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FY16 Summary Report: Participation in the KOSINA Project

Fuel Cycle Research & Development

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Used Fuel Disposition Campaign
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Kevin McMahon, SNL K.M.McMahon 9/22/16

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SUMMARY

Salt formations represent a promising host for disposal of nuclear waste in the United States and Germany. Together, these countries provided fully developed safety cases for bedded salt and domal salt, respectively. Today, Germany and the United States find themselves in similar positions with respect to salt formations serving as repositories for heat-generating nuclear waste. German research centers are evaluating bedded and pillow salt formations to contrast with their previous safety case made for the Gorleben dome. Sandia National Laboratories is collaborating on this effort as an Associate Partner and this report summarizes that teamwork.

Sandia and German research groups have a long-standing cooperative approach to repository science, engineering, operations, safety assessment, testing, modeling and other elements comprising the basis for salt disposal. Germany and the United States hold annual bilateral workshops, which cover a spectrum of issues surrounding the viability of salt formations. Notably, recent efforts include development of a database for features, events, and processes applying broadly and generically to bedded and domal salt. Another international teaming activity evaluates salt constitutive models, including hundreds of new experiments conducted on bedded salt from the Waste Isolation Pilot Plant. These extensive collaborations continue to build the scientific basis for salt disposal.

Repository deliberations in the United States are revisiting bedded and domal salt for housing a nuclear waste repository. By agreeing to collaborate with German peers, our nation stands to benefit by assurance of scientific position, exchange of operational concepts, and approach to elements of the safety case, all reflecting cost and time efficiency.

ACKNOWLEDGMENTS

We are delighted with the organization and assembly of this report expertly delivered by Laura A. Connolly of Sandia National Laboratories. Kevin McMahon reviewed this report.

Sandia National Laboratories is grateful to numerous German colleagues for allowing us to participate in their examination of bedded salt for a high-level nuclear waste repository. Principal Investigators include: S. Fahland, J. Hammer. S. Heusermann, T. Kühnlenz, S. Mrugalla, and K. Reinhold from Bundesanstalt für Geowissenschaften und Rohstoffe (Federal Institute for Geosciences and Natural Resources); N. Bertrams, W. Bollingerfehr, S. Dörr, W. Filbert, and E. Simo from Deutsche Gesellschaft zum Bau und Betrieb von Endlagern für Abfallstoffe GmbH (The German Society for the Construction and Operation of Waste Repositories); D. Buhmann, J. Kindlein, J. Mönig, and J.Wolf from Gesellschaft für Anlagen- und Reaktorsicherheit GmbH (Society for Plant and Reactor Safety) and W. Minkley and T. Popp from Institut für Gebirgsmechanik GmbH (Institute for Geomechanics).

The German Federal Ministry for Economic Affairs and Energy has been a strong supporter of collaborations between Germany and the United States, and we are thankful for inclusive leadership provided by M. Bühler and W. Steininger on the subject matter of this report.

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ACRONYMS

BGR	Bundesanstalt für Geowissenschaften und Rohstoffe (Federal Institute for Geosciences and Natural Resources)
BMWi	Federal Ministry for Economic Affairs and Energy (Germany)
DBE TEC	Deutsche Gesellschaft zum Bau und Betrieb von Endlagern für Abfallstoffe GmbH (The German Society for the construction and operation of waste repositories)
DOE	Department of Energy (US)
EIS	Environmental Impact Statement
ELSA	Project: Shaft Seals for HLW Repositories
GRS	Gesellschaft für Anlagen- und Reaktorsicherheit GmbH (Society for Plant and Reactor Safety)
HAW	High-Activity Waste
HLW	High-Level (Radioactive) Waste
IfG	Institut für Gebirgsmechanik GmbH (Institute for Geomechanics)
KOSINA	Konzeptentwicklung für ein generisches Endlager für wärmeentwickelnde Abfälle in flach lagernden Salzschichten in Deutschland sowie Entwicklung und Überprüfung eines Sicherheits- und Nachweiskonzeptes (Concept development for a generic final repository for heat-generating wastes in flat-bedded salt layers in Germany as well as development and examination of a safety and verification concept)
NE	Nuclear Energy
NEA	Nuclear Energy Agency
PTKA	Water Technology and Waste Management (Germany)
SNF	Spent Nuclear Fuel
UFD	Used Fuel Disposition (US DOE-NE)
US	United States
VSG	Vorläufige Sicherheitsanalyse für den Standort Gorleben (Preliminary Safety Analysis for the Gorleben Site)
WEIMOS	Weiterentwicklung und Qualifizierung der gebirgsmechanischen Modellierung für die HAW-Endlagerung im Steinsalz (Further Development and Qualification of the Rock Mechanical Modeling for the Final HLW Disposal in Rock Salt)
WIPP	Waste Isolation Pilot Plant

