
ENCOURAGING INNOVATIVE HOMELAND SECURITY TECHNOLOGIES

TO: CHRISTINE HARTMANN-SIANTAR (LAWRENCE LIVERMORE NATIONAL LABORATORY)

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SUBJECT: ENCOURAGING INNOVATIVE HOMELAND SECURITY TECHNOLOGIES

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EXECUTIVE SUMMARY

The terrorist attacks of 9/11 have demonstrated the existence of a new threat to America's security. Terrorists may try to strike undefended cities with unconventional weapons; new technologies are needed to defend against these new threats. The national laboratories have traditionally been in the forefront of R&D for national security, with many past successes. However, traditional R&D practices may not be the most cost-effective method; and overall development costs are likely to be a factor that affects the ultimate production and deployment of these technologies.

The Lawrence Livermore National Laboratory has asked the Goldman School of Public Policy's (GSPP) Homeland Security Research Center to recommend strategies that promote the research, development, and deployment (RD&D) of innovative homeland security technologies.

We apply the analytical framework of innovation economics to three specific technologies: scanning cargo containers for hidden nuclear materials, detecting bioweapons in the environment, and measuring biological exposure to radiation (a "rad kit"). We find that a competitively supplied market for products using these technologies requires *open-source optimization*, where the national labs retain patent rights to their discoveries, purchase optimization research through competitive contract,

and release this information to producers with minimal restrictions. We recommend the following incentive institutions for each technology under analysis:

Table 1 Summary of Innovation Incentives

	Research	Design	Optimization	Production
Sole-Source License (Current Practice)	Grants	Grants	Sole-Source License	Sole-Source License
Cargo Screening	Grants	Grants, Competitive Contract	Competitive Contract	Open Source
Biosensors	Grants, Prizes	Competitive Contract	Competitive Contract	Open Source
Rad Kit	Grants, Open Source	Matching Contract	Matching Contract	Matching Contract

INTRODUCTION: NEW TECHNOLOGIES FOR NEW THREATS

The possibility that terrorists may utilize technologies of incredible destructive and/or disruptive power against the country requires new technologies to defend against these threats or, at the very least, mitigate the consequences of an attack. Of the many threats that have been defined, research groups at the Lawrence Livermore National Laboratory (LLNL) are interested in developing technologies to screen cargo for nuclear weapons material, assess exposure to radiation, and detect biological agents in the environment. Though existing incentives have produced valuable technologies in the past, strategies tailored to homeland security technologies may more optimally research, develop, and deploy these technologies.

Overcoming the shortcomings of the current system of incentives will require an integrated RD&D strategy comprising a system of incentives (grants, contracts, patents, prizes, etc.) to produce more innovative technologies. Consequently, LLNL has asked the Goldman School of Public Policy's (GSPP) Homeland Security Research Center to recommend strategies that promote the research, development, and deployment (RD&D) of innovative homeland security technologies. Recent work in the field of innovation economics offers an analytical framework by which the effects of various innovation incentives (grants, contracts, patents, prizes, etc.) can be analyzed and understood.¹

Utilizing these insights into innovation incentives and the underlying technological challenges, this analysis will recommend a system of incentives to encourage the development and deployment of innovative cargo screening systems, biosensors, and radiation dose assessment kits ("rad kit") with the goal of arriving at these innovations at the lowest possible cost to society.

¹ Scotchmer, Suzanne. Innovation and Incentives. Cambridge: Massachusetts Institute of Technology, 2004.

METHODOLOGY

It is often presupposed that intellectual property rights, such as patents, provide adequate incentives for the production of innovative technologies.² However, a single solution for every procurement problem does not exist. Instead, a procurement strategy must be finely tailored such that it offers an optimal mix of strengths and weaknesses to maximize the likelihood of achieving a stated innovation goal.³ Arriving at this procurement strategy requires:

- Understanding the relevant technical challenges and the characteristics that affect research, development, and deployment
- Understanding available innovation incentives and assessing their strengths and weaknesses
- Evaluating these incentives against a set of criteria and assessing the tradeoffs.

UNDERSTANDING TECHNOLOGICAL CHALLENGES

Understanding the characteristics of the RD&D process and the specific challenges that must be overcome is necessary to determine the choice of mechanisms to encourage innovative solutions. The following list models the RD&D process as a series of discrete, qualitatively different steps that must be accomplished to bring a technology to market:

- **Basic Research:** The objective of basic research is to gain more comprehensive knowledge or understanding of the subject under study without specific applications in mind. Basic research advances scientific knowledge, but frequently does not have specific immediate commercial objectives.

² Scotchmer, Suzanne. Innovation and Incentives. Cambridge: Massachusetts Institute of Technology, 2004.

³ Maurer, M. Stephen, The Right Tool(s): Designing Cost-Effective Strategies for Neglected Disease Research, Preliminary, February 28, 2005.

- **System Design:** Designing the system is the process of defining the interaction between the components of a system to perform a specified task. The primary goal of this stage is to provide “proof-of-concept” that demonstrates the technological feasibility of the system.
- **Commercial Optimization:** Optimizing the system for commercial viability requires designing a system that is effective in real world operating conditions under practical constraints (cost, reliability, mass production processes, etc.)
- **Production:** Production is the process of producing or assembling the product.
- **Purchase and Deployment:** Purchase and deployment is the process of selling and distributing products to customers.

ALTERNATIVES

The following innovation mechanisms are analyzed for each stage of the RD&D process identified above. A discussion of the strengths and limitations of these incentives is summarized in Table 2 and the interested reader can find a complete discussion of these mechanisms in Scotchmer.⁴

- **Patents:** are legal rights that exclude competitors from lawfully producing, using, or selling an innovation.
- **Contracts:** are a legally binding agreement between two parties that rewards researchers for the completion of a specified task.
- **Grants:** provides funding upfront in exchange for a researcher’s promise to carry out an approved project or activity.

⁴ Scotchmer, Suzanne. Innovation and Incentives. Cambridge: Massachusetts Institute of Technology, 2004.

- **Prizes:** are given to recognize and reward an entity for producing innovations.
- **Open Source:** are projects that are open to the public which draw on other projects that are freely available to the general public.

Table 2 Incentive Mechanism Matrix⁵

Type of Incentive	Advantages	Disadvantages	How it works	Best uses
Patents	<ul style="list-style-type: none"> Reward is tied to value – weak test of efficiency Information is disclosed publicly De-centralized. It gathers diffused ideas, value assessments and risk information. There is no need to negotiate with a sponsor. Risk are borne by individuals Concentrates costs among users 	<ul style="list-style-type: none"> Deadweight loss Duplicate Costs (Patent races) - It does not regulate entry into patent race, leading to too many entrants Poor allocation. It does prioritize the most effective innovator, or the best idea. Reward is not related to cost or effort of invention. So some ideas receive rewards that are too high and unneeded for innovation It leads to suboptimal innovation. (Since the rewards are only profits, which are less than the value of the innovation. 	<p>Patents provide the innovator the right to exclude and regulate competition. It provides them market power and the ability to set prices above marginal cost (near zero), allowing them to recoup costs and secure rewards.</p>	<p>Patents are best used when you want the individuals who use the invention to bear the cost, or when expertise and information about innovations are diffused.</p>
Grants	<ul style="list-style-type: none"> De-centralized. It gathers diffused ideas. It rewards the better ideas and, to an extent, the most efficient innovators Everyone is free to use the knowledge and apply it towards innovations. Eliminates Deadweight loss Good for Basic Research Useful to subsidize innovation were costs are lower than value but higher than potential profits 	<ul style="list-style-type: none"> Decision-making is centralized which sometimes fails to gather information about value and risk. Likelihood of cheating depends on innovators dependence on future grants and them having more than one idea. More centralized control over the funding. 	<p>Person with ideas present the idea and applies for a grant. The grant board, composed of experts in the field, decides to fund ideas. Future Grants depend on the innovator delivering on past grants.</p>	<p>Basic Research. It is also an effective means of addressing suboptimal innovation in the private sector (orphaned ideas).</p>
Prizes (Blue Sky)	<ul style="list-style-type: none"> Avoids Deadweight Loss Everyone is free to use the knowledge and apply it towards new innovations Innovation is de-centralized and driven by the individual. Co-opt innovation with dispersed benefits Gets closer to optimal innovation 	<ul style="list-style-type: none"> Potential of paying out too early, when there are better ideas around the corner. Need to measure or observe the value of the innovation. Less likely to fund innovations w/ concentrated benefits. Need an alternative buyer (or patent) if the prize is too small for the innovator. Duplicate costs. Poor allocation. The most effective inventor and the best idea does not always win out It is hard to allocate costs to the users of the good. No system to establish the value. 	<p>Inventors invent and take their innovations to a prize committee and, in essence, try to convince them to buy the innovation.</p>	<p>Useful means to eliminate deadweight loss, and not exclude customers. Prizes are usually better than patents if the innovations value is observable.</p>
Prizes (Targeted)	<ul style="list-style-type: none"> Avoids Deadweight Loss Everyone is free to use the knowledge and apply it towards new innovations Achieves goals Addresses problems of sub optimal innovation Requirements are contract-like 	<ul style="list-style-type: none"> Does not provide incentives for unexpected innovations. Less likely to fund innovations w/ concentrated benefits. Need an arbitrator. Greater Administrative costs. You have to set the specs and be able to verify them. Paying out too early. Better innovations around the corner. Duplicate Costs. It is hard to allocate cost to the users of the good. No system to establish the value. 	<p>The prize-giver specifies the goal and the criteria that have to be met to receive the prize. They review the innovation to see if they meet the requirements and grant the prize.</p>	<p>Very good when you have a goal and costs are lower than value but higher then potential profit. Good for basic research</p>
Contracts	<ul style="list-style-type: none"> Similar to targeted prizes, except that the innovator with the best ideas is selected ahead of time. It is also a useful way of spotting the effective innovators (those who meet goals). 	<ul style="list-style-type: none"> No duplicate costs. We need to be able to observe and verify value, costs, and specs. Moreover, a method is needed so companies reveal the net value of their ideas (true value and true costs). Less competition means a lower probability of success. 	<p>Same as above, except that there is a preliminary stage. The firms present their ideas, plans, and estimates, and then the prize giver decides who runs the innovation.</p>	<p>Good for applied research where costs are large (avoid duplicate costs) and value/results are measurable.</p>
Open Source	<ul style="list-style-type: none"> Avoids deadweight loss Everyone is free to use the knowledge Free-access model Discoveries are published and disclosed Accelerates progress Leverages small budgets where costs are huge 	<ul style="list-style-type: none"> A bigger reward may lead researchers to withhold intermediate progress The motive to publish can be an impediment to sharing Requires mutual disclosure to work most effectively 	<p>Researchers and academics publish or disclose their discoveries, making it available to be advanced and/or commercialized.</p>	<p>Good where market value is low and with little incentive for private investment. Good when additional researchers are needed to move discoveries forward faster.</p>

