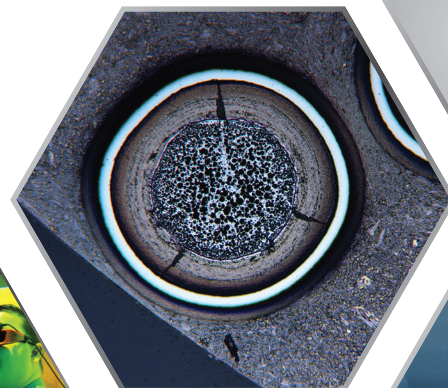
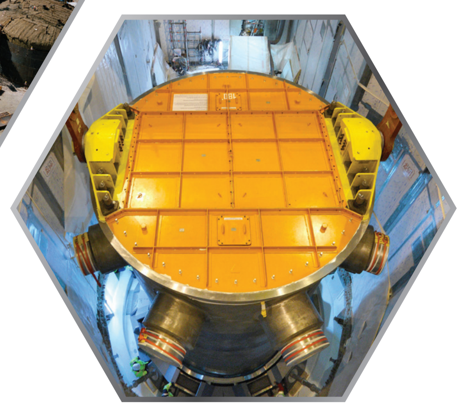
June 2017 | Special Report

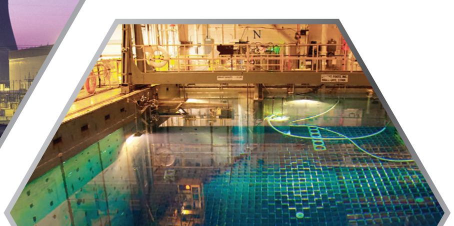
ANS NUCLEAR GRAND CHALLENGES









American Nuclear Society

A MESSAGE FROM ANS PRESIDENT ANDREW C. KLEIN

As I considered how ANS could best forward the interests of nuclear professionals during my term as president (June 2016-June 2017), I was compelled by the idea of identifying the technical nuclear challenges that need to be resolved by 2030 in order to help solve some of the economic, sociological, or political issues that we face as a society.

It was important to engage ANS members in the selection process, because they are the specialists best positioned to know the current landscape and potential for the future of nuclear technologies. We launched the Nuclear Grand Challenges effort by first conducting a roundtable brainstorming session with more than 125 nuclear professionals at the ANS Winter Meeting in November 2016. Then all ANS members, as well as the public, were invited to submit their ideas. The responses we received far exceeded my expectations, with nearly 300 separate recommendations submitted, many of which were similar enough to consolidate.

Those suggestions were categorized by specialty areas then vetted by the appropriate ANS Professional Divisions. The divisions were invited to submit up to three suggestions for the final Nuclear Grand Challenges from their areas of expertise. Those items were then reviewed and voted on by all members of the ANS board of directors, as well as the division chairs.

The results are the ANS Nuclear Grand Challenges described in this report. I hope these will provide an opportunity for our members and other interested parties to drive conversations about the difficult things we need to address to advance the benefits of nuclear science and technology for future generations. This report was created to catalog the identified challenges and provide focus for those who will continue our mission to share information by engaging the public and policymakers and foster advancements in nuclear technology. I look forward to being actively involved in finding solutions.

PUBLIC ENGAGEMENT

CHALLENGE: Transform the way the nuclear technologies sector thinks about public engagement.

HOW: *To change the way the public views nuclear energy, we must first transform the way the nuclear sector thinks about public outreach, transitioning from a "deficit model" approach toward an "engagement model" approach for outreach.*

BACKGROUND: The nuclear technologies sector's approach to public outreach is currently not structured. At this time, it relies very heavily on scientists, engineers, and other nuclear professionals to "educate" the public on a volunteer basis, using what is known as the deficit model of communication. This technique assumes that we must transfer our technical knowledge to the public and they will then support nuclear technology. Unfortunately, the evidence shows that this technique is largely ineffective when used outside of an educational setting, and can even backfire.