1. INTRODUCTION

In July 2013, Germany implemented the legal basis for a new site selection process for a high-level (radioactive) waste (HLW) repository. This *Site Selection Act* implements a science-based selection process for a HLW disposal site and requires a safety case to provide waste isolation over a one-million-year time horizon. The implementation process is overseen by a Repository Commission, which is tasked with 1) defining a site selection process, 2) defining site selection criteria, 3) developing methodology to compare the safety of repository systems in different host media, and 4) delivering a final report in June 2016. In the process of completing these tasks, the Repository Commission identified bedded salt as a host medium for which repository design and safety concepts were missing. Water Technology and Waste Management (PTKA, Germany) and the Federal Ministry for Economic Affairs and Energy (BMWi, Germany) launched a project called KOSINA on July 1, 2015 to address this knowledge gap. (KOSINA = Konzeptentwicklung für ein generisches Endlager für wärmeentwickelnde Abfälle in flach lagernden Salzschichten in Deutschland sowie Entwicklung und Überprüfung eines Sicherheits- und Nachweiskonzeptes, which translates to *concept development for a generic final repository for heat-generating wastes in flat-bedded salt layers in Germany as well as development and examination of a safety and verification concept*).

KOSINA advances a concept for a generic repository for heat-generating waste in German bedded salt, as well as reviews and adapts existing safety and safety demonstration concepts. KOSINA membership includes

- BGR – Bundesanstalt für Geowissenschaften und Rohstoffe (Federal Institute for Geosciences and Natural Resources)
- DBE TEC – Deutsche Gesellschaft zum Bau und Betrieb von Endlagern für Abfallstoffe GmbH (The German Society for the construction and operation of waste repositories)
- GRS – Gesellschaft für Anlagen- und Reaktorsicherheit GmbH (Society for Plant and Reactor Safety)
- IfG – Institut für Gebirgsmechanik GmbH (Institute for Geomechanics)
- Sandia – Sandia National Laboratories (Associate Partner)

The project has a fixed performance period from July 1, 2015 until February 28, 2018. Eight packages describe the work. All KOSINA partners share a planning package as well as responsibility for final reporting. Lead responsibility is divided among remaining technical packages. Sandia National Laboratories joined KOSINA as an Associate Partner in late March 2016 by virtue of a letter commitment. (See Appendix A.)

Germany did not previously consider bedded salt formations for HLW disposal even though bedded salt hosts underground hazardous waste disposal facilities. Therefore, the KOSINA project was addressed in BMWi's new research concept as an important issue to improve knowledge and perform investigations that clarify conceptual questions and to contribute to the technical-scientific basis for the safety-oriented evaluation of potential repository systems in host rocks available in Germany.

Since 1987, nuclear waste disposal in the United States (US) has concentrated on bedded salt while similar efforts in Germany emphasized geologic domal salt. The US is once again considering possible repository choices and therefore has parallel interests in relevant

differentiating characteristics of bedded and domal salt. In Germany and the US, rock salt remains one of the potential host rock formations. Consistent and close collaborations between German repository scientists and US peers have generated agreement that common goals of salt repository in bedded or domal salt provide an excellent opportunity for both countries. Each country has advanced salt repository science and engineering developed and applied over several decades for the specific purpose of providing the necessary expertise for developing a safety case for salt disposal. The KOSINA mission builds upon and uses this expertise.