⁵ Based on Scotchmer, Suzanne. Innovation and Incentives. Cambridge: Massachusetts Institute of Technology, 2004. The initial draft of this document was graciously provided by Josh Bode, GSPP MPP 2005

CRITERIA

These alternatives discussed above are subjected to a number of criteria to judge their ability to produce the desired innovation. The social challenges that these innovation mechanisms must address form the basis of the following criteria:⁶

- **Efficient Procurement:** Efficiently procuring innovation requires that the costs of producing the innovation are kept as low as possible.
- **Efficient Access:** Efficient access allows others to make use of an innovation, ideally without restriction or usage fees. Intellectual property rights typically limits efficient access by excluding others from using the innovation.
- **Agency Problems with Sponsors:** The possibility that a sponsor may renege on a promise to reward a researcher will deter researchers from working on a problem. Such problems usually occur for incentives (such as contracts) that supply the reward upon completion of a task.
- **Agency Problems with Researchers:** Researchers may not fulfill their promises to sponsors. Such problems usually occur for incentives (such as grants) that supply the reward prior to the completion of the task.
- **Eliciting Information:** This criteria measure the ability of the institution to draw out information on innovative technologies or processes.
- **Feasibility:** The feasibility of a particular institution is based on a number of factors such as political, management, and financial issues that constrain the ability to pursue an alternative.

⁶ Maurer, M. Stephen, The Right Tool(s): Designing Cost-Effective Strategies for Neglected Disease Research, Preliminary, February 28, 2005.

RD&D STRATEGY

Recommendation: An open source design strategy is recommended if a sole-source licensing strategy is expected to result in a monopoly. However, a sole-source licensing strategy may be acceptable if competing technologies are expected.

Though somewhat counterintuitive, this analysis will first seek to understand the last stage of the RD&D process (purchase and deployment) as it has implications on upstream RD&D tasks. Once this “end-game” is understood, strategies to minimize overall RD&D costs are discussed. Formulating an overall RD&D strategy allows us to recommend technology-specific incentives that are required to achieve the recommended strategy.

PURCHASE AND DEPLOYMENT

Recommendation: The DHS should generate demand through regulation and rely on competitive market mechanisms to seek the lowest cost supplier.

Table 3 Purchase and Deployment Mechanisms

Incentives	Procurement	Access	Agency Problems w/ Sponsor	Agency Problems w/ Researcher	Eliciting Information
Government Purchase	Good	Poor	Poor	Poor	Poor
Monopoly	Poor	Poor	N/A	N/A	Poor
Competitive Market	Good	Good	N/A	N/A	Good

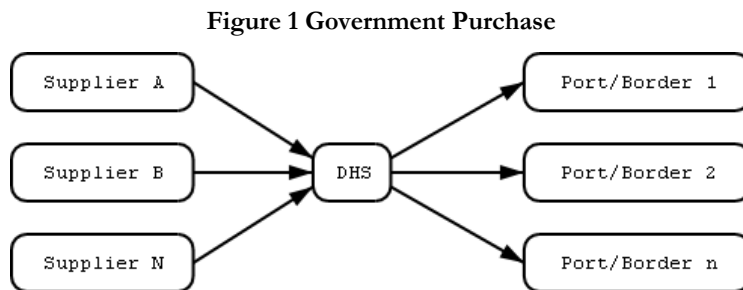
Though purchasing and deploying homeland security technologies is largely in the hands of the federal government (e.g. the Department of Homeland Security), the purchase and deployment process has implications on preceding stages of research and development that are important to understand. The following purchase and deployment mechanisms will be analyzed:

- **Government Purchase:** A government agency purchases technologies from supplier(s) for distribution to the ports and borders.
- **Markets:** Technologies are purchased directly from suppliers.

Before continuing, it is important to understand that the demand for homeland security technologies is expected to support a few and possibly many suppliers. However, the DHS must stimulate demand through regulation (e.g. mandating a technology standard, implementing and enforcing a performance standard, fines based on inspections and testing, etc.) since market forces are unlikely to generate demand for these systems. With such regulation and given the number of customers in the U.S. (ports and border crossings, first responders, cities, etc.), the demand for these devices and associated services is expected to be significant from domestic sources alone. Demand will expand significantly for cargo screening systems if the U.S. government seeks international cooperation to screen cargo before arrival at U.S. ports and borders.

Government Purchase

A government agency, e.g. the Department of Homeland Security (DHS), could purchase homeland security technologies from suppliers for distribution to customers, such as the ports and borders as shown in Figure 1.



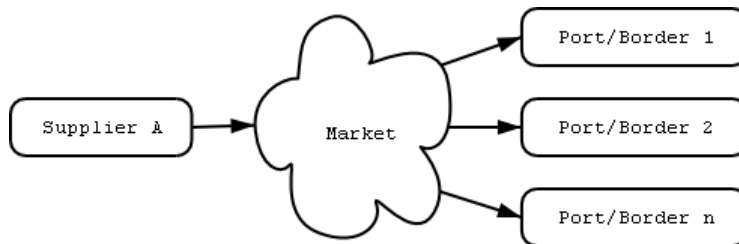
As the only customer in town, the government agency is a monopsonist and enjoys considerable market power – allowing it to set a price that equals the marginal cost of production. Though the marginal cost is the lowest possible price for each additional unit, a price this low would not cover the supplier’s fixed costs and would limit market entry. The government agency could mitigate this

problem by promising a reasonable rate of return to the suppliers, but such a strategy does not motivate firms to contain costs.

Markets

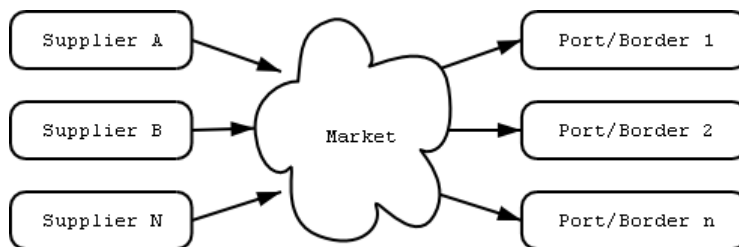
Purchasing technologies directly from suppliers avoids the problems associated with a government middleman. One must be careful to avoid the scenario depicted in Figure 2 where a single supplier supplies the entire market. The resulting monopoly allows the supplier to price the products well above the marginal cost of production.

