Expansion of the U.S. National Seed Storage Laboratory: Program and Design Considerations (1988)

Pages
32

Size
8.5 x 11

ISBN
0309319412

Work Group on the National Seed Storage Laboratory; Work Group on the National Plant Germplasm System; Subcommittee on Managing Plant Genetic Resources; Committee on Managing Global Genetic Resources; Board on Agriculture; National Research Council

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This project was supported under Agreement No. 59-32U4-6-75, Agricultural Research Service, between the U.S. Department of Agriculture and the National Academy of Sciences. Additional funding was provided by Science and Education, U.S. Department of Agriculture; Agency for International Development, U.S. Department of State; Calgene, Inc.; Monsanto Co.; W. K. Kellogg Foundation; Pioneer Hi-Bred International, Inc.; Rockefeller Foundation; and the World Bank.

Available from:
Board on Agriculture
National Research Council
2101 Constitution Avenue, NW
Washington, D.C. 20418

Printed in the United States of America

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*Through December 31, 1987

PREFACE

The National Academy report *Genetic Vulnerability of Major Crops*, published in 1972, made many scientists and policymakers aware of the urgency of conserving what has become known as biological diversity. Since that time concern has broadened. Scientists have seen that not only crop resources, but many other living systems are threatened with extinction—particularly the biological resources in the world's tropical and arid regions. Numerous reports from national and international organizations have addressed the increasing concern over agricultural and development practices and policies that may accelerate this destruction. What has emerged from these issues is the realization that nations not only have a responsibility to alleviate such losses, but also to actively maintain global biological diversity.

The genetic resources of the world's agricultural crops are the portion of biological diversity that have had the most significant impact on human society. Selection and cultivation of wild plants throughout human history have led to the development of landrace plant varieties and, through modern plant breeding principles, to today's high-yielding cultivars. With the rise of plant genetics, breeders developed germplasm collections to support their work.

The National Research Council established the Committee on Managing Global Genetic Resources in November 1986 to assess national and international efforts to manage genetic resources with particular emphasis on those significant to agriculture. The committee has set forth an agenda that will examine technical, legal, political, social, and economic issues. The committee's goal is to provide authoritative, scientifically-based reports that will heighten awareness of the importance of these basic resources and enhance their collection, conservation, management, and use.

While the activities of the committee are broad in scope, this report deals with a narrow subject. Its focus is the expansion of the National Seed Storage Laboratory (NSSL) in Fort Collins, Colorado. An expert work group of the parent committee was charged with providing information to aid in planning and designing a new storage facility to be located in Fort Collins. Specifically, the group was asked to:

- Examine the operation of the existing facility and how it could best incorporate new additions to the NSSL.
- Recommend options to modify the present facility and construct new laboratory and storage facilities.
- Develop recommendations for the placement, connection, insulation, and design of mechanically refrigerated seed vaults, cryovat rooms, seed handling and testing rooms, research laboratories, offices, and other supporting facilities; and their efficient operation, based on projected program requirements and the needs of long-term storage.
- Consider the security of the buildings and grounds against natural or manmade disaster.

The U.S. Department of Agriculture provided supplemental funding to the Committee on Managing Global Genetic Resources to assist in the preparation of this report. In the process of performing such a study, many issues were raised regarding the place of the NSSL in the National Plant Germplasm System (NPGS) and the coordination of parts of that system with the NSSL. Additional questions were raised about the selection of particular sites for the NSSL or other NPGS facilities. Such issues are important, will be examined by other work groups of the Committee on Managing Global Genetic Resources, and, when appropriate, be addressed in reports by those work groups.

Peter R. Day
Chairman, Committee on
Managing Global Genetic Resources

ACKNOWLEDGMENTS

On behalf of the members of the Work Group on the National Seed Storage Laboratory, Work Group on the National Plant Germplasm System, Subcommittee on Managing Plant Genetic Resources, Committee on Managing Global Genetic Resources, and Board on Agriculture, I express our appreciation to the U.S. Department of Agriculture (USDA) for the opportunity to participate in the planning of one of the key facilities in the NPGS. Safeguarding plant germplasm—most of which is irreplaceable—is a national priority that underlies the agricultural security of this nation as well as many others. The United States has an important role in encouraging, fostering, and supporting such work throughout the world.

We convey special thanks to Henry Shands, National Program Leader for Germplasm of the Agricultural Research Service (ARS), who provided us with information, materials, enthusiasm, and encouragement throughout the development of this report. We are grateful to Steve Eberhart, Director of the NSSL, and his staff who gave generously of their time.

We also wish to thank the staffs of the Mountain States Regional Office of the ARS, Colorado State University, and USDA/ARS Facilities Construction Management Division for their guidance and willingness to provide the work group with much relevant data.

The work group also wishes to thank Carole Spalding, administrative secretary for the study. Finally the work group thanks John A. Pino and Michael S. Strauss for assimilating and expressing our findings in this report.

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Chairman, Work Group
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OVERVIEW

The Work Group on the National Seed Storage Laboratory (NSSL) of the Committee on Managing Global Genetic Resources examined the future needs of the NSSL in relation to its projected mission within the National Plant Germplasm System (NPGS), the current operations with existing facilities, and the initial project proposal for NSSL expansion. The work group focused primarily on the function of the NSSL as a base collection storage facility for crop genetic resources.

The work group concluded that as a base collection site the existing facility has antiquated refrigeration technology and insulation in the cold rooms; presents difficulties for assuring safe, secure storage of plant germplasm; and will not meet expected future space requirements. The existing facility appears to hamper work efficiency and operational costs. Hence, upgrading and expansion are justified.