2. KOSINA

2.1 Overview and Context of the KOSINA Project

The KOSINA project focuses on the analysis of integrity of the geological barrier for generic locations in bedded salt and salt pillows by means of geomechanical model calculations. Salt domes are distributed mainly in northwestern Germany; whereas central Germany contains flat or bedded salt formations and parts of northeast Germany contain salt pillow structures. The latter geologic formations are called bedded salt generically and have extensive lateral dimensions. The KOSINA research and development project advances a disposal concept and safety case development of a generic repository for heat-generating waste in such flat-lying salt formations in Germany.

Bedded salt formations differ from domal salt structures in many ways, of which lateral extent and vertical thickness are two of the most obvious geometric considerations. Hansen et al. (2016) provide a summary of differences between bedded and domal salt pertaining to disposal of heat-generating nuclear waste. Bedded salt repository concepts have not been developed for heat-generating radioactive waste and spent fuel in Germany; however, these efforts embody many scientific intersections with the Waste Isolation Pilot Plant (WIPP) repository in the US. The WIPP site in New Mexico has been an operating repository for long-lived transuranic waste of military origin. The facility resides at 650m depth in the bedded Salado Formation.

Long-term safety records and operational issues also profit from extensive experience accumulated from storage of chemical and toxic waste in flat-lying salt formations in Germany. This experience does not include the influence of heat and therefore KOSINA undertakes a mission specifically addressing heat-generating waste disposal in bedded salt.

German salt programs developed a reference concept for disposal of heat-generating radioactive waste and spent fuel in a salt formation. This concept places self-shielded POLLUX® containers on the floor of excavations in domal salt and reprocessed waste canisters in vertical holes. Germany has advanced a preliminary safety analysis for the Gorleben site (Vorläufige Sicherheitsanalyse für den Standort Gorleben or VSG. Among multiple considerations, design of geotechnical barriers (plugs and seals) was developed accompanied by assembly of a substantial technical database applied to the analyses. Here again we acknowledge an existing salt repository database comprising noteworthy background information applicable to a repository in flat-lying formations.

2.2 KOSINA Work Program Structure

KOSINA is set within a political context. The German Site Selection Act provided the legal basis for a new site selection process. A methodical approach outlined requirements for generic repository concepts in potential host rock formations of salt, clay and crystalline rock. Germany

developed a preliminary safety case, VSG, for domal salt. Clay and crystalline concepts and demonstrations are in progress, as well. Similar need for advancements in bedded salt gave rise to KOSINA. The major objective of KOSINA concerns development of a technical site-independent concept for a repository for heat generating waste and spent fuel on the basis of generic geologic models for bedded salt including a safety demonstration concept. Overarching goals comprise a generic model with parameters, a safety demonstration concept, technical repository designs, and demonstration of geomechanical integrity.

To achieve the major objective, the work program is broken into eight packages:

WP 1: Compilation of basic planning data and requirements (all)

WP2: Development of generic geologic models and derivation of model parameters (BGR and IfG)

WP3: Development of safety / safety demonstration concepts (GRS)

WP4: Analysis of geo-mechanical integrity (BGR und IfG)

WP5: Development of repository designs for 4 variants (DBE TEC)

WP6: Analysis of radiological consequences (GRS)

WP7: Evaluation of operational safety (DBE TEC)

WP8: Synthesis report (all)

The lead agency for each package is identified in parentheses.

3. US/German Interactions

Similarity between the goals of the German Site Selection Act and goals of the US Department of Energy, Nuclear Energy (DOE-NE) used fuel work packages identify several areas for potential collaboration. Structurally, KOSINA work packages could have potential overlap with DOE-Managed SNF/HLW Research (also referred to as defense repository). This is due to several factors, including the work scopes of work packages, the focus on generic repository design in various host media (crystalline, salt, and argillite), and maturity of the work package relative to KOSINA. The defense repository program is formulating relatively new work packages, which can benefit from ongoing, well-defined, collaborative activities.

3.1 Information Exchange in Hannover

Between March 14 and March 23, 2016 Frank Hansen, Ed Matteo, Courtney Herrick and Charles Choens held extensive technical interactions with several German research entities. Discussions ranged over a wide swath of subjects, with KOSINA playing a key role. Only one traveler (Matteo) was supported by DOE-NE funding. The other travelers received support from DOE, Environmental Management and Sandia internal funding. The BGR was the primary host. In addition to kicking off collaboration in the KOSINA project, the group participated in the Nuclear Energy Agency (NEA) Salt Club meeting, identified capabilities and research of mutual advantage, and perhaps most importantly, introduced early-career US repository researchers to many German peers.

