short half-life of these isotopes, hospitals need to replace sealed sources frequently and Russia is the sole source provider in the world of Gd-153 and the majority supplier of Co-57.

Stable isotopes play a particularly important role in the production of innovative new radiopharmaceutical therapies. These include Ytterbium-176 (Yb-176) for the production of non-carrier added Lutetium-177 (Lu-177 is a beta-emitter for therapeutic application) and Zinc-68 (Zn-68) for the production of copper-67 (Cu-67 is a beta-emitter for therapeutic application). Both Lu-177 and Cu-67 are being used to develop the next generation of targeted radiopharmaceutical therapies that will enhance the treatment of disease especially cancer. However, the stable isotopes needed to commercialize these targeted radiopharmaceutical therapies are either sole sourced or predominantly sourced from overseas.

Foreign supplied radioisotopes also play a crucial role in supporting US oil, gas and coal production – interruption of supply would quickly result in shortages and cause significant revenue losses to American energy sector producers. Radioisotopes such as Iridium-192 (Ir-192) and Selenium-75 (Se-75), when encapsulated in sources, assure operational safety in refineries and pipelines by carrying out “radiography” of metal structures to test for corrosion, leaks and cracks. The DOE Office of Science Isotope Program provides major amounts of Se-75 through production at the High Flux Isotope Reactor in Oak Ridge, Tennessee. However, the three largest suppliers in the world of these radiography sources procure Iridium-192 primarily from two powerful high-flux reactors in Russia.

Foreign produced Americium-241 (Am-241) is used to build neutron sources for Oil Well Logging applications and smoke detectors. Russia is the largest source for Am-241 with very limited amounts produced domestically since the late 1970s. Russian reactors also provide Barium-133 (Ba-133), used in extraction and refining to separate oil, water and gas. Ba-133 has recently been produced at the High Flux Reactor in Oak Ridge, Tennessee using Russian sourced Barium-132 (Ba-132). Ba-132 is an enriched stable isotope and is only available from Russia.

Please note that Exhibit 1 includes a number of isotopes produced through a supply chain heavily reliant on overseas production⁸.

⁵ University of Missouri Research Reactor

⁶ National Academies of Sciences, Engineering, and Medicine Report on Molybdenum-99 for Medical Imaging; <https://www.nap.edu/catalog/23563/molybdenum-99-for-medical-imaging>

⁷ Cancer.net; <https://www.cancer.net/cancer-types/prostate-cancer/statistics>

⁸ Information available through selling entities public websites

Beyond support to domestic production of Mo-99 by NNSA, the DOE has also been a supportive and constructive partner through efforts of the Office of Science, Isotope Program to domestically produce both radioactive and stable isotopes that are needed because commercial production has not been established or is not sufficient to meet U.S. medical and industrial demands. The DOE Isotope Program accomplishes this through a network of production sites that utilize national laboratory resources such as the High Flux Isotope Reactor at Oak Ridge National Laboratory, the University of Missouri Research Reactor, and the Low Energy Accelerator Facility at Argonne National Laboratory to name a few. Exciting new DOE projects such as the Facility for Rare Isotope Beams at Michigan State University, and the U.S. Stable Isotope Production and Research Center (SIPRC), being built in Oak Ridge, Tennessee, are intended to expand the nation's capability to enrich stable isotopes for medical, industrial, research, and national security uses. The SIPRC will house two types of isotope separation equipment: Electromagnetic Isotope Separators (EMIS), and Gas Centrifuge Isotope Separators (GCIS).

DOE especially plays a critical role in producing and distributing isotopes needed in scientific research and for initial medical clinical development, as there are not sufficient commercial incentives for production of such isotopes. CORAR and its member companies believe that where commercially feasible, medical, and industrial radioisotopes should be produced by the private sector. Various companies are currently developing reactor and non-reactor capabilities to help scale up domestic production of essential, mature market medical radioisotopes such as Mo-99, I-131, and Xe-133. In addition, private sector projects are underway to increase domestic supply of Actinium-225 (Ac-225 is an alpha-emitter for therapeutic application), Lu-177, and Cu-67 for targeted radiotherapies through the use of particle accelerators and reactors. CORAR believes that when diverse commercial production sources can meet U.S. demand, the DOE Isotope Program should exit the market for such isotopes, consistent with the mission of the DOE Isotope Program.

CORAR is aware of additional opportunities being explored by industry stakeholders to augment domestic supply of essential medical and industrial isotopes such as the use of current nuclear power reactors as a neutron source for isotope production. Also, some have considered using advanced nuclear reactors in the future for isotope production.

CORAR wants to thank the committee for the opportunity to highlight these issues and would recommend that the committee continue to support the DOE's research, development, and production activities. Also, CORAR suggests that the committee support an increase in DOE's industry and government cooperation through a stakeholder and agency advisory committee to help define the nation's isotope needs and help identify opportunities to increase domestic isotope production.

I thank you for the opportunity to testify today, and I would be pleased to answer any questions.

Respectfully Submitted,



Michael J. Guastella

Exhibit 1

Medical Isotopes	Stable	Isotope Details
Cobalt-56 (Co-56)		Calibration standard
Cobalt-57 (Co-57)		Medical Imaging
Cobalt-60 (Co-60)		Cancer treatment and medical product sterilization
Cesium-137 (Cs-137)		Cancer treatment, Thickness gauging, flow detection
Cadmium-112 (Cd-112)	Stable	Target material for In-111 production
Erbium-168 (Er-168)	Stable	Production of Er-169 used for radiation synovectomy
<i>Gadolinium-153 (Gd-153)</i>		<i>Medical Imaging Quality Control Source (SPECT)</i>
Germanium-68 (Ge-68)		PET imaging, cancer treatments
Nickel-64 (Ni-64)	Stable	Target material for Copper-64 production which is used for cancer diagnosis
Palladium-103 (Pd-103)		Treatment for Prostrate Cancer
<i>Rubidium-83 (Rb-83)</i>		<i>Cancer treatment, target for Sr-82</i>
<i>Ruthenium-106 (Ru-106)</i>		<i>Brachytherapy for treatment for ocular melanoma</i>
Thallium-203 (Tl-203)	Stable	Target material for Thallium-201 production used in heart imaging.
Tin-112 (Sn-112)	Stable	Cancer diagnosis of brain, liver kidney tumors
<i>Molybdenum-98 (Mo-98)</i>	Stable	<i>Target material for Mo-99 production</i>
<i>Molybdenum-100 (Mo-100)</i>	Stable	<i>Target material for Mo-99 production</i>
Rhenium-185 (Re-185)	Stable	Production of Re-186 for cancer treatment
Samarium-152 (Sm-152)	Stable	Production of Sm-153 used in cancer treatment
Uranium-235 (U-235)		Research reactor fuel and irradiation targets for Mo-99 production
Ytterbium-176 (Yb-176)	Stable	Production of non-carrier added Lutetium-177 for cancer treatment
Yttrium-88 (Y-88)		Medical diagnostics, LED's
Xenon-124 (Xe-124)	Stable	Production of Iodine-123 and Iodine-125 radioisotopes for imaging and cancer treatment
Xenon-133 (Xe-133)		Production of Xe-133 for evaluation of pulmonary function and lung imaging
Zinc-68 (Zn-68)	Stable	Target material for Ga-67 and Cu-67 production

Please note: highlighted italic isotopes are single sourced from Russia.

Industrial Isotopes	Stable	Isotope Details
Americium-241 (Am-241)		Oil/Gas exploration
Barium-133 (Ba-133)		Oil/Gas exploration
<i>Barium-132 (Ba-132)</i>	Stable	<i>Target Material to US DOE for Ba-133 production</i>
<i>Cadmium-109 (Cd-109)</i>		<i>Metal analysis/lead in paint</i>
Cerium-139 (Ce-139)		Used in Metal production
<i>Helium-3 (He-3)</i>		<i>Oceanic transient tracer, fuel for nuclear fusion reactions</i>
Iridium-192 (Ir-192) Disks		Industrial Radiography
<i>Krypton-85 (Kr-85)</i>		<i>Radioactive tracer, Arc discharge lamps, exit signs</i>
Polonium-210 (Po-210)		Static remover
Selenium-75 (Se-75)		Industrial Radiography
Tellurium-122 (Te-122)	Stable	Target material for I-122 gamma imaging
Xenon-124 (Xe-124)	Stable	Instrumentation for radiation detection

Please note: highlighted italic isotopes are single sourced from overseas.

The CHAIRMAN. Thank all of you for doing a great job and we appreciate it. We will start our questioning now, and I am going to start with Dr. Shannon Bragg-Sitton.

U.S.-based companies are working with the national labs to bring advanced nuclear technology to market, technologies that can generate high temperatures needed for manufacturing. We know that the industrial sector is difficult to decarbonize because of the technological challenges and the volume of energy that must be replaced with non-emitting technologies. The manufacturing industry in the U.S. uses about 25 exajoules—Did I say that correctly?—exajoules of energy. About 20 percent of this is from electricity, 40 percent from steam, and 40 percent from fossil-fired combustion, and over 90 percent of the primary energy required is currently derived from the combustion of fossil fuels.

So can you explain the advantages of advanced nuclear plants for process heat applications or hydrogen production? What I am trying to look at is the price model too, there, to make it more competitive price-wise. If we are going to be replacing our fossils, I want to make sure that we have the horsepower to do it.

Dr. BRAGG-SITTON. Thank you so much for that question, Senator Manchin.

Absolutely. Advanced reactors can provide us with high-temperature heat to produce hydrogen very efficiently. Using that high-temperature heat and electricity, we can produce hydrogen approximately 30 to 50 percent more efficiently than by just using electricity alone. And we can provide that heat directly via steam or via stored energy in energy storage systems to support that industrial application and bring those costs down such that we can bring back domestic manufacturing—and steel manufacturing—all without the carbon emissions associated with it. And these industrial applications can be very efficient, can be produced just as efficiently as with fossil resources, but doing so without emissions provides a significant advantage over these competing technologies.

The CHAIRMAN. Do you see—it looks like nuclear is the—if we are going to decarbonize the industrial sector, I do not believe, personally, that we can do it with renewables. So we need to do it with something that has the horsepower and basically is dispatchable 24/7. Is nuclear the way to go?

Dr. BRAGG-SITTON. Yes, I believe it is.

The CHAIRMAN. Dr. Chodak.

Dr. CHODAK. Yes, Senator.

The CHAIRMAN. Mr. Guastella.

Mr. GUASTELLA. Yes.

The CHAIRMAN. Okay, it is good to get that understanding. In light—and this is to Dr. Chodak. This will be yours. In light of recent legislation that developed an emergence of U.S. companies building advanced reactors in the next decade, my legislature is working in West Virginia to reverse the civil nuclear that restricts the construction of nuclear plants in the state. I think we are going to get that done. They understand. Several potential sites in West Virginia and across the country have preexisting infrastructure. We have coal-fired plants that are going down. I think my friend in Wyoming has a coal-fired plant. Everything is there. The base is there to work off of.

So would that be the way for us to go as we are taking fossil coal off of the grid, but having all the interchangeable—the switch stations right there on that site. Would that be our best way to get up and running quicker?

Dr. CHODAK. Yes, Senator. If you can hit the targets that they are talking about for us—if they can build them for, you know, \$2,000 to \$3,000 per KW, and if they can get a levelized cost that's competitive at around \$50 per megawatt-hour, then nuclear technology makes a tremendous amount of sense.

The CHAIRMAN. Doctor, let me see, you are saying that is five cents, five cents a kilowatt-hour is what you are talking?

Dr. CHODAK. Right.

The CHAIRMAN. Okay. At five cents, I do not see that in my energy reports every day. I see it being up there high in the 9, 10, 11, 12—even higher.

Dr. CHODAK. So the five cents is just the generation cost and then on top of that you have the cost to actually transmit it. So the generation cost is probably around five cents.

The CHAIRMAN. And how does that compare with natural gas, combined cycle, and coal?

Dr. CHODAK. Three-dollar natural gas would be closer to three cents per kilowatt-hour.

The CHAIRMAN. Three cents, okay, and coal?

Dr. CHODAK. And coal is right around in there too. Natural gas and coal are probably around \$20 to \$30 a megawatt-hour.

The CHAIRMAN. So nuclear is higher.

Dr. CHODAK. Nuclear is—

The CHAIRMAN. Is there any way that you can see—through advanced technology and how we basically are using this money that we are talking about, a good bit of money for research and development—can we get that cost down or does the new generation of nuclear—will that bring it down?

Dr. CHODAK. Senator, I believe it will. Those are the targets they are talking about and we are talking about 10 years from now. So the cost of power 10 years from now is likely going to be above that three cents per kilowatt-hour. It is going to be closer to four or five cents. I think at those prices then nuclear can be competitive. The key is to get through the first-of-a-kind costs and that is where we need a lot of collaboration at the state and federal levels because there are additional costs associated with that. And so the programs that the DOE is engaging in to do the R&D are very, very helpful in that regard, but also remember that these are 40-year cycles.

As a utility, my job is to be cost-effective for my customers. That's the number one thing after—

The CHAIRMAN. I want to take the liberty of asking one more question, if you don't mind.

Dr. CHODAK. No.

The CHAIRMAN. The liberty of asking one more question is this: We had a program that was presented to us called CEPP (Clean Energy Performance Program), which we were going to pay utilities to—and the carbon, the fossil cycle, if you will—and it was basically geared toward coal. And I understand, coal has gone from 52 percent of basically producing the power for our country, down to

19 percent. People do not realize, we are going in the right direction, if that's what they want. But the bottom line is we had gas fill the back—come back and fill the baseload. So we had baseload power. Going down that cycle, do we have anything that will replace the dispatchable baseload power by 2030 if we took all of our fossil off? Can any of you answer? Do you think we would be in jeopardy of not having dispatchable power? Baseload?

Dr. BRAGG-SITTON. Absolutely. We need to have that dispatchability, that nuclear energy.

The CHAIRMAN. But the way this program was going, your thought? Did you know a little bit about the CEPP?

Dr. BRAGG-SITTON. No, I did not.

The CHAIRMAN. Okay. Well, you ought to read up on it.

Dr. CHODAK. Senator, I am familiar with the CEPP and you're absolutely right. If you were to remove baseload generation dispatchable power from the grid by 2030 then you couldn't guarantee the reliability and stability of the grid.

The CHAIRMAN. So reliability, first of all, and the cost would have been outrageous too, I am understanding.

Dr. CHODAK. Exactly.

The CHAIRMAN. Okay.

Mr. Guastella.

Mr. GUASTELLA. Senator Manchin, I am not an expert in power, so—

[Laughter.]

The CHAIRMAN. Okay. Well then, I am going to let you pass on that one.

[Laughter.]

The CHAIRMAN. Senator Barrasso.

Senator BARRASSO. Let me testify that Senator Manchin is an expert in power and how to use it.

[Laughter.]

Mr. GUASTELLA. He certainly sounds like he is.

The CHAIRMAN. Thank you, Senator.

[Laughter.]

The CHAIRMAN. Oh, boy.

Senator BARRASSO. Dr. Chodak, TerraPower has announced plans to build its Sodium advanced nuclear reactor in my home State of Wyoming. This reactor will be the first of its kind built anywhere in the world. It will also be the first time a nuclear reactor uses the infrastructure and workforce from a retired coal plant. Why are utilities interested in advanced nuclear technologies like TerraPower's Sodium reactor?

Dr. CHODAK. Senator, they're interested because it complements renewables very well and supplies the dispatchable resources. You know, when we talk about 24/365 regardless of the weather, we saw what happened in Texas with Uri. We saw all the devastation that that caused. We saw the challenges that you see in California today where they are—the California Public Utility Commission just went out and said, "Hey, we need gas resources. We need dispatchable power to make sure the lights don't go out."

There are still days in a row where you don't have the wind blowing and it's very cloudy, and so you have to have that dispatchable resource. And small modular reactors are flexible.

They can load-ramp. They are small in size so they take a much smaller footprint. I believe the Natrium reactor takes about a 44-acre footprint, very small footprint. And because it has the molten salt energy storage device in it, it can ramp up from 345 to 500 megawatts. That's considerable ramp-up during a time when solar energy is dropping off at the end of the day—everybody is coming home, turning on their computers, turning on their lights, turning on their stoves—and that's exactly when solar power is going away. That's when that Natrium reactor can respond. And small modular reactors are flexible in design to be able to do that.