This is partly influenced by the way which certain scientific issues, such as nuclear safety or climate change, are framed, and by whom, which strongly affects how an issue is perceived. At the heart of the sector's approach to outreach is the idea that many members of the public claim that they trust scientists over activists or other public figures. Unfortunately, this approach has a major flaw. Gaining trust has very little to do with occupation, and almost everything to do with "warmth" – an intuitive sense of a person (or brand) we glean before any words are even exchanged. This paradigm was uncovered not by PR specialists or political operatives, but by social scientists, a group that is now driving the consensus around how to best engage on challenging scientific issues like nuclear.

An evidence-based "engagement model" communications approach is the current state of the art, and there is a tremendous amount of research as well as functional models to look to for guidance. As the name suggests, the engagement model shifts from a one-way information transfer with a focus on changing people's minds in a single interaction, to a two-way dialogue rooted in listening, respect, and building longer-term relationships that would shift understanding on a scientific issue over time. Many other scientific communities have successfully moved to this approach in recent years, with much of the research and dialogue in scientific communication being spearheaded by the American Association for the Advancement of Science.

LOW-DOSE RADIATION

CHALLENGE: Establish the scientific basis for modern low-dose radiation regulation.

HOW: *Establish the scientific basis and guidelines for the health effects of low-dose radiation and replace the current Linear-No-Threshold approach with a modern, science-backed model for nuclear radiation safety.*

BACKGROUND: The Linear-No-Threshold (LNT) model is based on high dose rate nuclear weapons data. Its application to nuclear reactor, medical, and irradiation applications is tenuous at best. New evidence in radiation and chemical toxicity fields is suggesting that LNT models are likely overly conservative, and the way in which they are used makes this conservatism inordinately expensive. While LNT is very straightforward to regulate, scientific evidence from the past several decades has indicated that low doses of radiation do not pose risk of cancer in a linear fashion, as is well-established among higher doses of radiation.

Today, the principle of As Low As Reasonably Achievable (ALARA) has in many cases lost the "reasonable" aspect, as nuclear power plants micromanage every milliroentgen (mR) of worker dose in order to meet metrics of dose reduction. Unnecessary fear of low doses of radiation has adversely impacted safety and enabled cumulative costs to build up within the U.S. nuclear energy industry such that building and maintaining plants is now overly cumbersome and expensive.

If the LNT model can be replaced with a modern, scientifically defensible model, underpinned by the latest microbiology research methods (genomics, proteomics, metabolomics, etc.), we can achieve both higher levels of safety while reducing unnecessary operations and waste disposal costs. One approach may be to establish a generally-accepted common measure of risk and a de minimis "threshold of regulatory concern," socialized, and incorporated into relevant standards and regulation. Ultimately, this effort could enable broader, more cost-effective applications of nuclear technologies, which in turn would provide significant additional benefits in cleaner air, less carbon, and more lives saved from deadly diseases.

FUEL CYCLE

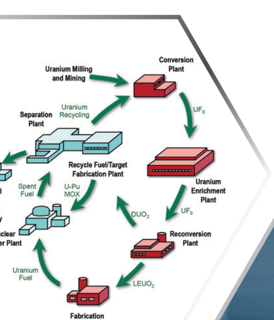
CHALLENGE: Close the nuclear fuel cycle.

HOW: *Firmly establish the pathway that leads to closing the nuclear fuel cycle to support the demonstration and deployment of advanced fission reactors, accelerators, and material recycling technologies to obtain maximum value while minimizing environmental impact from using nuclear fuel.*

BACKGROUND: Addressing nuclear waste disposal and closing the nuclear fuel cycle would have many significant public benefits. It must be commensurate with the design of any emerging commercial nuclear products. Reducing the stockpiles of used nuclear fuel and excess stocks of highly-enriched uranium would significantly reduce the worldwide potential for proliferation of nuclear materials. The costs and maintenance of large independent spent fuel storage facilities would be greatly minimized, saving billions of dollars in waste storage and associated security costs. Additionally, it would include streamlined government regulations and permit expedited regulatory reviews, certification, and licensing for advanced reactors. Furthermore, it would enable enhanced public support for nuclear technologies and increased governmental funding for the development of advanced high-level waste-burning reactors.