On behalf of the DOE, Sandia participates in three major collaborations with German salt researchers:

1. US/German Workshop on Salt Repository Research, Design and Operation (Sandia 2016),
2. Joint Project WEIMOS (Weiterentwicklung und Qualifizierung der gebirgsmechanischen Modellierung für die HAW-Endlagerung im Steinsalz (Further Development and Qualification of the Rock Mechanical Modeling for the Final HLW Disposal in Rock Salt)) on benchmark modeling of WIPP Rooms B&D, and
3. KOSINA (developing).

Below is a day-by-day summary of the meetings that transpired:

March 16: KOSINA: Partners DBE, BGR, IfG, GRS, PTKA, and Sandia. A summary of the interim report (Fahland et al. 2016) provided a project status. Institutional leads presented status and detail of work packages. At this time, Sandia committed to send a letter of intent to participate in KOSINA and identify those areas most promising (see Appendix A).

March 17: Presentations by Sandia regarding Defense Repository program from which collaboration areas are being defined. US programs are beginning separate repository studies for defense waste, which will include bedded and domal salt. Additional presentations of WIPP closure systems emphasized performance of reconsolidated crushed salt. BGR staff reviewed and demonstrated laboratory capabilities.

March 18: Presentations and discussions of geomechanical and numerical modeling focused on Morsleben and Gorleben site investigations. Investigations of clay as a repository candidate formation were discussed. BGR presented a review of the Site-Selection Act and the Repository Commission progress.

March 21: Status of characterization of Backfill and Sealing of Underground Repositories for Radioactive Waste in Salt (BAMBUS) reconsolidated salt was presented by IfG and Sandia (Hansen 2016). Additional discussion examined backfilling and closure issues and research. Discussion in the afternoon centered on salt percolation. Note: Percolation was included in the 7th US/German workshop held in Washington, DC. (Sandia 2016).

WIPP issues dominated the remainder of the day, including recovery to operational readiness, laboratory investigations of damage and healing, creep at low deviatoric stress, and tensile/extensile response. Note: On July 21, 2016, approximately 4500 pounds of 12-inch diameter WIPP salt arrived at IfG to commence this testing. German research laboratories are performing these experiments at no cost to the US DOE as part of the Joint Project WEIMOS.

March 22: Collaborators meeting in Hannover participated by video link in the NEA Salt Club meeting. BGR staff demonstrated large-scale repository visualization using 3-D geological models.

The principal benefits of the trip include: 1) Explicit description of Germany's approach to and strategies for generic repository design in salt, 2) Broad overview of experimental and modeling capabilities and resources within BGR and its affiliated organizations, and 3) Network connections to personnel and organizations responsible for various areas of repository research and development.

Upon return to the States, Sandia participants held a series of debrief meetings to communicate objectives of KOSINA to UFD leadership. This included briefings given to Senior Managers associated with UFD, the National Technical Director of UFD, and defense repository work

package managers. The DREP work package managers held a brainstorming session and identified the most fruitful areas of collaboration.

3.2 Thermal Calculations

The 7th US/German Workshop on Salt Repository Research, Design and Operation held in Washington, DC. in early September 2016 provided an opportunity for German and US researchers associated with KOSINA to exchange information and share preliminary results. Both programs emphasize thermal analysis of emplaced waste packages and an example of similar calculations is provided below. Thermomechanical response of the disposal system will govern operational safety, determine waste package spacing, influence drift geometry and underground layout, affect sealing strategy, and ultimately define overall lateral extent of the repository. In addition, thermal analyses test other model parameter sensitivity, such as varying surface storage time before disposal, thermal conductivity of host media, engineered barrier system design elements, and thermal output per waste package for different waste types.