Senator BARRASSO. Mr. Guastella, particle accelerators and nuclear reactors are used to produce medical isotopes—elements which doctors use to diagnose and treat cancers, a number of diseases. Research reactors and particle accelerators provide the bulk of these isotopes. What kind of opportunities do existing commercial reactors present for medical isotope production and then also, what kind of opportunities do advanced reactors like TerraPower present for medical isotope production? So both the advanced and the traditional?

Mr. GUASTELLA. Well, Senator, thank you. Thank you for that question. I am not a nuclear engineer so what I would like to do is submit that question for the record so that we can respond with more detail.

To your point, research reactors and particle accelerators are currently being used in the U.S. There is a lot of research and development being done right now, particularly with particle accelerators in the U.S. commercially, and I think it would be a good thing to actually take that question offline and then provide some additional information to the Committee. Thank you.

Senator BARRASSO. So could you explain why it is important for the United States to maintain and enhance our ability to produce medical and industrial isotopes?

Mr. GUASTELLA. Well, we are dependent—like I mentioned in my opening comments—we are significantly dependent on foreign-sourced materials. That includes molybdenum. The daughter isotope of molybdenum is technetium, and about 75 percent of all nuclear medicine procedures require technetium, and what we have seen in the past is when we have issues like the start of the pandemic when commercial flights were canceled from Europe, we had a significant issue with access here in the U.S. and accessing those products.

So increasing domestic production is incredibly important to ensure accessibility to needed isotopes and there are many others, not only radioactive, but stable isotopes also.

Senator BARRASSO. Dr. Chodak, one more for you. The world is looking to expand the use of nuclear energy to meet its environmental and energy goals. U.S. leadership in the nuclear energy sector, I believe, is critically important. To what extent can utilization of nuclear reactors for non-electric applications like hydrogen production further enhance our leadership in terms of energy and around the world?

Dr. CHODAK. Well, Senator, as I alluded to in my testimony, I have firsthand experience with being at the negotiating table with international nuclear authorities and the question that was leveled

at us, no matter what we said, was “Well, you guys aren’t deploying anything. You haven’t built anything in 30 years. Why should we listen to you?” In essence, that was their argument, which is very difficult to argue against. Very difficult to argue with that.

If we are out there deploying, leading the way in technology, and defining systems and out there showing how it can be done, how nuclear technology can be used for all these non-electric uses, then we are able to have a seat at the table and have a conversation and credibly argue for international policy that we believe to be correct.

Senator BARRASSO. Thank you. Thank you, Mr. Chairman.

The CHAIRMAN. Thank you, Senator.

Now we are going to go to Senator Cortez Masto.

Senator CORTEZ MASTO. Thank you, Mr. Chairman. Thank you. This is an incredibly important panel. So I appreciate you all being here.

Let me follow up on Senator Barrasso’s question, Mr. Guastella, to you. With respect to the production of medical isotopes, I am interested in how we can utilize the current nuclear reactors for the production of it versus the advanced technology that we are looking at. Which one is better? So whatever research you put together and you submit, would you please submit it to my office as well?

Mr. GUASTELLA. Absolutely.

Senator CORTEZ MASTO. Thank you. Because I think this is an important issue. Are you familiar with the GE-180 Tracer?

Mr. GUASTELLA. I am not, no.

Senator CORTEZ MASTO. Okay. So the GE-180 Tracer was approved by the FDA to help really understand the underlying causes of Alzheimer’s and Parkinson’s, and it happened in Las Vegas at the Lou Ruvo Clinic—Cleveland Clinic, by one of our doctors. And this is a perfect example of supporting what you are saying—

Mr. GUASTELLA. Right.

Senator CORTEZ MASTO [continuing]. Why this production—medical isotopes are so important. But in layman’s terms, can you explain? When people hear medical isotopes, that is very confusing, I think, and it doesn’t explain how this is utilized to help uncover the causes and determine, really, what we are trying to understand with Parkinson’s disease, Alzheimer’s disease, and so many others. Can you explain it in layman’s terms how it is utilized?

Mr. GUASTELLA. Sure. Let’s take a simple example using PET imaging. So the GE machine that you mentioned, I’m sure, is a machine that is used to produce PET isotopes. So we will take PET imaging, and a fairly generic use of that technology in the diagnosis of cancer. So a fluorine-18 radioisotope is attached to a sugar molecule—glucose—and that is injected into a patient and glucose is used by every cell in the body, but cells that are particularly active, that have a much higher level of metabolism, absorb more of that. And so, with PET imaging using fluorinated glucose (FDG), physicians can actually diagnose where cancer has metastasized. That same technology can be used with a patient that has been diagnosed with cancer, and then used after treatment to determine if some of those tumors have actually decreased in size or actually gone away.

So it is a nice example of how nuclear medicine and PET imaging can be used, not only in diagnosis, but in forming treatment.

Senator CORTEZ MASTO. Thank you so much.

And then, you ended your testimony talking about the need for a stakeholder agency advisory committee. Can you talk a little bit about your vision for that? What do you anticipate? If we were to put something together like that what would be its duties and functions? What are you thinking?

Mr. GUASTELLA. The Isotope Program, basically, through the NSAC (Nuclear Science Advisory Committee), underwent a review of isotope needs. It was the NSACI—*isotope subcommittee*—that has done that twice. The last report was in 2015. We think, as an industry association, it would be helpful to actually provide another report working with stakeholders, industry, researchers, clinicians, the Isotope Program (DOE), to evaluate current needs, potential opportunities moving forward, and the resources needed to accomplish the goals of the action items that come out of that committee.

Senator CORTEZ MASTO. Thank you.

Dr. Chodak, let me ask you this. When it comes to all things nuclear, can you expand on the need for state and local input? Do you think it is important to have state and local input as we look and move forward on all of these areas?

Dr. CHODAK. Yes, as a utility it is absolutely essential that we not only serve customers with safe, reliable power, but we serve them in the way that they want to be served. And we need to work very collaboratively with state and local governments to ensure that everybody is on board with the way that we serve. There are multiple options to serve customers, and generally speaking, we try to remain technologically agnostic. Now, we are looking for the solution that provides that reliable, low-cost power, but also one that communities are willing and interested in having as part of their mix.

Senator CORTEZ MASTO. Thank you. I appreciate it.

Thank you, Mr. Chairman.

The CHAIRMAN. Thank you, Senator.

Senator Cassidy.

Senator CASSIDY. Dr. Bragg-Sitton, hello.

One of the things we hear and read about for smaller, micro nuclear reactors is to help isolated communities after natural disaster. Louisiana was hit recently by hurricane Ida. There were a lot of transmission lines that were down, but one of the ways that they brought electricity back more quickly was by firing back up a mothballed natural gas plant in New Orleans to allow at least a local distribution. Similarly, after hurricanes Delta and Laura in Jeff Davis Parish, the local generating capacity was destroyed. So to what degree could a small or micro nuclear reactor help this? Obviously, I am begging the answer—it could help a lot. So what I am really asking is, what is the likelihood of this happening safely, and on what timeframe?

Dr. BRAGG-SITTON. Thank you for that question, Senator Cassidy.

We have a number of companies that are interested in the development of microreactors for many applications, whether those be for deployment for permanent installations, remote communities, or

for emergency deployment. Microreactors offer us the opportunity to have high-density energy in a very small package. Many of these microreactors are characterized by factory manufacturing, factory assembly, and rapid shipment to site for operation within just a few days. And there are a number of companies working on these to ensure that they will be available this decade as well as programs under the Department of Energy and the Department of Defense that are enabling rapid development.

Senator CASSIDY. What would be the cost of such a reactor? How long could it be used for? And what would be the cost per megawatt-hour and how does that relate to conventional or traditional forms of energy?

Dr. BRAGG-SITTON. With regard to operational time, many of these reactor technologies are designed to operate with extremely long fuel cycles, where our traditional plants today require refueling every 18 to 24 months. These microreactors are designed to offer long life cycles of 5 years, 10 years, or even 20 years of operation so that they could be set down onsite and operated for those long periods of time.

With regard to cost, we believe that they will be quite competitive with other energy sources that could be deployed in those types of regions, but for the record, I would like to provide a detailed answer after communicating with some of those companies to understand their current cost numbers.

Senator CASSIDY. So the way you answered that suggests to me that it might be more expensive but if you are in a region where electricity is already more expensive, it would be competitive, but if you are in a place where electricity tends to be less expensive, it might be a little bit more highly priced.

Dr. BRAGG-SITTON. Yes, that is correct, in that if we were looking at a remote region that is currently dependent on diesel generators, this would be much more cost effective than those diesel generators. But if we are looking to deploy something in a region that has large centralized power plants today, it might be a bit more expensive. So they will not be applicable to all applications, but in many applications, they will be a ready source of reliable, dispatchable energy to meet those needs in emergency situations or to provide that long-duration, sustainable power to remote communities or remote industrial facilities.

Senator CASSIDY. And what is the capacity? How much energy could they produce for this long life cycle?

Dr. BRAGG-SITTON. These microreactors that could be packaged in the small transportable units are on the order of megawatts. So a few megawatts of electricity up to 10 or maybe 20 megawatts of electricity, really bound by the requirements of that factory manufacturing and easy shipment to site via truck, rail, barge, types of technologies.

Senator CASSIDY. I have a lot of petrochemical industry, and obviously there has also been interest among the steel and cement and other energy-intensive industries to lower their carbon intensity. Now, this sounds like a way that they could have an onsite means by which they could, for that portion of their consumption that is related to firing a boiler, they could help decarbonize, correct?

Dr. BRAGG-SITTON. Yes, these types of technologies are something that could provide both the electricity to drive those processes, but also the heat that is necessary to drive the processes, and they can be sited very close to those applications and be dispatchable when that energy is needed for a very long duration of time, as I mentioned.

Senator CASSIDY. Now, in the life cycle—you talked about expense—if you are speaking about that long of a life cycle, you would be avoiding all the input costs for whatever your traditional form of energy would be as well as theoretically your repair costs for lines. If there is an Ida and it blows down your transmission lines, there is a cost of repair. Under this circumstance, co-located, you would be potentially more secure, but also avoid that kind of life-cycle expense of maintaining a grid. Am I begging an answer again or do you think that is reasonable?

Dr. BRAGG-SITTON. I think that is reasonable—that these types of systems can support regional microgrids for both heat and electricity and therefore be much more secure under a variety of events, whether those be weather related or otherwise, and provide that reliable energy for those long durations. And those long life cycles, those refueling cycles that are much longer, mean that we have much fewer operations required onsite. And in fact, after that 10 or 20 year life cycle for that plant, we would then simply replace the core and refurbish that back at a factory.

Senator CASSIDY. Got it. Thank you very much. I yield.

Dr. BRAGG-SITTON. Thank you.

The CHAIRMAN. Thank you very much. I am going to go just a quick second round. If anybody else wants to, I only have one question to any of you or all of you or whoever wants to answer.

My state energy production is about 96 percent coal for my electricity needs in my state. And we export quite a bit of power from our state. Do you believe, for the State of West Virginia, the best direction for it to go would be—as we transition—to nuclear? Does it make sense because of the footprint that we already have, the substations we already have, everything—connection, doesn't need any new transmission, doesn't need anything except a new plug-in model?

You can start right here. We will go down.

Dr. BRAGG-SITTON. Great. Thank you so much for that question. As Dr. Chodak mentioned, those coal sites offer us with significant infrastructure that these nuclear plants can come in and thereby reduce the cost of installing these plants, so those low numbers to make those very competitive. We can take advantage of the grid interconnection and many studies are being conducted to better understand how much of the other assets in that region can be leveraged.

Now, another opportunity that those sites offer us is that we now have a carbon-based feedstock that isn't going to production of electricity, but we could instead use that high-quality heat and electricity from a nuclear plant that goes into that site to process that carbon-based feedstock into higher-value consumer products, thereby enhancing the economic development of those communities that are being impacted by this energy transition. So I think there is a really tremendous opportunity here.

The CHAIRMAN. We are going to have to bring you to West Virginia, do a little confab there and get everybody on the right track.

Dr. Chodak.

Dr. CHODAK. Senator Manchin, I will just add, first off, I agree with everything that was just said and I would just add that if you look at it today, CCS, you know, fossil generation with carbon capture and storage and nuclear are the only two emission-free dispatchable sources that we really have that can go multi-days or even seasonal. And when you look at West Virginia, West Virginia's geology is wonderful to look at, but in terms of storing CO₂, not so good.

The CHAIRMAN. Right.

Dr. CHODAK. And so, it's an outstanding opportunity for a small modular reactor to come in there. The key is, we need to be able to get the cost down and be able to take down the risk of that first-of-a-kind through energy policy. When you layer in the secondary sources, you know, we have a chemical industry there in West Virginia, along the river, where the process heat, the hydrogen production and hydrogen production potential for export to the rest of the country—

The CHAIRMAN. Yes.

Dr. CHODAK [continuing]. You're now looking at West Virginia doing what it used to do with coal only now it's doing it with nuclear.

The CHAIRMAN. Good.

I know you are not an energy person.

[Laughter.]

Mr. GUASTELLA. I would defer to the experts here on the panel, and if it actually increased medical isotope production domestically, it would be a win across the board here.

The CHAIRMAN. Thank you all. I am going to have to run, but Senator Barrasso is going to take over.

Senator BARRASSO [presiding]. Thank you. Thank you so much. I will do that.

Dr. Bragg-Sitton, what more can be done to support private-sector efforts to use nuclear energy for non-electric application?

Dr. BRAGG-SITTON. There are a number of efforts that are underway that are helping significantly to demonstrate these advanced reactor technologies. For example, the Advanced Reactor Demonstration Program is supporting those first demonstrations of private-sector concepts, the Sodium reactor by TerraPower has been mentioned and is planned for demonstration in Wyoming and the X-energy Xe-100 reactor will be initially demonstrated in the State of Washington. These demonstration projects get us considerably down the path toward commercial deployment, but we do need those commitments to be sustained—not just demonstration, but deployment. Commercial-scale deployment of these technologies needs continuing support. We need to look at policies that help to promote that. We need to understand how these technologies not only provide us with reliable heat and electricity, but also that reduced carbon emission that is so important to achieving that net-zero economy.

And the pathway to decarbonizing industry is very challenging. There are not very many technologies that can do this. So I would

say continued support to ensure that we get to large-scale commercial deployment of these technologies that will help us toward that net-zero future is essential.

Senator BARRASSO. When we get to this point of future deployments and the scope that you are talking about in the long-term future, I understand these reactors will be smaller, safer, and more efficient. What kinds of opportunities do these specific characteristics—something that is smaller, safer, and more efficient—present for the siting and for the economic viability of nuclear energy?

Dr. BRAGG-SITTON. The smaller packages offer us the opportunity to locate these plants, these reactors, much closer to their end-use so that transport of heat is much shorter, much reduced heat loss. The smaller packaging also opens that opportunity for factory manufacturing that I mentioned with microreactors. The same thing applies to small modular reactors where we can begin to produce these in large numbers in a factory assembly line type of process such that they no longer become an onsite, one-of-a-kind application. We can reduce cost dramatically through that type of manufacturing approach which then, when we get to those “nth-of-a-kind” systems, then our costs come down significantly overall.

Senator BARRASSO. Mr. Guastella, can you talk a little bit about targeted alpha therapy? That seems to be a promising option for cancers that are no longer responsive to some conventional treatments. Could you describe this treatment and how nuclear energy can enable the production of a new class of isotopes to help in our fight against cancer?

Mr. GUASTELLA. Sure. Actinium-225 is an alpha emitter. It is unfortunately in short supply right now and anything that we can do to increase the production of actinium-225 would be helpful. There is a lot of work being done right now in using alpha emitters like actinium-225 in the treatment of cancer. So, for example, a high percentage of prostate patients express a protein—a prostate-specific membrane antigen, and the use of an alpha emitter like actinium-225 to a carrier—a protein or a monoclonal antibody that would be specific to that antigen—would now provide a very targeted therapeutic for patients that express that particular antigen. And that really is kind of the definition of precision medicine.

And what is also helpful is that the carrier protein—monoclonal antibody, or whatever—can also be used with a diagnostic isotope. So you can identify the appropriate patients and then use a radiotherapy, like actinium, to treat the patient.

Senator BARRASSO. Great.

Senator Cortez Masto.

Senator CORTEZ MASTO. Let me talk a little bit about another opportunity here and I am curious if it does exist—around water purification. Obviously, western states—I am one of them, also Senator Barrasso—we all have concerns about a drought happening right now in the West and how we augment some of our water, particularly along the Colorado River. I know that in the past there have been projects trying to couple the desalination with existing nuclear power plants, and unfortunately, the cost is very high. So I am curious, both Dr. Bragg-Sitton and Dr. Chodak, if the advanced nuclear technology is going to be able to couple with this type of water purification and bring those costs down, or just your

thoughts, in general, about the state of desalination and is it in our purview? Is it in 10, 20 years? Is it something that is viable but also economically viable as well?

