ROBOTICS AND INTELLIGENT MACHINES IN THE U.S. DEPARTMENT OF ENERGY

COMMON QUESTIONS AND ANSWERS

1. Q – What is the DOE Robotics and Intelligent Machines (RIM) Initiative?
A – The RIM Initiative is a $45 million, FY01 R&D program within the U.S. Department of Energy (DOE), sponsored by the Offices of Defense Programs, Environmental Management and Science. Its primary objective is to accelerate the rate at which these and other DOE Program Offices will meet their mission objectives. In many instances, robotics technology offers DOE Program Offices the only sufficiently safe, cost-effective, and/or accurate means to achieve their goals. More specifically, the RIM Initiative has as its goal assisting DOE to:

- **Protect worker health and safety.** DOE intends to remove workers from the dangers of radioactive, explosive, toxic, and other hazardous materials. RIM is an obvious, and in some instances the only means to accomplish this. For example, one such goal identified in the *Robotics and Intelligent Machines Roadmap*[1] developed in 1998, is to reduce personnel exposure to hazards by 50% by 2002

- **Reduce costs.** The capabilities of RIM have the potential to advance so rapidly that initial capital costs of the systems will be easily compensated for by a decrease in operating costs. This will assist DOE to meet its manufacturing, monitoring, decontamination and decommissioning goals in the face of inflation and other budgetary pressures. As illustration, the *RIM Roadmap* identifies a goal of reducing the time and cost for refurbishment of appropriate stockpile hardware by 20% by 2004.

- **Improve product quality.** RIM provide DOE with the opportunity and the capability to eliminate many design- and production-related manufacturing defects. For example, the *RIM Roadmap* identifies the goal a reduce the occurrence of manufacturing defects in refurbished stockpile hardware to 50% of current levels by 2004.

- **Increase productivity.** While the remote systems of the past were characterized by slow, painstaking operations required to ensure safety, emerging RIM will offer improved safety while increasing efficiency and enabling much higher facility throughput. For example, the *RIM Roadmap* identifies basic research activities aimed toward revolutionizing intelligent machines concepts and controls methodologies for manipulative tasks such that personnel needs and turnaround time are reduced by 80%.

Because RIM is not in itself a mission of the Department, the Initiative does not include within its scope the many other and often substantial efforts DOE currently supports (e.g., upgrading and operating robotics and intelligent machines at sites throughout the complex, or work for

[1] The *Robotics and Intelligent Machines in the U.S. Department of Energy: A Critical Technology Roadmap,* is available from the Intelligent Systems and Robotics Center at Sandia National Laboratories and is located on the Internet at www.sandia.gov/ISRC.

other Federal agencies). Nevertheless, these activities are important, and management of the RIM Initiative will incorporate information about them into an integrated multi-year plan.

2. Q – How will the RIM Initiative be funded?
A – Research and development supported by the Initiative will be funded with approximately $15 million in FY01 from each of three Offices within the DOE: Defense Programs, Environmental Management and Science. While the efforts proposed under the initiative will be managed as an integrated program, the funding of individual projects will fit within and follow each Office's preferred resource allocation processes.

3. Q - How will the RIM Initiative be Managed?
A – The RIM Initiative will be managed by a Core Management Group (CMG) of DOE PSO representatives, reporting individually to their own PSOs, but collectively to the DOE R&D Council. Those PSOs directly funding the RIM Initiative (currently DP, EM and SC) will be responsible for managing their projects under the Initiative, and for providing the CMG with plans for proposed R&D as well as information on the status of other RIM-related efforts within their purview. Non-funding PSOs will also be asked to provide information on their needs and activities related to RIM. The R&D Council will be responsible for reviewing the progress of the initiative and for communicating its accomplishments to the Secretary and Undersecretary of Energy. The Core Management Group will also draw on information and support from non-DOE entities and advisors, as well as from the DOE Laboratories, plants and sites.

