AGENCY FOR INTERNATIONAL DEVELOPMENT
WASHINGTON, D. C. 20523
BIBLIOGRAPHIC INPUT SHEET

FOR AID USE ONLY
Batch 70

1. SUBJECT CLASSIFICATION

A. PRIMARY
Food production and nutrition — AN10-0000-0000

B. SECONDARY
Agricultural engineering and structures

2. TITLE AND SUBTITLE
Report of IBPGR Working Group on Engineering,Design and cost aspects of long-term seed storage facilities

3. AUTHOR(S)
(101) Int.Board for Plant Genetic Resources

4. DOCUMENT DATE	5. NUMBER OF PAGES	6. ARC NUMBER
1976	23p.	ARC

7. REFERENCE ORGANIZATION NAME AND ADDRESS
IBPGR

8. SUPPLEMENTARY NOTES *(Sponsoring Organization, Publishers, Availability)*

9. ABSTRACT
The FAO made recommendations in 1975 on the standards and procedures to be used in storing seeds for long-term and medium-term conservation. To further this work, the International Board for Plant Genetic Resources (IBPGR) established a Working Group that met at FAO, Rome, in August, 1976, to define the engineering, design, and cost aspects of long-term seed storage facilities. This report presents the findings of that group. It includes discussion and recommendations concerning the following: types of seed to be stored; moisture content and storage temperature; seed drying and the control of moisture content; routine moisture determinations and germination tests; size of accessions and the volume of the cold room; selection of a site for a storage facility; seed bank construction; design of the cold storage room; insulation; refrigeration plant; air circulation; safety precautions; design standards; cost of prefabricated cold rooms; ancillary rooms and equipment required; and total cost of facilities for long-term seed storage. Appendices to the report identify the participants in the Working Group, present the IBPGR list of crop priorities and their seed storage characteristics, and discuss the use of deep-freeze chests for long-term storage of small seed collections.

10. CONTROL NUMBER
PN-AAE-523

11. PRICE OF DOCUMENT

12. DESCRIPTORS
Materials
Seed production
Storage

13. PROJECT NUMBER

14. CONTRACT NUMBER
AID/ta-G-1272 GTS

15. TYPE OF DOCUMENT

AID 590-1 (4-74)

AGPE:IBPGR/76/25
December 1976

CONSULTATIVE GROUP ON INTERNATIONAL AGRICULTURAL RESEARCH

Report of IBPGR Working Group on Engineering, Design and Cost Aspects of Long-term Seed Storage Facilities

INTERNATIONAL BOARD FOR PLANT GENETIC RESOURCES

Rome, 1976

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PREFACE

The International Board for Plant Genetic Resources includes in its terms of reference "the determination of minimum standards for conservation and regeneration of stocks of both seeds and vegetative material". FAO, through its Panel of Experts on Plant Exploration and Introduction, had made recommendations in 1975 on the standards and procedures to be adopted in storing seeds for long-term and medium-term conservation.

In order to further this work, the IBPGR established a Working Group to investigate the engineering, design and constructional aspects of economical seed storage facilities.

The Working Group, the composition of which is shown in Appendix I, met at FAO, Rome, 18-20 August 1976 and this report represents the findings of the Group. It will be appreciated that the report relates mainly to long-term conservation facilities, but many of the recommendations, e.g. on seed drying, germination testing and other technical aspects, are applicable to medium-term storage of seeds.

REPORT

Types of seed to be stored

1. Seeds can be divided into two major groups according to their viability characteristics:

> The first group, to which most arable crops belong, is described as 'orthodox'. In this group the period of viability is increased logarithmically by decreasing the temperature and moisture content of the seeds and, in species where the appropriate constants have been determined, it is possible to make rough predictions of the period of storage for viability to fall to a given level under any storage environment. However, even within this 'orthodox' group there is considerable variation between species in the length of the storage period which can be achieved under any given set of conditions, varying from comparatively long periods for many of the major cereals, through intermediate periods for some of the grain legumes, to relatively short periods for some grasses and several vegetable species (e.g., onion and parsnip). In some species (e.g., lettuce) it is known that there may be considerable genotypic variation in seed longevity between cultivars.
>
> The second group comprises species which are described as 'recalcitrant' since seeds of these species do not obey the general rules which apply to the majority of species which comprise the 'orthodox' group. In particular, using present technology, they cannot be dried without damage and, under ambient conditions, have relatively short viability periods. Many of the large-seeded tree species are included in this group (e.g., citrus, coffee, cocoa, oil palm).

