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Department of Energy
Nevada Operations Office
P. O. Box 14100
Las Vegas, NV 89114-4100

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M. W. Frei, Engineering & Licensing Division, Geologic Repository Deployment, DOE/HQ (RW-23) FORSTL

TRANSMITTAL OF FY 85-86 COPPER ALLOY TEST PLAN--MILESTONE M-202

The attached subject plan is being transmitted to you for your information. The plan reflects the division of responsibilities between BWIP and NNWSI in order to avoid a duplication of efforts and costs and completes our Level 1 Milestone M-202.

Should you have any questions upon your review of the plan, please contact Michael Valentine on FTS 575-1557.

Vern F. Witherill

Vern F. Witherill, Chief
Technology Development and
Engineering Branch
Waste Management Project Office

WMPO:VFW-591

Enclosure:
As stated

cc:w/encl.
P. E. Lamont, BWIP
M. D. Valentine, WMPO

cc:w/o encl.
L. D. Ramspott, LLNL, Livermore, CA.
C. Jonson, SAIC, Las Vegas, NV.

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Sent to Jerry Ashley

BWIP 1383
NNWSI 651

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fm. Valentine
NNWSI TEST PLAN FOR COPPER AND COPPER BASE ALLOYS (to FRC Sm Lutherall
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The purpose of this test plan is investigation of the performance of copper and copper-base alloys in the tuff geochemical environment to determine whether these materials can achieve the 300-1000 year containment objectives as established in the NRC Regulations (10CFR Part 60). Development of this test plan is in response to the memoranda from M. Frei [April 23, June 21, August 24] and, more recently, the memorandum dated October 25 [Ralph Stein to D. L. Vieth and O. L. Olson].

To date, the NNWSI Metals Barriers Selection and Testing sub-task (WBS Element 2.2.3.2) has focused on austenitic stainless steels and alloys as the waste package containment materials for a repository located in Yucca Mountain. The testing program is aimed at determining which grade of austenitic stainless steel or alloy, among the several proposed candidates (304L, 316L, 321, 825) and modifications of the basic grades of these, would meet the containment requirements. The testing program considers the different forms of corrosion (general, localized, and stress-assisted) which could occur under different circumstances in the repository environment. The final selection of container material will then be based on results from the testing program which indicate which material possesses sufficient resistance to the form(s) of corrosion most likely to limit attainment of the 300-1000 year containment service life under the most likely occurring physical and chemical environments.

1.0 NNWSI STRATEGY FOR EVALUATING COPPER AND COPPER-BASE ALLOYS AS NUCLEAR WASTE PACKAGE CONTAINER MATERIALS

Evaluation of copper and copper-based alloys as waste package container materials is an opportunity to investigate an alternative alloy system to the austenitic stainless steels. Copper and its alloys offer many of the same advantages as the austenitic stainless steels and certain unique advantages. Copper and its alloys are, like the stainless steels, high toughness materials and are readily fabricable by a variety of processes. Copper, alone among the engineering metals, can thermodynamically co-exist with aqueous environments under certain conditions. Thermodynamic stability may be an important argument in demonstrating that the selected waste package container material can attain the long-term service performance objective. However, under particularly oxidizing aqueous conditions copper readily corrodes, because the different copper oxides or cations are the thermodynamically stable species. Irradiated environments are expected to be oxidizing. Some copper-base alloys are more resistant to corrosion in oxidizing environments than is pure copper. Therefore, much of the NNWSI investigation effort will be initially focused on the corrosion and oxidation performance of copper and copper-base alloys in irradiated environments.

NNWSI plans to work closely with the copper industry associations in the United States. These organizations are the Copper Development Association (CDA) and the International Copper Research Association (INCRA). NNWSI representatives have met with representatives from these organizations. The copper-industry organizations have recommended a list of five candidate materials for consideration as nuclear waste package containers in a tuff repository. Because these organizations are information sources on the corrosion and oxidation behaviors, as well as the fabricability and weldability of the candidate materials, they will help to guide the test program. Further, organizations which in the past have performed research and development work for CDA and INCRA may be organizations to undertake the NNWSI-sponsored work on copper nuclear waste containers. Recently, the copper industry associations have co-operated with the Swedish KBS in their nuclear waste container designs, and the information generated by the KBS research activities will be helpful in guiding the NNWSI effort.