Figure 2 Market with single supplier (monopoly)



Avoiding a monopoly requires that a number of suppliers produce similar products as diagrammed in Figure 3. This system reveals the lowest cost supplier as firms compete with one another for a share of the market.

Figure 3 Market with many suppliers (competitive) or few suppliers (oligopoly)



However, it is not clear whether many or only a few suppliers will emerge in response to the demand generated through regulation. Though the presence of many suppliers will lead to more competition,

the possibility an oligopolistic system, where only a few firms supply the market, is likely to be tolerable. An oligopolistic system may be competitive enough provided that the firms do not exercise market power. If this is indeed the case in the cargo screening market, a competitive oligopoly may even be desirable since firms can reinvest their modest profits to fund more research and development.⁷ As a result, a competitive system is recommended to reveal the lowest cost supplier.

STRATEGIES

Recommendation: An open source design strategy is recommended if a sole-source licensing strategy is expected to result in a monopoly. However, a sole-source licensing strategy may be acceptable if competing technologies are expected.

Table 4 RD&D Strategies

Strategy	Procurement	Access	Agency Problems w/ Sponsor	Agency Problems w/ Researcher	Eliciting Information	Feasibility
Sole-Source Licensing (Current Practice)	Poor to Good*	Good	N/A	N/A	Good	Good
Open Source Optimization	Good	Good	Moderate	Moderate	Good	Moderate
Open Source	Poor	Good	N/A	N/A	Good	Good
"Manhattan Project"	Poor	Good	N/A	N/A	Moderate	Moderate

* Depends on competition

The overall RD&D strategy should result in a competitively supplied market that reveals the lowest cost supplier and minimizes the total cost to society. The advantages and disadvantages of the following RD&D strategies are considered:

- **Sole-Source Licensing (Current Practice):** A single firm brings the system to market
- **Open Source Optimizaiton:** Obtain all necessary design information and open source this information such that any firm can produce the system.

⁷ Friedman, Lee. PP210B Lecture

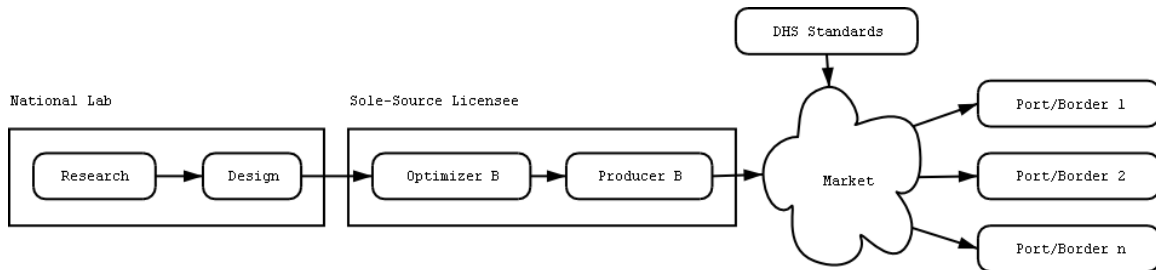
- **Open Source:** The lab releases all rights on the system and allows any interested party to bring the system to market.
- **“Manhattan Project”:** The lab carries out all tasks and brings the system to market.

Sole-Source Licensing (Current Practice)

Recommendation: A sole-source licensing strategy is recommended if the licensee will not have a monopoly on the active interrogation cargo screening market.

LLNL is currently pursuing a sole-source contract with General Electric (GE) to bring LLNL’s cargo screening technology to market.⁸ This results in the RD&D system diagrammed in Figure 4 where LLNL completes the research and design stages while licensing the remaining optimization and production tasks to GE.

Figure 4 Sole-Source Licensing



This strategy increases the cost of supply this technology since the licensee has a monopoly on the lab’s technology. Implementing a competitive process to select the licensee is unlikely to be effective since a monopolist would have little incentive to reveal its true costs once it has been selected. Though the lab could revoke the license if it believes the firm is setting prices too high, determining a fair price is difficult since the true costs of bringing the system to market are not well known by the lab.

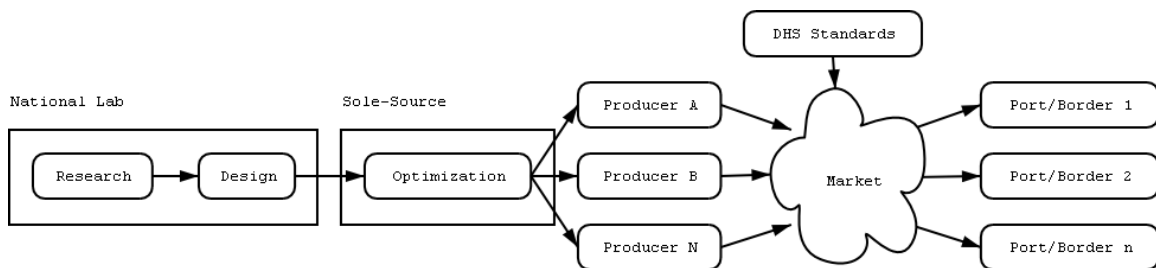
However, a monopoly on the lab’s technology may not lead to a monopoly on the entire cargo screening market if many firms supply comparable products. If this is indeed the case, the licensee will have a strong incentive to contain costs to be competitive. A sole-source licensing system has the added benefit of shifting the financial risk and management burden to the licensee.

Open Source Optimization

Recommendation: An open source optimization strategy is recommended if a monopoly is expected.

If a sole-source licensee is expected to have a monopoly on the entire cargo screening market either naturally or by a technology standard imposed by the DHS, an open source production strategy diagrammed in Figure 5 is likely to result in the competitive supply of the lab’s technology.

Figure 5 Open Source Optimization



This strategy requires that the lab complete the research and design processes followed by obtaining the necessary information on the optimized design. Open sourcing this optimization information allows any firm to produce the systems and the resulting competition between production firms reveals the lowest cost producer.

The key to this strategy requires that the lab retain intellectual property rights on the optimized design information. This requires the lab to compensate the optimizing firm for forgone profits that could have been earned by bringing the technology to market. However, one can minimize these

⁸ Hartmann-Siantar, Christine. Personal Interview. February 8, 2005

costs through another competitive selection process that reveals the lowest cost optimizer. Since optimization is a relatively routine process, a number of firms with existing capabilities may be interested in profiting by supplying this information. The risk of overpaying for this optimization information may be tolerable when one considers the risk of overpaying for products supplied by a monopolist.

Though such a system results in the duplication of fixed production costs, these fixed costs are not expected to be large since LLNL's system relies on "off-the-shelf" technologies that are not too capital intensive. Since many firms are capable of integrating existing "off-the-shelf" technologies using open source design information, one would not expect these fixed production costs to significantly affect the price - the relatively small set up costs would be averaged over many units. This observation is less likely to be true for more capital-intensive production processes.

This strategy will unfortunately shift much of the financial burden to the lab. By adopting this strategy, the lab must allocate more resources to acquire the optimization information and to manage the RD&D process. However, one must realize that the taxpayer is funding the entire RD&D process since the government funds research and will be purchasing the systems. Though it may be difficult for the lab to justify this new strategy, Congress should be indifferent to when it pays. For example, if one were to adopt a strategy of licensing the technology to a single source, the cost of optimization will be included in the final price of the system. And in comparison to this single-source licensee strategy, Congress should prefer an open source optimization strategy since it is expected to have lower costs to society by avoiding a monopoly.

This strategy also has the side affect of shifting the management burden to the lab. Successfully managing this process requires that the lab specify exactly what it wants from the optimizer such that all information necessary for production is provided. Though some amount of feedback between

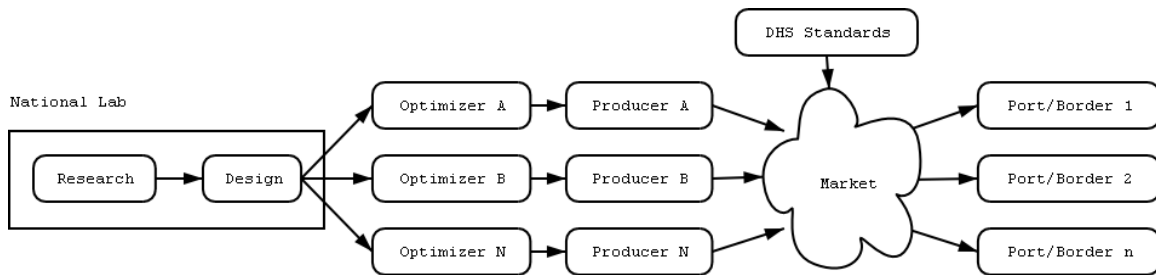
optimization and production is inevitable, minimizing this overlap is necessary to prevent the situation from degenerating into the single-source licensee strategy. The lab must also ensure that the optimizer does not tailor the optimized product to their production process to prevent the optimizer from gaining an advantage over other producers. Though this problem can never be completely eliminated, the optimizer is not expected to have a significant advantage over other producers due to the “off-the-shelf” nature of the components.