2. It is impossible to give any general recommendation for the storage of recalcitrant species at this time. Consequently all the recommendations in this report refer to orthodox seeds. A list based on the IBPGR priorities, which indicates whether a species is orthodox, recalcitrant, or whether we do not have sufficient information for classification at the present time, is shown in Appendix II. This list should not be considered as definitive and it may need to be revised as further information becomes available.

Conditions of storage

3. The Working Group accepted as a general recommendation, the proposed Preferred Standards for long-term seed storage installations as included in Appendix IV (revised July 1975) of the Report of the Sixth Session of the FAO Panel of Experts on Plant Exploration and Introduction. These preferred standards specify storage at -18°C, or less, in air-tight containers at a seed moisture content (wet weight basis) of 5±1%.

4. The arguments for specifying really good storage conditions such as those in paragraph 3 are threefold:

> (1) loss of viability in store is associated with a considerable amount of genetic change and thus regeneration (growing a sample of the seed stock to provide a fresh sample of seed for storage) should be instituted as soon as viability has begun to fall significantly, i.e., as soon as viability has fallen by 5-10%;
>
> (2) the costs of regeneration are high, and the difficulties and dangers are considerable, moreover, loss of purity can occur through mechanical mixing and cross-pollination, and in genetically heterogeneous samples, selection can occur depending on the environmental conditions in which the regeneration is carried out; and

(3) the capital and running costs of providing really good conditions are not much greater than for providing storage conditions of inferior quality.

5. In certain specific instances, however, the Working Group suggested that it would be possible to relax the temperature standard to -10°C. This temperature would be acceptable in cases where the responsibility of a seed bank was restricted to a single species or a few species where the intrinsic viability is high and where the viability characteristics are well-known, e.g., in the common cultivated cereals such as wheat and rice. However, when a seed bank has responsibility for a wide range of species, or when it is known that some of the species have poor viability characteristics (e.g., some grasses, vegetables and grain legumes) then it would be advisable to insist on the preferred storage conditions as specified in paragraph 3.

Seed drying and the control of moisture content

6. Accessions of seeds need to be dried to approximately 5%. This is a considerably lower moisture content than is used in commercial practice and, as a consequence, there is no standard commercially-produced equipment suitable for drying small batches of seed to this level. Seed drying is a technology which requires further study and development but, in the meantime, there are various alternative safe practices which can be used by seed banks.

7. Seed drying methods depend essentially on bringing air of very low relative humidity into contact with the seeds. The relative humidity of the air is commonly reduced by raising its temperature. However, when the initial seed moisture content is high (above 18%), in most species it is not safe to raise the air temperature in forced-ventilation driers above 40°C. Since the extent to which relative humidity can be reduced by heating to 40°C is limited, a single-stage drying technique based on heating the air to 40°C cannot be used in most climates for drying seeds down to 5%. However, a hot-air drier running at 40°C can be used as the first stage in a number of two-stage methods. If the seed is pre-dried to 11% or less during the first stage, then a second stage drying temperature of 60°C is safe for most species. Using such a technique, it would be possible to dry seeds to approximately 5% in virtually any climate. This technique is used for example, by the National Seed Storage Laboratory at Hiratsuka in Japan.

8. A number of other techniques could either be used as an alternative second stage to the one described above, or as the sole method of drying. These include forced-air drying techniques based on lithium chloride (as used by the Genebank in Braunschweig-Völkenrode, FRG) or placing seed to equilibrate in a cabinet in which the relative humidity is controlled at 15% or less by any other technique. The Seed Bank at the Royal Botanic Gardens, Kew, U.K., is developing a promising small-batch drier based on the water-removing properties of molecular sieves.

9. Whichever system is adopted, a newly established seed bank will need to satisfy itself that the technique and procedures are reliable and safe, by carrying out initial trials.

10. After the seed has been dried the moisture content can be maintained during storage by using hermetic containers. The alternative to hermetic storage would be to use 'open' containers and control the relative humidity of the atmosphere in the cold room. However, in order to achieve a satisfactory low relative humidity for this purpose (i.e., approximately 15% R.H.) it would be necessary to install specialised dehumidification equipment (e.g., systems depending on the dehydrating properties of lithium chloride). Operating such a system at sub-zero temperatures presents some technical difficulties and because of these it may not be entirely reliable. Furthermore, its cost may be of the same order as the refrigeration plant. It should also be pointed out that hermetic storage (in contrast to 'open' storage) would prevent any rise in moisture content which could occur rapidly in open storage if there should be a power failure. Accordingly, once the seed has been dried, it is strongly recommended that the moisture content is controlled by hermetic storage as recommended by the FAO Panel of Experts on Plant Exploration and Introduction.