Dr. BRAGG-SITTON. Thank you so much for that question. Idaho National Laboratory partnered with Arizona Public Service a few years ago to look at that exact question. How can we utilize excess energy from the Palo Verde Generating Station to desalinate water? It is a very interesting scenario there in that they have an ample amount of brackish groundwater rather than sea water. And so, looking at that resource and looking at reverse osmosis technology, which is commercially available at large scale, we actually found that there were reasonable opportunities to bring those costs down, to make that affordable, to provide cooling water for that plant, which currently uses municipal wastewater for cooling, or to provide that to the agricultural regions or potable water for those growing communities west of Phoenix.

So there are some opportunities available and it does depend on the water source. It depends on the economic competitiveness of how else that electricity would be used and, in that case, it was curtail electricity due to rising solar penetration in that region, or use it to produce this clean water. So there may be some viable options with technology we have today and we see many countries, in the Middle East, for example, that are looking to enhanced water processing desalination to support their communities as well. Reverse osmosis is driven purely by electricity to drive that process. There are also thermally driven desalination processes that may become more affordable as we begin looking to the higher temperature applications that are available with advanced reactors. So I do think there is a considerable pathway toward that.

And another item to consider is that these advanced reactors, in many cases, don't use water themselves for cooling. They use advanced cycle. So they can provide a positive output of water without using cooling water to operate.

Senator CORTEZ MASTO. Thank you.

Dr. Chodak, anything to add to that?

Dr. CHODAK. I would just add a little bit to that. That was a great answer. Just a little bit to add to that would be—small modular—because it is modular, it can be built in the factory, so it is a lower cost. So when you think about a small modular reactor, the targets they are talking about, the numbers they are talking about, about \$2,000 to \$3,000 a KW, compare that to existing, you know, AP1000 designs, which are, you know, \$6,000 to \$12,000 per KW. So there is significantly less capital cost and then the “smaller” means they can be sited closer to where that water is going to be used because they have a much smaller footprint, and because you are designing it upfront, you can design that cycle and optimize it for that specific use. So there are multiple layers of potential cost savings and additional utility that you can get out of these designs.

Senator CORTEZ MASTO. Thank you. Thank you very much, Mr. Chairman.

Senator BARRASSO. Thank you. Senator Murkowski.

Senator MURKOWSKI. Thank you, Mr. Chairman and thanks for the hearing today. One of the things that I miss about not being Chairman of the Committee is, you know, before you would get to

sit and listen to all this great stuff. Now I am like everybody else, I come air-dropping in right at the end when everyone is trying to wrap up. I get the gavel again. So thank you for that, Mr. Chairman.

[Laughter.]

Senator MURKOWSKI. But these are important issues, when it comes to nuclear, particularly the advances that we are seeing with advanced nuclear reactors and small modular reactors. We just got an announcement a couple of weeks ago now that Eielson Air Force Base—the Department of Defense—will be hosting the first pilot of a microreactor there. I am really excited to see the application there and what it can mean for us in remote areas, not only on military installations, but greater application elsewhere. So I love the topic.

I mention my excitement but one of the things that I had been focused on, certainly in years previous to this is, as we think about these advanced reactors, we need advanced fuel. And so, we talk about HALEU (High-Assay Low-Enriched Uranium). Of the ten reactor designs selected for the advanced reactor demonstration program, nine use HALEU. So I have tried to focus on this as a supply chain issue and raising the concern. My understanding is that today, HALEU is only commercially available from Russia. So I would like to have a little bit of a discussion here this morning since everybody else is gone and I have the gavel here.

What do we do? Do you all agree that we need to develop domestic supply here to produce HALEU. I would hope that we think that that is preferable to reliance on foreign sources. And if so, really, what is our biggest obstacle here? Is this primarily an economic and market issue? Is it a public policy problem? What do you think we can do to build up this fuel source? What more can we do on the infrastructure side?

So let's start with you, Dr. Bragg-Sitton.

Dr. BRAGG-SITTON. Thank you, Senator Murkowski.

You've kind of hit the nail on the head on one of our challenges to these advanced reactors. With regard to High-Assay Low-Enriched Uranium, we have different pathways to get there. We know how to do it. This is something that we can do at our national laboratories and working with our fuel fabricators here in the United States. And it is essential that we have a domestic supply of this resource. It provides us the opportunity to build these advanced reactors that can be put in smaller packages and operate more efficiently.

So what do we need to do to make sure that we have that resource available?

We need to make sure we put the investment in to establish that supply chain. Why haven't we done that before? Well, the demand wasn't necessarily there from the commercial sector previously. And now that we see this very large interest growing in the private sector to develop and deploy these technologies, now we're beginning to have that demand for this resource, for HALEU, and we need to put the investment in to develop the capability to fabricate those fuels.

Senator MURKOWSKI. So it has really just been a chicken and an egg type of a thing?

Dr. BRAGG-SITTON. In my opinion, yes, frankly, that is a part of it. Until the demand is there, the supply chain won't be there. We know how to do it. We know how to get there, but we need to invest in it to make sure that we can have that resource available.

Senator MURKOWSKI. Okay. Others on this point?

Dr. CHODAK. I would just add, just to concur that this is not amazing new technology. We absolutely know how to do this. It's just that the market isn't there and so the supply isn't there.

Senator MURKOWSKI. So you know, last year, we established a program within DOE to support the domestic availability of HALEU. Can anyone give me an update on the current status of that program? Has the Department been active in standing it up and getting it going?

Dr. BRAGG-SITTON. Yes, the program has stood up. That's actually led out of my laboratory by a colleague of mine and that has been moving forward, but again, we need to have that continued investment to move those processes forward, whether that is producing HALEU from existing materials or enriching materials down the line. But yes, things are moving forward, but we need more investment.

Senator MURKOWSKI. Okay.

One last question, and we are certainly hearing this in Alaska. I mentioned the microreactor that will be deployed up in the interior part of the state, but I think educating and informing the public about the reality of modern advanced nuclear systems still remains a challenge. I think for so many, particularly in a state like Alaska, where we just do not have any nuclear power to speak of, so many still envision Three-Mile Island. They think of Chernobyl when they think of nuclear even though the small modular reactors and the microreactors are really a world apart in terms of safe operations.

So I know that you all are focused on the technology, the research, the deployment, but I think we also recognize that we have to do more when it comes to educating people that this nuclear is not just about clean energy, but it is also safe technology. How do we make this transition? We are doing it on the technology side. We are transitioning. But are we doing it in the public mindset? What more can we be doing there? I throw that out to any of you.

Dr. CHODAK. If I could just chime in, I can give you a good example. At our Cook Nuclear Plant on Lake Michigan, the community there are the strongest supporters of the Cook plant possible. And that occurs because the management of that plant invites people to come into the plant, to tour the plant, to see what's there and explain the technology. We have a visitor center that has models where we go in and we bring in school kids and we explain to them, "Here's how the plant works." And when people understand what something is, then they're no longer afraid of it. And when we start talking about these advanced designs that—particularly the inherently safe designs, where you can walk away from the facility at 100 percent power, and physics and the nature of it, because it's a smaller size and a higher power-to-surface-area ratio, the thing just naturally cools down and shuts itself down. And when you start explaining those things to people, and they get that understanding, then I think the fear level drops.

Now, that's no small feat to help them understand it and you do it almost one community at a time, but I think certainly, the story is an excellent one. And it's just a matter of education.

Senator MURKOWSKI. We do have to get the word out.

Mr. GUASTELLA. And Senator Murkowski, I would say from a medical isotope perspective, it is very similar. It's not community, it's patient by patient. So there is trepidation by patients when they walk into a nuclear medicine department and you know, they see a radiation sign, and some will freak out—but educating patients that we're talking about a very low level of activity, they are very short-lived. The half-lives of the isotopes that we use in healthcare are very short. They are excreted from the body efficiently. And again, patient by patient and with some of the educational efforts that are being done, not only by industry, but by the Society of Nuclear Medicine and Molecular Imaging, I think we are making some efforts. And with some of the new therapies, for example—Senator Barrasso asked about these a little bit earlier—the targeted alpha therapies that use isotopes like actinium. We continue to make inroads, especially when they are so efficacious and help patients.

Senator MURKOWSKI. Good, well, thank you.

Well, and as I have indicated my interest, voila, everybody else shows up. So I am going to turn the gavel back.

Senator BARRASSO. Everybody wants to be where you are. Even the Senior Senator from Idaho, Senator Risch. Four Republicans, no Democrats.

Senator RISCH. Well, it couldn't be a better day.

[Laughter.]

Senator BARRASSO. Well, and the——

Senator RISCH. Go ahead.

Senator BARRASSO [continuing]. And the first witness, magnificent.

Senator RISCH. Yes.

Senator BARRASSO. From the Idaho National Lab.

Senator RISCH. That is great. Thank you.

Senator BARRASSO. That we toured together.

Senator RISCH. Yes, thanks so much.

Senator BARRASSO. As well as Senator Murkowski.

Senator MURKOWSKI. Yes, it is very true.

Senator RISCH. That was not your first trip to the lab, was it, Senator?

Senator MURKOWSKI. No, and it is not going to be my last either.

Senator RISCH. That's good.

Well, thank you, and thank you, Senator Barrasso and to the Chairman for holding this hearing. This is something, I think, that most people aren't aware of. If they are aware of the importance of nuclear energy, most people do not drill down this far. So it is important that we do explore these kinds of things.

I am proud to represent the nation's flagship nuclear energy laboratory at the Idaho National Lab, which we still have the first three light bulbs there that were lit by nuclear energy. So we are very, very proud of that. We built 52 reactors over time at INL. Some demonstration, some actually working, but Senator Murkowski, you were talking about Alaska and not having access to

nuclear power. At the lab right now they are building the SMR, the small modular reactor, which will serve a smaller community, but you will be interested to hear that they are also on the drawing boards for the microreactor that a lot of us have been pushing for a long time. Look, if you can put it on a ship and drive a ship with it, why can't you put it on a trailer and take it to deepest, darkest places of the world, you know? So anyway, I think that is certainly the future. Whether people want to or not, obviously, we are going to run out of these fossil fuels and probably stop using them even before we run out of them, but this is the only way to deliver a load. The Idaho National Laboratory is on the front edge of that. There is no question about that.

From the safety standpoint that was just being discussed, I think most people, again, when you talk about—if they throw Three-Mile Island in your face or Chernobyl—you can always come back with, “Look, the entire navy is run on nuclear reactors.” They are all over the world now. We only have 93 in the United States, but they are growing dramatically all over the world. And it is the safest, one of the safest things to do in the world. We just do not have those kind of things [Chernobyl style reactors], you know, we have better engineering and everything else. So it is important, I think, that all of us be advocates for how safe, not only how clean nuclear energy is, but how safe it is.

So the area that we are talking about today, I think, is particularly important and I think that Shannon, it is good to have you here. You are recognized worldwide as a pioneer in this field of non-electric applications for nuclear energy. And I think it is particularly important that we be focusing on this now as our nuclear fleet continues to shrink. Originally, it was just from wearing out or time. Now economics is playing a lot more—a lot bigger role in that—particularly when you have other forms of energy being used alternately to substitute for the nuclear in the power that is generated.

So I would like each of you, if you would, for a minute, to talk about the urgency of finding these additional economic streams as to how that will help maintain the fleet that we have.

Shannon, why don't you go first, since you are from Idaho.

Dr. BRAGG-SITTON. Thank you, Senator Risch.

It is essential that we act quickly. The existing fleet of nuclear plants, as you mentioned, is experiencing financial pressures as we see more and more variable renewable resources coming online. That variability requires our baseload or traditionally baseload generation to respond to that and to dial back power. That's not necessarily the best economic performance. These plants can do it. They can technically provide that flexible response, but if we don't operate these to the fullest extent possible, we're essentially throwing away some of that resource and throwing away what we could be utilizing. If we only look first at decarbonizing the electric sector, I think we're going to miss a really elegant solution to use these powerhouses of clean heat and electricity to support broader decarbonization.

A nuclear plant is a producer of heat, which we then convert to electricity. So using that heat directly to support these areas that are very difficult to decarbonize and probably shouldn't always be

electrified or can't be electrified, we can then come to a solution that still needs that reliable, resilient grid and meets that demand at all times, working right alongside other clean energy generators, like renewables, like fossil with carbon capture, but then using the excess heat and electricity to get to those hard-to-abate sectors and we can get to those net-zero goals much more rapidly if we looked at these holistic solution sets.

Senator RISCH. I appreciate that.

Dr. CHODAK. Senator, not only do we get to those goals much more rapidly, but we get there much more cost effectively. If you look at the existing fleet today, part of the reason they are economically challenged is because the playing field is not at all level. They are bringing value to the grid in terms of dispatchable capacity that is available and there is no real market mechanism that compensates them appropriately for that. And then they are thrown into an energy market where they are competing against renewable resources that have investment tax credits and production tax credits, which can drive down the price for power to actually negative numbers so that you have to pay to keep your unit online to deliver power. That is an unreasonable situation, particularly since these assets are so incredibly valuable for us meeting our decarbonization goals.

So I think one of the things we can do for the existing fleet is to put them on a level playing field and give them a production tax credit and make those tax incentives such that they can actually use them by using direct pay mechanisms to provide that support and level the playing field so those units can compete.

Senator RISCH. Level playing field is incredibly important.

Mr. GUASTELLA. Senator Risch, from a medical isotope perspective, in the U.S., all the medical isotopes that are produced domestically are done either through research reactors like the University of Missouri Research Reactor, as an example, or particle accelerators. Power reactors in Canada, for example, are being used for a certain amount of isotope production and I would defer to the experts whether the nuclear power fleet here in the U.S. is actually capable of doing some of the same things. Anything that we can do to increase domestic supply would be important. So I certainly think that folks would be open to looking at those opportunities.

Senator RISCH. What is the situation? When I was Governor in the mid-part of the first decade of this century, we had no supply in the United States. We were totally reliant on Canada or from Europe, as I recall. We did some work at INL to get up and running in that regard and it was really critical, particularly with the short half-lives of some of the isotopes. What is the situation now?

Mr. GUASTELLA. Well, you are probably referring mostly to molybdenum. Ninety percent of the molybdenum sourced in the U.S. is still foreign-sourced, either from Europe, South Africa, or Australia. We do have one domestic supplier—NorthStar in Wisconsin. There are others that are looking at becoming domestic producers. SHINE in Wisconsin, also, is another commercial organization that is getting close, but we are still working on increasing domestic supply of molybdenum and certainly many of the other isotopes that are needed by healthcare professionals.

Senator RISCH. I appreciate that. So important in the medical field.

Well, with that, I will close. I just want to say that I appreciate the Chairman and the Ranking Member doing this. I think the economics of this is so important and the fact that we do look at these alternative things.

The Chairman, Senator Manchin and I drew and got passed the Integrated Energy Systems bill, which was signed into law last year, which is accelerating this research at the DOE, which we appreciate all your work on it and it is so important in helping to keep online these 93 reactors that we have left. I expect that that is going to turn around, but it is going to take some time, there is no question about that. I yield back. Thank you very much.

Senator BARRASSO. Senator Hoeven.

Senator HOEVEN. Thank you, Mr. Chairman.

Dr. Bragg-Sitton, you know, I know we are talking about nuclear here, but also, I want to ask you, in addition to nuclear, do you agree that we need to accelerate the deployment of carbon capture technologies allowing us to continue to benefit from our abundant, low-cost, dependable fossil energy resources? And that is something, obviously, that the Ranking Member and I have a lot of in our states, is a lot of coal-fired electricity, and do you think with carbon capture we can and should make those investments to continue that baseload generation?

Dr. BRAGG-SITTON. So carbon capture is a little outside of my main technical area, but I will say that to get to these ambitious goals we have to achieve that net-zero economy, it is going to take everything we have in our toolbox. We will need renewables. We will need nuclear. We will need fossil with carbon capture. And how we accomplish that carbon capture does require some additional research. We also are looking to direct air capture to capture CO₂ that is already emitted in our environment. And I think those technologies will play a significant role in the solution and those nuclear plants could be sited right alongside those fossil plants and other plants that emit CO₂ to help drive that capture technology to reduce costs.

Senator HOEVEN. That is a very interesting idea.

What are some other ways to improve the commercial viability for advanced reactors and bring technology to scale?