4. Q - Why does the Department of Energy Need a RIM Initiative Now?
A– Today, DOE faces a number of overarching challenges. It must:

- Remove its workers from almost all hazardous environments to meet the pressure of rising regulatory standards;
- Lower the cost of its operations in the face of inflationary and other pressures on its budget;
- Reduce the environmental impact of its operations; and
- Find the means to perform operations that are necessary, yet too hazardous for humans to perform, and for which no alternatives are currently available.

During the development of the *RIM Roadmap*, it was determined that RIM could assist the Department by reducing costs in manufacturing and in site clean-up, improving worker safety, improving the monitoring and surveillance of special nuclear materials, and by reducing the environmental impact of its operations while making a significant contribution to the science and technology base supporting the country's robotics and intelligent machines capabilities.

Robots would seem a reasonable way to approach these challenges. However, DOE's efforts in the late 80's and early 90's to apply robotics and intelligent machines (RIM) technology to its operations were met with mixed success—they were a technology before their time. As a result, the DOE launched smaller-scale efforts in the 1990s, first to develop a focused, needs-based, science and technology foundation for RIM, and then to deploy that emerging RIM S&T into systems operating at the DOE's plants. This approach, with its emphasis on continuity and integration from *research* to *development* to *application and deployment*, is proving successful. In the last several years systems have begun continuous successful operation, performing tasks that could not have been done by any means other than RIM, human or mechanical. For example, explosive disassembly at the DOE's Pantex plant is now handled by robots.

Furthermore, in recent years members of DOE's RIM R&D community have received six R&D 100 awards and more than 35 patents.[2] Finally, as a derivative of the work they have done for DOE, these scientists and engineers have successfully formed numerous agreements to work for other Federal agencies as well as more than 40 Cooperative Research and Development Agreements with industry.

5. Q - What Is the Federal Role (as Opposed to the Private Sector Role) in This Initiative?
A – Because of the breadth of the RIM initiative, it is imperative that there be awareness and use of the R&D conducted in other agencies when appropriate. To this end, in 1995, a MOU was signed between the Robotic Industries Association and the IEEE Robotics and Automation Society with the express intent of integrating needs for robotics with the related R&D. A committee – the Robotics and Intelligent Machines Cooperative Council (RIMCC) – was formed to carry out the intent of the MOU, and has representatives from industry, academia, and the Federal agencies. This group is chaired by a technical manager from Sandia National Laboratories, and continues to provide a broad forum for integration. In addition to the RIMCC, there is already significant cross-fertilization of activities. As examples, the DoD is using DOE technologies as it explores the demilitarization of it millions of tons of conventional munitions. And DOE laboratories are supporting DARPA with mobile robot technology as it carries out R&D for the future battlefield. There are additional interactions with the DoD as well as NASA, NIST, and NSF.

6. Q - How Does the RIM Initiative Relate to Work Being Done by Industry, Universities, and Other Federal Agencies?
A – As a general statement, industrial equipment, whether off-the-shelf or built-to-specification by industry will be used by the initiative. Use of the off-the-shelf equipment was part of the successful approach of the mid-90s. Because of the environments in which hardware must operate for DOE – radioactivity, explosives, corrosives, etc. – built-to-specification equipment is often required. However, standard industrial equipment, whether off-the-shelf or built-to-specification, does not provide the flexibility needed to achieve the cost reductions, improvements in worker safety, and so on, which are the objectives of the initiative. In manufacturing parlance, DOE's operations are almost all one-of-a-kind or small lot operations. This is obviously true for DOE's manufacturing and materials handling, and is also true for its site clean-up operations. Targeted research to give robots the capability to be cost effective in small lot operations was a key enabler in the successful deployments of the mid-90's, and is the basis for the science and technology portion of this initiative.

Industry will carry out most of the deployment of the technology developed. Industry will supply almost all of the hardware – robots, computers, and sensors – that is deployed. All of the science and technology developed by this initiative will be transferred to industry by mechanisms that are in place within the Federal government.