Adoption of an advanced reactor-based nuclear waste disposal solution through closing the nuclear fuel cycle would enable advanced reactors to burn remaining inventories of used nuclear fuel that are currently stored at commercial and government nuclear facilities to produce significant amounts of electricity. Nuclear waste would be minimized, eliminating the need for large waste disposal facilities. Concepts, in addition to reactor solutions, would also be possible and developed, such as innovative and safe approaches utilizing Accelerator Driven Systems. These systems remove the long-term radiotoxicity of spent fuel, generate energy to recover its cost, eliminate the need for a large geological repository, and avoid the use of fuel reprocessing steps.

The current approach to the U.S. nuclear fuel cycle was formulated for reasons that are less convincing to many than they may have seemed generations ago. This has left the nuclear industry highly vulnerable to a stalled nuclear waste disposal pathway. The "most promising" fuel cycles very well could be the fuel cycle families identified in the U.S. Department of Energy's Fuel Cycle Options Nuclear Fuel Cycle Evaluation and Screening Study report series (fuelcycleevaluation.inl.gov). This evaluation and screening work evaluated the breadth of fuel cycle options available in the context of nine evaluation metrics (waste management, proliferation risk, material security risk, safety, environmental impact, resource utilization, development and deployment risk, institutional issues, and financial risk/economics).



RADIOISOTOPES

CHALLENGE: Ensure continuous availability of radioisotopes.

HOW: *Develop a dependable technical approach to ensure the continued availability of radioisotopes – including rare, short-lived, less available radionuclides for medical, energy, research (aerospace, nondestructive analysis), and national security applications.*

BACKGROUND: U.S. domestic production of key radioactive and stable isotopes has significantly diminished, leaving patients and industry vulnerable to disruptions of our mostly foreign supply. New diagnostic and therapeutic agents are not being developed due to the lack of a reliable isotope supply, and difficult investment and regulatory climates.

REJUVENATE INFRASTRUCTURE

CHALLENGE: Rejuvenate nuclear technology infrastructure and facilities.

HOW: *There is an urgent need to rejuvenate and build the infrastructure, facilities, and skilled associated scientific staff involved in the research, testing, development, and deployment of advanced nuclear technologies. Maintaining this national testbed is critical to support vibrant commercial nuclear businesses.*

BACKGROUND: Developing new technologies and their use in nuclear applications is an expensive proposition. Due to the high level of quality and reliability required for nuclear applications, navigating the complex path from development to implementation and profitable production can be a daunting and cost prohibitive process. Ensuring that there is clear guidance for new and existing suppliers will lead to competitive and cost-effective options available in nuclear technologies markets. In addition, having reliable, consistent guidance will assist regulators in quickly processing new applications.

Developing the national assets of research and test facilities, be they government-operated or commercial, would provide a consistent basis for testing and approving new technologies.

This applies not only to new technologies, but also to the development of replacement equipment needed for older systems.

For years, the attitude has been to operate systems to failure, because by then there would have been a replacement system, process, or part. Then is now. In many cases the replacement system or process, or more frequently the needed parts to maintain the current capability, does not exist. Now it will cost more to consider, design, build, and operate the needed replacement facilities. Now it will cost even more to restore needed systems to prior standards, and even more to meet many of the current standards.

The higher costs are coming at a time when it is more difficult to acquire the necessary funds to perform everything that nuclear professionals are being requested to perform. On top of that, additional funds are required for infrastructure maintenance to keep plants operating into the future. None of these funds are stable into the long term. Companies are spending significant funds to replace operations due to aging infrastructure. They must also finance ongoing maintenance program upgrades, which in turn lead to more spent on maintenance. Additional costs are being incurred working off legacy and deferred maintenance and facilities upgrades to extend their lives. Many times, issues arise due to the cost associated with upgrades and replacements.

ADVANCED MATERIALS

CHALLENGE: Accelerate development and qualification of advanced materials.

HOW: *Use science-based design to reduce the development and qualification timeline for new nuclear fuels and advanced materials that can withstand extreme fission, fusion, and space power and propulsion environments.*

BACKGROUND: Advanced fission and fusion reactor designs offer many potential benefits, but will require new materials to be optimized. These advanced reactors have unique challenges that call for materials to resist corrosion when in prolonged contact with liquid salts or liquid metals, remain strong at elevated temperatures in a neutron field, maintain structural integrity when exposed to high fluxes of light ions and high heat flux, resist reaction in a loss of coolant event, and more.