Open Source

Recommendation: An open source optimization strategy is not recommended due to the higher costs to society arising from the duplication of effort.

In this scheme, the lab releases its intellectual property rights on the system and allows any firm to use the information to bring the system to market as diagrammed in Figure 6.

Figure 6 Open Source



While competition between multiple firms will reveal the lowest cost supplier of the lab’s technology, the optimization and production stages will be duplicated. Since these tasks only need to occur once, this system will lead to higher costs to society as firms race to bring this technology to market. These redundant efforts are wasteful since these resources could be used to develop alternative technologies.

Furthermore, this process may degenerate into a monopoly since firms will patent the products derived from the lab’s design. The market power resulting from patent rights allows the firm to exclude competitors and set higher prices. This monopoly problem may be exacerbated if other firms are discouraged from entering the race once it is known that another firm has a head start on adopting the lab’s technology.

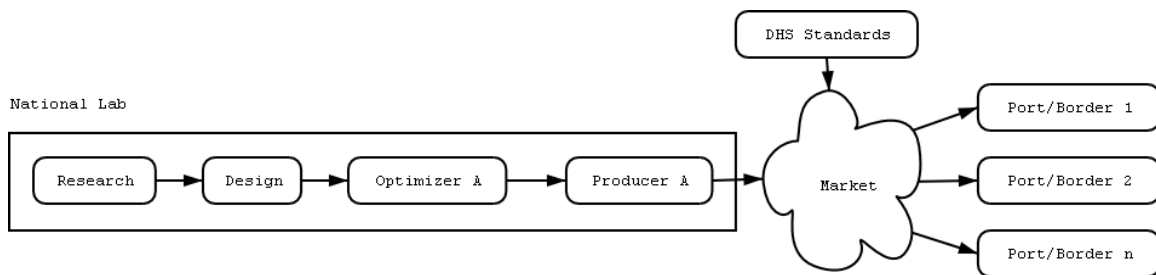
As an additional observation, the lab should continue patenting its research and system designs to prevent other firms from gaining monopoly rights on an existing design. In addition to limiting duplication, patents held by the lab have the added benefit of forcing firms to pursue other technologies and increase the diversity of systems on the market.

“Manhattan Project”

Recommendation: A “Manhattan Project” strategy is not recommended since the lab is poorly suited for optimization and production tasks.

Like the government effort to produce an atomic bomb, a “Manhattan Project” RD&D strategy tasks the lab with performing all stages of the RD&D process as shown in Figure 7.

Figure 7 Manhattan Project



Though the lab is a nonprofit entity and would supply the market at the marginal cost of production, this strategy is likely to result in overpriced products. Instead of taking advantage of existing facilities and capabilities, this strategy would require a significant investment by the lab to acquire the

necessary optimization and mass production capabilities. Furthermore, as a government entity, the lab does not have the same incentives or culture to contain costs like a private firm.

OUTLINE

The remaining sections of this report will recommend a set of technology-specific incentives designed to achieve the recommended strategies. Since the lab is familiar with its current strategy of pursuing a sole-source license, the following discussions will focus on the alternative strategy of Open Source Optimization for the following three technologies.

- Cargo Screening
- Biosensors
- Rad Kit

CARGO SCREENING

RECOMMENDATIONS

Table 5 Recommended Cargo Screening Incentives

	Research	Design	Optimization	Production
Sole-Source License (Current Practice)	Grants	Grants	Sole-Source License	Sole-Source License
Open Source Optimization	Grants	Grants, Competitive Contract	Competitive Contract	Open Source

IDENTIFYING THE THREAT

The use of even a crude nuclear device against the United States, though considered a low probability event, has unacceptable consequences that force the nation to counter this threat.⁹ One scenario postulates an adversary smuggling nuclear material (in a nuclear explosive or to be used in one) in a cargo container through a port or border crossing. This scenario necessitates a screening system so that cargo is the least attractive path by which a terrorist could smuggle nuclear material into the country.¹⁰

This is a daunting task. Given the ubiquity of radioactive materials and the ability to shield radiation, systems that passively scan for radiation emanating from cargo have difficulties detecting well-shielded special nuclear materials (SNM) and frequently cannot distinguish SNM from innocuous items.¹¹ Reducing this false positive rate (i.e. false alarms due to kitty litter) is essential to minimize the economic impacts on commerce. Reducing the false negative rate (i.e. SNM failing to trigger alarms) is critical for homeland security.

Given the limitations of passive screening methods, a strategy for screening cargo necessitates multiple technologies to form a multi-layered barrier against the threat of smuggled nuclear materials.

⁹ Gozani, Tsahi. Nuclear Engineering Department Colloquium. University of California, Berkeley. Etcheverry Hall, Berkeley. April 4, 2005.

¹⁰ Hartmann-Siantar, Christine. Personal Interview. February 8, 2005

¹¹ Buddemeir, Brook. Presentation. American Nuclear Society. Francesco's, Oakland. March 17, 2005.

One such barrier is an active interrogation cargo screening system that uses a source of radiation to induce nuclear reactions in the cargo and measures the ensuing response. These systems are expected to have significantly lower false positive and false negative error rates.

This section will *not* discuss the efficacy of an overall screening strategy. This analysis will instead focus on recommending a strategy that minimizes the cost of researching and developing active interrogation systems and deploying these systems to *all* ports and borders.

RD&D CHALLENGES

Understanding the characteristics of the steps in the research, development, and deployment (RD&D) process determines the choice of incentives. The following list models the RD&D process as a series of discrete, qualitatively different steps that must be accomplished to deploy cargo screening systems to the ports and borders:

- **Basic Research:** Gain an understanding of the interaction of radiation with matter and identify physics mechanisms for the detection of hidden SNM.
- **System Design:** Design an active interrogation system using the information obtained from basic research.
- **Commercial Optimization:** Optimize the system for assembly-line production and ruggedize the system for the rigors of real operating environments.
- **Production:** Produce the devices in a factory using the design information from commercial optimization.
- **Purchase and Deployment:** Purchase the devices from suppliers and deploy them to the ports and borders.

TECHNOLOGY SPECIFIC INCENTIVES

Having an understanding of the purchase and deployment “end-game” and the recommended strategies that result in a competitively supplied market, technology specific incentives can now be examined for the front-end RD&D tasks:

- **Basic Research:** Gain an understanding of the interaction of radiation with matter and identify physics mechanisms for the detection of hidden SNM
- **System Design:** Design an active interrogation system using the information obtained from basic research
- **Commercial Optimization:** Optimize the system for assembly-line production and ruggedize the system for the rigors of real operating environments.
- **Production:** Produce the devices in a factory using the design information from commercial optimization.

Basic Research

Recommendation: Continue funding the most promising research with grants.

Table 6 Basic Research Incentives

Incentives	Procurement	Access	Problems w/ Sponsor	Problems w/ Researcher	Eliciting Information	Feasibility
Grants	Moderate	Good	Good	Good	Good	Good
Contracts	Poor	Good	Poor	Good	Poor	Poor
Patents	Poor	Poor	N/A	N/A	Poor	Good
Prizes	N/A	N/A	N/A	N/A	Poor	N/A
Open Source	N/A	N/A	N/A	N/A	N/A	N/A

A cargo screening device based on active interrogation requires knowledge of nuclear physics, the interaction of radiation with matter, and radiation detection techniques. Research institutions such as the national laboratories and universities have been at the forefront of creating and developing this knowledge since and before the days of the Manhattan Project. Consequently, radiation detection is

a relatively mature field whose basic science is well known and understood. Though revolutionary technologies are not expected in the near-term, new technologies could lead to smaller and less expensive cargo screening systems.¹²

The most important challenge for basic research is to elicit the required information that enables the design of a cargo screening device. Basic research is typically funded by grants due to uncertainties in the value of the work. In contrast, patents typically fail to motivate basic research since the rewards are too uncertain for those seeking to profit from patents. Contracts also fail to motivate research since such tasks are frequently not specific enough to be procured by a contract. And given the expectations for evolutionary progress, prizes are not expected to elicit critical information.