The Basalt Waste Isolation Project (BWIP) is also evaluating copper and copper-base alloys in their waste package container material selection and testing program. Certain common areas between the NNWSI and BWIP test plans have been identified. An agreement has been reached between the two projects on a single effort in these common areas to avoid duplication of work and to attain the scheduled milestones in a timely manner.

2.0 NNWSI EVALUATION PLAN FOR COPPER AND COPPER-BASE ALLOYS

2.1 Parallel Test Program

NNWSI plans to evaluate the five candidate materials recommended by CDA-INCRA under anticipated and episodic environmental conditions which may occur around a waste package emplaced in a repository in Yucca Mountain. The evaluation plan for copper effectively parallels the effort on stainless steels as nuclear waste container materials. Except where specific galvanic effects are the object of investigation, copper and stainless steel specimens cannot be placed in the same test vessel because of potential cross-contamination of the test environment due to production of corrosion products from the dissimilar metals. Copper and copper-base alloys have generally lower mechanical strengths than austenitic stainless steels and the fabrication and welding processes for producing and closing the canister may vary from the processes proposed for stainless steel containers. Waste package designs based on copper or copper-base alloys may differ considerably from those proposed with austenitic stainless steels as the container material. In many of the corrosion tests (stress corrosion testing, in particular), specimens are worked and heat treated to simulate the fabrication and welding process conditions. Because of all of these differences between copper and austenitic stainless steels, parallel testing efforts are needed for the two alloy systems.

The present NNWSI schedule, in conformance with the Mission Plan, calls for selection of container materials at the end of FY-87. At this time, a decision on which alloy system (copper or stainless steel) will be made if the corrosion test programs on each have indicated that candidates in each alloy system are likely to meet the containment service life of 300-1000 years in the tuff repository. The evaluation plan and schedule were developed with this decision point in mind.

2.2 Candidate Copper-Base Materials

The candidate materials recommended by the CDA and INCRA are:(1) CDA 102 - oxygen-free high-conductivity copper; (2) CDA 172 - copper-beryllium; (3) CDA 181 - MZC copper - an oxygen-free copper with small additions of Mg, Zr, and

Cr; (4) CDA 613 - aluminum bronze; and (5) CDA 715 - 70/30 copper-nickel. These candidates were considered on the basis of their expected corrosion resistance in aqueous environments (water and steam), and in the case of CDA 172 and 181 for their increased mechanical strength at the moderately high temperatures expected to develop in the near-package environment (120-250°C, depending on the waste form, waste age, and package design). As these higher strength alloys are considerably more expensive than the other candidate alloys (which are largely strengthened by solid solution and work hardening), their performance investigation will be pursued if design analysis indicates that a high-strength material is required. CDA 102 is the reference material for the KBS waste package in a granite repository; its inclusion in the NNWSI program will help to link results from the two programs.

2.3 Corrosion Susceptibility of Copper and Its Alloys

The initial efforts in testing CDA 102, 613, and 715 will be centered on corrosion/oxidation testing in irradiated environments relevant to the the geochemistry and hydrology at the Yucca Mountain repository horizon. CDA and INCRA concur in this initial emphasis because of the paucity of published data for copper in irradiated water and steam. The dominant environmental conditions in a tuff repository are expected to be oxidizing -- aerated steam with possible episodic intrusions of oxidizing vadose water. Irradiation of these environments may form chemical species such as HNO_3, NO_3^-, NO_2^-, NH_4^+, N_2O_4, H_2O_2, which are known to be corrosive to copper. Ammonia in combination with oxygen or other oxidant causes stress corrosion cracking of a variety of copper-base alloys. Therefore, this initial work will focus on establishing the threshold radiation levels the different candidate materials can tolerate before excessive corrosion degradation occurs. Some of the candidate alloys are expected to be more corrosion resistant in these environments than pure copper. Conjoint effects such as temperature, mechanical stress (residual, thermal, and service), and metallurgical microstructural changes in and around welds will also be considered.