The work group stresses that the current assessment is not based on intrinsic deficiencies in the NSSL's original design or construction. Rather, technologies to maintain germplasm and the magnitude of responsibility for germplasm maintenance at the NSSL have changed considerably over the past three decades. The time has come for development of a facility that allows the appropriate use of technologies and enables the NSSL to meet its expanding national and global responsibilities.

The work group anticipates an expanding role of the NSSL in the NPGS. The work group also anticipates a greater role for the NSSL in encouraging and supporting international activities. Research on preservation technology and the maintenance of germplasm that originates in or is fostered by the NSSL will be increasingly important for improving management of all materials in the NPGS. The NSSL has a significant role in training domestic and foreign scientists. Equally important is NSSL's activity in educating the general public about its work in preserving the genetic resources that are the foundation of modern U.S. agriculture.

Among the projected activities, preservation of plant germplasm as seed under conventional cold storage (around $-18^{\circ}C$) should have the highest priority. The usefulness of cryogenic storage for selected materials should not be discounted, however. In addition, new methods for storing pollen, dormant buds, *in vitro* cultures, tissues, and DNA should be accommodated as the methods become feasible and appropriate. Research will be crucial to development of improved storage and management procedures.

The report of the work group endorses an architectural and engineering feasibility study that would examine possible design alternatives. Suggested guidelines, programmatic concerns, and structural and facility issues that should be addressed are posed. The following are some of the key issues that are addressed:

- The global and national roles of the NSSL in the preservation of crop genetic resources.
- The inadequacy of present facilities to maintain the current and future germplasm collection.
- Further development of the NSSL's capacity to train scientists from the United States and abroad; the consideration of the important public education role served by the NSSL; and the provision of appropriate facilities within an expansion.

- The need for a design that organizes work areas, laboratories, storage rooms, offices, a maintenance shop, and other areas to provide maximum efficiency of operation, security, and flexibility to meet the expanding needs of the NSSL.
- The necessity to enable future adoption of appropriate, new technologies for storing a variety of forms of germplasm.
- The need to assess the various threats to the security of the NSSL collection and develop a cost-effective design that deals with the most significant threats.
- The need to examine maintenance of germplasm at the NSSL with regard to adoption of those technologies and solutions that are the most cost-effective and biologically sound. Options would include the use of mobile shelving in storage vaults, modular construction of vaults, cryopreservation of seed and other forms of germplasm, and selection of seed containers.
- The need to continue to seek trained, motivated staff members for the NSSL. Suggestions are made to hire individuals with expertise in computer hardware and software or other physical plant and equipment maintenance in full-time, on-site jobs.

The work group recognizes the need to adjust construction specifications to funding availability. The group believes that planning should be based on cost-effectiveness, scientific principles, reliability of different types of storage, and security of conserved germplasm in establishing relative priorities and resource allocation.

There is no evidence that the present structure is unsound. Comprehensive renovation would be possible, particularly since the internal walls are not structurally load bearing. Thus, the work group found no reason not to consider remodeling the existing building to become an integrated part of the new facility. The existing building could provide much needed space for administrative offices, meeting rooms, a library, and expanded research space. The space in the present building would be more than adequate for the projected needs of the Plant Germplasm Preservation Research Unit. The construction could then comprise storage vaults and associated laboratories. The work group recommends that some design alternatives incorporating the existing facility be considered. The final design should be selected on programmatic, functional, and cost-effective grounds.

Location of the storage vaults above- or underground is less important than assuring that security concerns are adequately addressed. Preventing water damage from flooding or ground seepage should be one of the most important security concerns. Underground construction could significantly increase potential for such damage. Decisions regarding above- or underground construction must be based on a thorough feasibility study of designs for vaults that are underground and partially or fully aboveground.

Regardless of the final construction plan, consideration must be given to minimizing the potential disturbance to the present collection when moving it. While there are no presumed reasons why the collection should not be moved twice—for instance, first to temporary storage and then to the new vaults—the dangers of loss and misplacement of accessions during two moves should not be underestimated. It is preferable, therefore, that the collection be moved from its present location directly to the new vaults. Furthermore, the new vaults should be thoroughly tested to assure that cooling, safety, and back-up systems are fully operational before any materials are moved. If there is a need to move some current staff members or activities to temporary locations, it is preferable to move those not directly associated with storage or monitoring.

The human element in the management of plant genetic resources should not be overlooked in the NSSL expansion. New, expanded facilities, new storage technologies, and the growing collection will require additional staff members. Emphasis should be placed on retaining and rewarding superior individuals for managing the collection. For those in positions of responsibility, incentives such as training and promotion will ensure continuing high-quality efforts. Even if the new complex is modern and efficient, its success as a world-class genetic resources management facility still depends upon the efforts of its staff.

INTRODUCTION

The concern of national leaders, scientists, farmers, and merchants with the acquisition, conservation, and use of plant germplasm traces back to before the earliest days of the colonies. The National Plant Germplasm System (NPGS) has been developed to assure preservation of the genetic materials essential to the nation's agriculture. Throughout the development of the NPGS, improvements and modernization have occurred that reflect past experience, new technologies, and broadened national and international responsibilities.

Since the 1940s, when the National Research Council's (NRC) Committee on Plant and Animal Stocks expressed concern about the lack of appropriate facilities for the storage of important agricultural germplasm (NRC, 1945-1948), interest and concern for the management of crop genetic resources has increased and the technologies for preserving plant germplasm have greatly improved. Maintaining the large and significant NPGS collection at the NSSL will require a modern facility that can use the best of current technologies and adapt to new methods as they are developed. Additionally, as a cooperator in the international effort to manage the world's genetic resources, the NSSL will require expanded programs and facilities.

The designed capacity of the NSSL was for 180,000 accessions in 10 storage rooms of varying sizes. Initial storage conditions were 4°C and 32 percent relative humidity (RH) in rooms insulated with 1/2 inch of plaster over 4 inches of cork (James, 1972). As protocols for storage advanced, refrigeration equipment was altered to achieve storage at 0°F (more commonly expressed as −18°C), although no improvement in insulation was made.