Dr. BRAGG-SITTON. I think we need to build it. I think that bringing those technologies to the commercial sector requires commitment. It requires us to develop and demonstrate those technologies and get to the finish line by deploying those technologies at scale, such that we can bring costs down, and make them cost competitive. And producing these multiple product streams will be a part of that cost competitiveness. When we look to buildout of additional resources, we often look to just the electric sector and we make decisions based on the cost of that electricity, but bringing back that conversation on leveling the playing field, part of that is looking at all the assets these technologies bring to the forefront. Renewables will play a role, but most of those renewables provide only electricity and that is only part of our energy use. These advanced reactors offer those additional opportunities for heat and electricity that can support such a wide array of industrial applications—

chemical manufacturing, bring back some of the domestic steel manufacturing. We need to value those product streams and bring that into the decision process when new plants are built.

Senator HOEVEN. Thank you.

Dr. CHODAK. And Senator Hoeven, specifically to your question around what can we do to make these technologies more cost-effective and more competitive—so the challenge is that they are first-of-a-kind technologies, and as a result they tend to be more expensive, and that is my colleague's argument on why we need to build them, right? Because if we build them, then they are no longer first-of-a-kind because we get those lessons learned and we get to save and learn on the "nth" cost savings. But starting off as a utility, we try to be very much technology agnostic—whatever is in the best interest of our customers in terms of cost and reliability, that is what we are going to go with.

And if you want to level the playing field with renewables, then an investment tax credit, not unlike what renewables have, particularly in the solar field and if you can get rid of the requirement to normalize those costs, those are benefits that pass directly to our customers. So if I can take that tax credit and pass that benefit directly to my customer and it reduces that cost to my customer, that greatly incentivizes that technology and it enables me to bring that technology to my customers.

Senator HOEVEN. Very good. Thank you, Dr. Chodak.

And then, Mr. Guastella, given our reliance on foreign sources for isotopes, particularly from Russia, what steps should the U.S. take to increase our domestic production capabilities?

Mr. GUASTELLA. Well, we are taking steps currently to increase domestic supply. There are several core member companies, two of which I have already mentioned, that with help from the Department of Energy and the grants of cooperative agreements, are either currently producing or are close to producing some of the primary radioisotopes that are used in nuclear medicine—molybdenum, xenon, iodine-131 used for thyroid disease. In addition, there are efforts right now to install a fleet of particle accelerators to produce some of the radiotherapies like actinium, for example, directly or by using stable isotopes and irradiating those either in cyclotrons or particle accelerators. And there are some core member companies that are working toward that end also.

So efforts are being made. Also, as I had mentioned earlier in my testimony, the efforts with the Department of Energy Isotope Program have been extremely helpful and the collaboration between industry and the DOE is necessary right now to continue to provide much-needed isotopes that may not be commercially viable at this point, but certainly needed by researchers and physicians in looking at new treatments and new diagnostics.

Senator HOEVEN. Thank you. Thank you, Mr. Ranking Member.

Senator BARRASSO. Senator Risch, any additional thoughts or questions?

Senator RISCH. Yes, you piqued my interest in a question. You know, some time ago there was a lot of excitement about hydrogen. That was going to be the new "save the world" kind of idea, new shiny object. And that did not mature very much, it does not seem like. Can you give us your thoughts on that? Where that is? Where

it is going? Whether it has the potential everybody thought it had at the beginning?

Dr. BRAGG-SITTON. Thank you very much. Hydrogen is a very significant focus right now. And why is it such a focus? It is because hydrogen is a highly versatile energy carrier and we can produce it without emissions when we use non-emitting heat and electricity from nuclear energy. And this hydrogen can be stored so that it can be used now or it can be used later or even transported to end users. So it is essentially a chemical energy storage means and by producing that hydrogen, it gives us these additional revenue streams for our operating plants.

Senator RISCH. Is there an industry developing around that?

Dr. BRAGG-SITTON. Yes. So hydrogen is an avenue to decarbonization of the electricity grid, transportation, and industry. My colleagues at the Renewable Energy Laboratory and Argonne National Laboratory have looked at market growth for that hydrogen and those estimates range from growth on the order of 4 to 16 times depending on different assumptions being made. That hydrogen can be used to produce electricity with reversible fuel cells or via combustion in gas turbines. Without emissions, we can use that in transportation for fuel cell vehicles or through the production of synthetic liquid fuels to begin meeting the needs for heavy duty transport or maritime or aviation transport that won't be electrified or are very difficult to electrify.

And in regard to industrial applications, there are significant growth opportunities. Now, I mentioned in my early remarks, hydrogen is available today and we see that mostly through breaking down methane, which has those CO₂ emissions associated, but if we use clean hydrogen, we can use that in upgrading iron ore to create steel, so a domestic manufacturing opportunity for steel without the associated emissions that are traditionally a part of that process. We can use it to upgrade coal and biomass to produce alternative fuels and chemicals. And as we start valuing this clean energy resource and these clean avenues to achieving these consumer products, we do anticipate a significant growth in those hydrogen markets and a significant opportunity for clean hydrogen. We are already seeing that demand for clean hydrogen from non-emitting sources is growing significantly in places like Europe, where a premium is being paid for that.

And as we develop these technologies further, we will be able to reduce those costs and achieve this Energy Earthshot goal and the Hydrogen Earthshot goal of reducing the cost of clean hydrogen dramatically over the next decade, which will, again, grow that market considerably.

Senator RISCH. Interesting.

Dr. CHODAK. Senator, I was at a conference just yesterday, the Association of Edison Illuminating Companies (AEIC), where I listened to executives from Mitsubishi Heavy Industries (MHI), who have a project where they are working to develop green hydrogen. And if you look at the major turbine manufacturers, they are developing turbines to be able to run on hydrogen. In the transportation industry, you also have oil companies looking at potentially transitioning from using hydrocarbons to generating hydrogen for the transportation industry. So the answer is not if hydrogen is

going to be part of the future, it is just a matter of when and at what cost. The real challenge is around—particularly for electricity use and energy storage—you know, we make a product and the electricity that is turning these lights on right now came off a generator less than a second ago. And it is not easy to store for more than four to six hours. That is the limit of existing technology. Hydrogen is that technology that allows us to store it so that, for example, in areas where you don't have the sun shining all year long, which have a really strong summer, I can take some of that solar energy, put it into hydrogen and then take that hydrogen and use it later back during off-season periods where I don't have as much solar power.

And there are all kinds of opportunities with small modular reactors to create that hydrogen that gets used in that infrastructure, both for transportation and also potentially for electricity generation.

Senator RISCH. Thank you.

Thank you, Senator Barrasso.

Senator BARRASSO. Well, thanks so much and I think, as Dr. Bragg-Sitton just said, issues with what we are seeing in Europe now with energy prices even more expensive than they are here, more issues of energy poverty that are going on there, that we need to continue to develop our opportunities here in the United States. So thank you for that.

Thank you all for being here today. We are very grateful for your testimony. I think it was a very important hearing. Members are going to have until the close of business tomorrow to submit additional questions for the record. We would ask you to be thoughtful as well as expedient in replying to those. With that, the Committee stands adjourned.

[Whereupon, at 11:31 a.m., the Committee was adjourned.]

APPENDIX MATERIAL SUBMITTED

U.S. Senate Committee on Energy and Natural Resources
November 4, 2021 Hearing: *The Potential Non-Electric Applications of Civilian Nuclear Energy*
Questions for the Record Submitted to Dr. Shannon Bragg-Sitton

Questions from Ranking Member John Barrasso

Question 1: Nuclear technology has been used to power deep space missions for years, including missions to Mars and Pluto. NASA is now looking to expand the use of nuclear technologies to support our nation's return to the Moon and our first manned mission to Mars.

- a) Can you explain why nuclear technology is so attractive for providing electric power on the surface of the Moon and Mars?

Studies have shown that surface power needs start at approximately 40 kWe for a manned Lunar or Martian base; this is most efficiently provided by a small fission system. Nuclear fission provides a highly dense energy source that can support reliable, resilient energy supply without refueling and minimal to no maintenance for many years. The small footprint for a nuclear energy source allows it to be packaged for transport and deployment to the Lunar or Martian surface with minimal site preparation. This resource can provide ample power for operations at a fixed base, including support for associated science missions. Additionally, heat produced by this energy source can support site operations, including maintaining a comfortable habitat and providing heat and electricity to support surface activities, such as *in situ* resource utilization.

- b) Can you explain why nuclear technology is so attractive for powering rockets that would enable a return to the Moon or a manned mission to Mars?

Nuclear energy sources provide a distinct advantage over conventional energy production for long duration missions or large power needs. Nuclear energy is a high-density energy source, meaning that a large amount of energy can be packaged in a small volume, and it can be utilized to support direct thermal propulsion or electricity production for electric propulsion systems. Advanced nuclear propulsion systems (alone or in combination with chemical propulsion systems) have the potential to substantially reduce trip time compared to fully non-nuclear approaches. Shorter trip time reduces risks associated with space radiation, zero gravity, launch and orbital assembly requirements, providing substantial benefit to both the crew and equipment onboard.

Nuclear thermal propulsion is conceptually similar to chemical propulsion, where the “combustion chamber” is replaced by a nuclear fission reactor and the “working fluid,” typically hydrogen, provides reactor cooling and vehicle propellant as it exits through a nozzle. Performance improvement over chemical rockets results from the lower molecular weight of propellant for nuclear thermal systems, providing twice the specific impulse – essentially a measure of the propulsion system efficiency or “gas mileage.”

Nuclear electric propulsion is similar to terrestrial nuclear systems, where the heat produced by nuclear fission is converted to electrical power. That electrical power is used to produce thrust through acceleration of an ionized propellant in an electric propulsion system. These systems provide relatively low thrust, such that they may need to be coupled to a chemical propulsion system to provide the necessary thrust to escape Earth's gravity, but they can provide specific impulse that is two orders of magnitude (as much as 100x) greater than chemical propulsion systems.

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Note that nuclear propulsion is not being actively considered for Lunar missions, where ordinary chemical rocket engines are quite capable. However, both nuclear thermal and nuclear electric propulsion are under consideration for a crewed Mars mission, as reviewed by the *ad hoc* committee on Space Nuclear Propulsion for the National Academy of Sciences, Engineering, and Medicine the National Academy of Science (final report released February 2021, available at <https://www.nap.edu/catalog/25977/space-nuclear-propulsion-for-human-mars-exploration>).

Question 2: Research reactors at national laboratories produce much needed isotopes, including Idaho National Laboratory's Advanced Test Reactor, and Oak Ridge National Laboratory's High Flux Isotope Reactor. The Department of Energy is currently executing a project to deploy a new research reactor, the Versatile Test Reactor (VTR). Could the VTR help address our domestic isotope production needs? If so, how?

In FY 2019, the DOE Office of Nuclear Energy (NE) announced its plans to build a Versatile Test Reactor (VTR). The VTR is planned to be a sodium-cooled fast reactor that uses high energy neutrons to test and develop advanced reactor fuels and materials. DOE NE and DOE Isotope Program (IP) personnel have discussed the possibility of isotope production capability at the VTR, and have subsequently established a working group to explore this opportunity in further detail. While isotope production is not part of the mission need, constructing a VTR facility presents a potential opportunity to utilize another source for reactor production of critical isotopes in short supply, especially those isotopes favorably produced in a fast neutron spectrum.

The expert working group was tasked with identifying the parameters and/or accommodations needed to enable an isotope production capability at the VTR. The goal of this effort was to evaluate the VTR conceptual design and provide recommendations on how to best facilitate isotope production. The full report from this working group is provided as an attachment. Key findings/recommendations from the expert working group are summarized here:

- The DOE IP can benefit from the VTR and the production of radioisotopes for which the fast neutron spectrum of the VTR is advantageous and for which existing neutron irradiation sources are inadequate to meet domestic demand.
- The installation of a rabbit system is essential for many of the desired short-lived isotopes. The large irradiation volume available in the VTR is attractive for increased production of a highly desired isotope or simultaneous irradiation of many different samples.
- The VTR rabbit tube is better suited to a medical isotope R&D mode than routine production mode. Radioisotopes to consider for irradiation in the rabbit include ⁶⁷Cu, ⁷⁷As, ⁴⁷Sc and ^{117m}Sn.
- Routine irradiation of longer-lived radioisotopes in one or more reflector positions is feasible and attractive for the VTR.
 - Radioisotopes to consider for irradiation in reflector positions include ⁸⁹Sr, ¹⁴⁷Pm, and ⁶³Ni.

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- For production of isotopes sensitive to the thermal or epithermal part of the neutron spectrum, such as ^{60}Co , spectral tailoring could be considered by adding metal hydride moderation outside the core. The substitution of ^{60}Co targets for B_4C shield assemblies in VTR could be explored.
- Fabrication, certification, and procurement of multiple Type B casks by DOE IP or other customers for isotope shipments off the VTR site would be needed.

Question 3: Some advanced nuclear reactor developers have highlighted isotope production as a potential non-electric application. These advanced nuclear reactors include university-based research reactors, such as the molten salt research reactor under development at Abilene Christian University.

a) What opportunities are there to use existing or new research reactors for the production of medical isotopes here in the United States?

There are currently multiple reactor and accelerator facilities in the U.S. in government, university, and private locations that produce isotopes for medical applications:

- University of Missouri Research Reactor (MURR), currently producing over 40 types of isotopes
- Advanced Test Reactor at Idaho National Laboratory, producing Co-60
- High Flux Isotope Reactor (HFIR) at Oak Ridge National Laboratory, producing multiple isotopes including W-188, Cf-252, and Ac-227
- University of Washington Cyclotron, producing At-211
- BLIP Accelerator at the Brookhaven National Laboratory, producing Ti-44, Cu-67, and Ac-225
- IPF Accelerator at Los Alamos National Laboratory, producing Ge-68, Sr-82, and Ac-225
- LEAF accelerator at Argonne National Laboratory, producing Cu-67
- SHINE Technologies using accelerators to produce Mo-99

Using new or existing research reactors can enable multiple production sites, which will reduce the risk of supply disruptions in the event of unexpected downtime and ensures domestic supply. Production of medical isotopes is typically proportional to neutron flux, so the high flux present in some research reactors is beneficial for higher isotope yields. Research reactors can also have the ability to tailor neutron flux energy for a specific isotope production application, rather than a general neutron flux that may not be ideal for production of specific isotopes. With additional production sites, additional sites for processing and distribution of isotopes will be needed. These facilities could be located at individual reactors, or in a regional facility to realize economies of scale. Further, isotopes with short half-lives may require on-site or regional processing facilities to minimize the amount of material that decays during transportation between production and processing sites.

b) Are there features of advanced reactors, especially liquid fueled reactors, that make them well-suited for isotope production and delivery?

Coolant purification systems in liquid fueled reactors have the potential to remove fission products and activated isotopes produced from nuclear processes. This could enable recovery of fission products like Molybdenum-99, Strontium -89 and -90, and activated isotopes like Actinium-225 from the liquid reactor fuel. Features like a rabbit tube could be included in advanced reactors, which would make it

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easier to insert irradiation targets into the reactor and reduce the amount of time needed to remove the isotope from the reactor when irradiation is complete. Decreased processing time decreases the amount of isotope that decays prior to use, which can drive the economics of production and distribution of product. For isotopes with short half-lives, on-site or regional processing facilities may be needed to reduce the amount of isotope that decays during transport.

Question 4: Puerto Rico is considering the use of small modular reactors and micro-reactors to provide reliable and emissions-free power to the island.

a) Why are these types of advanced nuclear reactors an attractive option for islands, such as Puerto Rico?

Industrialized island territories around the world, such as Puerto Rico, share similar electricity market characteristics as well as similar energy challenges. Advanced reactors possess the design features to address such challenges. Historically, island territories have faced high dependency of imported fossil fuels, thus presenting a combined environmental, resilience, and reliability challenge that could include import disruption, vulnerability to spikes in global market prices, and air quality concerns. Replacement of fossil fuel resources with significant build-out of renewable energy sources poses a new challenge for increased grid flexibility in these island communities, as well as putting strain on the limited land area available for development.

Small-scale reactor options under development range in size from a few megawatts (i.e., microreactors) to a few hundred megawatts (i.e., small modular reactors) to support distributed energy demands, as would be present for an island community. These nuclear technologies can support a wide range of applications, including providing reliable, resilient electricity and heat/cooling to remote towns or small grids during normal conditions, and also powering water purification facilities, critical infrastructure, data centers, and industrial facilities. The small size and portability of microreactors also offers the opportunity to supply energy for disaster relief, such as following a hurricane, with many of these designs also offering the opportunity to restart without requiring off-site power (meaning that they can be restarted after shutdown even if the regional grid is down as a result of the weather event).