11. Three types of container are considered suitable for hermetic storage: glass jars or vials; metal cans; and laminated foil packets.

12. The seals on screw-cap jars are not always perfect. Consequently, it is recommended that if they are used, indicator silica gel, or silica gel with cobalt chloride indicator paper, should be included so that if a leak should occur, this can be detected. Glass vials which are sealed by annealing the glass are relatively safe, but inconvenient.

13. Sealed cans are safe and relatively convenient. They can easily be resealed after withdrawing a sample. Vacuum sealed cans have the advantage that faulty cans can be detected with the use of a tuning rod, but since can failure is rare, and since minor improvements in longevity (resulting from removal of oxygen) would probably be minimal, it does not seem necessary to recommend vacuum canning as a standard procedure; neither does it seem necessary to recommend sealing in nitrogen or other inert gas. Sealing in air at atmospheric pressure would be satisfactory.

14. Laminated foil packets are convenient and have already been adopted by at least one seed bank. However, they cannot be recommended for general use at the present time without further precautions being taken. A seed bank wishing to adopt them immediately can guard against possible failure either (a) by enclosing foil packets in an additional sealed container (e.g., a glass jar) or (b) by controlling the relative humidity of the store at about 40% R.H., using conventional refrigeration techniques, and this would ensure that the moisture content of the seeds would not rise above 8-10% should there be a packet failure. Providing the packets are obtained from a reliable manufacturer and have a robust specification (e.g., outer layer 16.76 g/m^2 Melinex (syn. Terylene), middle layer 33 g/m^2 aluminium foil, inner layer 46 g/m^2 polythene) and providing the sealing technique is adequate, further experience may well show that these additional precautions are unnecessary. Such packets could be obtained in bulk at a cost of about $110 per 1000 packets.

Routine moisture determinations and germination tests

15. The procedural methods for dealing with accessions will affect accession size and thus the size and cost of cold stores.

16. When an accession is received by a seed bank, it may be necessary for it to be cleaned and dried, and it will certainly be necessary for its moisture content to be determined and its percentage viability assessed.

17. Since different moisture determination techniques give different results, it is recommended that the methods prescribed by the International Seed Testing Association (ISTA) be adopted (International Rules for Seed Testing, 1976; Seed Science & Technology, Vol. 4, No. 1); although it is recognised that when seed is limited, as it often will be, it may be necessary to reduce the quantity of seed which is used for the determination below that which is officially recommended.

18. The initial germination test on accessions should also be carried out using the procedures for selecting and testing prescribed by the ISTA. This involves the use of 4 x 100 seeds. In order to conserve seed, it is suggested that subsequent tests during storage be carried out on 2 x 100 seeds. If such a test indicates a drop in viability of 5%, then it should be repeated immediately on a further 2 x 100 seeds. If the combined results confirm that a significant drop in viability has occurred (which can be checked by consulting the compatability table published in the ISTA Rules, 1976), then it is recommended that the seed bank arrange to regenerate a sub-sample of the accession. It is suggested that the regeneration procedure is instigated as soon as there is a significant drop in viability because of the high level of genetic mutation which accumulates in the surviving seeds as viability declines.

19. In many crop species an initial viability of 80% or more is normally expected, and if on receipt it is less than this, arrangements should be made at once to regenerate a sample of the accession. However, in some species the initial viability is typically less than 80%.

In such cases, it is suggested that immediate regeneration would only be necessary if the initial viability test indicates a viability which is less than about 85% of the expected initial value.

20. Using the storage conditions recommended here, the rates of decline in viability for most species are likely to be extremely slow; indeed no significant drop in viability would be anticipated in good quality seeds of some of the major crop species for a century or more. Consequently, it will not be necessary to carry out routine tests to monitor viability more frequently than every 10 years. However, when a new seed bank is established, it is recommended that an additional routine germination and moisture determination test is carried out on a representative sample of the accession during the first 3-5 years in order to check that the system is operating satisfactorily.

The size of accessions and the volume of the cold room

21. The size of the cold room will be influenced by the number of accessions, the number of seeds in each accession, and the size of the seeds.