Materials must be developed and qualified for each of these areas so that they can be implemented in new reactors. Materials issues lie at the heart of many of the technology issues that need to be solved. Without advanced materials, adequately qualified so that they can be used in engineering designs, we will never have a viable fusion or advanced fission power plant. This is a multi-faceted challenge that benefits not only nuclear energy research, but has applications for many other industries.

The current development and qualification timeline is long, especially due to limited experimental facilities and capabilities for in-reactor material irradiation testing. Significant scientific advances over the past few decades have enabled us to improve our understanding of irradiation effects on materials, including predictive capabilities. As such, we believe we can utilize these advancements to accelerate the materials qualification timeline, effectively reducing that barrier against deployment of future reactor technologies. Realizing this goal will include smart use of advanced modeling approaches, the establishment of experimental facilities and data generation for validation analysis (especially for advanced reactors), and reconsideration or modification of existing requirements for in-reactor material irradiation testing.

Additionally, decades of ion beam irradiation have proven it to be an extremely useful tool to enhance the understanding of radiation damage in materials for nuclear applications.

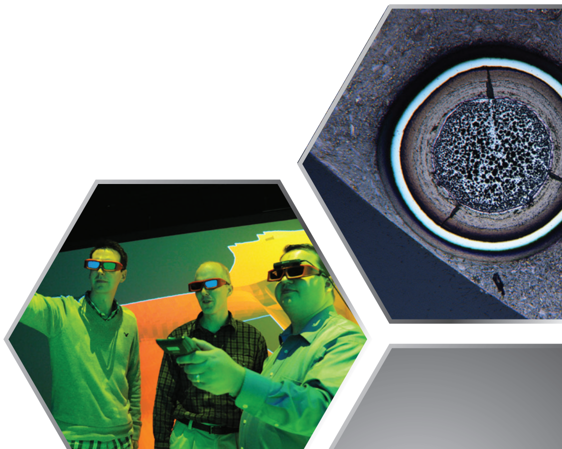
Inducing radiation damage utilizing ion beams in structural materials and fuels causes high displacement damage rates and therefore accelerates the research on the materials response under these conditions.

SIMULATION/EXPERIMENTATION

CHALLENGE: Accelerate utilization of simulation and experimentation.

HOW: *Integrate experimentation and simulation to enable the development of first principles predictive simulation capabilities that are necessary to transition nuclear energy system design and licensing from reliance on experiments to reliance on modeling and simulation.*

BACKGROUND: In the past half century, the nuclear energy industry and regulatory agency approach to nuclear system design and licensing has relied significantly on experimental testing. This conventional paradigm embraces conservative design principles and has ensured nuclear safety, but at the cost of extensive experiments required by the current licensing process to validate modeling and simulation tools currently in use for core design. Additionally, the lengthy and complex software quality assurance process required by the licensing authority prevents many from using newly-available models or tools, thus further delaying the use of new



simulation tools that are closer to a true predictive capability. These two issues combined deter licensing authorities from trusting the predictive capabilities of software and increases the reliance on new experiments.

The challenge thus becomes to develop and improve versatile predictive simulation capabilities that can easily integrate new models without a lengthy re-qualification process, while designing and developing a set of broad, challenging, and well-instrumented experiments that can clearly demonstrate the predictive capability of the new simulation tools and identify the areas in which the tools need improvement. Significant computational challenges exist in quantifying the impact of uncertainties on nuclear reactor performance in a multiphysics context.

Software development standards have increased significantly over the years, but the quality assurance process remains uneven. Legacy codes have been grandfathered into the licensing regime, while new codes require a significant quality assurance process, dissuading attempts to integrate advancements. At the same time, experiments have become so cost-prohibitive that laboratories and industry rely on old experiments that often lack the detail and precision needed to validate advanced first principles simulation capabilities.

Addressing this challenge requires a greater trust in first principles modeling and simulation capabilities and the definition of simpler guidelines in the development of quality-assured software. Additionally, high-fidelity software should be used to design a set of broad critical experiments in order to gain support in the construction of such facilities. A new paradigm that closely integrates these experiments and predictive simulations for the design and licensing process is needed.