Grants provide the best means by which to fund the most promising areas of research. Though, grant researchers are typically less constrained by cost, the possibility for overpayment is not a major concern as basic research typically represents only a small fraction of total RD&D expenditures.¹³

Though grant-sponsored research is frequently patented, a “publish or perish” culture in academic environments encourages researchers to share information in the open literature. Though this sharing of information is similar to open source, an open source system similar to that which exists in software is largely precluded by the relatively high cost of conducting basic research.

Grants have the added benefit of rarely causing problems with the sponsor since researchers are paid in advance. Other mechanisms that provide rewards upon completion of the task (patents, contracts, and prizes) generate uncertainty in the minds of the researcher, necessitating a larger reward to offset the possibility that the rewards may not materialize.

¹² UCLA Fusion Neutron Source

¹³ Maurer, M. Stephen, The Right Tool(s): Designing Cost-Effective Strategies for Neglected Disease Research, Preliminary, February 28, 2005.

Grants are particularly effective given the management challenges with the researcher arise since monitoring and controlling research is at odds with maintaining an environment in which researchers can be creative. Furthermore, funding agencies do not have the ability to judge the value of the research a priori and rely on a peer-review process to judge the results. However, the expectation of “doing business” again with the sponsor deters researchers from misusing their funds.

SYSTEM DESIGN

Recommendation: The remaining steps of the system design process can be accomplished within the lab with grants, though some tasks could be outsourcing to other firms with competitive contracts. The lab should recognize that private firms will have incentives to design systems. Open source?

Table 7 System Design Incentives

Incentives	Procurement	Access	Agency Problems w/ Sponsor	Agency Problems w/ Researcher	Eliciting Information	Feasibility
<i>Grants</i>	<i>Moderate</i>	<i>Good</i>	<i>Good</i>	<i>Good</i>	<i>Good</i>	<i>Good</i>
<i>Contracts</i>	<i>Good</i>	<i>Good</i>	<i>Moderate</i>	<i>Good</i>	<i>Good</i>	<i>Good</i>
Patents	Poor	Poor	N/A	N/A	Good	Good
Prizes	N/A	N/A	N/A	N/A	N/A	N/A
<i>Open Source</i>	<i>Good</i>	<i>Good</i>	<i>N/A</i>	<i>N/A</i>	<i>Good</i>	<i>Poor</i>

The separation between basic research and system design is frequently blurred since it is difficult to stop researchers from thinking about implementing their ideas. Nevertheless, system design constitutes a distinct step that follows basic research. Designing the system requires that the researcher specify the components and the interaction between them, conduct feasibility studies, assess the performance of the system via simulation and experiments, etc. For example, Rick Norman at LLNL believes that LLNL has designed a credible system that is capable of quickly detecting fissile material in cargo containers. However, a data processing system is required to translate the signals from the detectors into a signal that is easily interpreted by an operator.¹⁴ In the

¹⁴ Norman, Rick. Personal Interview. April 14, 2005

private sector, Tsahi Gozani at Rapiscan has adopted a different active interrogation method based on a differential die-away technique developed at the Los Alamos National Laboratory (LANL).¹⁵

Once the basic research is available, the national laboratories and private firms are both capable of designing an active interrogation cargo screening system as it only requires readily available engineering expertise. However, given that some uncertainty still remains about the feasibility of the design, grants should be used to support lab efforts to design a system. On the other hand, the private sector will be motivated by patents to design a system. Consequently, it is important for the lab to obtain intellectual property rights on the design to ensure efficient access by excluding others from patenting a similar design. This also has the welcome side effect of forcing competitors to pursue alternative technologies.

However, some aspects of system design may be more amenable to a competitive contract. For example, many firms can produce the software that processes data from the cargo screening system and presents the operator with a clear signal indicating the presence of nuclear material. Furthermore, the requirements for this software can be well defined. In fact, the lab may be able to avoid contracts altogether by harnessing the power of the open source software community to produce this software. However, the lab loses a great deal of control over the software development as it would be at the whim of the open source community.

COMMERCIAL OPTIMIZATION

Recommendation: Create a competitive process that awards a contract to a single firm to optimize the system and retain intellectual property rights on the optimized design.

¹⁵ Gozani, Tsahi. Nuclear Engineering Department Colloquium. University of California, Berkeley. Etcheverry Hall, Berkeley. April 4, 2005.

Table 8 Commercial Optimization Incentives

Incentives	Procurement	Access	Agency Problems w/ Sponsor	Agency Problems w/ Researcher	Eliciting Information	Feasibility
Grants	Poor	Good	Good	Moderate	Poor	Good
Contracts	Good	Good	Moderate	Moderate	Good	Good
Patents	Poor	Poor	N/A	N/A	Good	Good
Prizes	N/A	N/A	N/A	N/A	N/A	N/A
Open Source	N/A	N/A	N/A	N/A	N/A	Poor

“Bench-top” systems are usually not well suited for use in real operating environments and must be optimized such that the system is reliable, low cost, usable, etc. Optimization of systems typically occurs via simulation and computer aided design, though prototypes may be assembled and tested at this stage. Therefore, eliciting information is not a major challenge since many firms are able to optimizing radiation detection systems. Furthermore, the private sector has more expertise and experience in performing this task.

Though the strategy of retaining intellectual property rights raises the costs of procuring optimization information, a competitive contract would seek out the lowest cost provider of this optimization information. The risk of overpaying is tolerable due to improved accessibility to the optimization information. Minimizing agency problems between the sponsor and researcher requires the contract to be well specified.

PRODUCTION

Recommendation: Release the optimized system description into the open source and allow any firm to produce systems with this information.

Table 9 Production Incentives

Incentives	Procurement	Access	Agency Problems w/ Sponsor	Agency Problems w/ Researcher	Eliciting Information	Feasibility
Grants	Poor	Good	Good	Moderate	Poor	Good
Contracts	Moderate	Good	Moderate	Moderate	Good	Good
Patents	Poor	Poor	N/A	N/A	Good	Good
Prizes	N/A	N/A	N/A	N/A	N/A	N/A
Open Source	Good	Good	N/A	N/A	Good	Good

A production system is necessary to mass-produce cargo screening systems such that they can be purchased by the ports and borders. The challenges of production include tasks such as locating the factory, optimizing the production process under cost and time constraints, implementing quality control, organizing logistics (labor, capital, parts & supply chain), etc.

Finding the lowest cost producer is the key objective in the production stage. Since many of the components of LLNL's system is "off-the-shelf" or easily manufactured, eliciting information on production processes is not a major challenge. Furthermore, once the optimization information is available, specific information about production processes is relatively unimportant provided that the products meet quality standards and any changes to the design are properly documented. And having paid for the optimization information, competition between producers will readily reveal the lowest cost producer such that prices are roughly equal to the marginal cost.

BIOSENSORS

RECOMMENDATIONS

	Research	Design	Optimization	Production
Sole-Source License (Current Practice)	Grants	Grants	Sole-Source License	Sole-Source License
Open Source Optimization	Grants, Prizes	Competitive Contract	Competitive Contract	Open Source

IDENTIFYING THE THREAT

The anthrax mail attacks of late 2001 demonstrated the possibility of terrorist attacks with biological weapons. Though vaccines could be used to inoculate the population against these threats, monitoring the environment for biological agents is an alternative strategy for defending against biological attacks. Rapid detection of biological threats in the environment provides key information on the type of agent and its spatial distribution, allowing effective public health responses to be mounted quickly. Early detection may also allow the target population to minimize their exposure and undertake other protective measures.

As described by a recent National Research Council (NRC) study, this "detect-to-warn"¹⁶ strategy requires a detection time on the order of minutes or hours to be effective. To provide these "detect-to-warn" capabilities, the ultimate goal of biosensor development is to produce a "smoke detector" for bioweapons - an inexpensive and unobtrusive device that detects agents quickly and is capable of functioning unattended for long periods of time. Livermore has been at the forefront of research in this area; the Biological Aerosol Sentry Information System (BASIS)¹⁷, deployed during the 2002

¹⁶ National Research Council (2005). "Sensor Systems for Biological Agent Attacks: Protecting Buildings and Military Bases". National Academy Press, Washington, DC

¹⁷ Fitch, J. Patrick, Raber, Ellen, Imbro, Dennis R. (2003). "Technology Challenges in Responding to Biological or Chemical Attacks in the Civilian Sector". *Science* 302: 1350-1354

Winter Olympics, and the Autonomous Pathogen Detection System (APDS)¹⁸, recently licensed to GE¹⁹, were developed wholly or in part at Livermore.

RD&D CHALLENGES

Building a viable biosensor device requires the development of a number of component technologies²⁰. Here we identify the separate RD&D tasks involved in developing a biosensor device, and at a high level, examine the economic incentives that are most suited to each task. This analysis will focus on basic research and system design; issues of product optimization and deployment are analyzed in Purchase and Deployment section above.