Seeds were originally stored in screw-top metal cans. As space became limited, heat-sealed pouches consisting of one layer each of paper, foil, and polyethylene were adopted. These are more flammable than the cans and unproven for long-term durability. Consequently, use of the pouches may engender a greater need for attention to fire-control systems in storage facilities.

Since its conception in 1944, the NSSL's primary mission has been the preservation of plant germplasm (USDA, 1981). The collection has grown to its present 232,000 accessions at an increasingly rapid rate since 1970. Nearly one-third of the total has been added since 1980 (Table 1). This growth has taxed what have proven to be limited capacities and resources.

As the collection has grown, the role of research has also gained prominence. Research should be an important part of the NSSL's role of conserving and managing the base

Table 1 NSSL Collection Accessions Since 1970

Period	Accessions Received	Average per Year	Percent of Present Collection
1970 to 1974	15,642	3,128	6.7
1975 to 1979	22,551	4,510	9.7
1980 to 1984	42,777	8,555	18.4
1985 to 1987	28,397	9,466	12.2

NOTE: The present size of the collection is 232,000 accessions.

SOURCE: S. Eberhart, National Seed Storage Laboratory, personal communication, 1988.

germplasm collection of the NPGS. It should support the management of the collection and not compete with or be divorced from such activities.

Many of the accessions held by the NSSL are no longer available in other base collections or in the field. Some accessions are landraces that have been lost because of the introduction of new varieties, encroachment of development, or environmental crises in the regions where they arose. Others are wild species that are now rare. Still others are breeding lines or genetic stocks no longer held in public, private, or university collections.

The NSSL also supports international germplasm activities, although space limitations of recent years have hampered this. For some large international collections, such as maize from the Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT) in Mexico and rice from the International Rice Research Institute (IRRI) in the Philippines, the NSSL holds duplicate samples as insurance against loss. Although such materials are not incorporated into the U.S. germplasm collection, the NSSL's function fulfills part of the international responsibilities of the NPGS. Similar agreements between the NPGS and international institutions could provide security back-up to the NSSL for its collections in a cost-effective way.

In the late 1970s, the United States joined a collaborative network of base collections established by the International Board for Plant Genetic Resources (IBPGR). The NSSL was designated as a base collection site for 19 crops: maize, millets, rice, sorghum, wheat, *Phaseolus*, soybean, *Vigna unguiculata*, *Allium*, *Amaranthus*, *Curcubita*, *Cucumis*, *Citrullus*, eggplant, okra, sweet potato, tomato, sugarcane, and cotton (Hanson et al., 1984). This activity has further heightened the influence and importance of the NSSL in the United States and the international community.

EXPANSION OF PROGRAMS AND FACILITIES AT THE NSSL

Under the administration of a laboratory director, two Agricultural Research Service (ARS) research units conduct NSSL's activities. These units are the Seed Storage and