[2] A partial list of DOE sponsored RIM-related patents and R&D100 Awards is provided in Appendix A of *Robotics and Intelligent Machines in the U.S. Department of Energy: A Critical Technology Roadmap,* available from the Intelligent Systems and Robotics Center at Sandia National Laboratories and located on the internet at www.sandia.gov/ISRC.

Some of the most fundamental work has been done at the universities, and those researchers will be an important part of the research done as the initiative targets it more toward environment and defense. However, there are areas such as cooperative robotics and programming environments for intelligent machines which are significantly under-researched, but which are needed if this is to fully achieve the desired benefits.

7. Q - What Are Specific, Quantifiable Benefits Over the Period of the Five Year Initiative?

A – The RIM Roadmap identified numerous functional objectives, RIM capabilities needed within specific timeframes. A summary list of these is provided in the table below.

PSO	FUNCTIONAL OBJECTIVES
Defense Programs	• Time and cost for refurbishment of appropriate stockpile hardware reduced by 50% • Worker exposure to hazards to 30% of current • Production defects reduced by 90%
Fissile Materials Disposition	• 75% reduction in exposure • 50% increase in operational throughput • 75% reduction in monitoring cost *These are examples. There are goals specific to different MD facilities.*
Nuclear Energy, Science and Technology	• Enable extreme environment operations/reduce risk at Chornobyl • Improve DOE reactor and commercial reactor operation • Reduce exposure (75%) and costs (50%) associated with maintenance of depleted UF_6 cylinders in storage
Nonproliferation and National Security	• Improve surveillance, accountability, and protection of domestic and international weapons-grade nuclear material
Environmental Management	• Personnel exposure reduced by 90% • Secondary waste reduced by 75% • Productivity increased by 300%
Science	• Inherently distributed missions in dynamic, uncertain environments • Sensor integration for distributed robot systems • Revolutionary collaborative research using remote and virtual systems • Intelligent machines concepts and controls methodologies for manipulative tasks • Predict safe life of welded structures • Energy resources exploration and ecological land control • Improved operation of SC strategic facilities to meet programmatic needs
Energy Efficiency and Renewable Energy	• Diffusion of manufacturing technology for renewable energy equipment • Diffusion of intelligent processes for resource efficiency/reduction of waste
Fossil Energy	• Technology diffusion, e.g., technologies for safety and productivity in extreme environments
Environment, Safety, and Health	• Worker health and safety

8. Q - Defense Programs Has the ADAPT Program and Is Now Adding Robotics and Intelligent Machines (RIM) To It. Why Wasn't RIM Included Before? Why Is Additional Money Needed For RIM?

A – RIM has always been part of ADAPT albeit at a lower level of importance and funding. Robotics has seemed like an obvious way to approach the objectives of lowering cost, reducing cycle time and reducing worker exposure to hazards. However, through the early 90s, Defense

Programs' efforts were met with mixed success largely because industrial robot technology works well for mass production but was not cost effective for DP's small lot operations. As a result small scale efforts were launched in the mid-90's to develop an appropriate science and technology base, and then to carefully deploy the S&T into operating systems within the DOE's plants. This *research to development to application* approach has met with significant success; for example, robots now handle material storage at Pantex. This and other successes in Defense Programs have led to the proposal for larger scale deployment of the approach and it was the organizing thought used to develop the Program Plan.

9. Q - EM has the Robotics Crosscutting Program (Rbx). How is the Robotics and Intelligent Machines (RIM) initiative connected to Rbx? What is the management structure that will ensure the appropriate connectivity?

A – The current focus of the DOE weapons complex cleanup by EM is based on the document entitled, "Accelerating Cleanup: Paths to Closure," which emphasizes closure of most smaller sites by 2006. Consequently, near-term deployment of innovative technologies which address the immediate needs of the end-user are pursued to meet this short-term goal. Coupled with government wide budgetary constraints, this technology development approach has left little room for early R&D in the area of RIM. Moreover, EM's current research portfolio in this area does not significantly further or impact the United States' technological position in RIM development.