- **Basic Research:** Develop a mechanism that can identify biological agents and distinguish bioweapons from other organisms, technologies to prepare an environmental sample for analysis, and transducer technologies to sense the biological agent.
- **System Design:** Create a database of pathogen signatures that uniquely identifies the biological threat using the detection mechanism identified through basic research. Design a system that samples the environment for biological agents.

BASIC RESEARCH

Table 10: Basic Research Incentives

Incentives	Procurement	Access	Problems w/ Sponsor	Problems w/ Researcher	Eliciting Information	Feasibility
Grants	Moderate	Good	Good	Good	Good	Good
Contracts	Poor	Good	Poor	Good	Poor	Poor
Patents	Good	Poor	Good	Good	Good	Good
Prizes	Good	Good	Moderate	Good	Good	Moderate
Open Source	N/A	N/A	N/A	N/A	N/A	N/A

¹⁸ McBride, Mary T. et al (2003). "Autonomous Detection of Aerosolized Bacillus anthracis and Yersinia pestis", *Anal. Chem.*, 75 (20), 5293 -5299.

¹⁹ Kirkpatrick, Melanie (2005). "The Anti-Doomsday Machine". *The Wall Street Journal*, April 25, 2005.

²⁰ National Research Council (1999). "Chemical and Biological Terrorism". National Academy Press, Washington, DC

Identification Mechanism for Pathogens

Recommendation: Continue funding promising research with grants and patents. Consider prizes as an alternative.

The first requirement in detecting harmful biological agents is to develop a mechanism to identify them in the environment and distinguish them from other organisms. The NRC categorizes possible detection mechanisms according to their identification method as listed below:

- **Sequence-based:** Nucleic acid sequence-based identification is based on an organism's genetic sequence (e.g. DNA amplification and identification with PCR)
- **Structure-based:** identification based on surface structures (e.g. monoclonal antibodies, ligands)
- **Chemistry-based:** identification based on chemical or physical properties of pathogens (e.g. mass spectroscopy)
- **Functional-based:** identification based on reactions of natural organisms or cells (e.g. canaries in a coal mine)

A number of these technologies already exist and are widely used in biotechnology (e.g. monoclonal antibodies and DNA identification with PCR). Others are under active research (e.g. ligands, mass spectrometry), and it is likely there are still unknown techniques waiting to be discovered. This field of research is notable for a number of reasons:

- *Commercial value (Procurement).* Even though this research falls under the category of basic research, innovations in this area will likely be commercially valuable to the medical and biotech industries. Monoclonal antibodies and PCR, for example, have generated hundreds of millions of dollars in revenue.

- *Possibility of new discoveries.* Unlike the case of cargo screening, where the known laws of physics exhaust the possible methods of identification, current knowledge has not yet reached the limits of physical possibility.
- *Eliciting information.* Relevant knowledge in biotechnology is not limited to the national labs or even the United States.

These stylized facts suggest the use of patents and grants, and those incentive structures have in fact been quite successful in biotechnology. Prizes, however, are an interesting alternative.

Patents: As described above, patents encourage commercially valuable innovation by ensuring that inventors cover their R&D costs through licensing fees, but create economic inefficiency by imposing higher costs on consumers, which in this case may include cumulative innovations that build on previous invention. For example, Roche's ownership of a portfolio of PCR patents allows them to charge higher prices for users of the *Taq* polymerase. Patents are also decentralized, which makes them effective in eliciting effort from diverse sources. Patents are an obvious fit for this type of research, and the many thousands of patents granted to the biotech industry bear this out.

Grants: Grants have a proven track record in funding basic science. Much of the research done in this area has been funded with grants, including the creators of the first monoclonal antibody process (who could have patented their work, but did not).

Prizes: Prizes, like patents, are also effective in eliciting effort from diverse sources. If the prizewinner is required to make their innovation public, then a prize can avoid the problems of monopoly prices associated with patents. The problem lies in setting the prize amount and specifying the winning conditions; if the prize amount is lower than the expected value of licensing fees from patents, then developers will choose to patent anyway (but in which case no money is

spent by the prize sponsor, save for administrative costs). In this area, where the possible limits to technologies are still ill-defined, a blue-sky prize for, say, a new technique for identifying pathogens may spur widespread effort towards this goal.

The following two stages are similar, so we consider them together.

Sample Collection and Preparation

Recommendation: Fund promising research with grants and patents. Consider prizes as an alternative.

Samples of candidate organisms must be extracted from the environment; for example, if the target environment is the air, then aerosol particles must be taken from the air and delivered to the identification mechanism. This has to be done without harming the organisms in the sample, while also concentrating them to a sufficient density to allow identification. Most current identification techniques are wet, which requires samples to be transferred to a liquid. Finally, the sampling and preparation system must work in unpredictable outdoor environments as well as inside a lab.

Develop a Transducer

Recommendation: Fund promising research with grants and patents. Consider prizes as an alternative.

The result of the identification mechanism, which is usually a chemical or biological process, needs to be converted into information readable by a human being or a computer; for example, by changing color or causing fluorescence in the event of a successful detection.

- *Commercial value (Procurement).* Both of these technologies will be highly useful to industry, and research is being actively pursued by many biotech companies.

- *Eliciting information.* As in the case of research on developing an identification mechanism, the relevant expertise in this area, which overlaps parts of chemistry and mechanical engineering, is widespread, and important innovations can come from all over the world.

As before, the nature of this research challenge suggests the use of patents and grants to encourage innovation. Prizes remain a possible alternative that can alleviate some of the problems associated with patents.

SYSTEM DESIGN

Table 11: System Design Incentives

Incentives	Procurement	Access	Agency Problems w/ Sponsor	Agency Problems w/ Researcher	Eliciting Information	Feasibility
Grants	Moderate	Good	Good	Moderate	Good	Good
Contracts	Good	Good	Moderate	Good	Good	Good
Patents	Poor	Poor	N/A	N/A	Good	Good
Prizes	N/A	N/A	N/A	N/A	N/A	N/A
Open Source	N/A	N/A	N/A	N/A	N/A	N/A

Database of Pathogen Signatures

Recommendation: Fund the development of DNA pathogen signatures with contract research.

For any given identification mechanism, a database of signatures of target pathogens will determine the types of biological agents that can be identified. These signatures may have different characteristics, depending on the mechanism; for example, antibodies that bind to surface markers (epitopes) on all *Bacillus* species will identify *Bacillus anthracis*, but will also generate false positives from non-anthrax *Bacillus*. DNA-based identification, on the other hand, can be highly specific, but mutation of the target organisms may obsolete a static library²¹.

- *Commercial value (Procurement):* Databases on rarely encountered pathogens may not have much commercial value.

²¹ Fitch, J. Patrick et al (2002). "Rapid Development of Nucleic Acid Diagnostics". *Proceedings of the IEEE*, 90(11), Nov 2002

- *Secrecy (Access)*: It may be desirable to limit access to this information (for example, the genetic sequences of highly virulent pathogens).
- *Eliciting Information*: Widely scattered expertise is probably not required.

The relatively specific nature of this task makes it suited to contract research, as does the need control access to this information, due to its sensitive nature. Competitive bidding can be used to find an efficient price for contract research.

RAD KIT

RECOMMENDATION

Table 12 Rad Kit Recommendation

R&D STAGES	Research	Design	Optimization	Production
<i>Current Practices</i>	<i>Grants</i>	<i>Grants, Patents</i>	<i>Competitive Contract, License</i>	<i>Competitive Contract, License</i>
<i>Rad Kit Recommendations</i>	Research Grants, Research Contract, Open Science Network	Matching Grant, Competitive Contract	Matching Contract, Competitive Contract	

IDENTIFYING THE THREAT

Developing radiation detection biomarkers have been identified as a high priority technology by an interagency working group created by the Office of Science and Technology Policy and the Homeland Security Council to mitigate the consequences of a terrorist attack using radiological and nuclear devices.²²

In the public panic following a dirty bomb attack, many members of the public will desire treatment regardless of whether or not they were exposed to significant levels of radiation. Successfully mounting a public health response to mitigate the consequences of this attack requires knowledge about the radiation doses received by individuals.

Currently, low dose exposures to radiation are difficult to assess following exposure. In the event of a dirty bomb attack on a population, one could estimate the radiation dose to an individual if one knows the individuals exposure history based on a number of factors such as proximity to

²² Pellmar, T.C. Rockwell, S. and the Radiological/Nuclear Threat Countermeasures Working Group, Priority List of Research Areas for Radiological Nuclear Threat Countermeasures, Radiat. Res. 163, 115-123 (2005).

contaminated areas, the length of exposure, etc. Ideally, a direct measurement could be made to determine this dose.