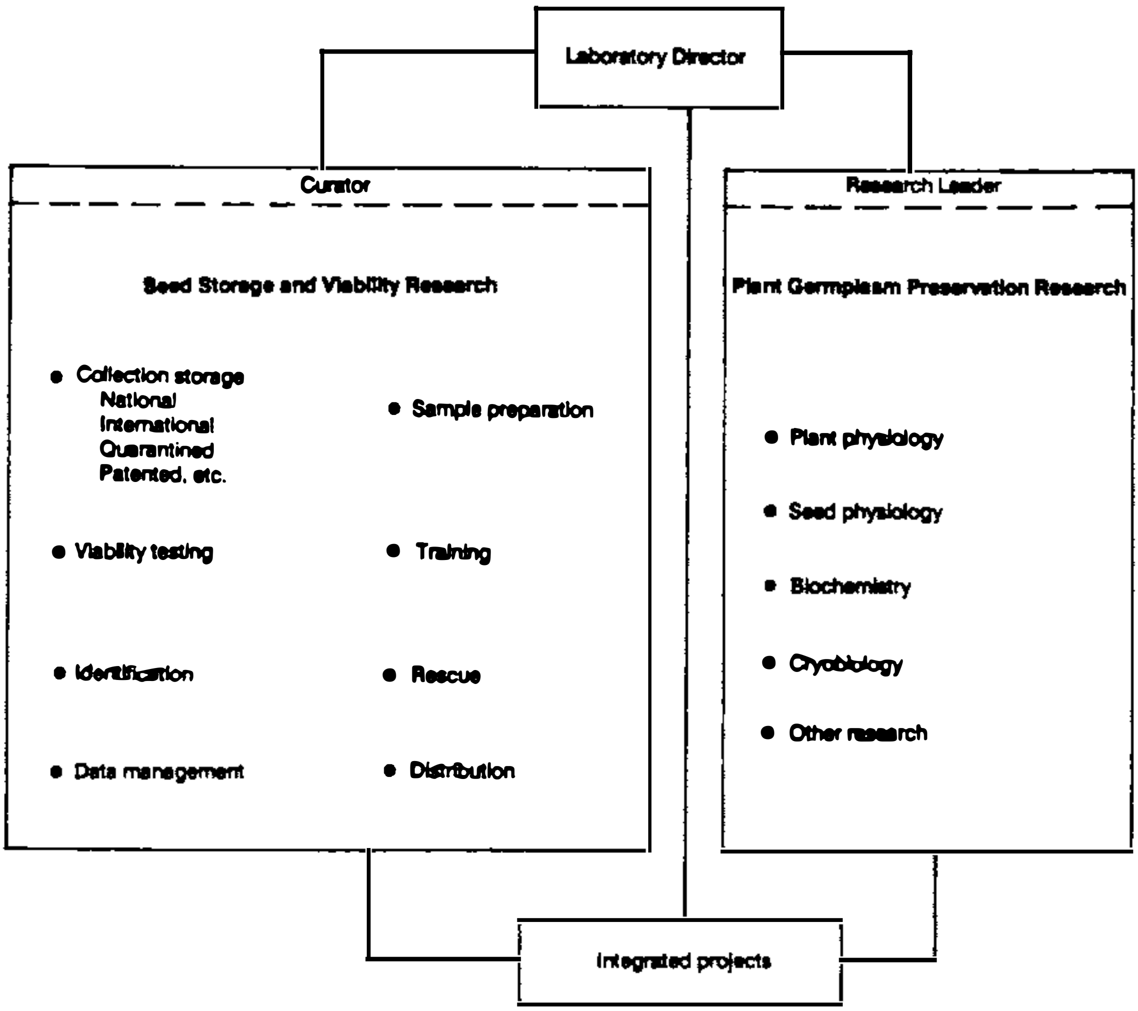

FIGURE 1 Overview of organizational units of the NSSL and their activities.

Viability Research Unit, responsible for conserving and maintaining the germplasm collection; and the Plant Germplasm Preservation Research Unit, responsible for researching new technologies for preservation and the physiology and biochemistry of seeds or tissues under storage (Figure 1).

As the physical plant and various activities at the NSSL expand, there will be an increased need to monitor and maintain essential equipment. Emergency power generators and other standby equipment should be designed to operate automatically. Consequently, there is an increased need for on-site maintenance capabilities. The addition of an individual skilled in maintenance, a suitably equipped maintenance shop, and a store of essential spare parts should also be considered.

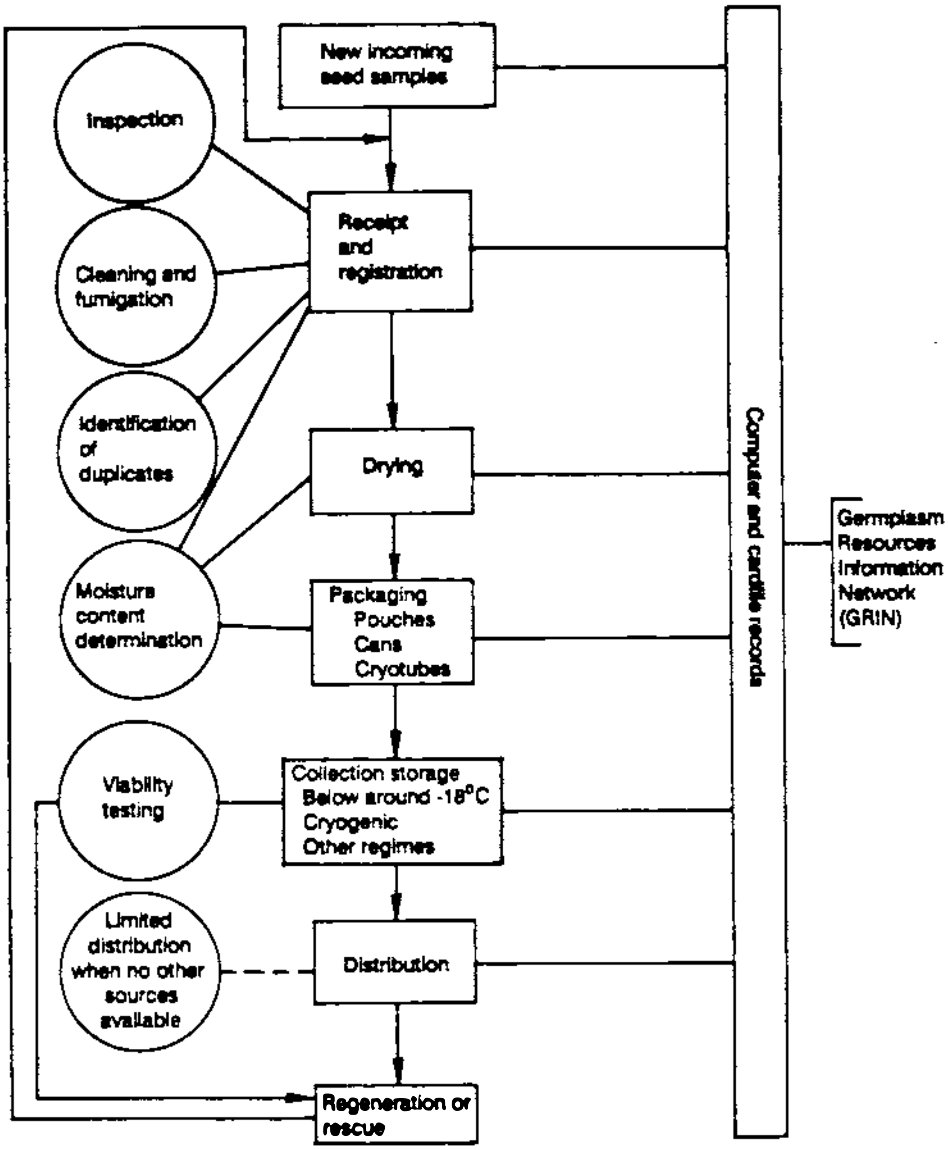

FIGURE 2 Operational flow of accessions in the NSSL.

curator to oversee the activities of this unit is essential. More technicians will be needed to keep pace with the growing NSSL collection. As techniques such as cryopreservation are introduced, even more assistance may be needed to prepare and monitor accessions. The efforts of this unit's technical staff are crucial to the NSSL's central mission of preserving plant genetic resources. Training and supporting staff members to enable them to accomplish the many tasks associated with collection storage and management must have high priorities.