EM's approach to R&D in robotics has been primarily through its Rbx. The program is responsible for the development of remote and automated systems that meet the near-term needs that its Focus Area customers have identified. Rbx has a product line structure aligned with four Focus Area customers, which addresses their near-term robotics technology needs. The Focus Areas are:

- Tanks Focus Area,
- Mixed Waste Focus Area,
- Deactivation and Decommissioning Focus Area, and
- Nuclear Material Focus Area.

The Rbx provides EM with a fully established program infrastructure that is able to function in a bi-directional capacity for RIM by:

- identifying long term, intractable RIM cleanup needs of the EM user community in conjunction with its Focus Area customers and
- managing the R&D cycle from early applied research through technology development and final deployment of RIM technology by the EM user.

In carrying out this R&D cycle, the Rbx will leverage RIM research by the Offices of Science and Defense Programs into the appropriate tech development stage while drawing on the resources of the national labs, academia, the private sector, and other government agencies.

10. Q - EM has a science program jointly administered with the Office of Science (SC). What will be the benefits to EM from the RIM funding proposed by SC?

A – The Environmental Management Science Program (EMSP) is funded by EM and administered in cooperation with SC. The EM Focus Areas, through the EMSP, identify the

long-term technology cleanup needs that historically have centered on core Focus Area problems, which has resulted in little to no robotics technology support.

The funding for RIM proposed by SC targets seminal RIM technologies that will set in motion a wide spectrum of breakthrough solutions. EM and SC will closely coordinate the basic RIM/SC science results to ensure its additive impact on the EM program. These solutions will map directly into EM projects under the six broad EM R&D areas of:

- Advanced Remote Handling;
- Advanced Waste and Task Environment Characterization;
- Remote Work System Mobility; Task-Driven Computer-Aided Engineering;
- Remote Operator-Machine Interface/Cooperation; and
- Remote Operations Simulation and Training.

11. Q - EM has the University Research Program for Robotics (URPR). What is its role in the RIM Initiative? How does the work done by URPR compare with the research being proposed by the Office of Science for the RIM initiative?

A – Historically, the URPR has provided R&D in the area of robotics with a focus primarily on near term environmental cleanup needs. Given the RIM/SC-proposed basic research, the URPR could extend its function, in those areas of expertise, to assist in the transition of key R&D products into the applied research area. Where appropriate, the URPR could also assist Rbx in the bridging of this research to Focus Area customers.

Q – The Office of Science is funding other robotics activities. How will they be connected to this activity?

A – Other Office of Science-funded robotics activities are facility or product oriented. The RIM basic research is intended to help them. Specific examples of basic research activities include cooperating robots, and research on programming environments for DOE's small lot operations.

Q - How are these activities differentiated from those at NSF?

A – The motivation for RIM is DOE missions, including energy, environment and defense. RIM science will support the DOE missions, as well as U.S. industry and society. NSF focuses mostly on industry and society. Both NSF and DOE fund basic research in robotics. NSF funds exclusively universities. DOE funds national laboratories and universities. Many of the leading researchers in robotics are at national laboratories (ORNL, Sandia, INEEL).

Q - What is the track record of previous SC-funded robotics research?

A – The SC-funded research has resulted in over 200 technical articles in the peer-reviewed literature, books, patents, and 3 R&D 100 awards. The work is very well cited, and DOE scientists are requested to participate in missions of national interest by other agencies, including NASA and DoD.

Q – Will universities participate in carrying out the RIM basic research activities?

A –Both universities and national laboratories will participate in RIM basic research. National laboratories will assume the leadership because of the track record of their previous work for the Department, the uniqueness of their laboratories, their understanding and involvement with DOE missions, and the cross-disciplinary synergy on a large scale needed to achieve revolutionary advances.