For decades, LLNL has been a leader in the field of biological dosimetry, the measurement of the effects of radiation exposure on biological organisms. Prior to the era of terrorism and during the Cold War, LLNL's work was primarily in response to protecting and monitoring workers on atomic weapons and in fields where x-ray technology was being developed and used. Alternatively, in the case of cellular (*in vitro*) measurement of high dose radiation exposure, the lab developed a chromosome painting technique requiring *in situ* hybridization.²³ Today, first responders on the streets of New York could not use these methods to assess, quickly and accurately, injuries from low-level radiation exposure. These devices are not disposable, nor are they sensitive enough to detect cellular or genetic damage resulting from a dirty bomb or a nuclear explosion.²⁴

Currently, a team of LLNL scientists in the Biosciences Directorate division is engaged in the next generation research required to detect and characterize the earliest molecular responses of humans to ionizing radiation (IR) and pathogen infections. By all indications, research has accelerated to the point where the discovery of a biomarker is for a disposable rad kit is rapidly progressing. Indeed, LLNL's 2003 low-dose IR research led to the several watershed discoveries:

- Cellular response pathways that were qualitatively different from those employed at higher doses

²³ Radiation Dose Assessment can be viewed at www.LLNL.gov/str/Robison.html+biodosimetry...

²⁴ According to Robert Adams, Homeland Defense Info Kit Part 3: Radiological Weapons, 2002: In 1997, Alexander Lebed, former Russian national security advisor, claimed that Russian military had lost track of around 100 "suitcase bombs." These bombs, actually called "nuclear demolitions," are portable nuclear weapons, usually weighing no more than 60 pounds, each possessing a yield of between 1 and 10 kilotons... in a small town could effectively remove it from the map, and cause an unprecedented nationwide panic that would overshadow even the fear created by the dreadful events of 9/11.

- Low dose exposure resulted in early changes in genes detected in several areas including synaptic signaling and in late changes involving metabolic pathways like protein synthesis
- A technique invented by several scientists for rapid non-invasive indicators of tissue specific cellular damage

Moreover, the lab is currently engaged in research to provide new knowledge of the early cellular responses to low-dose IR to reduce the uncertainty of assessing risk at low-dose levels. It also expects to identify genes whose expression is associated with low dose IR exposure and susceptibility for adaptive response.²⁵

While it is unclear whether this current research will lead to the discovery of the most effective, disposable biomarker, it is certain that LLNL scientists are responding to the call to advance the systems required to measure low dose exposure among civilian-based populations with the goal of enhancing triage, treatment decisions and risk assessment.

Radiation energy that travels in the form of waves, or high-speed particles, is everywhere: cell phones, microwaves, electrical power lines, and the sun. When does radiation energy become dangerous? How can we tell? In the homeland, we know a dirty bomb is dangerous, but detecting the presence of one is quite different from detecting your exposure level after it explodes. While there is much speculation and concerns about the economic disruption a dirty bomb can cause, the greatest motivation for the current research stems from the fact that it is now possible to treat low dose radiation exposure and to establish basic defenses against dirty bombs.²⁶

²⁵ Biosciences Directorate 2005 research agenda is outlined in Molecular Mechanisms and Cellular Consequences of Low-Dose Exposure to DNA Damaging Agents, which can be viewed at http://www.llnl.gov/bio/groups/radiation_biology/molecular_mechanisms.html

²⁶ Inbar, Dan, Coming Clean About Dirty Bombs, Government Security Technology Solutions in Defense of the Homeland, April 1, 2004.

Given an explosion of a crude deadly radiological bomb fashioned from stolen nuclear material and a few sticks of dynamite, the grand challenge is assessing the level of human exposure, quickly and accurately. LLNL has established that IR exposure has the potential to alter function and to cause pathology of the blood-forming system. The degree to which radiation pathologically alters this vital organ system depends on a variety of radiological (radiation, dose, dose rate, quality) and biological (age, sex, genetic makeup) factors. The goal is make this assessment following an event using a kit that possibly works with a mouth swab, blood sample, or hair follicle, and registers low false negatives and tolerable false positives. Such a kit would have enormous social value.

The following system of incentives is recommended for the development of a radiological “rad kit,” a disposable device that detects low-level radiation exposure within our bodies at the cellular level. The table below summarizes Lawrence Livermore National Lab’s (LLNL) current R&D procurement practices and this study’s recommendations based on an analysis using new approaches to incentivizing innovation.²⁷

R&D Challenges

Unfortunately, the problems identified by LLNL are also enormous:

- **Basic Research:** Low dose versus high dose: What does that mean in terms of tolerance thresholds? What are the tolerable false negative and positive ranges? Are there gene/protein sets that turn on and off across populations and genders? How can LLNL meet the human trial requirements in a timely and cost effective manner?

The threat may be in the offing, the social value is very compelling, but what if the market is not large enough to entice private sector investment? How can the rad kits be developed and produced

²⁷ Suzanne Scotchmer, author and Steve Maurer, co-author of Innovation and Incentives, Massachusetts Institute of Technology, 2004.

otherwise? Is the market large enough to entice private sector investment for the following R&D stages?

- **System Design**
- **Commercial Optimization**
- **Production**

SOCIAL CHALLENGES

In addition to the research problems, what are the challenges for LLNL outside the lab and beyond its role as researchers or sponsors of research? The emerging challenges relevant to the rad kit R&D could include:

- **Eliciting Information:** Keys to the method that best fits the requirement are spread among several disciplines.
- **Agency Problems with Researchers:** Constant questioning regarding the possibility of ever solving the science problems required for an effective, disposable in vitro biomarker
- **Feasibility:** Fears regarding consequences of inaccuracy create high risk for lawmakers and approval agencies
- **Agency Problems with Sponsors:** Multiple research players diffusing the effort and delaying a consensus on best method
- **Development Time:** Human testing require a radiation-centric source for subjects with double strand breaks and biological variety: Will the FDA relax the stringent human trial requirements?

- **Procurement:** Improving the business proposition seems the only way to entice the private sector. Can LLNL do this without overpaying and creating deadweight loss in the short-term and without discouraging future innovation and public-private partnerships in the long-term?

ANALYSIS OF R&D INCENTIVE MECHANISMS

The following analysis uses the Table below to as a basis of criteria for determining the best incentive mechanism that will achieve the function of each R&D stage. It summarizes the specific challenges of the R&D process, which will be analyzed individually. Each recommendation will be stated up front along with a chart that qualitatively summarizes the reason why other incentives were not chosen, followed by the discussion supporting the recommendation.

Table 13 Summary of R&D Problems and Challenges

<i>R&D Stages</i>	<i>Basic Research</i>			<i>4 Design</i>	<i>5 Optimize</i>	<i>6 Production</i>
	<i>1 Identify Biomarker</i>	<i>2 Identify Detection Limit</i>	<i>3 Conduct Human Trials/Screening</i>			
Functions	Leverage all existing and new	Independently verify injury inference in low dose range	Remove population and gender confounds	Encourage investment at lowest possible cost		
Criteria	Eliciting Information	Feasibility Agency Problems w/Sponsors	Development Time: Agency Problems w/Researchers	Procurement		

BASIC RESEARCH

Identify Biomarker

Recommendation: Maintain Current Practice

R&D Stage 1 – Basic Research Identify Biomarker					
Social Function	Procurement	Access	Agency Problem w/Sponsor	Agency Problem w/Researcher	Eliciting Information
Grants	Good	Good	Good	Good	Good
Contracts	Moderate	Moderate	Good	Good	Moderate
Patents	Good	Poor	Good	Good	Moderate
Prizes	Moderate	Good	Moderate	Good	Good
Open Source	Good	Good	NA	Poor	Good

Research, funded by grant, is well underway in the 1st R&D Stage. The question is whether research grants are working “optimally.” Theoretically, grants should work better at the basic research stage. In this form of basic research, grants have been proven to be an effective stimulate. Patents are always possible when it comes to new ideas, however, with no commercial value no one will risk money pursuing this discovery without an expected return on investment. Therefore, grants are the preferred incentive. It appears to be satisfactory, so the recommendation is that LLNL continues doing what is doing to fund the discovery of the biomarker best suited for the rad kit.

LLNL’s progress toward determining the indicators of low dose IR injury is demonstrated by discovering changing in the messenger RNA (mRNA), gene expression and cell cycle pathways.

The social challenge of Eliciting Information is being addressed not only by funding for research, but also for investment in the highly skilled and accomplished human capital required to staff LLNL’s Bioscience Directorate division.