Table 2 Seed Storage and Viability Research Unit Activities and Areas Requiring Space

MISSION-RELATED
Receiving and records (registration)
Fumigation for selected samples
Seed processing
Drying
Packaging for cold storage[a]
Seed viability testing, including space for germinators
Temporary holding
Processing and testing of quarantined materials
Cold storage (different materials may require different areas and regimes)
Packaging for cryogenic storage
Cryogenic storage (requires cryotanks)
Quarantined materials storage
Cold storage for international back-up holdings
Cold storage for patented, registered, or voucher materials
SUPPORT-RELATED
Administration
Staff offices
Meeting and conference room(s)
Public reception
Library
Records
Computer and data management
Office supply storage
Laboratory supply storage
Laboratory waste disposal
Bulk liquid nitrogen storage
Emergency generator
Power panel
Physical plant
Equipment and physical plant maintenance

NOTE: The number, size, and placement of areas for these activities should be based on scientific and design considerations.

[a]The cold storage temperature is around -18 C.

Storage of National and International Collections

While various species may require different storage regimes, there are some general guidelines. Cold storage at below around 0°F (−18°C) has been most frequently suggested. Seeds are dried to below 5 ± 2 percent moisture on a wet weight basis. Seeds should be held in airtight containers that are stored under a RH of approximately 40 percent. (RH is less of a concern when seed containers are sealed against moisture penetration. The level stated is only likely to be achieved if appropriate air-conditioning equipment is installed.)

For long-term storage the IBPGR has proposed similar criteria, which should be considered as minimal standards (Cromarty et al., 1982; Ellis et al., 1985; IBPGR, 1985).

NSSL storage vaults must be secure against fire, flood, or other unintentional or intentional damage. The design must allow for conventional storage, cryopreservation, and technologies that may be developed in the future. Adoption of some technologies may require attention to particular details. Cryopreservation in liquid nitrogen, for example, requires rooms with oxygen monitoring and adequate ventilation.

Decisions on insulating materials used in the walls of storage vaults will affect future operating costs. The thickness of the chosen insulating material and the material itself should provide thermal stability (minimum desirable thermal conductivity of 0.017 to 0.023 W/m°C) for no less than 30 years. The choice of insulating materials should depend upon cost, thermal benefit, and long-term durability. Current international trends to restrict the use of chlorofluorocarbon refrigerants may affect the choice of insulation or refrigerants.

Mobile shelving in cold (around −18°C) storage rooms will allow more efficient use of space. Although more expensive than static shelving, mobile shelving allows a 40 to 50 percent increase in storage capacity for the same amount of floor space. This capacity can generate a savings in the average operating expense for each accession. Whether the total capital costs for a facility of similar capacity are lower for mobile or fixed shelves depends upon the costs of mobile shelving when compared to building additional vault space. Based on its own estimates, the work group considered the adoption of mobile shelving to be justified.

In general, the requirement for seed storage space is most economically met by fewer and larger cold rooms. While these rooms might be suitable for the major portion of the NSSL collection, the work group identified several sets of materials, such as quarantined accessions, international collections, and patented materials, that would be better stored in separate rooms. To allow maximum possible flexibility, primary construction of a large vault area, with the actual storage rooms installed as modular partitions of that space, would be preferable. This design would allow expansion of the storage capacity as the space is needed and consequently save on future operating costs. There is no reason to install all anticipated cold rooms initially. The cost of modular rooms is small compared with the cost of a new facility. With long-range planning, the addition of new cold-storage units should be possible as part of annual maintenance costs. The work group estimated that the NSSL collection could be expected to grow to between 450,000 and 600,000 accessions over the next 35 years. The cost of modular construction with mobile shelving would currently be approximately $200,000 to $370,000 for 200,000 accessions, depending upon the number of cold rooms constructed.

When the NSSL gains new, enlarged storage space, it will be pertinent to review the choice of seed storage containers. The trilayered pouches currently used are efficient in the use of space, inexpensive, and adjustable to the amount of seed stored. No information was available to the work group on the suitability of the pouches to prevent moisture uptake; research may be needed to assess this. Although hermetically sealed cans require greater space and are less flexible, they are more durable and provide more reliable airtight, long-term storage. Thus, RH changes during storage or handling, which may cause increases in seed moisture, do not affect samples in these cans. As new materials arrive or existing accessions are regenerated, the NSSL should consider preserving at least a portion of each for long-term storage in hermetically sealed metal cans.

Cryopreservation using liquid nitrogen, at temperatures from −150 to −196°C, can allow storage for potentially long periods of time. In theory, the need to use up samples for regular viability tests could be significantly reduced under cryopreservation; fewer tests would allow the holding of smaller samples. Research is under way at the NSSL to assess cryopreservation's applicability to a variety of species and determine its advantages, such as improvement in longevity relative to conventional (around −18°C) storage. The problem with such research is that loss in viability at low (subfreezing) temperatures occurs very slowly, making it difficult to obtain conclusive results even over several years.

Cost constraints exist for the adoption of cryopreservation techniques. The work group estimated that capital costs for a cryogenic seed storage system would be three to four times greater than those for equivalent conventional storage; operating costs of cryogenic storage could be four to five times greater than those of conventional storage. These estimates assumed a similar accession size for both stores; total capacity of approximately 500,000 accessions for each; 4,000 accessions per cryotank (size and estimated costs of cryotanks provided by the NSSL); modular construction of and mobile shelving in the conventional store; two to three months reserve supply of liquid nitrogen stored onsite (in addition to that in cryotanks); and a loss rate of 1.5 percent of the total reserve supply of liquid nitrogen per day. Possible additional costs to provide adequate ventilation in a cryogenic storage area were not included. The work group did not know state and federal codes relative to cryogenics, but noted that construction of underground cryogenic facilities and the movement of liquid nitrogen through subsurface lines are restricted in some countries. These factors must be considered in adopting cryogenic storage technologies.