The small size of these systems also substantially reduces costs of the associated building materials, such as concrete, relative to traditional large-scale systems. The advanced safety features incorporated in micro and small modular reactor designs translate to fewer on-site safety measures necessary to ensure safe, reliable operation in space-limited, remote communities. All of these aspects combine to result in relatively low capital and operating costs, making them a good option for smaller utilities and companies looking for a long-term source of clean energy at a reasonable cost, with additional units added as demand increases.

Focusing in on Puerto Rico's energy needs, the electricity demand remains high all year long (load profiles remains above 80% all year round). This contributes to high plant usage and high maintenance shutdowns, which is currently the primary contributor to blackouts in Puerto Rico due to a lack of

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sufficient working reserves. Advanced reactors present an energy source option having the highest degree of reliability to support year-round high energy consumption.

The pharmaceutical industry in Puerto Rico represents its largest export sector (FY 2019, \$16.4B). Local industry stakeholders are in dire need of reliable energy sources to ensure competitiveness, and furthermore secure the resilience of the U.S. drug supply chain. At present, 98% of Puerto Rico's electricity depends on fossil fuel imports (i.e., liquid natural gas, coal, oil), exacerbating the impact of global market price fluctuations on Puerto Rico's economy. Advanced reactors present the only zero-emission energy source that could replace the much-needed baseload power.

Over the next decade, Puerto Rico's utility plans to add 3.5GW of installed solar photovoltaic (PV) capacity. This would require a more flexible grid that could adapt to such penetration of renewable sources. Advanced reactors present an alternative to provide baseload capacity, and the enhanced flexibility of these designs will also easily adapt to grid fluctuations that will result from high solar penetration. Puerto Rico's utility plans to split the central grid into eight mini grids to better support emergency scenarios. As described above, emerging advanced reactor technologies will be available in a size to accommodate to such a grid and to provide flexible operation to respond to emergency situations.

[Note: Recently developed fact sheets on microreactors and small modular reactors can be found at <https://www.nice-future.org/featured-publications.html>.]

b) What is the current status of the efforts to site a small modular reactor or micro-reactor in Puerto Rico?

Current efforts in Puerto Rico are focused on market and site suitability studies for advanced nuclear reactors. The Nuclear Alternative Project is leading these efforts as a Puerto Rican-led initiative with the support of the U.S. DOE. The site suitability effort focuses on developing a ranking of sites based on Regulatory Guide 4.7, which will then be made available to nuclear vendors and developers. The goal is for both market and site suitability efforts to help inform policy in Puerto Rico to include advanced reactors as part of Puerto Rico's strategic energy transformation.

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Questions from Senator Lisa Murkowski

Question 1: In Alaska, the cost of heat can be higher than the cost of electricity. I am very interested in hearing more about the possibility of combining heat and power from nuclear power in remote locations. Is advanced nuclear capable of this, and are there companies currently exploring this potential? Can you speak to some of INL's efforts in this area?

Advanced reactors offer new economic and operational models, including non-grid applications that utilize heat and/or power that can be provided directly by the nuclear plant. This next generation of reactors will encompass a variety of technologies that are flexible enough to support the unique energy needs of different communities. Some advanced reactor designs will use coolants such as gas, liquid salts, or liquid metal, allowing them to operate at higher temperatures than the water-cooled designs that are predominant today, increasing their operating efficiency and allowing them to directly support industrial heat demands, including chemical production facilities or hydrogen production, in addition to providing lower temperature heat to support district and building heating, water purification, and more.

A particular class of advanced reactors, called microreactors, is being developed that can support remote deployment to provide both heat and electrical power. These reactors are being designed such that they can be readily transported to the application site, operated for several years, and then be removed. Several companies are working to develop such reactors, including companies supported by DOE's Advanced Reactor Demonstration Program, including BWXT and Westinghouse and privately-funded efforts including the Oklo Aurora reactor, which has a license application under review by the Nuclear Regulatory Commission. The DOE's Microreactor Program is developing technologies that support these private sector developers and is developing a small microreactor, called MARVEL, that will provide an early-stage demonstration to address challenges related reactor demonstrations, deployments and applications. More information about these reactors can be found at: <https://inl.gov/trending-topic/microreactors>.

Light water reactors that are currently producing electricity as a part of the current U.S. nuclear fleet are considering the technical and economic potential of non-grid products to enhance their financial viability and their flexibility to support variable grid demand. Idaho National Laboratory researchers, in partnership with several other national laboratories, have developed analysis and optimization tools to support high fidelity, region-specific technical and economic assessment of candidate energy systems prior to making a decision on commercial deployment (see https://ies.inl.gov/SitePages/System_Simulation.aspx for further details). Based on detailed analyses supported by INL, four plants around the U.S. are actively working to integrate hydrogen production into their operations: Exelon, Nine Mile Point Nuclear Plant (electrical integration, 2022 operation); Energy Harbor Davis Besse Nuclear Station (electrical integration, 2023/24 operation); Xcel nuclear plant (to be named, electrical and heat integration, 2023 operation); APS/Palo Verde Generating Station (increased scale, electrical integration; 2024 operation). These demonstration projects will provide significant experience that will aid more rapid deployment of advanced reactor that support both grid and non-grid applications in "integrated energy system" configurations.

INL has additionally developed significant experimental capabilities to advance the readiness level of nuclear-driven integrated energy systems. These non-nuclear facilities utilize electric heating to emulate fission systems, coupling physical hardware to computational models of the nuclear subsystems, to support model validation and

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November 4, 2021 Hearing: *The Potential Non-Electric Applications of Civilian Nuclear Energy*
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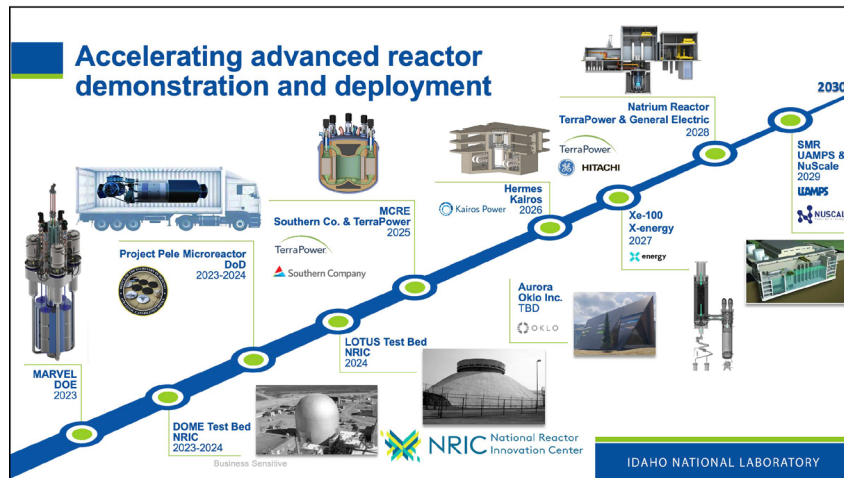
initial technology demonstration. This facility includes representation of multiple subsystems, both through virtual system integration (via real-time connections to test facilities at other DOE laboratories, academic institutions, or industry) or physical integration with scaled demonstration hardware. This facility allows for demonstration and validation of specific technologies (e.g., components, subsystems), sensors, control architecture, integration hardware, data analytics and data management, and related cyber security approaches. In this manner commercial risk can be reduced prior to nuclear system demonstration.

[Note: Recently developed fact sheets on advanced reactors and integrated energy systems can be found at <https://www.nice-future.org/featured-publications.html>.]

Question 2: Nuclear is one of our best options to decarbonize our economy, particularly its energy and industrial sectors. How well do the timelines for deployment of advanced reactors and industrial decarbonization line up? Are advanced reactors capable of supplying industrial heat on a trajectory commensurate with industrial emissions reduction?

The Biden Administration has established a goal to achieve a fully decarbonized electricity sector by 2035 and net zero emissions economy wide by 2050. Advanced nuclear reactors in development today expect to see initial deployments before the end of the decade—before 2030 (see figure below illustrating the expected demonstration and deployment timeline). These initial deployments are expected to provide clean electricity to the grid, but some developers also seek to use these technologies to produce hydrogen or to directly use heat to support a wide range of applications, including industrial processes and water desalination, or to support other regional industrial demands (e.g., ammonia and fertilizer production; steel manufacturing). If these initial demonstration and first commercial systems are followed by wide scale deployment of advanced nuclear systems, we can realize the potential for economy wide decarbonization supporting the 2050 goal. Advanced reactor based integrated energy systems would allow nuclear energy generation to effectively touch all major manufacturing industries as well as smaller industries, offering potential for dramatic emissions reduction. These nuclear plants would provide heat and power under all weather conditions, ensuring reliable, firm heat and power to support industrial customers. Most advanced nuclear designs would also provide long operating times before refueling would be required. For example, current fleet plants are refueled every 18-24 months, but many advanced reactors extend this time to 5, 10, or even 20 years before they must be refueled.

U.S. Senate Committee on Energy and Natural Resources
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Report of the Versatile Test Reactor
Working Group on Isotope Production
September 2021



Overview of the Working Group Effort/Process

In FY 2019, the Office of Nuclear Energy (NE) of the Department of Energy (DOE) announced its plans to build a Versatile Test Reactor (VTR). This new research reactor will be a state-of-the-art facility for advanced reactor research, development, and testing. It is planned to be a sodium-cooled fast reactor that uses high energy neutrons to test and develop advanced reactor fuels and materials. VTR could be completed as early as 2026 at the site of one of DOE's national laboratories.

DOE NE and DOE Isotope Program (IP) personnel subsequently met to discuss the possibility of isotope production capability at the VTR. While isotope production is not part of the mission need, constructing a VTR facility presents a potential opportunity to utilize another source for reactor production of critical isotopes in short supply, especially those isotopes favorably produced in a fast neutron spectrum. NE and IP agreed that it would be worthwhile to explore this opportunity in further detail through use of an expert working group focused on identifying the parameters and/or accommodations needed to enable an isotope production capability at the VTR.

A Working Group on Isotope Production was established to assess the parameters and/or accommodations needed to enable an isotope production capability at the VTR. The goal of this effort was to evaluate the VTR conceptual design and provide recommendations on how to best facilitate isotope production. The working group met via several video teleconferences (VTC) with the NE VTR team who provided briefings/material on the VTR conceptual design and operational plans. Further VTCs were held by the Working Group to discuss recommendations and information received. The final product of the Working Group is this Report identifying and explaining the parameters and/or accommodations recommended for isotope production at the VTR. Working Group recommendations are provided at the end of this Report.

Working Group Members

Dr. Susan Hogle is a nuclear engineer and group leader at Oak Ridge National Laboratory (ORNL) specializing in the design, analysis, and optimization of targets for production of radioisotopes. Her primary research interests are in development of advanced radioisotope production techniques, in particular the production of heavy actinides, as well as modeling and simulation of radionuclide transmutation.

Dr. Leonard Mausner, retired, was the head of the Medical Isotope Research and Production group at Brookhaven National Laboratory (BNL). He is an internationally recognized leader in the research, production, and application of medical isotopes, including many aspects of targeted alpha therapy. In his role at BNL, he had responsibility for the operation of the Brookhaven Linac Isotope Producer (BLIP) and the Isotope Processing Laboratory, as well as leading the research effort in radioisotope development. He is co-author of the chapter on reactor production of isotopes in the Handbook of Nuclear Chemistry.

Dr. Saed Mirzadeh, retired, was technical lead for medical isotope research and production at ORNL. He is an internationally recognized leader in the research, production, and application of medical isotopes, including many aspects of targeted alpha therapy. Several of his patented radioisotope generators are the foundation for the production and purification of radioisotopes used in nuclear medicine applications. He is co-author of the chapter on reactor production of isotopes in the Handbook of Nuclear Chemistry.

Dr. J. David Robertson is a professor in the Chemistry Department at the University of Missouri and Executive Director of the University of Missouri Research Reactor (MURR). As Director, Dr. Robertson has overall responsibility for the research reactor including safe and reliable operation of MURR, leadership for the research and education mission of MURR, and income generation through products and services. His research is focused on the development of isotopes for applications including cancer therapy, nuclear batteries and nuclear forensics.

Mr. David Wootan is a nuclear engineer at Pacific Northwest National Laboratory with extensive experience in isotope production in the Fast Flux Test Facility (FFTF), a 400 MWth sodium cooled fast reactor that operated for about 10 years at Hanford. He developed flux tailoring for isotope production optimization at the FFTF.

Isotope Production Considerations

Neutronics Considerations

The run cycle time of the VTR is proposed to be 100 days long, followed by 20 days for refueling. For radioisotope production, especially for medical applications, the half-lives of the desired radioisotopes are often much shorter than 100 days. To avoid a saturation condition with likely buildup of undesired impurities, sample irradiation duration should ideally be less than or equal to the half-life of the desired product. Therefore, to accommodate shorter irradiations, an ability to insert and remove samples quickly during reactor operation without reactor reactivity impact is imperative. This facility has been incorporated into existing research reactors and is needed in the VTR. The baseline design of the VTR is to include such a facility, often called a “rabbit” system.

The preferred location for the VTR Rabbit is row 5 of the core (numbering beginning at row 1 at core center, see Figure 1) adjacent to the reflector. This position has adequate fast flux and minimizes the reactivity impact on the core from sample insertion and removal. Larger radial gradients are associated with the outer row positions compared to the center location, but this is not a major impediment to isotope production in the VTR Rabbit. Radial gradients across the VTR Rabbit and isotope production target should be small due to the small radius of typical isotope production targets. The axial profile of the flux in the core is roughly Gaussian shaped. Having one rabbit capsule near the peak flux axially would not introduce large axial gradients, since the flux will be relatively constant over the isotope sample height. If larger volumes are needed for medical isotope studies, then increasing the target diameter, chaining multiple capsules together axially, adding an extra rabbit or adding partial moderation to increase the epithermal flux could be considered.

Fast spectrum reactions are preferred since that is the normal spectrum for the rabbit vehicle. No spectrum tailoring is needed in that case. Compared to the central flux trap in the ORNL High Flux Isotope Reactor (HFIR), the fast spectrum, >2 MeV flux, is only about 60% higher in the row 5 VTR Rabbit location than in the HFIR, so the advantage would be largely in the VTR Rabbit volume compared to the HFIR target volume.

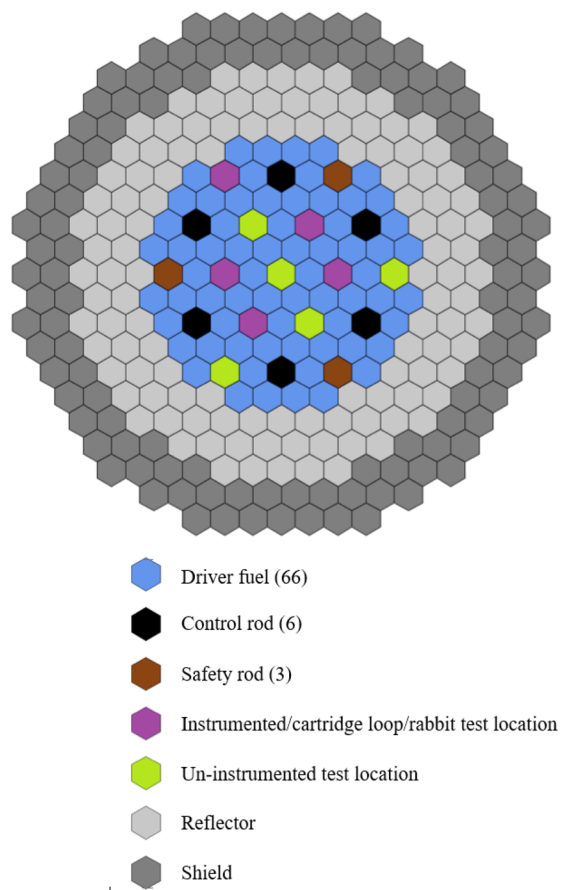


Figure 1. VTR Reference Core Layout

Calculated total flux in the reflector region (row 7) varies between $0.5\text{--}1.0 \times 10^{15}$ n/cm²-s over an approximate 100 cm axial distance. The total flux varies radially at the midplane, declining by about a factor of two between the side facing toward the fuel assembly compared to away. The neutron energy spectrum in the reflector drops off sharply above 1 MeV and there is a substantial epithermal and thermal tail to the distribution. Since the threshold for most (n,p) reactions requires neutron energies above 2 MeV, this location in the reflector region would not be ideal for such reactions. A row 7 location cannot support an isotope production rabbit system but could be used for irradiation of longer-lived isotopes if demand exceeds production capability at other reactors.