EXPEDITE LICENSING

CHALLENGE: Expedite licensing and deployment of advanced reactor designs.

HOW: *Expedite the development and deployment of advanced reactor concepts by developing a practical path forward for applying innovative approaches to licensing inventive advanced reactor designs that reduces the regulatory burden while still ensuring safety. The regulatory system needs to meet the pace of commerce.*

BACKGROUND: Eliminating the difficulties facing the licensing and construction of new nuclear power plants would bring great benefits. These issues are associated with both evolutionary reactor construction as well as the construction of advanced reactor concepts. Other industries, such as the transportation or pharmaceutical industries, have achieved what appears to be a better balance between allowing for growth and innovation while maintaining safety standards. In the early years, nuclear power plant construction was done quickly, and if it could be done so again this could have a major impact on the feasibility, attractiveness, and profitability of a project. Additionally, siting and supply chain and vendor interactions can be some of the most expensive and potentially time-intensive aspects of a construction project. Without improvement, future nuclear power plant construction will remain unattractive as an investement.

Institutional difficulties associated with obtaining design certification for novel reactor technologies could be avoided by first constructing and operating a prototype plant that has sufficient extra margin and safety features to justify near-term Nuclear Regulatory Commission (NRC) approval for prototype construction and testing. This process is explicitly contemplated in 10 CFR 50.43 e(2), but is seldom or never used. Such a process could be carried out with the expectation that the results of testing and operation of a prototype plant would support subsequent expeditious certification of a viable commercial (as opposed to prototype) design.

The default path of direct design certification for a commercial design by analysis and scaled-down test facilities has proven to be extremely lengthy, even for Generation 2 plants, for which Part 50 safety requirements already exist. For other technologies lacking a current Part 50 equivalent, design certification within the traditional paradigm looks even more difficult. The proposed license-by-prototype approach would be loosely analogous to the lead test assembly approaches now used for new Light Water Reactor (LWR) fuel designs.

Data emerging from special surveillance and testing performed over many years in the first reactor module or modules would support the safety case for all subsequent reactor modules. Safety analysis for early testing in the lead reactor modules would credit the larger safety margins that exist during early operation.

KNOWLEDGE TRANSFER

CHALLENGE: Expedite nuclear education updates and knowledge transfer.

HOW: *Expedite updates to the higher education Nuclear Engineering curriculum to better match today's needs. It must include the cross-disciplinary nature of today's research and the business and communications skills needed for an entrepreneurial path, while improving the transfer of* *knowledge and expertise in nuclear science and technology from the current generation to future generations.*

BACKGROUND: The nuclear workforce is aging, and the current university Nuclear Engineering curriculum needs to be updated. The average age of nuclear scientists and engineers in the nuclear energy industry, national laboratories, and universities is over 50. These professionals have a wealth of knowledge that is not necessarily written in books. As these workers leave the workforce, much of that knowledge is being lost.

Effective means to transfer that knowledge to the newest group of scientists and engineers needs to be developed and implemented. Additionally, the Nuclear Engineering curriculum in U.S. universities stands essentially unchanged over the past 20-plus years. With the advent of new reactor designs and the challenges within materials science to meet the needs of these new designs, the curriculum structure must be reviewed and updated to better meet the needs of industry, suppliers, and research organizations. Inclusion of courses in advanced reactor design, small reactor design and operation, and materials science may need to be included. If we do not know our history, we are doomed to repeat our predecessors' mistakes.