Cryopreservation provides many advantages. Cryopreservation could lengthen storage periods for many small-seeded species, such as *Allium*. Additionally, cryogenic storage could allow long-term maintenance of meristems, buds, in vitro cultures, embryos, and pollen. For these purposes, research on cryopreservation as a storage technology for the NSSL should be pursued. Many species, such as the cereal grains, currently occupy large amounts of storage space maintained at around −18°C. In these cases, alteration of management protocols *alone*, such as reduction of accession size, could provide significant space and cost savings.

Separate cold storage for materials that are part of international and other non-U.S. collections or those held under quarantine should also be provided. Some materials, such as rice from the International Rice Research Institute, are held in the large cartons in which they arrive; adjustable shelving should be considered for the room in which such collections are kept. Similarly, for efficient management and safety, materials that are not part of the NSSL collection, such as Plant Variety Protection samples, should be separately maintained from the primary collection.

Sample Preparation

The proposal to increase the space for seed processing and viability testing from approximately 1,400 to just over 5,000 square feet is modest, given the anticipated growth of the NSSL collection. Space for sample preparation, which includes seed drying, counting, cleaning, packaging for storage, and fumigation, must be clean and dry. These sample preparation areas should be near receiving areas. Drying and temporary holding facilities for the collection should be separate from testing areas, which may be more humid, and from similar drying or holding areas in the Plant Germplasm Preservation Research Unit.

Before storage, seeds must be checked to determine the moisture content and appropriately handled if water content is too high for storage. Drying rooms and equipment for this purpose should have a range of temperatures and humidities that enable processing of all potential samples. Dehumidification and refrigeration controls in such rooms should be mechanically separate for greater efficiency. Air locks in holding and storage rooms, required in many tropical regions, are probably unnecessary. If considered, however, air locks should be designed to discourage their use as supplemental storage.

Testing and Identification

Laboratories for viability testing should be convenient to storage vaults. Interim holding facilities, which are maintained at around $-18^{\circ}C$, could reduce the frequency of access to the main collection. This would allow the main collection to be located farther from testing and preparation areas.

Testing laboratories generally contain running water and equipment, such as germinators, which increase RH. These laboratories should be separate from seed drying, cleaning, processing, and packaging areas. There should be enough space in testing laboratories to incorporate new methods of seed testing and analysis as they are developed. The current area of approximately 1,400 square feet, which encompasses sample preparation and viability testing, is too small. New facilities should be larger.

Data Management

Inadequate data management can weaken efforts to provide efficient storage, testing, and management. It is expected that the GRIN will provide data management assistance to the NSSL. Thus, any locally developed software records should be compatible with GRIN. There is a need to employ a trained individual with the primary responsibility of maintaining the hardware, software, and communications associated with data management.

Accession management information should continue to be maintained in computer- and card-based systems. Facilities for data processing should be in a clean, secure area. The 800 square feet of space and eight-person staff designated for data processing should be sufficient. A local area network may help people gain access to data records. This network should not be so large or so complex that it is hard to maintain, makes access difficult, or endangers valuable records.

Rescue

Occasionally seeds have poor viability or are few in number. They then must be increased under controlled conditions. This process is important for accessions that are rare or otherwise unobtainable. Greenhouse facilities and controlled environment chambers are essential to this activity. Adequate greenhouse facilities owned by the ARS are already available, but consideration should be given to increasing the controlled environment space.

Distribution

Distribution is a limited function at the NSSL and pertains primarily to sending out materials for regeneration. Although requested materials are generally sent from the appropriate active or working collection located elsewhere in the NPGS, there is a need to be able to distribute materials from the NSSL on a limited basis. (This procedure, as well as delays while seed is regenerated, have occasionally led to the mistaken impression that the NPGS does not freely distribute its holdings.) It is expected that such activities could be part of seed processing and occur in the area designated for that purpose.

Quarantine

Some accessions are held under conditions of quarantine because of the actual or potential presence of pathogens and may, therefore, require special attention (Figure 3). These accessions present no danger while in storage, but there is potential for mixing of quarantined and unquarantined material during processing or testing. Processing and testing of quarantined accessions should be restricted to a laboratory designated for that purpose. The laboratory should have its own storage area or separate access to the storage areas and separate germinators, seed dryers, and a fume hood. Ducts in this laboratory should isolate airflow from the rest of the collection.

Training

The NSSL is expected to have an increasing role in training germplasm workers from the United States and other nations. Such training will range from technical instruction to opportunities for research by visiting scientists. An important part of the overall program, training can occupy a significant portion of staff time. Staffing levels should be considered when training programs are designed. The meeting and library facilities previously discussed are necessary for training. When compared to the benefits, the costs for these additions are justified.

Plant Germplasm Preservation Research Unit

Improving technology to preserve germplasm requires a research program with appropriate facilities that are adequately staffed and properly directed. Many fundamental aspects of seed storage have not been studied. A long-range plan that identifies critical questions and provides direction to research activities is needed. NSSL research facilities should reflect the expected research needs of these priorities.

A research leader, responsible to the director, administers the research program at the NSSL. Hiring six scientists and a support staff consisting of eight research technicians, two to four graduate students, one secretary, and five to ten part-time employees is proposed and appears justified. Encouraging visiting scientist appointments and providing opportunities for postdoctoral research would make specialized scientific expertise available.