Thermal or epithermal reactions will require some spectrum tailoring by altering the axial position of the rabbit or adding external moderation by adding pins outside of the VTR Rabbit tube. Flux tailoring on a large scale may negatively impact the VTR performance and not be acceptable given the other missions and this effort does not seem to offer much advantage compared to existing research reactors such as the high flux thermal reactors like HFIR or the Idaho National Laboratory (INL) Advanced Test Reactor (ATR) or the University of Missouri Research Reactor (MURR).

Targets and VTR Rabbit

In the row 5 rabbit location, an assembly volume with fast flux greater than 1×10^{15} n/cm²-s would be about 13 L. The VTR Rabbit volume would be much less than this. Since medical isotope targets are generally quite small, especially with isotopically enriched targets, this is more than adequate volume. The calculated total flux in row 5 at the axial center varies across a 12 cm diameter assembly from approximately 3.2 to 3.9×10^{15} n/cm²-s, with the lower value adjacent to the reflector, increasing toward the core center. If a single capsule is being irradiated this difference is not significant. Even if two small capsules located adjacent to each other are irradiated, this variation is not a serious problem for radioisotope production. In the rare instance that maximum yield is required in an isotope target, it can be placed in the slightly higher flux position.

There is considerably more irradiation space available vertically in the rabbit tube. Simulations of the total flux in the axial direction do exhibit a noticeable fall off from the fuel center plane. In a row 5 location the maximum total flux at the center line is about 3.2×10^{15} n/cm²-s. The vertical distribution full width at half maximum (FWHM) extends approximately ± 50 cm around the center line so samples placed within this zone would all be irradiated at a flux $> 1.6 \times 10^{15}$ n/cm²-s. The neutron energy also falls off from the fuel midplane and this may have an impact on reaction cross section. Nevertheless, this arrangement would then allow useful isotope production of multiple targets stacked vertically, perhaps ten or more depending on capsule size. This capability allows increased production of a single isotope or a variety of products to be irradiated simultaneously and is a significant advantage. A single rabbit capsule

that is up to 100 cm long would require a small radius of curvature of the rabbit tube above the reactor head to the receiving hot cell and such a long rabbit capsule would be spatially impractical. Instead, it should be possible to design a train of connected shorter sample capsules for easier insertion/extraction. The mechanical design of the capsule loading/unloading system in the hot cell is made more complicated by this idea but it is important to maximize efficient utilization of available neutrons. The mechanical system being developed at Texas A&M University is for a single capsule and would need to be modified to accommodate experimental testing of a stacked rabbit assembly.

However, for axially stacked capsules, careful consideration of the compatibility of multiple different samples for simultaneous irradiation is required, both in terms of the flux required, the length of the irradiation, the cross-section variation as a function of neutron energy, and the thermal load on each sample. In practice it is likely that less than the spatially maximum number of samples would be used. To maintain consistent vertical locations, dummy capsules may have to be used if less than a full load of samples is needed. This strategy can also be used to better tailor the flux and neutron energy for specific targets along the axial distance.

For longer irradiations that would not need a rabbit, a dismountable test assembly (DTA) could be used. It would be un-instrumented, except that several pins could be retrieved from the assembly in the reactor vessel and replaced during reactor shutdowns and the assembly could continue irradiation. The DTA could possibly be used for longer-lived isotope production that does not require the use of a rabbit. The pin arrangement of this assembly appears better suited for flux tailoring, where the rows of pins might contain shield and moderator, with the removable pins dedicated to isotope production. A Normal Test Assembly (NTA) placed in the reflector space would be like a DTA, except that it would not have removeable pins.

The other significant concern that needs to be addressed is the thermal simulations of target performance and the testing of the accuracy of the predictions. Target cooling is an obvious concern and needs to be addressed during the reactor design stage. It has been proposed to use helium as the secondary coolant inside the rabbit tube, with molten sodium as the primary coolant outside. Also, it is assumed that helium would also be used in a pneumatic system to drive the capsules in and out. It is anticipated that the temperature of the helium coolant would be monitored and adjusted if needed in the capsule insertion/retrieval area. The high temperature of the helium coolant and the need for high volume continuous flow might require that the helium source for the intermittent pneumatic drive be entirely separate from the helium coolant.

The thermal hydraulic simulations of target internal temperatures will be critical. The amount of heat generated in the rabbit is governed by the helium flow rate and density in the rabbit, as well as by the capsule diameter, material of construction, capsule wall thickness, and gas gap dimensions, all of which are not fixed yet. The ultimate temperature of the rabbit tube wall, rabbit capsule wall, and sample material will depend on the sample mass and reaction cross section. Template calculations need to be performed for several test cases at bounding

conditions of large target mass, large reaction cross section, and significant gamma/beta internal heating in concert with cooling system engineering. DOE IP can provide typical rabbit loading conditions for isotope production to obtain useful data.

The choice of capsule material to contain the samples also will have an impact on these simulations. Aluminum (Al) has often been used for such purposes, for example in the HFIR hydraulic tube. However, the high temperature of the VTR sodium primary coolant (300-500°C), and the likely high temperature of the helium secondary, rabbit coolant may get close enough to the Al melting point (660.3°C) to cause softening. It is therefore recommended that other capsule materials be investigated. Suggestions include Ti, 316 SS, SiC, SiO₂, V, V-4Cr-4Ti, and Zircalloy-4. They have high melting points and adequate strength but lower thermal conductivity than Al. Titanium and high purity quartz will not activate much in a fast neutron flux. Another possibility is graphite which has very good thermal conductivity and good chemical resistance. In a short irradiation not much carbon-14 will be created in a graphite capsule. Graphite has been used extensively in the peripheral pneumatic tubes in HFIR but such irradiation is in essentially a pure thermal neutron spectrum. There can be irradiation induced creep and some radiation damage to graphite in the fast flux of the VTR, but for the relatively short irradiations envisioned to produce medical isotopes it should be fine as a capsule material. Calculations of target internal temperatures should thus include these different capsule types.

The thermal hydraulic simulations also need to be cognizant of the physical and chemical form of potential target materials as well as interaction with the capsule. For example, powder targets will have much lower thermal conductivity than solids or foils. In order to produce ⁶⁷Cu for example by the ⁶⁷Zn(n,p) reaction it is likely that a metal target will melt due to the relatively low melting point of Zn (419.5°C), so a compound with higher melting temperature is needed. Zinc oxide has a very high melting point and reasonable theoretical thermal conductivity. Note that thermal conductivity data of many prospective target compounds in powder form may not be readily available as it is a function of particle size, crystalline form and temperature. Note that oxide targets can interact with V, V alloys, and zircalloy so other capsule materials should be used. Gas pressure increase in molecular compound targets is a possible concern depending on the vapor pressure at high temperature or due to radiolytic decomposition. A similar situation exists for production of ^{76,77}As by (n,p) reactions on ^{76,77}Se as elemental Se also has a low melting point (220°C). Therefore, early input from the isotope community to the thermal hydraulic simulation effort is recommended to achieve realistic internal target temperature results.

Because of concerns with chemical compatibility with the primary sodium coolant, any items that could come in contact with sodium though normal or accident conditions will need to be made from steel. So the material for at least the outermost rabbit capsule will be steel.

The location of isotope processing has not been decided. It may be co-located with the reactor site or samples may need to be shipped elsewhere. For offsite shipment it may be advantageous for target capsules to have secondary containment. In this case the outer capsule would be opened in the receiving hot cell, and the inner capsule, for example a quartz ampoule, would be packaged for shipment. This arrangement would however reduce target heat transport to the coolant.

Isotope Suggestions

The following recommendations are based upon information provided by the VTR group on flux profiles in the VTR rabbit located in Row 5 where it will be possible to insert and remove samples during an operation cycle. The activity values described below are based on a 2 MeV flux of $3 \times 10^{14} \text{ n cm}^{-2} \text{ s}^{-1}$; a 6 MeV flux of 7×10^{13} ; and a 10 MeV flux of 1.6×10^{13} . The cross sections used in the activity calculations were taken from the Evaluated Nuclear Data File (ENDF) accessed through the National Nuclear Data Center (NNDC) at BNL. The activity calculations are first order and do not include effects of product burnup during irradiation.

Strontium-89 ($t_{1/2} = 50.52 \text{ d}$) can be produced in the HFIR from irradiation of enriched ^{88}Sr . Irradiation of 1 gram of ^{88}Sr for one 25-day cycle, followed by a 20-day decay, produces approximately 0.7 Ci of ^{89}Sr . The same amount of irradiation in the VTR produces approximately 0.5 Ci of ^{89}Sr . Increasing the irradiation time to a full 100-day cycle produces approximately 1.3 Ci of ^{89}Sr . The current application for this isotope is for pain palliation of metastatic bone cancer. ^{89}Sr is one of several isotopes used for this treatment. Production of this isotope is highly attractive in the VTR reflector region.

There is an existing U.S. market for the isotopes ^{32}P ($t_{1/2} = 14.27 \text{ d}$) at 6-8 Ci/month, ^{33}P ($t_{1/2} = 25.3 \text{ d}$) at 3-4 Ci/month, and ^{35}S ($t_{1/2} = 87.2 \text{ d}$) in small quantities. These are all presently produced in Russia. All three of these isotopes could be made in high specific activity and in Ci quantities through (n,p) reactions at VTR in the rabbit assembly. ^{32}P and ^{33}P would require enriched ^{32}S and ^{33}S targets (grams) but the target material could be readily recycled in well-established production processes. ^{35}S could be produced from natural KCl targets (grams) placed in the reflector region. The ability to produce these isotopes at the VTR would reduce the Nation's vulnerability to a single foreign source for these radioisotopes.

A driving force behind the clinical application of radiopharmaceuticals in precision medicine is the ability to selectively direct, or target, radiolabeled molecules to active sites of human disease. To effectively accomplish this goal, both a diagnostic and therapeutic radionuclide must be strategically attached to a biological targeting vector for delivery to a disease biomarker (e.g., a cancer-specific cellular receptor). Theragnostic radiopharmaceuticals offer

the unique opportunity to use information derived from patient specific diagnostic imaging studies to determine the therapy approach with respect to drug pharmacokinetics, biomarker density, and patient dosimetry. Theragnostic pairs of isotopes of the same element greatly reduce the amount of effort and cost required to bring a radiopharmaceutical to market. Finally, because high specific activity isotopes are needed when targeting a disease site, there is a distinct advantage to using (n,p) reactions at the VTR to make the isotope as the product of interest can be chemically separated from the target material. Clinical application of these isotopes would require tens of Curies on a weekly basis. Present demand for radiopharmaceutical development and preclinical trial is much less.

- ^{77}As (therapeutic, $t_{1/2} = 38.83 \text{ h}$) and ^{74}As (diagnostic, $t_{1/2} = 17.8 \text{ d}$). Both isotopes can be made in Ci quantities from targets (grams) of enriched ^{77}Se and ^{74}Se , respectively. The target material could be recycled from the chemical separation process. There is interest into bringing this novel theragnostic pair to market. Researchers at the University of Missouri (with support from the DOE IP) have developed novel, stable ligands for the application of these isotopes to permit preclinical testing that could lead to large clinical use.
- ^{67}Cu (therapeutic, $t_{1/2} = 61.83 \text{ h}$) and ^{64}Cu (diagnostic, $t_{1/2} = 12.70 \text{ h}$). Curies of ^{64}Cu can be made from grams of enriched ^{64}Zn whereas it will take tens of grams of enriched ^{67}Zn to make Ci quantities of ^{67}Cu . Again, with the (n,p) reaction, the target material could be recycled after each production run. There is an emerging market developing for this theragnostic pair and the DOE IP is already working with at least one company on using these isotopes in clinical studies. Adding production at VTR to the photo-nuclear production [based on the $^{68}\text{Zn}(\gamma, n)^{67}\text{Zn}$ reaction] already underway at Argonne National Laboratory (ANL) would provide increased production capacity and redundancy the pharmaceutical industry will demand to make the investment in a final drug product.
- ^{47}Sc (therapeutic, $t_{1/2} = 3.349 \text{ d}$) and ^{44}Sc (diagnostic, $t_{1/2} = 3.93 \text{ h}$). Curies of this isotope could be produced via the n,p reaction on enriched ^{47}Ti targets (grams) that are recycled as part of the production process. While it is also possible to make large quantities of ^{48}Sc , it is our opinion that this isotope would not be used as a radiopharmaceutical because of the high-energy gamma-rays accompanying its decay. The imaging agent of this theragnostic pair is ^{44}Sc which can be provided through a generator loaded with the long-lived parent isotope ^{44}Ti ($t_{1/2} = 59.9 \text{ y}$). Unfortunately, the threshold for the (n,3n) reaction to make ^{44}Ti is above 20 MeV. Alternative production routes for ^{44}Ti , like those being investigated at BNL and LANL, will need to be developed to bring this theragnostic pair to clinical application.

Another threshold capture reaction is the $^{230}\text{Th}(n, 2n)$ reaction for production of ^{229}Th . While production via this route in the VTR is approximately one order of magnitude greater than in the HFIR, it is still multiple orders of magnitude below production through (n, γ) neutron capture route at HFIR starting with ^{226}Ra . Production of ^{229}Th is not considered competitive in the VTR.

Several isotopes were further considered for production in the VTR due to the large epithermal flux. While these isotopes are not produced through threshold fast captures, each have significant production cross sections in the epithermal energy region.

Promethium-147 ($t_{1/2} = 2.62$ y) can be produced in the HFIR from irradiation of enriched ^{146}Nd . Irradiation of 1 gram of ^{146}Nd for one 25-day cycle, followed by a 50-day decay, produces approximately 2.5 Ci of ^{147}Pm . The same amount of irradiation in the VTR produces approximately 0.4 Ci of ^{147}Pm . However, increasing the irradiation to a full 100-day cycle produces approximately 1.5 Ci. While the yield per day of irradiation is lower, the large target volumes available in the VTR could make production of large (100kCi+) quantities of ^{147}Pm more feasible. Use of the VTR rabbit would not be necessary. Longer lived radio impurity ^{146}Pm ($t_{1/2} = 5.53$ y) is approximately 100 times greater in VTR-produced Pm than in HFIR-produced Pm, but still represents only 0.0015% of the activity. The current application for this isotope is the development of radioactive micro-power sources. While curie quantities will facilitate the development of these technologies, the deployment of these devices for the envisioned applications will require kCi amounts of the isotope. It should also be recognized that ^{147}Pm used in these devices will need to be essentially free of ^{146}Pm .

Tin-117m ($t_{1/2} = 14.00$ d) has been produced in the HFIR by the $^{117}\text{Sn}(n,n')$ reaction. Irradiation of 1 gram of ^{117}Sn for one 25-day cycle, followed by a 5-day decay, produces approximately 0.20 mCi ^{117m}Sn . The same irradiation in the VTR produces approximately 0.12 mCi. Production of this isotope is feasible in the VTR and could be useful for supplementing production of this short half-life isotope during outages of other reactors.

Nickel-63, ^{227}Ac , ^{60}Co , and ^{14}C production in the VTR are all one or more orders of magnitude lower than in HFIR. Nickel-63 is a low-energy beta emitter with a long half-life (100 y) that is available in a convenient physical form that enables repeatable, low-waste manufacturing of the radioactive source. Gas chromatography system that utilizes ^{63}Ni electron capture detectors are up to 1,000 times more sensitive than gas chromatography systems that use either flame ionization or thermal conductivity detectors. The applications of these systems include food and pesticide analysis, forensic toxicology, controlled substances identification and environmental monitoring for greenhouse gasses. In addition, ^{63}Ni sources are used as the electron source in field deployable ion mobility spectroscopy systems. These systems are extensively deployed by the Department of Homeland Security and the U.S. military for detecting trace amounts of explosives, narcotics, chemical warfare agents and industrial chemicals in the field. In 2020, industry reported to the Basic Energy Sciences Advisory Committee (BESAC) on The Scientific Justification for a U.S. Domestic High-Performance Reactor-Based Research Facility that the demand for reactor irradiation space to produce ^{63}Ni greatly exceeds the available capacity of HFIR and SM3 (Russia). Production of ^{227}Ac , ^{60}Co , and ^{14}C is less attractive in the VTR.

The above calculations assumed a row 5 VTR rabbit location. The fast flux is approximately a factor of two higher near the center of the core compared to row 5. A location for the VTR rabbit closer to the core center should be considered if threshold type reactions are desired.