22. The ideal number of seeds for an accession in a base* collection will depend mainly on the number and size of sub-samples which will need to be withdrawn for routine testing and for transfer to active* collections. The size of sub-sample for routine germination testing has already been discussed. The size of sub-sample for transfer to active collections will depend mainly on the need to represent adequately the genetic variability contained within the accession. In the case of genetically homogeneous material (e.g., established varieties of self-pollinating crops, or F1 hybrids) it is clear that the sub-sample size necessary for routine germination testing will also be ample for transfer to active collections. It is much more difficult to make logical proposals about sub-sample sizes for transfer to active collections which adequately represent the variability of genetically heterogeneous accessions, since the problem has not been sufficiently studied and involves complex considerations of population genetics and ecology. Nevertheless, in order to arrive at some rational estimate of the ideal accession size, it is provisionally recommended that the size of each accession in main base collections should, if possible, not be less than about 4,000 seeds for genetically uniform material and 12,000 seeds for heterogeneous material. In duplicate collections at other centres, these numbers could be reduced to 1,000 and 3,000 seeds respectively.

23. For most hard seeds, the volume in cm^3 can be estimated by multiplying the 1000-grain weight in grams by a factor of 1.3 - 1.5. Seeds with appendages, such as grass seeds, occupy a greater volume in relation to their weight. In order to make some rough estimates of the overall capacity required by seed banks in general, we have taken 12,000 seeds of one of the common cereals such as rice, wheat or barley as being typical of seeds in the medium-size range. In wheat this number of seeds would weigh just over 500g and occupy about two-thirds of a litre. Thus a container of 1 litre capacity should be ample. It has further been assumed that the container might be cylindrical and would occupy shelf space equivalent to a square prism of 1,300 cm^3. It is thought that this allowance would also be sufficient to estimate storage capacity for a system in which an accession is packaged in sub-samples of 200-400 seeds which are kept in a rectangular container.

* base collections: for long-term conservation and not for general distribution

active collections: for medium-term storage, regeneration, evaluation, distribution, etc.

24. Calculations show that the use of mobile shelving (compactor systems) as used, for example, in libraries, in place of more conventional static shelving, would double the number of samples which a store of a given volume could contain. In view of this, and taking into account the fact that mobile shelving costs about one-third of the cost of the cold storage room into which it fits, it is evident that for a given number of samples it is more economical to use a smaller cold store equipped with mobile shelving rather than to use a store of twice the volume and furnished with static shelving. The cost of the larger store with the static shelving would be about 50% greater per sample than the smaller store with mobile shelving - even if it is assumed that static shelving can be produced locally at negligible cost. If some allowance is made for the cost of static shelving, then the economic advantage of mobile shelving is even greater. Accordingly, it is recommended that mobile shelving be used.

25. When using mobile shelving complete access to all material can be provided by allowing for two passageways (80-100 cm wide) at right-angles to each other. In addition, in order to allow sufficient air circulation between the inner surfaces of the cold room and its contents, so as to prevent unacceptable temperature gradients, it is recommended that there should be a minimum gap of 20 cm between the shelves and the walls and beneath the lowest shelf and the floor. It would also be convenient to leave a gap of at least 50 cm above the shelves to allow for lighting and ducting. With these assumptions, and making reasonable allowance for the space occupied by the shelves themselves, and for some measure of inefficiency in packing, estimates have been made of the number of accessions which could be held in cold rooms of various volumes (see table on following page). From these it seems that the individual foreseeable requirements of many seed banks could be accommodated within the range of 85-200 m^3. However, because of economies of scale and because certain seed banks may need to store more or larger accessions, estimates up to 282 m^3 (about 91,000 samples) have been included in this report.

26. As a procedure for estimating the cold storage space required when a seed bank is being established, it is suggested that an attempt is made to assess the probable number of accessions which are anticipated over the next ten years, and base the capacity required on this estimate. It is more economical to construct a single cold storage room of this capacity than to provide the equivalent space in several smaller cold storage rooms. But in order to cope with possible increases in capacity which may be required in the more distant future, it would be advisable to design the lay-out of the first cold storage room and its associated facilities so that a second cold storage room could be added in the future without difficulty, should it be required.

Selection of site

27. There are a number of important factors to be considered in the selection of a site for a long-term storage facility. Most of these are obvious, but it may be prudent to state some of the major factors:

(1) Socially stable area within reach of security personnel;

(2) Reliability of mains electricity supply and voltage stability;

(3) Suitability of substratum for foundations, adequate drainage, and absence of flooding;

(4) Situation away from dangerous chemical or fuel storage areas; and

(5) Easy access to the area where seeds of active collections are threshed, dried and cleaned; although these processes which produce heat and dust should not be in the same building.