Figure 3-1 represents typical preliminary analysis results from the KOSINA Partners (Kühnlenz et al. 2016), while Figure 3-2 illustrates similar thermal analysis results from a defense repository investigations. The blue line (C') in Figure 3-1 denotes temperature profile in the waste-package horizon and other curves correspond to stratigraphic units. As one would expect, the highest peak temperatures occur in the disposal zone and adjacent units. A similar calculation performed by Sandia (Matteo et al. 2016) plots thermal projections of waste package surface for several different waste types in Figure 3-2. Parameter variations allow sensitivity studies of storage time, buffer conductivity, and waste types with different thermal decay rates. Wastes forms captured in calculations pictured in Figure 3-2 include HLW from Savannah River and Hanford. The HLW glasses, plus defense-related spent nuclear fuel (SNF), calcine waste at Idaho National Laboratory, and the cesium-strontium capsules, comprise >95% of the total defense-related waste that would be emplaced in a defense repository (DOE 2014).

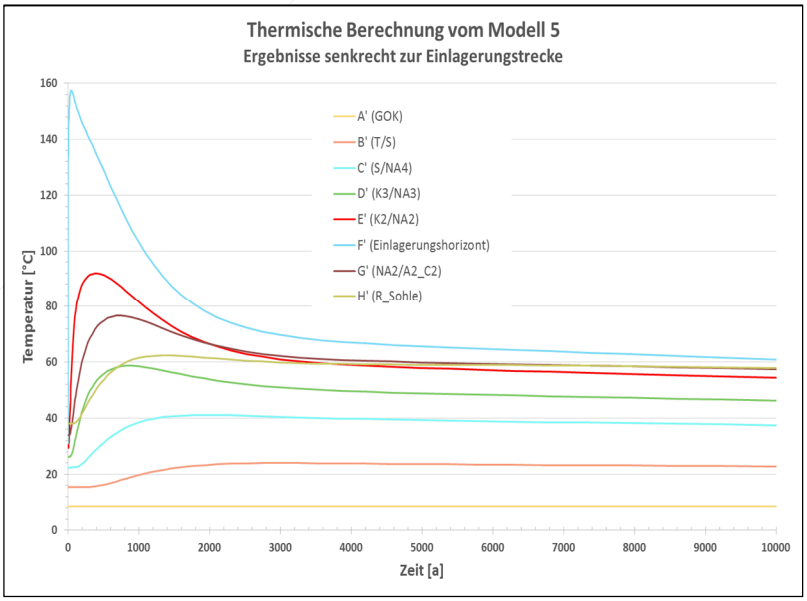

Figure 3-1. Thermal profile for differing horizons in salt disposal stratigraphy.

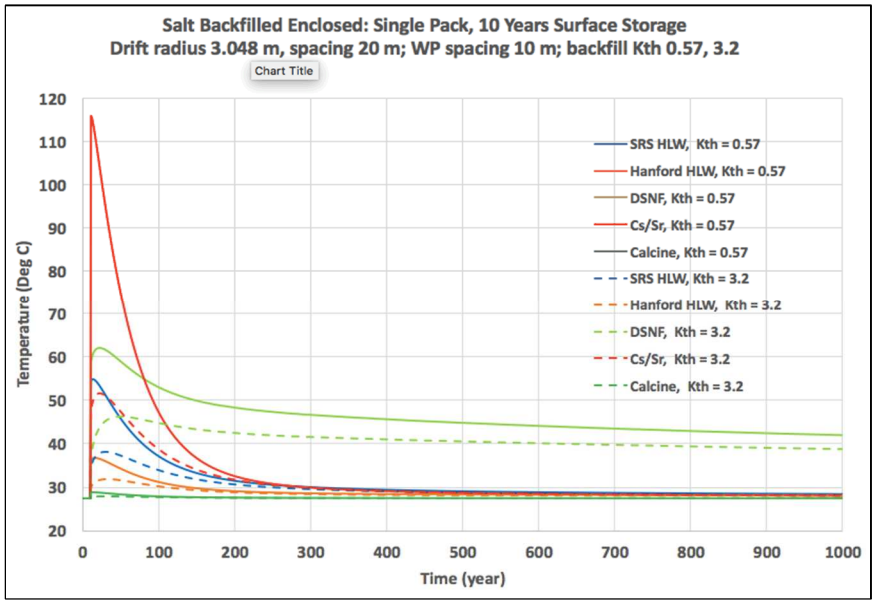

Figure 3-2. Thermal profile example calculation for defense repository.