The possible degradation modes are general corrosion, localized corrosion such as pitting attack, crevice attack, and selective leaching, and stress-assisted corrosion (stress corrosion cracking). Pitting attack on copper occurs in some fresh waters and in some sea waters when CO_2 or sulfides are present. As with many other metals, creviced regions may be preferentially attacked because of the environmental differences between the crevice and bulk surface areas. Selective leaching (sometimes called "parting") is a corrosion phenomenon where the less noble alloy constituent is apparently leached away leaving behind a porous mass of the more noble copper. Selective leaching occurs in certain oxidizing conditions. Copper alloys stress corrosion crack in the presence of ammonia compounds. Pure copper is, of course, immune to selective leaching and is virtually immune to stress corrosion cracking. The occurrence of these different corrosion degradation modes will be surveyed in the relevant tuff geochemical environment.

While the corrosion resistance of copper and its alloys depends on the inherent thermodynamic nobility of copper in aqueous environments, in the neutral pH range of associated tuff groundwater protective oxides are expected to form on copper. The recommended alloys with nickel, aluminum, and beryllium and other additions would tend to favor oxide formation. In these cases, the corrosion resistance depends on the nature and mass transport properties of the oxide film and the kinetics of its formation and dissolution. These alloys will tend to behave as "active-passive" alloys (like stainless steels in this regard), so that the corrosion test program will revolve around discerning which mode is operative. Thus the corrosion performance of copper and its alloys may be ascribed to both a thermodynamic basis and a kinetic basis.

2.4 Package Design Considerations

Thicker sections of copper or copper-base alloy may be required in designs for tuff waste package containers because of the lower yield strengths of some of the candidate copper materials and inclusion of a corrosion allowance because of a possibly higher general corrosion rate of the copper materials relative to the corresponding values for austenitic stainless steels. Whether or not thicker sections will be needed depends on results of the corrosion testing program and design and strength analyses. A great advantage in locating the repository horizon above the water table is the absence of a hydrostatic stress on the container, so that relatively thin canisters possess sufficient strength. On the other hand, a thick container wall attenuates the gamma radiation flux emitted by the waste with the result that less radiolysis of the environment may occur and the corrosion rate may be decreased. Thicker sections are usually more difficult to weld, and as more material is needed, the cost per package increases. These trade-offs will be evaluated in design concepts developed specifically for copper alloys.

2.5 Economic Considerations

Economic considerations are also an issue. The current price of copper is higher than that of low-carbon austenitic stainless steels. As with any metal, the availability (domestic and foreign) and the price during the operational period of the repository may impact on the selection. Further, the mass and purity of copper (or other metal) may attract future generations to re-enter the repository to recover this potential resource. These economic issues - and their social implications - will be addressed as part of the analysis of copper as a nuclear waste container material.

2.6 Quality Assurance

Because copper or a copper-base alloy may be selected for fabrication of nuclear waste containers, data generated in the testing and evaluation of these materials may ultimately be used in support of a repository license application. Therefore, the pertinent elements of the NNWSI QA Project Plan will apply to these copper and copper-base alloy testing and evaluation activities.

2.7 Peer Review of the Copper Test Plan

A peer review group will be established to review, evaluate, and critique the copper test plan and to assess the test results as they become available. Support for this activity will come directly from DOE/NV. The Metallurgy Division at the National Bureau of Standards is identified as the organization which will lead this activity.

2.8 Common Work Areas between NNWSI and BWIP

Discussions between waste package task representatives from NNWSI and BWIP have identified common work areas in the two projects. These work areas will be undertaken in a joint effort, with either NNWSI or BWIP taking the lead in organizing and initiating the work. The common work areas are:

1. Analysis of the effects of thickness of the container on reduction of the gamma radiation flux in the near-field package environment. BWIP will initiate the work in this area.

2. Cost and availability of candidate copper and copper-base alloys over the repository construction and operation period. NNWSI will initiate the work in this area.

3. Development of fabrication processes to produce waste package containers. For "thin" containers, these processes may include conventional fabrication from seamless pipe or from rolled and welded plate. For "thick" containers, the feasibility of alternative processes such as hot isostatic pressing (as in the KBS designs) and different casting oprations may be explored. NNWSI will initiate the work in this area.