TABLE OF ROUGH ESTIMATES OF STORAGE FACILITIES OF VAROUS CAPACITIES
(Costs in US$)

Number of accessions (1000 cm^3 each, i.e., > 0.5 kg.)	Volume of cold room required (using mobile shelving)	Area of cold room	Area of ancillary facilities	Total area of cold store and ancillary facilities
22,800	85 m^3 (3000 ft^3)	34 m^2	212 m^2	246 m^2
31,900	113 m^3 (4000 ft^3)	45 m^2	214 m^2	259 m^2
56,200	183 m^3 (6500 ft^3)	73 m^2	220 m^2	293 m^2
91,200	282 m^3 (10,000 ft^3)	113 m^2	228 m^2	341 m^2

Cost of cold room including safety devices & standby generator + 33% freight	Cost of mobile shelving + 33% freight	Costs of buildings & services including architect's fees for cold room & ancillary facilities (assuming $150-600/m^2$)	Cost of laboratory equipment & furniture including 33% freight	Total cost	Cost of cold room and shelving per accession	Total cost per accession
$	$	$	$	$	$	$
26,700	6,650	36,900 - 147,600	48,500 - 69,800	12,765-244,765	1.20	4.95 - 10.74
27,500	8,250	38,850 - 155,400	48,500 - 69,800	123,100-260,950	1.12	3.86 - 8.18
38,000	11,000	43,950 - 175,800	48,500 - 69.800	141,450-294,600	0.87	2.52 - 5.24
51,400	21,150	51,150 - 204,600	48,500 - 69,800	172,200-346,950	0.80	1.89 - 3.80

Seed bank construction

28. As envisaged, a seed bank will consist of a main building containing a standard cold room and another partitioned space for ancillary facilities. The construction of the outer protection shell will be dictated by the local climatic conditions, building regulations and the availability of materials. However, when only small collections are to be stored, other methods are suitable (Appendix III).

Design of the cold storage room

29. It has already been pointed out that there need be no special provision to control relative humidity in the cold store, providing accessions are stored within sealed containers. Nevertheless, in order to prevent icing of the evaporator, and to maintain the integrity of the insulation, it is essential that ingress of moisture into the store is minimised. Furthermore, in order to prevent rusting of any ferrous materials, the relative humidity should not exceed 70%. Consequently, the insulating materials should be adequately sealed against moisture ingress, and in this respect prefabricated panel construction is considered preferable to, safer than, and in most circumstances cheaper than locally built structures. In addition, an air-lock should be provided at the entrance to the cold room. With efficient management it should not be necessary to control the temperature or humidity of the air-lock since the store would only be entered a few times each week, at most. If it were envisaged that the store would be entered much more frequently than this, then in humid tropical climates it would be essential to control the relative humidity of the air-lock at about 30%. This could be conveniently achieved with a lithium chloride humidity control device or some other appropriate system. But it would be preferable to ensure limited frequency of entry through efficient management.

30. If these precautions were taken, relative humidity in the store would automatically be controlled below 70% and, using conventional compressor refrigeration techniques, possibly as low as 40%. As mentioned earlier in this report, it would only be necessary to consider specifically controlling relative humidity at a value as low as 40% if there were some doubt about the reliability of the sealed containers. If it were decided to do this, then the R.H. could be controlled at a guaranteed value of 40% or less by using a small secondary refrigeration plant in which the refrigerant was evaporated at a lower temperature than the main refrigeration plant.

Insulation

31. The thickness of insulation for -10°C to -20°C should be 100-130 mm (4-5 inches) with a thermal conductivity of about 0.017 W/m deg. C; such insulation should meet the economical running requirements of both temperate and tropical countries. A reliable type of insulation should be used so that it retains its thermal properties, resists the attack of pests and vermin, and contains a fire retardent.

32. Doors should be heated to prevent icing, and seals should remain effective without shrinking or warping. Floors should either be ventilated or heated to prevent frost heave. All electrical wiring and fittings should be accessible and designed for low temperature operation.

Refrigeration plant

33. In view of its well-tried reliability, availability, and ease of maintenance, it is recommended that conventional direct or indirect vapour-compression refrigeration should be used. Such systems can be obtained as package units, factory tested systems for operation under tropical conditions.

34. The refrigerant used should be one that is common and readily available in order to facilitate recharging should there be a leakage.

35. Standard commercial refrigeration units and direct expansion, forced ventilation room coolers are recommended. Air-cooled condensers should be used rather than water-cooled condensers, since if water-cooled condensers should be used failure of the refrigeration plant could occur through failure of the water supply or because of impurities in the water.