These datasets exemplify commonality of a class of analyses applicable to generic salt repositories. As with other collaborations, such as thermomechanical benchmarking, thermal conductivity, radioactive decay, and temperature evolution illuminate other common technical pursuits. Since each program uses different computational and numerical methodologies to conduct thermal analysis, a benchmarking exercise would provide insight to the validity and/or applicability of each approach. Since US and German programs are in generic repository design mode, this type of collaboration is well timed to help inform repository design elements.

As the plan for continuing US/German collaboration on KOSINA takes form, short-term, direct collaboration is vital to initiate exchange and build momentum. More broadly, steps for drafting a project plan include: 1) identifying areas where programmatic and technical overlap exists between DOE-Managed SNF and HLW Work Packages and KOSINA, 2) coordinating interfaces between the institutions, 3) drafting a plan that outlines goals and deliverables, and 4) arranging logistics to reach goals and milestones. Initial goals (1 and 2) have been realized through technical and social exchanges between US and German researchers at the March 2016 meeting in Hannover and the September 2016 US/German workshop in Washington, DC. Furtherance of collaborations requires careful consideration in terms of events, schedule, budget and scope. An important aspect of the initial planning phase will be to find existing collaborative vehicles, such as WEIMOS, Full-Scale Demonstration of Plugs and Seals, US/German workshops, and NEA Salt Club, to help streamline meeting logistics or otherwise facilitate US-KOSINA collaboration.

4. SUMMARY

The KOSINA Project is about halfway through its intended period of performance, which ends in February 28, 2018. German resources derive from several lead agencies representing national repository expertise. The work-scope breakdown describes essential elements of a safety case for a generic repository. Experience going through a process such as this with renowned experts is invaluable to Sandia staff.

KOSINA parallels the German VSG effort and represents a second iteration of safety assessment. This program defines not only scope of various elements, it provides a

comprehensive answer to the enduring *how much is enough* question. Similar generic programs in the United States can gauge their own geologic repository programs from KOSINA research and publications.

KOSINA partners meet approximately monthly. It would be impractical for Sandia to place staff members at each meeting. Therefore, participation by Sandia needs careful orchestration. In addition to KOSINA, Sandia National Laboratories participates with German researchers on the WEIMOS Joint Project. Combining meetings of WEIMOS and KOSINA near the same time and place in Germany would optimize Sandia/Department of Energy return on investment. Such occasions could facilitate face-to-face interactions between early-career staff and international peers dedicated to similar research programs. In the end, our programs gain vital information regarding the status of repository science and engineering, as well as affirm that our national programs are consistent with international repository science.

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Appendix A

Sandia National Laboratories
Operated for the U.S. Department of Energy by
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To: Michael Bühler, Karlsruhe Institute of Technology
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From: F. Hansen, Senior Scientist 6930
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Subject: Intent by Sandia to Participate in the KOSINA Project

German salt repository experts are undertaking a project called KOSINA, which is of great interest to repository programs in the United States. This letter expresses the intent of Sandia National Laboratories to participate in the KOSINA project to the extent practicable. Participation by Sandia is predicated on acceptance of this proposal by German partners and will be undertaken by Sandia Laboratories within budget constraints of their existing repository investigations.

The KOSINA project is considering bedded salt formations for heat-generating nuclear waste disposal. As this program advances, activities described in various work packages will compare many safety case facets of bedded salt to those for domal salt. US repository programs are moving in a similar direction, considering differences and similarities of bedded and domal salt as they pertain to nuclear waste disposal.

Representatives of Sandia Labs participated in the most recent KOSINA meeting in Hanover Germany on March 16, 2016. Work Packages were described for the following efforts:

- WP1: Data basis and waste characterization.
- WP2/4: Generic geologic models, parameters and numerical modeling.
- WP3: Safety demonstration concept.
- WP5: Disposal concepts.

Several areas of common interest were identified, such as generic model representation; application of a FEPs universal database; and possible comparison of KOSINA models with Sandia's PFLOTRAN simulations.

As with several previous partnerships, we expect the KOSINA project to advance both US and German programs technically, while engendering societal and regulatory credibility. Sandia is fortunate to collaborate with recognized world leaders on matters vital to our respective nations.

Exceptional Service in the National Interest