4. Development of welding processes and techniques, particularly emphasizing welding thick sections (one to several inches) and remote welding operations. BWIP will initiate the work in this area.

5. Formation of a peer review group to review and critique the copper test plan, particularly the corrosion-related parts of it. NNWSI will initiate the work in this area.

Because most of these common work areas do not involve actual testing and laboratory work, the joint work areas will have little impact on the respective NNWSI and BWIP budgets for evaluating copper. The lead organization for the above particular work area will make the contract arrangements and include in the statement of work the relevant details and requirements for both projects. No transfers of funds are anticipated for FY85 between the two projects. Some small modifications in the FY86 budgets may be needed; these details will be worked out at a later date between representatives of the two projects.

2.9 Evaluation Summary

The evaluation plan will therefore consist of three parts: (1) acquire a data base on which the long-term corrosion performance of the candidate copper and copper-base alloys can be assessed in the waste package environment; (2) analyze waste package designs based on copper as the container material and evaluating the impacts on the surface and sub-surface facilities of packaging the waste and handling the filled waste packages; and (3) assess the economic situation involved with using copper as a nuclear waste containment material. As critical pieces of information from part 1 are needed as input information to parts 2 and 3, it is logical that the corrosion test program receives priority in terms of schedule and allocation of resources.

3.0 SCHEDULE FOR EVALUATION OF COPPER AS A CONTAINER MATERIAL

3.1 Corrosion Survey Tests

The principal activity to be initiated in FY-85 is survey testing of the candidate materials in environments relative to a repository in Yucca Mountain. The purpose of the survey test activity is to determine the specific forms of corrosion degradation which are likely to be encountered and which will limit achievement of the container service life. This will require the acquisition and preparation of test materials, fabrication of test support hardware, test monitoring, and periodic measurement of test effects under both irradiated and non-irradiated conditions. As testing under irradiation conditions is expensive and limited by the number of available gamma irradiation facilities, a considerable amount of supportive testing will be performed in unirradiated but repository-relevant environmental conditions. In the survey mode, testing under unirradiated conditions serves to indicate the most instructive environmental and metallurgical conditions (temperature, stress level, alloy microstructure) in which to conduct the more limited number of irradiated tests.

Measurement of the electrochemical corrosion potentials in both irradiated and unirradiated environments is a useful parameter for discerning differences between the two environmental cases. The appropriate electrochemical potentials can then be applied to specimens exposed to unirradiated environments to simulate the radiation effect and allow a greater number of tests to be performed and data points to be acquired in a relatively short period of time. Electrochemical polarization techniques can be used to predict the breakdown of protective films or layers on the metal surface where localized corrosion can initiate. AC impedance techniques can be used to extend electrochemical polarization methods to moist atmospheres. Also, chemical analysis of the irradiated solutions may reveal the nature of the chemical changes, so that corrosion tests can be performed in modified environments to simulate radiation effects.

3.2 Participation of the Copper Industry

CDA and INCRA will be involved in the FY-85 activities. The copper industry has assembled a task group on nuclear waste containers. Some of the members of that task group reviewed the KBS design for a copper canister. Other task group members are particularly knowledgeable on the corrosion, fabrication, and welding of copper and its alloys. NNWSI will work closely with this task group in reviewing test results and recommendations for future work.

3.3 FY-85 Deliverable

A Level I (Headquarters Controlled) milestone is scheduled in time for Headquarters to make a preliminary evaluation report to Congress on copper as a nuclear waste container material at the end of FY-85. This evaluation will include available test results (hence the emphasis on electrochemical corrosion techniques) in the most critical area (irradiated environments). The design and economic parts of the evaluation will be included using available information and/or reasonable assumptions. Lawrence Livermore

National Laboratory will furnish a draft of this preliminary evaluation to DOE/NV by July 31, and NNWSI will review and furnish its draft to DOE/HQ by August 31, 1985.