36. It is recommended that a cold store should be provided with two separate refrigeration units capable of maintaining the desired storage temperature while operating for 18h daily under extreme temperature conditions. Because the maximum electricity load is governed by the large starting current of the compressor motor(s) the units should be switched on sequentially using current limiting starting techniques. In addition an automatic standby generator should be installed to provide sufficient power for at least one refrigeration unit and other essential services should there be a failure in the mains supply.

37. A three-phase alternating current power supply will be required. The estimated total connected load would be 20-45 kVA for the store sizes considered in this report.

Air circulation

38. If it is assumed that circulation spaces are left within the store as indicated in paragraph 25, then recirculation of air in the cold room to prevent unacceptable temperature gradients will be achieved using fans and ducting as conventionally employed in cold stores. The chilled air recirculation rate should be between 5-10 changes per hour. More sophisticated air-circulation systems should not be necessary, since a variation of 2°C within the storage space would be quite acceptable.

Safety precautions

39. In addition to providing two refrigeration systems and a standby generator, it is recommended that four devices should be incorporated in order to ensure that the temperature of the cold store operating at -18°C is maintained at the desired temperature. These are:

(1) a continuous temperature recording device;

(2) a temperature-sensitive switch which triggers an audible and visual alarm should the temperature rise or fall by more than 5°C from the control temperature;

(3) a temperature-sensitive switch which cuts off the fans and compressors should the temperature rise or fall by more than 10°C from the control temperature; and

(4) a wax cartridge which switches off the fans and compressors should the temperature rise to 40°C.

In all cases the temperature-sensitive elements should be sited in the upper regions of the store. Together these safety devices should not cost more than $3,000. In the case of the large stores, it is also recommended that a smoke detector be included in the air circulation system.

40. In areas where earth tremors are probable, the store should be constructed on a raft or some other device which minimises the possibility of damage; and in such areas nothing should be constructed above the cold storage room.

41. These precautions should be entirely adequate since if, in spite of them, there should be a failure in the refrigeration plant, the thermal time constant (i.e., the time taken for the temperature to rise through 67% of the range from the operating temperature to ambient) is likely to be 4-5 days in the larger stores. Furthermore, change in temperature

per se does not affect seed viability: the viability period is a function of the integration of temperature with time. Thus, for example, if there were a complete failure so that the temperature rose to ambient for two weeks, this would not be more serious than an initial delay of two weeks in putting the dried seeds into store on arrival.

42. In order to ensure the safety of people using the store, it is essential that the door is designed so that it can be opened from the inside. An indicator light should be placed on the outside of the store in a prominent position which is in parallel with the internal lighting circuit of the store. It is also recommended that a notice is placed on the door which indicates that nobody should enter the store without telling some other responsible person.

Design standards

43. It is recommended that specifications for tender be based on the standards of the American Society of Heating and Refrigeration Engineers (ASHRE) since these are considered the most helpful and are universally accepted.

Cost of prefabricated cold rooms

44. Prefabricated cold rooms which meet these specifications, including standby generators, should be obtainable at the following approximate costs, free on board (FOB), a European port:

		US$
85 m^3	(3,000 ft^3)	- 18,000
113 m^3	(4,000 ft^3)	- 18,500
183 m^3	(6,500 ft^3)	- 26,300
282 m^3	(10,000 ft^3)	- 36,400

Freight and insurance will, of course, vary with destination, but together are likely to be of the order of 33% of the FOB cost.

Ancillary rooms and equipment required for the operation of long-term seed stores

45. In addition to storing the seeds, there are a number of activities which need to be carried out in order to operate long-term storage facilities: the seeds need to be cleaned, dried, packaged, tested for viability, purity and moisture content; and records need to be kept. In some institutes where seed banks are being established there may well be existing laboratories, offices and equipment which could be used or modified for these purposes, but in others, all the appropriate facilities may have to be newly provided.

46. Irrespective of the size of the storage facility the same operations will need to be carried out at each seed bank, and thus the requirements are likely to be relatively independent of the size of the seed store. The following recommendations for minimum space requirements are based on this assumption, although it is realised that for a small establishment it may be possible to reduce these allocations without drastically affecting the efficiency of the organisation.