Spectral tailoring by adding metal hydride moderation outside the core in the VTR would soften the neutron spectrum by increasing the amount of thermal and epithermal flux, and would make production of isotopes sensitive to the thermal or epithermal part of the neutron spectrum, such as ^{60}Co , more attractive in the VTR. The substitution of ^{60}Co targets for B_4C shield assemblies in VTR could be explored if it is of interest. At one time, the production of ^{60}Co in the reflector region of FFTF was a potential mission for FFTF. An irradiation of a ^{60}Co production test assembly in the reflector region of FFTF was conducted.

Processing/Analytical Facilities

Depending upon the quantities handled, ^{32}P , ^{33}P , and ^{35}S could be produced in shielded glove boxes or hot cells. At this time, most applications for these isotopes do not require that they be produced under a Food and Drug Administration (FDA) quality program. The "industrial" isotope ^{60}Co would require a hot cell to unpack and prepare for shipment to the end user. Production of ^{63}Ni , ^{147}Pm , ^{67}Cu , ^{77}As and ^{47}Sc would require a hot cell to chemically separate the isotope from the target material and activation product impurities. However, given the long half-life of ^{147}Pm , it would be feasible to simply ship the irradiated targets to facilities elsewhere that have existing infrastructure for processing this material. In addition, for these isotopes the processing site must have adequate analytical capability (for example gamma spectroscopy, mass spectroscopy) to assure product radio nuclidic and chemical purity.

For clinical use the potential radiopharmaceutical isotopes, ^{67}Cu , ^{77}As and ^{47}Sc , would be used as an active pharmaceutical ingredient (API) and would need to be produced under a quality program that met the following requirements:

- 21 CFR 211, "Current Good Manufacturing Practice for Finished Pharmaceuticals".
(United States Food and Drug Administration)
- 21 CFR 210, "Current Good Manufacturing Practice In Manufacturing, Processing, Packing, Or Holding Of Drugs; General"
- ICH Q7A, "Good Manufacturing Practice for Active Pharmaceutical Ingredients"

Production under a Current Good Manufacturing Practice (cGMP) program requires significant investment in both infrastructure and personnel. It is recommended that any isotopes produced at VTR for use as an API be processed at a facility within the DOE Isotope Program that already has implemented cGMP programs (for example BNL, ORNL, and LANL). In this case, the targets would be unloaded in the VTR hot cell and shipped to a cGMP qualified facility. However offsite shipment for processing of the shorter lived ^{67}Cu , ^{77}As and ^{47}Sc would mean

substantial decay loss in transit. If increased supply of these isotopes to meet clinical demand eventually becomes necessary, full cGMP processing at the VTR site could be considered to minimize decay loss. However, the VTR operating schedule is not ideal to satisfy a year-round uninterrupted isotope supply. A production mode will require assured production amounts and schedule that a test reactor may not be suited for. A production mode will also require a means for alternate production when the VTR reactor is down for either scheduled refueling or unscheduled outages.

Shipping/Transfer Options

Targets in their primary encapsulation could be readily shipped from the VTR hot cell to end users or a centralized cGMP processing facility in either Type A or Type B packages. The University of Missouri Research Reactor currently irradiates targets of enriched ^{176}Yb that are encapsulated in quartz vials and ships those targets in Type A packages to Europe and the Middle East on a weekly basis. When the combined activities exceed the A2 value, irradiated target materials are shipped in a Type B package (owned by MURR and returned by the client). The DOE IP currently owns and uses many varieties of Type A packages that would be suitable for use at the VTR. Type B packages must be certified for the specific isotope contents, so they are not easily interchangeable for shipments with different isotope mixes.

Summary Recommendations

- The DOE IP can benefit from the VTR and the production of radioisotopes for which the fast neutron spectrum of the VTR is advantageous and for which existing neutron irradiation sources are inadequate to meet domestic demand.
- The installation of a rabbit system is essential for many of the desired short-lived isotopes. The large irradiation volume available in the VTR is attractive for increased production of a highly desired isotope or simultaneous irradiation of many different samples.
 - Design of an axially connected train of capsules in the rabbit system is highly suggested.
- The VTR Rabbit is better suited to a medical isotope R&D mode than routine production mode.
 - Radioisotopes to consider for irradiation in the rabbit include ^{67}Cu , ^{77}As , ^{47}Sc and $^{117\text{m}}\text{Sn}$.
- Routine irradiation of longer-lived radioisotopes in one or more reflector positions is feasible and attractive for the VTR.
 - Radioisotopes to consider for irradiation in reflector positions include ^{89}Sr , ^{147}Pm , and ^{63}Ni .
 - For production of isotopes sensitive to the thermal or epithermal part of the neutron spectrum, such as ^{60}Co , spectral tailoring could be considered by adding metal hydride moderation outside the core. The substitution of ^{60}Co targets for B_4C shield assemblies in VTR could be explored.
- Although aluminum is often used for sample encapsulation in many reactors, it is not recommended for use in the VTR due to the high ambient temperatures.
 - It is suggested that other capsule materials be investigated, including Ti, 316 SS, SiC, SiO_2 , V, V-4Cr-4Ti, and Zircalloy-4.
 - The physical and chemical form of potential target materials and interaction with the capsule material should be considered.
 - Early input from the isotope community to thermal hydraulic simulations for sample encapsulation is recommended to achieve realistic internal target temperature results suitable for isotope production.
- Fabrication, certification and procurement of multiple Type B casks by DOE IP or other customers for isotope shipments off the VTR site would be needed.

U.S. Senate Committee on Energy and Natural Resources
November 4, 2021 Hearing: *The Potential Non-Electric Applications of Civilian Nuclear Energy*
Questions for the Record Submitted to Dr. Paul Chodak III

Questions from Senator Lisa Murkowski

Question 1: Increased industrial electrification will mean increased load. This will mean we need to add even more generation, likely on a rapid basis. How likely are we to scale clean generation to meet this load without nuclear power? What will that mean for transmission?

Answer: The rate of increased electrification will vary across customer classes, including industrial, residential and commercial, as well as across different end-uses. Certain end-uses, such as transportation and climate control (heating and air conditioning), will likely have easier paths to electrify while energy-intensive industries using fossil fuels efficiently in large manufacturing processes may have a slower rate of adoption. The load created by increased electrification will be partially offset by recent trends in electricity consumption, influenced by energy efficiency programs, increased saturation of distributed energy resources, increasing electricity prices, shifting demographics, and a focus on industrial efficiency. However, an increased reliance on the grid due to more electrification only increases the necessity that it remain reliable.

Nuclear energy currently accounts for approximately 20% of our national electrical output. In comparison, non-hydro renewable energy only accounts for approximately 10% of our current electric output. Therefore, replacing our nuclear fleet with renewable energy would require approximately a 3-fold or more increase in renewable energy deployment. This is in addition to other renewable deployment to replace other resources.

Furthermore, nuclear energy is typically a very dependable generation resource with known quantities of energy being delivered 24/7/365. In contrast to renewable energy, which is predictable but more intermittent in production, nuclear power provides a stable non-emitting resource and, assuming current demonstration projects are successful, can provide support for hydrogen production as a non-emitting fuel capable of being stored for long periods of time like natural gas.

Clean energy can be scaled, but the pace of change needs to match supply chain, reliability and economic realities. The transmission grid will have to be modified and expanded to provide the reliable service our nation expects. This includes shifting our transmission network to tap economic wind and solar resources where they are most available, which is not typically near load centers. This requires a significant overhaul and increase in transmission infrastructure. Transmission needs, which are already large, would greatly increase and be accelerated in the absence of nuclear power. By contrast, Small Modular Reactors could likely be located at existing transmission system interconnection points.

Question 2: How dispatchable is nuclear? Will that change as new types of reactors become commercially available? Can advanced nuclear facilities be safely sited near industrial facilities?

Answer: Existing nuclear power plants are dispatchable, but not at a rapid rate. For example, some Midwestern nuclear power plants reduce reactor output at night to 65-80% of full power due to an increase electricity produced by wind turbines. Reactor output is then increased to 100% during the day when wind-produced electricity decreases. Existing nuclear reactors cannot be readily dispatched from the shutdown condition to full power due to the impact on plant equipment and the fact that it can take 1-2 days for a nuclear reactor to be brought online and to 100% power. Advanced design and small modular reactors have more flexibility to be dispatched because they are much smaller than existing reactors and are intended to be built in groups of 4, 6, or

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12 reactors so there is more flexibility in the range of power output for this group of reactors. In a general sense, nuclear reactors are not designed to dispatch in the short amounts of time that natural gas fueled power plants can because of the need to carefully control the plant and to condition the fuel. While existing nuclear reactors are very safe, advanced and small modular reactors are designed to be even safer. This increase in safety and small sizes means they can be easily located near industrial facilities.

Question 3: If you built a nuclear facility for the dual purpose of heat and steam for industrial use, who would own the nuclear asset? Is there precedent for a utility to sell steam, rather than selling electricity?

Answer: Yes nuclear facilities can be built for the dual purpose of heat and steam for industrial use. A recent article in the *New York Times* documents how a floating small modular reactor in Russia is today operating in this type of capacity. The US NRC would have to approve the licensing to do this. Some of the pairing of nuclear power plants with clean hydrogen production would use process heat from the nuclear power plant to produce hydrogen. The asset could be owned by either an electric utility, a merchant operator, or a private company. All of the ownership options would have to comply with regulations set by the US NRC.



The Council on Radionuclides and Radiopharmaceuticals, Inc.

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December 3, 2021

Darla Ripchensky, PMP
Chief Clerk
U.S. Senate Committee on Energy and Natural Resources
304 Dirksen Senate Office Building
Washington, DC 20510

Re: CORAR Response to Questions from Ranking Member John Barrasso and Senator Lisa Murkowski

Dear Ms. Ripchensky,

The Council on Radionuclides and Radiopharmaceuticals, Inc. (CORAR) appreciates the opportunity to provide responses to the Questions for the Record (QFRs) submitted to Mr. Michael J. Guastella (CORAR Executive Director) on November 9, 2021. These questions were submitted as a follow-up to the November 4, 2021 Hearing: *The Potential Non-Electric Applications of Civilian Nuclear Energy*. CORAR is an industry association of firms that manufacture diagnostic and therapeutic radiopharmaceuticals, radionuclides, and other radioactive products primarily used in medicine, research, and industry.

The following sections provide CORAR responses to the questions from Ranking Member Barrasso and Senator Murkowski:

Ranking Member John Barrasso Questions and Responses

Question 1:

What kind of opportunities do existing commercial reactors present for medical isotope production?

There are several examples of existing commercial reactors that have either explored medical isotope production or are currently pursuing medical isotope production. For example, General Electric-Hitachi (GEH) was awarded a cooperative agreement on September 30, 2009, by the National Nuclear Security Administration (NNSA), to pursue the use of power reactors as the source of neutrons to produce molybdenum-99 (Mo-99) via neutron capture. GEH and Exelon announced in September 2011 that they were jointly studying the feasibility of producing Mo-99 at the Clinton Power Station, a boiling water reactor (BWR) located in central Illinois. GE intended to use accessible instrumentation channels in BWRs for the insertion of the Mo-98

targets. However, GEH suspended the project in February 2012 because of an adverse market outlook.¹

The Canada Deuterium Uranium (CANDU) commercial power reactors are currently being used for certain medical isotope production in Canada. For example, BWXT Medical has publicly disclosed that they will be using the Ontario Power Generation (OPG) Darlington Nuclear Generating Station to produce the medical isotope Mo-99². Also, ITM Medical Isotopes GmbH has publicly stated that they are using Bruce Power Reactors to produce the therapeutic radioisotope Lutetium-177 (Lu-177)³. Both OPG and Bruce Power reactors utilize CANDU design technology which provides unique capabilities to irradiate targets for isotope production that commercial reactors in the U.S. don't currently possess. For example, CANDU designed reactors allow manufacturers to load and unload isotope irradiation targets into the reactor while it is operating while commercial reactors in the U.S. generally do not. In addition, any isotope manufacturer that considers using a U.S. commercial reactor to produce isotopes must determine if the reactor design provides adequate neutron flux⁴.

CORAR members believe that before any U.S. commercial reactor operator pursues opportunities to produce medical (or industrial) isotopes, technical issues that have prevented the broad use of these reactors for isotope production in the past must be addressed.

What kind of opportunities do advanced reactors, like TerraPower's Natrium reactor, present for medical isotope production?

Historically, the production of medical isotopes is largely dependent on multi-purpose research reactors that possess specific characteristics that make them ideal for producing these isotopes. However, as mentioned above, there are examples of CANDU power reactors producing a few specific medical isotopes (e.g. Co-60, Mo-99 and Lu-177) and advanced reactors could provide a future role to enhance domestic production.

Based on information in the public domain, there are several advanced reactor projects underway in the U.S. For example, TerraPower as part of the U.S. Department of Energy's (DOE) Advanced Reactor Demonstration Program (ARDP) is working to prove that the new Natrium Reactor's technology design, licensing, construction, and operational features can meet growing electricity needs with a goal of commercial electricity production by the late 2020s⁵. In preparing CORAR responses to these QFRs, TerraPower (a CORAR member company) provided additional comments as follows, "TerraPower's primary focus with its Natrium™ reactor technology is on developing advanced nuclear energy to meet growing electricity needs, mitigate climate change, and lift billions out of poverty. In our quest to accomplish this ambition, we are working with partners to build the first Natrium demonstration reactor at a retiring coal facility in Wyoming. For the Natrium demonstration reactor, our first focus is licensing and demonstrating this technology as an emission-free dispatchable electricity source. Although advanced reactors like those being developed by TerraPower could support future isotope production, at this time, medical isotope production at the Natrium demonstration reactor is outside the scope of our mission parameters."

¹ Molybdenum-99 for Medical Imaging, National Academy of Sciences, Engineering, Medicine 2016

² <https://www.bwxt.com/news/2020/09/24/OPG-and-BWXT-Make-Significant-Progress-in-Production-of-Life-Saving-Medical-Isotope-at-Darlington-Nuclear-Generating-Station>

³ <https://itm-radiopharma.com/news/press-releases/press-releases-detail-bruce-power-and-isogen-set-first-critical-milestone-for-exclusive-irradiation-service-provided-to-itm-for-its-production-of-no-carrier-added-lutetium-177-201>

⁴ Neutron Flux is measure of the intensity of neutron radiation, determined by the rate of flow of neutrons.

⁵ <https://natriumpower.com>

CORAR members welcome increased domestic medical isotope capabilities, including new reactor technologies. However, opportunities for any advanced reactor to produce medical isotopes will not be realized unless facility design planning begins in the early phase of the project. This planning should include a review of the reactor neutronics as well as reactor design that would accommodate isotope production (e.g. the ability to load and un-load isotope targets while the reactor is running). Also, we would encourage any advanced reactor project team to constitute an advisory panel of stakeholders from academia, healthcare, and industry to evaluate what medical isotopes could be produced in each type of advanced reactor design. Finally, CORAR members believe it would be helpful for any advanced reactor project team that wishes to explore medical isotope production, to study the lessons learned from current nuclear power reactor operators that produce medical isotopes (e.g. Bruce Power mentioned above).

Question 2: *I understand there are opportunities to produce low specific activity (LSA) Cobalt-60 in pressurized water reactors (PWRs) here in the United States. Could the Department of Energy facilitate the development of a domestic LSA Cobalt-60 production capacity by providing financial assistance to utilities operating PWRs?*

Given that no CORAR member company produces and distributes LSA Cobalt-60 (Co-60), we have received the response below from Nordion, Inc.⁶, a health science company that provides Co-60 used for sterilization and treatment of disease:

Existing commercial reactors offer scale of production which is important for high-volume isotopes such as Co-60. Virtually all of the global supply of LSA Co-60 comes from CANDU PHWRs (Pressurized Heavy Water Reactors) and RBMKs (Russian-designed graphite-moderated reactors), but these are limited in number with RBMK reactors scheduled to shut-down over the next decade. The CANDU and RBMK reactors currently producing LSA Co-60 represent approximately 10% of global operating power reactors. Light Water Reactors (LWRs), on the other hand, make up more than 80% of installed reactors, of which approximately 100 operate in the U.S. None of the U.S. LWRs currently are utilized for the production of LSA Co-60.