Research in several areas could greatly enhance germplasm management at the NSSL and provide valuable information for institutes throughout the world. For example, storage

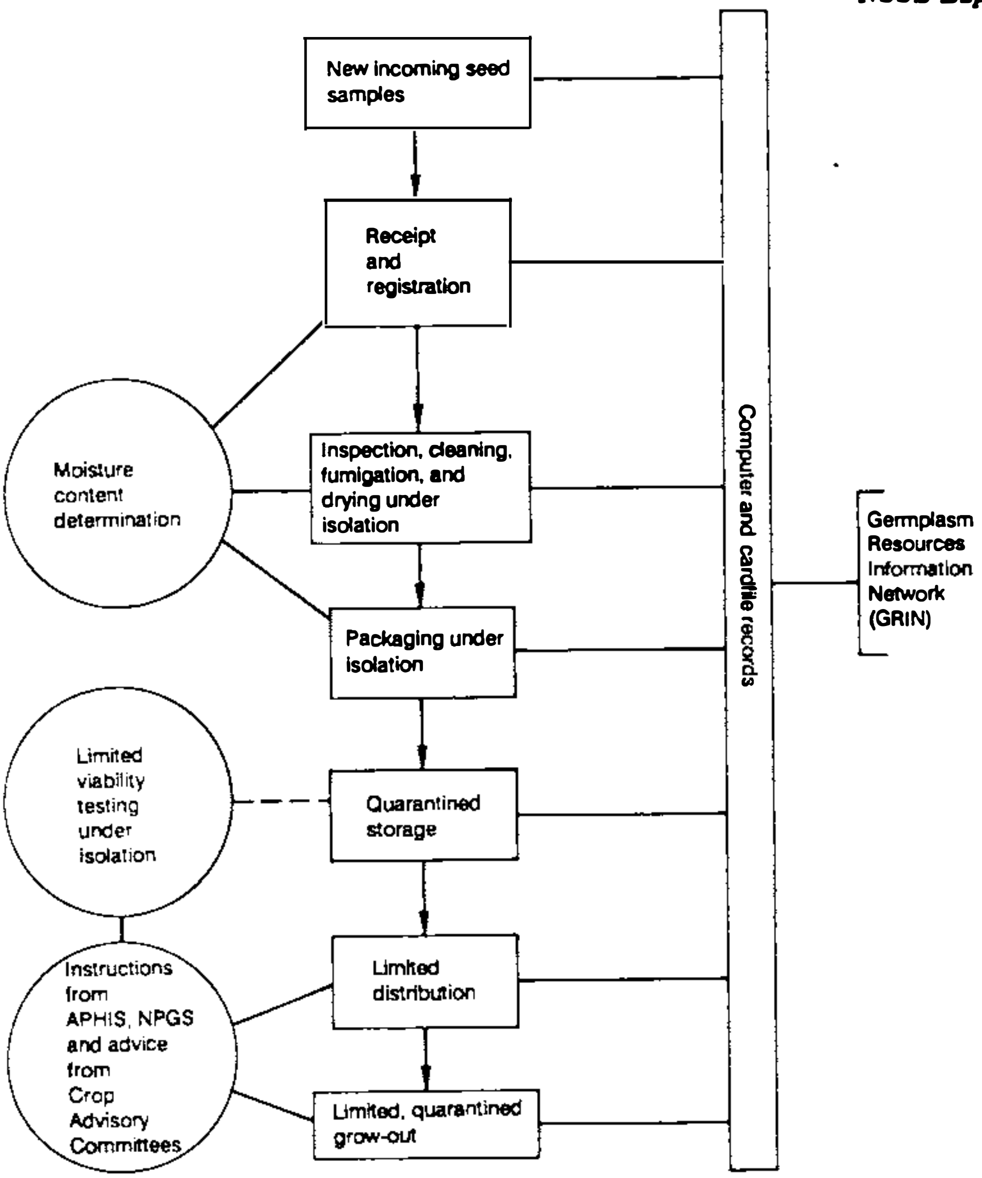

FIGURE 3 Operational flow of quarantined germplasm at the NSSL.

of pollen, tissue cultures, or DNA could provide important new technologies for conserving plant genes. Research on nondestructive tests of seed viability is needed because current protocols result in the loss of a significant portion of each accession to viability tests. Similarly, the mechanisms of seed deterioration under low moisture and temperature need study. Physiology of seeds that are difficult to store, such as high-oil content legumes, is another area for research, perhaps in collaboration with other NPGS units.

The work group's narrow charge did not provide for a detailed review of research at the NSSL. External (outside USDA) peer review would aid appraisal of current and future research in the Plant Germplasm Preservation Research Unit. This examination would be important in ensuring effectiveness of ongoing research, facilitating the development of long-term research goals, and coordinating these goals with other NPGS research activities.

Research laboratories should be distinct from those designed for viability testing. These laboratories need not be adjacent. Laboratories involved in activities such as cryopreservation, however, should be located near appropriate services and storage areas. Although they focus on the study of storage technologies, research efforts should not depend upon the same laboratories or vaults that are used for maintenance of the collection.

Scientists in the research unit will require access to facilities for seed drying and storage separate from those used for the primary collection. Laboratories should also have rooms and equipment capable of holding materials at temperatures from 5 to -196°C and ovens for a range of temperatures. Further, in vitro culture studies and some experimental grow-outs will require cabinets or related facilities with controlled temperature, humidity, and lighting. Additional equipment and space may be needed for specific research activities planned for this unit.

The projected research area increases current space. The area suggested should be examined with regard to long-range research goals and directions. Consideration must be given to purchase of equipment and construction of space that may have only limited use. The work group questions, for example, the wisdom of the proposal to install an electron microscope, which requires considerable outlay in equipment and construction costs. There may be the potential for shared use and support of such facilities already existing on the Colorado State University campus, however.

SECURITY

Climatic or geologic conditions and accidental or willful damage can endanger the security of a germplasm collection. All possible threats to security, however, are not of equal concern. Some may be more expensive to address than others. Decisions on designs that will address security concerns should be based on a feasibility study that considers the benefits, relative costs, and effects on programs.