Machinery room (refrigeration plant for cold store)	20% of area of cold store (but not less than 10 m^2)
Seed drying room	15 m^2
Seed cleaning room	30 m^2
Seed testing laboratory	40 m^2
Offices and records room	40 m^2
Store rooms	40 m^2
Toilets and service room	20 m^2
Total (excluding machinery room)	185 m^3

47. The cost of providing a building to house the prefabricated cold storage room and these ancillary facilities is difficult to estimate, since costs will vary very widely according to location, and may vary between about $150 and $600/m^2 (including services and architects' fees). These assumptions have been incorporated into the table on pages 6-7 in an attempt to set the upper and lower limits of the capital costs of providing a complete long-term storage facility.

Equipment required for ancillary rooms

48. In order to provide the essential services for a long-term seed store, the following equipment needs to be provided:

(a) Cleaning and drying

The number and types of cleaning equipment required will depend on the species which are being handled. In the case of a seed bank dealing with major cereals, for example, only one or two cleaning machines would be required, and these would together cost $3,000-$4,000. However, in the case of a seed bank which has a responsibility for a number of different species, e.g., beet, clover and grasses, then a variety of more complex machinery would be necessary, and the cost could rise to about $15,000. Seed drying equipment is likely to cost about $2,000.

(b) Germination testing and moisture determinations

The following is a list of the minimum amount of equipment required:

	US$
Centrifugal divider	600
Small hand tools	1,000
3 incubators (refrigerated) at $1,500 each	4,500
Domestic refrigerator	300
Forced draught oven	600
Precision balance (weighing to 0.001g)	1,000
Coarse balance (weighing to 0.1g)	300
Seed grinder	500
Total	8,800

In addition, in certain circumstances, the following equipment may also be required:

	US$
Blower (for preparing grass seeds for germination tests)	1,000
Copenhagen tank (for testing light-sensitive seeds)	1,000
	2,000

(c) Packaging equipment

Irrespective of whether laminated foil packets are used for storage, such packaging would in any case be very convenient for distributing samples; and sealing equipment for laminated foil packets would cost about $700. Canning equipment, if cans were used for storage, would cost about $1,300.

(d) Furniture

	US$
Laboratory	15,000
Office	10,000
Total	25,000

Freight and insurance charges: For developing countries, it would be necessary to increase these costs by up to 50%. But since it is known that the figure would be lower in some areas, and since it may be possible to obtain some items (e.g., furniture) locally, 33% has been added to the estimates for equipment shown in the table on pages 6-7.

The total cost of facilities for long-term seed storage

49. The table outlines the costs of cold stores of various sizes and their associated laboratories, offices and equipment. In some cases, suitable buildings, laboratories and offices may already be available and, for such situations, the penultimate column shows the cost per sample of providing cold storage and shelving; this varies from $0.80 to $1.20 per sample according to the size of the cold storage room. However, in many cases, it will also be necessary to build and furnish associated laboratories and offices. Accordingly, the final column shows the total capital cost per sample of providing a complete long-term storage facility. This final column shows more than a two-fold range of costs per sample for each size of cold store room considered. This two-fold variation results mainly from a four-fold variation in building costs which have been allowed for in order to cover the range likely to be met amongst different countries. Thus, the provision of a complete long-term storage facility may vary from about $1.90 to $10.75 per sample according to the size of the facility and its location.

SUMMARY OF MAIN RECOMMENDATIONS AND CONCLUSIONS

1. The recommendations apply to the storage of orthodox seeds (paras 1, 2).

2. Acquisitions should be stored in sealed containers at about 5% moisture content in a cold room held at -20°C. The temperature could be relaxed to -10°C in special cases (paras 3, 4, 5).

3. Suitable alternative sealed containers, with certain reservations, include glass jars, cans and laminated foil packets (paras 10, 11, 12, 13, 14).

4. In general, there is no need for special provision to control the relative humidity in cold storage rooms (paras 10, 14, 29, 30).

5. Seed drying needs to be carefully controlled; several alternative systems would be satisfactory (paras 6, 7, 8, 9).

6. Moisture determinations and periodic routine germination tests should be based on ISTA rules, with certain modifications in order to minimise the amount of seed used for these purposes (paras 17, 18, 19, 20).

7. Ideal sizes for individual accessions will depend not only on the requirements for routine testing but mainly on the genetic heterogeneity of the accessions. In base collections the ideal is likely to be within the range 3000-12000 seeds (paras 22, 23).

8. Careful consideration needs to be given to the siting of a cold storage facility (paras 27, 40).

9. Prefabricated panel construction of the cold room is recommended. The entrance door should be heated and an air lock provided. Precautions should be taken to prevent frost heave in the floor (paras 29, 31, 32).