Nordion reports that there are three general categories of costs associated with producing LSA Co-60 in U.S. PWRs (a type of LWR) which account for approximately 65 reactors in the U.S., or approximately 65% of U.S. LWRs. First, there are the technology development costs. Second, there are the startup costs at the reactor site – e.g. training, documentation, licensing, and regulatory approval. Third, because producing LSA Co-60 in PWRs requires the reactors to use 10 – 15% more uranium fuel, there are the costs associated with the purchase of this incremental increase in uranium fuel requirements. Financial assistance from DOE would be beneficial in all three categories, but particularly with respect to helping to offset the cost of the additional uranium fuel.

Question 3: *Some advanced nuclear reactor developers have highlighted isotope production as a potential non-electric application. These advanced nuclear reactors include university-based research reactors, such as the molten salt research reactor under development at Abilene Christian University. What opportunities are there to use existing or new research reactors for the production of medical isotopes here in the United States?*

⁶ <https://www.nordion.com>

The existing U.S. university research reactor that has the appropriate characteristics and operating schedule to produce medical isotopes is the University of Missouri Research Reactor (MURR). MURR currently produces the following medical isotopes: Iodine-131 (I-131 for thyroid cancer), Lutetium-177 (Lu-177 Lutathera for neuroendocrine tumors), and Molybdenum-99 (Mo-99 for Tc-99m generators for imaging). MURR is evaluating production of additional medical isotopes such as Terbium-161 (Tb-161).

CORAR members believe that existing or new research reactors that are designed with similar characteristics as MURR, and operate on a similar production schedule to MURR, have the opportunity to provide additional domestic medical isotope production and increase reliability of supply for U.S. healthcare providers and patients.

Question 4: *Research reactors at national laboratories produce much needed isotopes, including Idaho National Laboratory's Advanced Test Reactor, and Oak Ridge National Laboratory's High Flux Isotope Reactor. The Department of Energy is currently executing a project to deploy a new research reactor, the Versatile Test Reactor (VTR). Could the VTR help address our domestic isotope production needs? If so, how?*

CORAR members believe that adding domestic isotope production to the mission of the Versatile Test Reactor (VTR) would help address the lack of domestic production for a number of isotopes. For example, based on preliminary discussions with CORAR members, we believe the VTR could be useful in providing domestic production of Phosphorus-32 (P-32), Phosphorus-33 (P-33), Sulfur-35 (S-35), Arsenic-74 (As-74), Arsenic-77 (As-77), Copper-64 (Cu-64), Copper-67 (Cu-67), and Scandium-47 (Sc-47). Several of these isotopes are showing significant promise in advancing the diagnosis and treatment of cancer.

Question 5: *In your testimony, you mentioned that a stakeholder and agency advisory committee should be established by the Department of Energy to help define the nation's isotope needs and identify opportunities to increase domestic isotope production. Would you please elaborate on this need and how the advisory committee should be established to address the need?*

With the exception of Mo-99, which is managed by NNSA, the DOE Isotope Program has sole authority, within the Department of Energy, Office of Science, to domestically produce both radioactive and stable isotopes that are needed because commercial production has not been established or is not sufficient to meet U.S. medical, industrial, and research needs. Previously, when the Isotope Program transitioned from the Office of Nuclear Energy to the Office of Nuclear Physics in 2009, a request was made to the Nuclear Science Advisory Committee (NSAC) to establish a formal subcommittee (the NSAC Isotope or NSACI subcommittee) to identify and prioritize the compelling research opportunities using isotopes, to study the opportunities and priorities for ensuring a robust national program in isotope production and development, and to recommend a long-term strategic plan that will provide a framework for a coordinated implementation of the isotope program⁷. The NSACI Subcommittee produced two reports that established the foundation for the Isotope Program moving forward.

In the Spring of 2014, the NSAC re-established the NSACI Subcommittee with the following requests, “develop an updated Long-Range Strategic Plan for the Isotope Program; articulate the

⁷ <https://www.osti.gov/servlets/purl/1298983>

progress made by the Isotope Program toward the goals set by the 2009 NSACI reports; update and prioritize compelling opportunities for the Program; and indicate what resources would be needed in the timeframe 2016-2025 to increase the domestic availability of isotopes appropriate to the DOE Isotope Program portfolio and deemed to be critical for the Nation⁸.”

The 2015 NSACI Subcommittee report, *Meeting Isotope Needs and Capturing Opportunities for the Future: The 2015 Long Range Plan for the DOE-NP Isotope Program*⁹, included an updated Isotope Program long-range strategic plan. CORAR members believe that the Isotope Program has made significant progress toward the 2015 long-range strategic plan and continues to be an important partner in evaluating and supporting U.S. medical, industrial, and research isotope needs, consistent with their mission.

With this said, a formal multi-disciplinary advisory committee has not been convened to review and provide feedback to the Isotope Program since 2014. Also, CORAR has learned that in the FY 2022 DOE budget, the Isotope Program was moved out of the Office of Nuclear Physics and is now a stand-alone office, reporting directly to the Director of the Office of Science. With this move, the Office of Science, Isotope Program has lost the ability to constitute a subcommittee through the NSAC to conduct formal program reviews, including an evaluation of progress toward the 2015 long-range strategic plan.

Since the Isotope Program can no longer rely on a subcommittee of the NSAC to evaluate Isotope Program performance and progress, CORAR members recommend that the DOE Office of Science constitute an Isotope Program Advisory Committee which should include researchers, medical professionals, industry stakeholders, and other government agencies outside the DOE Office of Science (e.g. Department of Homeland Security, NASA, etc.). The advisory committee would formally review progress towards the 2015 long-range strategic plan objectives. In addition, the advisory committee could help evaluate and suggest steps to avoid any medical, industrial, or research isotope production shortages in the U.S., assess the international supply chain of medical, industrial, or research isotopes, and make recommendations to avoid or minimize any anticipated disruptions in the international supply of medical, industrial, or research isotopes. As a result, the advisory committee would help inform any needed updates to the Isotope Program long-range strategic plan, help establish current domestic isotope unmet needs, identify opportunities to mitigate reliance on foreign sources of medical, industrial, and research isotopes, and reinforce a current list of isotopes the Isotope Program should focus on, consistent with their mission when commercial production has not been established or is not sufficient.

Senator Lisa Murkowski Questions and Responses

Questions: *I am proud that Alaska has a gamma knife facility for diagnosing and treating brain cancer patients. I understand that a supply of the isotope cobalt-60 is required to operate the facility.*

Can you describe the process through which cobalt-60 is made, or generated, and what our domestic supplies look like today?

The Leksell Gamma Knife (Elekta Gamma Knife) is a stereotactic radiosurgery device that utilizes one hundred ninety two (192) high specific activity (HSA) Co-60 sources that are

⁸ Id. at 7.

⁹ Id. at 7.

collimated to produce precise beams of radiation to the target area of the brain. Unlike industrial or irradiation sources, the Co-60 utilized in the gamma knife must meet certain specifications. The Co-60 metal utilized in the Gamma Knife source must be in the form of 1.0 mm by 1.0 mm pellets that are assembled into sealed sources of specific lengths. The specific activity of the Co-60 pellets needs to be ≥ 250 curies per gram (Ci/g). The cobalt target within the reactor must accommodate the 1.0 mm x 1.0 mm pellets geometry and will require several years of irradiation to achieve the required specific activity. The production of Co-60 is the result of neutron activation of naturally occurring Co-59. This can only be accomplished in a nuclear reactor with a sufficiently high neutron flux, e.g. the US Department of Energy's Advanced Test Reactor (ATR) and High Flux Isotope Reactor (HFIR). Civilian nuclear power reactors in the U.S. do not have sufficient neutron flux for economical production of HSA Co-60 for the gamma knife.

The only reactor in the U.S. that has produced Co-60 for the Leksell Gamma Knife is the U.S. DOE's ATR located at Idaho National Laboratory. Unfortunately, the ATR has been unable to produce a sufficient supply of Co-60 to meet the needs of the U.S. Gamma Knife fleet. A redesign of the Co-60 target assemblies that was put into use in 2014 at the ATR limits the level of activation that the Co-60 pellets can achieve even after 5+ years of irradiation. This along with a limited space in the ATR for isotope production makes the U.S. dependent on foreign reactors and source manufactures to supply the US Gamma Knife fleet.

Are any further legislative changes needed to ensure an adequate supply of medical isotopes?

Legislation to provide the U.S. DOE with the level of funding necessary to develop a new cobalt target that could produce Co-60 in excess of 250 Ci/g and support irradiation of cobalt targets in the ATR, and possibly HFIR would be needed to secure a stable supply of HSA Co-60 for the U.S.

To ensure continued progress toward increasing domestic Mo-99 production, CORAR members believe that the NNSA, as part of their Mo-99 program, continue their support provided to the National Laboratories and their efforts to provide R&D and technical assistance to the potential domestic Mo-99 projects. Although CORAR is aware that NNSA does not intend to request additional Congressional appropriations for new Cooperative Agreement awards, Congressional direction to the DOE should be provided to ensure that the National Laboratories continue their assistance to potential domestic Mo-99 producers through at least the U.S. Government FY 2024, when the current Cooperative Agreements are completed.

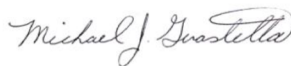
To address the heavy U.S. reliance on Russia for enriched stable medical (as well as industrial) isotopes, our nation must rebuild our capacity to produce these isotopes to meet increasing domestic demand. CORAR members believe that continued appropriations in current and future legislation are required to support the DOE Stable Isotope Production and Research Center at the Oak Ridge National Laboratory (ORNL). This is necessary to re-establish a U.S. production infrastructure for enriched stable isotopes, for which there is not a commercial supply and for those stable isotopes that can only be produced at DOE facilities. In addition, CORAR recommends Congress enact legislation that would establish and fund the Isotope Program Advisory Committee, consistent with our response to QFR 5 from Senator Barrasso.

Currently, many medical isotopes are produced in research reactors that rely on High Assay Low Enriched Uranium (HALEU) for reactor fuel and irradiation targets. Even with a shift to some non-uranium production technology for medical isotopes, HALEU will still be required for many years to come. In addition, the current DOE Advanced Reactor Demonstration Program (ARDP)

projects will require a significant amount of HALEU in the next several years to evaluate this technology for the future. Due to the projected increase in HALEU demand, CORAR members believe it is necessary to develop a reliable and sustainable domestic supply to satisfy both medical isotope production needs as well as the advanced nuclear power reactor program needs. This will require continued Congressional support and adequate appropriations to build out a domestic HALEU infrastructure, including public private partnerships for commercial enrichment capabilities.

Finally, the future of nuclear medicine with innovative new diagnostic and therapeutic radiopharmaceuticals that rely on medical isotopes such as Gallium-68 (Ga-68), Actinium-225 (Ac-225), and lutetium-177 (Lu-177) is very bright. For academia and industry to continue to innovate and bring new radiopharmaceuticals to U.S. patients, CORAR encourages Congress to support Research and Graduate training programs, through appropriated government grants and other government educational programs, to help fill the pipeline with knowledgeable and trained individuals in research, development, and commercialization to meet our current and future needs.

Respectfully Submitted,



Michael J. Guastella

**Statement for the Record by Mr. Chris Levesque, President and CEO of TerraPower
Full Committee Hearing on Potential Non-electric Applications of Civilian Nuclear Energy
Senate Energy and Natural Resources Committee
November 4, 2021**

Thank you for the opportunity to submit a statement for the record on the hearing on Potential Non-Electric Applications of Civilian Nuclear Energy. This is an important topic for the United States, and as a developer of nuclear technologies, TerraPower is delighted to be able to share our perspective.

TerraPower was founded over fifteen years ago by Bill Gates and other visionary leaders who identified the important role that advanced nuclear technology can play in solving some of the most difficult challenges facing the world. These challenges include the threat of climate change and global energy poverty, and the Committee is aware of TerraPower's Natrium™ reactor demonstration project, a TerraPower and GE-Hitachi technology project. The Natrium project will combine an advanced nuclear heat source with a molten salt energy storage system to provide firm, flexible carbon free generation as part of the Advanced Reactor Demonstration Program established in the Energy Act of 2020. The Committee may not know, however, that as TerraPower has worked on nuclear technologies for power generation, we've developed a set of skills and knowledge that have applications beyond providing clean electricity.

One of these areas of expertise involves the separation of radioactive isotopes that can provide cutting edge treatments to some of the hardest to treat and most prevalent cancers. This has enabled TerraPower to help turn Cold War era nuclear waste products into valuable medical treatments.

Today, Oak Ridge National Laboratory (ORNL) is currently storing a weapons useable fissile nuclear waste product – Uranium-233 – which was created during the laboratory's work to develop nuclear weapons in the last century. This material is stored in a 70-year-old deteriorating facility at ORNL, and the Department has spent millions of dollars to store, protect, and attempt to dispose of this material.

The storage, protection, and disposal of U-233 in this aging building costs the US taxpayers millions of dollars every year. However, an award-winning public-private partnership is both eliminating the waste and extracting useful isotopes from the waste to create medical isotopes that can be used to treat a variety of cancers.

TerraPower is working with ORNL, Isotek Systems, LLC (Isotek), and Cardinal Health to produce a powerful medical isotope – Actinium-225 – from this waste material. As the U-233 ages, it decays into Thorium-229. Isotek, who is managing the U-233 disposition program for DOE, removes the Thorium-229 and sends that isotope to TerraPower's laboratory in Washington. TerraPower then processes the Thorium-229 into Actinium-225, which is the medical isotope

used to fight cancer. As such, we are taking a starting material that was slated to be disposed of, and turning it into beneficial uses that will save lives.

Earlier this year, TerraPower signed a collaboration agreement with Cardinal Health – one of the largest companies in the United States. Cardinal Health and TerraPower will produce and distribute TerraPower's Actinium-225 product, which will be utilized in drug trials involving targeted alpha therapy for diseases such as breast, prostate, colon and neuroendocrine cancers, melanoma and lymphoma. The current global supply of Actinium-225 is very limited but with this collaboration, it is anticipated that the companies will be able to significantly increase availability of the radionuclide. This is a potentially game changing treatment option for patients suffering from some of the most difficult to treat cancers.

Taxpayers benefit in three ways from this innovative public-private project: First, the project will eliminate a stockpile of weapons usable nuclear waste product that costs DOE millions to safely secure and store. Secondly, TerraPower is paying the federal government for the material, and as a result, DOE estimates that taxpayers are expected to save \$90 million. Finally, and most importantly, because this project has been ongoing for several years, TerraPower and Cardinal Health will be able to accelerate advances in cancer treatment through the supply of Actinium – 225 as soon as next year. The TerraPower/Cardinal Health collaboration will create 100-times more Actinium-225 supply than currently exists. This project has been lauded as a win-win-win for taxpayers, and the project received the Secretary of Energy's Achievement Award in 2021.

The TerraPower medical isotope program is an example of the ways in which nuclear science, and the companies working to develop advanced nuclear reactors, are using nuclear technologies to benefit the United States beyond the production of carbon free electricity.

I would like to thank the Committee for its continued support of nuclear technology, and for holding this important hearing. If you have any additional questions, or require any additional information, please do not hesitate to let me know.

KAYLA YOUNG
(304) 340-3362

MINORITY CHAIR SMALL BUSINESS AND
ECONOMIC DEVELOPMENT
MINORITY VICE CHAIR NATURAL
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November 2, 2021

The Honorable Joe Manchin
United States Senate
306 Hart Senate Office Building
Washington D.C. 20510

Dear Senator Manchin:

I am writing to urge you to consider West Virginia for non-electric applications of nuclear energy. We have been working diligently to lift the moratorium on nuclear energy in West Virginia and have broad bipartisan support, so we are able to accept opportunities for the zero-emissions fuel source. Investments in renewable energy are key to West Virginia and our nation's economic future.

Nuclear can provide safe dependable energy to the grid on demand with operational flexibility. Non-electric application can include national security, hydrogen production, synthetic fuel production, and agricultural uses. All of these are vital to our environment and economy as part of an integrated system.

West Virginia currently has three coal fired power plants nearing the end of their useful life: John Amos, Mountaineer, and Mitchell, all operated by AEP on the PJM grid. These plants are repeatedly incurring hundreds of millions of dollars in repair increases to make necessary upgrades. As the world moves towards lowering emissions, West Virginia has the infrastructure and workforce available, and deserves the opportunity to diversify and be at the forefront of energy production.

West Virginia has a long proud history of being an energy producer for the United States. We should continue that tradition by transitioning to technologies that keep our environment safe and clean and rebuild our communities with opportunities for dignified work in the nuclear power and advanced manufacturing industries.

I appreciate your leadership and commitment to including West Virginia when looking to meet climate goals and moving our state forward with new opportunities through Nuclear energy.

As ever,

Delegate Kayla Young