Climatic Conditions

Climatic factors to be considered in the design of a new structure should include: wind frequency and force, snow, the potential for flooding (including that from a nearby dam), and daily temperature fluctuations.

Fort Collins, Colorado, is situated around 60 miles north of Denver near the foothills of the eastern slopes of the Rocky Mountains. The area has moderate temperatures, light summer rainfall, generally light but occasionally stronger winds, a monthly average of 70 percent sun, and low RH. From a climatic standpoint, it is an excellent location for a seed storage facility.

The climatic conditions of the Fort Collins area should be important considerations when storage rooms, air-conditioning equipment, and the thickness of structural insulation are designed. Heating and cooling degree-day data may be used to estimate operational costs. The number of days above 90°F gives a measure of the worst situation under which regular equipment or back-up refrigeration units may be required to operate. The work group was concerned that use of a cooling tower to distribute surplus heat might limit options for emergency back-up of refrigeration systems and may not be cost-effective.

Apparently because of local topographical features, tornadoes have generally bypassed Fort Collins. The tornadoes generally occur farther east. Although they are small in size and short in duration, they have caused structural damage. Winds in excess of 60 mph may be expected at least two or three times a year on average; maximum velocities of 100 mph are possible. While underground storage offers protection against high winds, aboveground designs that are equally secure may be possible.

It is unclear to what degree flooding might be a problem from rapidly rising groundwater following rain or local dam failure. The potential for flooding should be assessed; designs that prevent flooding damage should have high priority. Total annual rainfall for the Fort Collins area is typically 15 inches, which falls primarily in the late spring and summer. The highest daily rainfalls can exceed 4 inches. Precipitation at higher elevations that produce excessive runoff and raise groundwater or dam levels may also be significant. It would be prudent to assure adequate drainage at the NSSL. Passive protection, such as drains that do not require the functioning of mechanical pumps, is preferable because storms may interrupt main and emergency power supplies, rendering mechanical systems useless.

Geologic Conditions

Geologic conditions that should be considered in the design of a new structure include: groundwater, seismic history, radon contamination, and subsurface soil conditions.

Designs for the facility must adequately reduce or eliminate the potential for groundwater intrusion. Flooding and dampness from groundwater present the most immediate potential threat to security of the NSSL collection. They should be an important consideration in the decision of whether or not to place storage vaults below ground. This decision will require such information as water retention capacity of the soil and the depth and annual fluctuation of the water table.

Seismic activity may possibly affect the designed structural strength of the facility. Information on earthquakes or localized earth movements in the area should be sought as part of an overall design feasibility study. To the extent possible, measures should also be taken to assess the potential for radon gas contamination and to reduce exposure.

Constructing a seed storage facility between approximately 6 and 16 feet below ground takes advantage of subsoil thermal stability and reduced diurnal temperature fluctuation. An underground facility would be protected against solar radiation; this design may also have reduced operating costs for refrigeration. It could be argued, however, that similar benefits could be obtained with adequate insulation.

Intentional or Accidental Damage and Personnel Safety

As much as possible, provisions should be made in the design to prevent damage resulting from individuals or international conflict. The prevention of unauthorized entrance to storage rooms or working areas should be considered. While securing the facility against direct nuclear impact is probably impossible, the NSSL should be able to withstand shock waves from a nearby blast. The work group was not convinced, however, that this concern alone justified underground construction of storage vaults. James (1972) noted that the present facility is reinforced to withstand a nuclear blast three miles away.

Provisions in the design to ensure the safety of workers without sacrificing the security of the new facility or the collections within it are essential. For example, it is necessary to monitor workers while they are in the storage areas in the event of accident or injury. Emergency exits and alarm systems in the storage area will be necessary and should be linked to security within the building and on the Colorado State University campus. The handling of liquid nitrogen requires appropriate safeguards to prevent asphyxiation. Fire-suppression systems that protect workers while minimizing the potential for damage to stored materials should be part of the design. The need for such measures and devices cannot be overlooked; current local, state, or federal safety codes will provide the necessary guides.

REFERENCES

The USDA/ARS Facilities Construction Management Division, the NSSL, the NPGS, and Colorado State University provided planning documents, guidelines, program proposals, and other data.

Cromarty, A. S., R. H. Ellis, and E. H. Roberts. 1982. The Design of Seed Storage Facilities for Genetic Conservation. Rome: International Board for Plant Genetic Resources. 96 pp.

Ellis, R. H., T. D. Hong, and E. H. Roberts. 1985. Handbook of Seed Technology for Genebanks. Vol. 1, Principles and Methodology. Handbooks for Genebanks No. 2. Rome: International Board for Plant Genetic Resources. 210 pp.

Hanson, J., J. T. Williams, and R. Freund. 1984. Institutes Conserving Crop Germplasm: The IBPGR Global Network of Genebanks. Rome: International Board for Plant Genetic Resources. 25 pp.

International Board for Plant Genetic Resources. 1985. Cost-Effective Long-Term Seed Stores. Rome: International Board for Plant Genetic Resources. 38 pp.

James, Edwin. 1972. Organisation of the United States National Seed Storage Laboratory. Pp. 397-404 in Viability of Seeds, E. H. Roberts, ed. London: Chapman and Hall.

National Research Council. Committee on Plant and Animal Stocks. 1945-1948. Selected documents from the National Academy of Sciences records of the Committee on Plant and Animal Stocks. National Academy of Sciences, Office of Archives and Information Services. Photocopies.

U.S. Department of Agriculture. 1981. The National Plant Germplasm System. Current Status (1980), Strengths and Weaknesses, Long-Range Plan (1983-1997). Washington, D.C.: Science and Education, U.S. Department of Agriculture. 200 pp.