10. The use of mobile shelving to house the accessions in the cold store is economic and considered desirable (paras 24, 25).

11. Refrigeration should be carried out using direct or indirect vapour compression systems, using conventional refrigerants and air-cooled condensers. There should be adequate recirculation of the chilled air within the store (5-10 changes/h) (paras 33, 34, 35, 39).

12. Safety precautions which should be adopted include the provision of two refrigeration units and a standby generator, incorporation of various visible and audible warning devices should the refrigeration plant fail, and devices to ensure that nobody is accidentally locked in the store. Additional precautions should be taken where earth tremors are common (paras 36, 39, 40, 41, 42).

13. It is recommended that specifications of cold rooms should be based on ASHRE standards (para 43).

14. Ancillary rooms and equipment need to be provided for the operation of a long-term seed storage facility. Provision is required for seed drying, cleaning, testing and packaging, and for records and services (paras 45, 46, 47, 48).

15. It is judged that the requirements of many banks will be met by cold rooms within the range 85-200 m^3 (approximately 22,000-60,000 accessions), although this report has covered the range up to approximately 280 m^3 (90,000 accessions) to allow for special circumstances (paras 22, 23, 24, 25, 26).

16. The capital cost of cold storage rooms, including shelving, is likely to vary according to the size of the store from $0.80 to $1.20 per accession stored. The capital cost of providing a complete seed storage bank, with minimum satisfactory ancillary facilities, is likely to vary from $1.89 to $10.74 per accession, according to the size and location of the bank (paras 39, 44, 46, 47, 48, 49).

APPENDIX I

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APPENDIX II

IBPGR LIST OF CROP PRIORITIES INDICATING SEED STORAGE CHARACTERISTICS

Key:

N = characteristics not known	R = recalcitrant
O = orthodox	R?= probably recalcitrant
O?= probably orthodox	S = relatively short-lived

Priority 1

Wheat	O
Sorghum	O
Millets	O
Phaseolus	O
Coffee	R

Priority 2

Rice	O
Chickpea	O
Groundnut	O
Soyabean	O
Cowpea	O
Asiatic *Vigna* sp.	O
Cassava	N
Potato	O?
Sweet potato	O?
Bananas	N
Cotton	O
Oilpalm (S. American)	R
Sugar beet	O
Sugar cane	OS
Rubber	R
Cocoa	R

Priority 3

Barley	O
Maize	O
Oats	O
Rye	O
Pigeon pea	O
Pisum sp.	O
Vicia faba	O
Yam	O?
Jute	O
Brassica sp.	O
Oilpalm (African)	R
Olive	N
Safflower	N
Sunflower	O

Priority 4

Amaranthus sp.	O
Quinoa	O?
Teff	O?
Lablab	O?
Lentil	O
Lupin	O
Velvet bean	O
Wing bean	O
Minor tuber crops	N
Taro and other aroids	N
Kenaf	O?
Breadfruit and jack fruit	N
Niger seed	N
Sesame	O
Tea	R?

Priority requiring further study

Flax and linseed	O
Coconut	NS
Tung and candlenut	R?
Grape	N
Tree fruits and nuts	Mostly R
Vegetables	Mostly O, some OS
Forage crops	Mostly O, some N
Medicinal and drug plants	N
Trees other than food trees	Many R, many N, some O, some OS

APPENDIX III

THE USE OF DEEP-FREEZE CHESTS FOR LONG-TERM STORAGE OF SMALL SEED COLLECTIONS

Deep-freeze chests operating at approximately -20°C, such as those used domestically, are entirely suitable for the long-term conservation of seeds. Such chests have the advantages that they are often immediately obtainable locally, and that their number could be added to as a collection increased in size.

It has been suggested that a large seed collection could also be housed in this way. However, in terms of capital and running costs per unit volume of storage space, deep-freeze chests compare unfavourably with the smallest and most expensive cold room ($85m^3$) considered in this report which provides storage space at a cost of $314/m^3$ (including warning and safety devices). A typical chest, internal volume $0.3m^3$ ($13.5\ ft^3$), would cost about $350 in Europe and provide storage space at a cost of $947/m^3$ (excluding warning and safety devices). In other words, on this basis deep-freeze chests are likely to cost about three times as much as cold rooms.

Deep-freeze chests would be suitable for very small collections of seeds, particularly if at least one spare chest and a small standby generator were included in the facility. They could also be used as a temporary expedient while a major facility is being constructed. However, they would not seem to provide a suitable alternative to a large cold room for the long-term storage of major seed collections.