Identify Biomarker
Low dose versus high dose: What does that mean in terms of tolerance thresholds?
Eliciting Information: Keys to the method that best fits the requirement are spread among several disciplines.
RESEARCH GRANTS

Based on the Department of Defense (DOD) classification scheme for research, discovering the biomarker and method of measuring low dose radiation exposure in organisms is at about 6.25 on a 6.5 scale²⁸. The issue that is being resolved is what biological pathway can be measured quickly and precisely, with a disposable instrument? Is it a cellular pathway by blood, protein by swab, or gene expression by PCR? What method of measurement is best suited for firefighters, for example, to quickly assess the level of exposure, short-term and long-term damage, and initiate mitigating treatment – right on the spot?

It appears several methods of measuring low dose IR exposure will be determined in Stage 1 research. However, the question is which one will be verified as most effective in the Stage 2 detection limit research. In essence, how consistently sensitive are these biomarkers?

²⁸ Interview with LLNL's Christine Hartmann-Siantar, Physics and Advanced Technologies Directorate, March 14, 2005

Identify Detection Limit

Recommendation: Research Contract

R&D Stage 2 – Basic Research Identify Detection Limit					
Social Function	Procurement	Access	Agency Problem w/Sponsor	Agency Problem w/Researcher	Eliciting Information
Grants	Good	Good	Good	Good	Good
Contracts	Moderate	Moderate	Good	Good	Moderate
Patents	Good	Poor	Good	Good	Moderate
Prizes	Moderate	Good	Moderate	Good	Good
Open Source	Good	Good	NA	Poor	Good

Rather than combine R&D Stages 1 and 2, this analysis recommends separating them based on the different functions and challenges. While most grant and research project descriptions specify both by requiring the biomarker also detects cellular effects of low-dose exposures from one to 10cGy²⁹, the social challenges that form our criteria for incentive mechanisms: namely, independent verification, suggests a better result if we use a research contract for an outside researcher(s) to address it separately. It is assumed the lab will have the biomarker, now the need is to identify just how low it goes in testing exposure in tissue. It is also assumed that this will not require a formal human subject trial and the specifications of what the lab needs will be well defined. Therefore, a contract can be sued for this independent research, where again there is no commercial value – no patents. Moreover, a clear contract will force them to stick to the goal.

Identify Detection Limit
What are the tolerable false negative and positive ranges?
Feasibility: Fears regarding consequences of inaccuracy create high risk for lawmakers and approval agencies (i.e. FDA)
Agency Problems with Sponsors: Multiple research players diffusing the effort and delaying a consensus on best method
RESEARCH CONTRACT

²⁹ 15Gy is thought to be the dose of whole body radiation causing intestinal death in vertebrates.

The function of Stage 2 R&D is to determine how accurately the proposed biomarker can measure injury within the expected range. It is at the heart of the Grand Challenge to create a kit that measures quickly, precisely with no more false negatives or false positives than we have come to accept from an at-home pregnancy kit. If achieved, it would reduce the burden on hospitals following an attack, save many lives and rapidly diminish panic.

Independent verification of the biomarker's detection success will serve to assuage naysayers and bolster political support for further development if the kit is deemed by a diverse research community to have a low probability of failure.

Given that the over response rate of psychosomatic systems are 10 to 1 following a radiation exposure event, a test that can accurately detect dose levels would gain political support by serving to avert civil chaos.

To accomplish this is it proposed that LLNL test the biomarker discovery/method at cancer screening/treatment centers³⁰ under a research contract that requires the companies use the technique (as a back up to current practices) on patients exposed to 1-10cGy radiation treatments and report their findings.

Since all parties have a stake in ensuring the kit's precision, this recommendation is an incentive mechanism that facilitates widespread, independent verification of the biomarker's sensitivity within the 1-10cGy IR range. If the results are unsuccessful, researchers must return to the drawing board and either refine the biomarker method or choose another pathway. If successful, LLNL should publicize the results widely to build momentum and expectations for the next R&D stages.

³⁰ The number of patients with various malignant neoplasms who undertake radiation therapy is rapidly increasing up to 60% of all cancer patients in the US. OWAWA et al: Mitochondrial Cytochrome c Release in Radiation – induced T Cell Apoptosis, International Journal of Molecular Medicine, 10:263-268, 2002.

Conduct Human Trials/Screening

Recommendation: Open Science Network

R&D Stage 3 – Basic Research Conduct Human Trials/Screening					
Social Function	Procurement	Access	Agency Problem w/Sponsor	Agency Problem w/Researcher	Eliciting Information
Grants	Moderate	Good	Moderate	Moderate	Poor
Contracts	Moderate	Good	Good	Good	Moderate
Patents	NA	NA	NA	NA	NA
Prizes	NA	NA	NA	NA	NA
Open Source	Good	Good	Good	Good	Good

The recommended incentive mechanism for Stage 3 is an open science network that leverages the relationships with cancer screening/treatment centers initiated in Stage 2 and extends them in a mutually beneficial strategy: the lab gets the biomarker screened in a naturally radiation-centric setting and the cancer screening companies get a new quick and accurate method to use.

By using open science, the lab benefits by maximizing its knowledge it has already to solve a public good problem. The centers gain use of the biomarkers and increase the value of their information combined, whereas alone it is not worth much. A contract is costly, time consuming and will not leverage the information already out there.

In this approach, government uses open science to improve healthcare, healthcare uses open science to improve public safety. LLNL minimizes development time and increases the probability of receiving FDA approval with rigorous testing, but perhaps not at the standard clinical trial level.

Conduct Human Trials/Screening
Are there gene/protein sets that turn on and off across populations and genders?
How can LLNL meet the human trial requirements in a timely and cost effective manner?
Development Time: Human testing requires radiation-centric source for subjects with double strand breaks and biological variety:
Agency Problems with Researchers: Constant questioning regarding the possibility of ever solving the science required for an effective, disposable in vitro biomarker
OPEN SCIENCE NETWORK

Overcoming the challenge of confounds from individual variation of low dose exposure will go a long way toward gaining consensus in the scientific community that indeed the biomarker for a rad kit has finally been discovered.

Moreover, LLNL expands its network of partners and benefits by the feedback on how to improve the method for public use in the event of a terrorist attack.

Assuming LLNL overcomes the problem and social challenges of Stage 2, the next problems to tackle are those associated with the performance of the biomarker across populations and genders. While this stage of R&D is part of the Basic Research phase of determining confounding factors, it requires resources outside LLNL's capacity: screening backgrounds of perhaps 1,000 people in a day, ensuring a random sample of at least 50% men, 50% women and certain percentage of elderly and racial minorities is no longer a lab function.

DESIGN, OPTIMIZATION, PRODUCTION

Recommendation: Matching Contract

R&D Stage 4 – Design Prototype					
Social Function	Procurement	Access	Agency Problem w/Sponsor	Agency Problem w/Researcher	Eliciting Information
Grants	Poor	Good	Good	Good	Poor
Contracts	Good	Good	Good	Good	Moderate
Patents	Good	Poor	Good	Good	Moderate
Prizes	NA	NA	NA	NA	NA
Open Source	NA	NA	NA	NA	NA

A matching fund will get private industry to develop and design the biomarker prototype, which they may not otherwise do, by encouraging them to commit some of their own money which prevents a waste of time money R&D process. It will also be used to attract a partner to take the design through commercialization and production. This works best because patents will result in monopoly pricing and a competitive contract may not attract potential partners.

As the lab’s needs become more external and dependent upon outside partners in the private sector, the restrictions form little or no private sector interest and investment can jeopardize the rad kit’s ultimate development.

Thus far, grants, contracts, along with open science network are the recommended incentive mechanisms to accomplish the Basic Research required in Stages one

through three. What will it take to produce a prototype in State 4, optimize it for commercialization in Stage 5? Are they the same incentives required for Stages 6 production?

R&D Stages		
4	5	6
Prototype	Optimization	Production
Is the market large enough to entice private sector investment?		
Procurement: Improving the business proposition seems the only way to entice the private sector. Can LLNL do this without overpaying and creating deadweight loss in the short-term and without discouraging future innovation and public-private partnerships in the long-term?		
MATCHING CONTRACT		

Returning to the public call-to-action to the private sector, we must acknowledge the fact that the market for the rad kit is not large and, considering its intended use, we hope that there would not be a consistently recurring need for them.³¹

An early budget estimate projects the government will purchase 100,000 kits at roughly \$20 each. A \$2m market for a large pharmaceutical or biotech, or even a small medical kit maker is not very enticing. How can we improve the business proposition to entice the private sector? Using the projected \$2m of public funds as matching grant can be very compelling on many other levels.

³¹ Although the cancer treatment centers may offer a spin-off market opportunity