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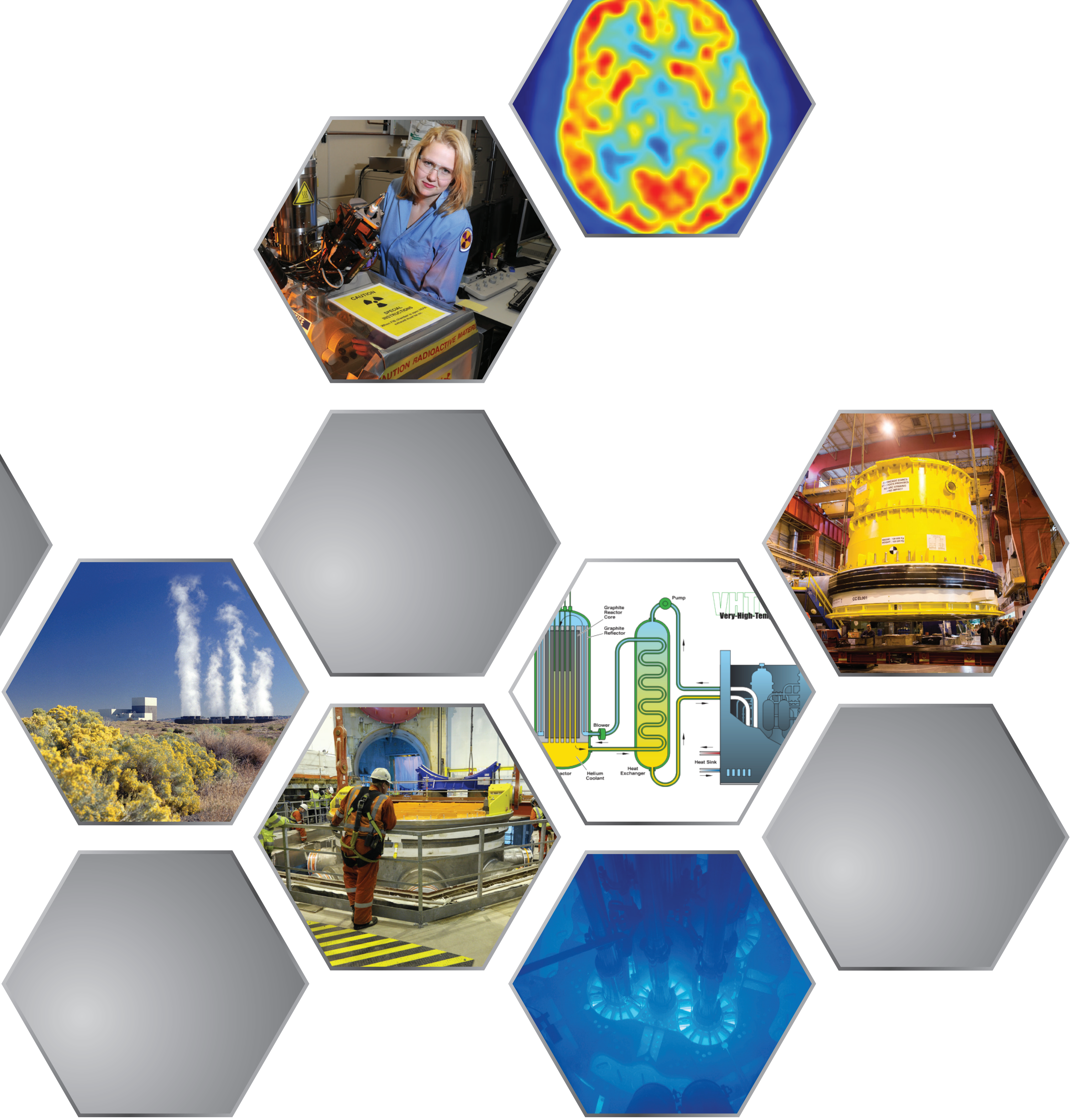
1 PET image, Wikimedia Commons
2 Materials & Fuels Complex Analytical Lab, Idaho National Laboratory
3 Columbia Generating Station - Unit 2, Energy Northwest
4 Flamanville-3 Nuclear Power Plant
5 Advanced Nuclear Reactor, Idaho National Laboratory
6 Very-High-Temperature Reactor, U.S. Department of Energy
7 Reactor Vessel Head, Tihang Nuclear Power Station
8 Alvin W. Vogtle Electric Generating Plant
9 Zion Station Fuel Pool
10 Underground Waste Containment Tanks, Handford Site
11 MOOSE simulation platform, Idaho National Laboratory
12 TRISO fuel particles, Idaho National Laboratory
13 Reactor Pressure Vessel, Flamanville Nuclear Power Plant



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