3.4 Planned Activities for FY-86

The level of funding for copper-container investigations is planned to increase substantially for FY-86. Some activity in FY-85 is therefore directed toward detailed planning of activities to be undertaken in the following year. In general, the survey tests will continue so that additional exposure time in the appropriate environments can be obtained. Additional kinds of tests for specific forms of corrosion will be started as the need is indicated by results from the survey tests. For example, if the survey tests indicate that localized corrosion is likely to be a problem, then more specific tests conducted in special crevice cells will be undertaken. If pitting attack is encountered, then more specialized tests aimed at determining the statistical nature of pitting will be planned. If stress corrosion cracking is an indicated failure mechanism, then more quantitative SCC tests - such as crack propagation measurements on a pre-cracked fracture mechanics test specimen - will be pursued. The behaviors of the pure copper CDA 102 and the different candidate alloys, principally CDA 613 and 715, will be investigated for these corrosion modes.

The mechanical properties of the candidate copper and alloys and their influence on waste package design will be addressed. If higher strength alloys are needed, more emphasis will be placed on testing CDA 172 and 181 at this point. These alloys require a post-fabrication and possibly post-weld heat treatment to attain the high strength microstructure. Performance of this heat treatment in conjunction with the processes for filling and handling the container in a remote handling facility may present technical and economic concerns. Further, the moderately high temperatures which will develop in the container after emplacement of the waste package in the tuff repository may compromise tne strengthening mechanism.

The fabrication and welding of copper-base nuclear waste containers will be addressed in work beginning in FY-86. Alternative fabrication processes such as the hot isostatic pressing operation proposed in the KBS design will be studied for possible application in the NNWSI project. The technical, as well as the economic, aspects of the process will be covered. Other fabrication processes which may merit further study include centrifugal casting. Welding processes for high purity copper and the different candidate alloys will be investigated for their application to closing nuclear waste canisters. If thick canister sections are prescribed, the closure weld of this heavy wall in a remote facility may present major technical challenges. NNWSI plans to work closely with CDA/INCRA with regard to these fabrication and welding investigations. Interaction between NNWSI and BWIP could foster a fruitful generic study of the fabrication and welding processes for nuclear waste containers, as the issues here are largely not site specific.

3.5 FY-86 Deliverable

The FY-86 deliverable will be a report on the survey testing begun in FY-85 and continuing into FY-86. This report would be Level II (DOE/NV Controlled) and will be due September 30, 1986. The report will summarize the results of the copper container research and development work and will indicate if a copper-base material is a viable candidate for nuclear waste containers in a tuff repository. A decision can be made at this point on whether to continue efforts on copper into FY-87. This report will also include an economic analysis of the promising materials (on the basis of the corrosion testing program) including costs of special heat treatments or other process requirements to allow a full evaluation of the candidate materials.

3.6 FY-87 Plans

If the corrosion test program indicates that copper or copper-base containers may attain the 300-1000 year containment life, then work should begin in FY-86 and continue on into FY-87 which addresses the possible interaction between a copper or copper-base container and other components in the waste package. These other components include the 304L stainless steel inner container (or pour canister) for defense and commercial high-level waste packages and the Zircaloy (or, occasionally, stainless steel) cladding on the spent fuel rods. A premature breach in the outer copper container can allow water to transport copper corrosion products inward and this modified environment could accelerate failure of the inner waste package components. The effect of copper corrosion products on the release rates of radionuclides from the vitrified or spent fuel waste forms would need to be addressed.

3.7 Schedule Summary

In summary, the FY-85 and 86 schedules are:

<u>FY-85</u>

1. Begin corrosion survey tests
   a. General corrosion rate determinations in non-irradiated J-13 well water in the 50-100°C range.
   b. General corrosion/oxidation rate determinations in non-irradiated aerated steam (formed from J-13 water) in the 100-300°C range.
   c. General corrosion rate determinations in irradiated water and steam environments selected from the ranges in a and b. Gamma dose rates on the order of 103 to 106 rads/hr.
   d. Electrochemical corrosion tests to measure potentials in irradiated and non-irradiated J-13 well water and to indicate localized corrosion susceptibilities.
   e. Stress corrosion susceptibility tests, slow strain rate, bent beam, and U-bends in selected environmental conditions from a, b, and c.

2. Form copper industry task group to review test results and guide future testing efforts.

3. Plan activities in detail for FY-86, based on FY-85 survey test results, to focus on specific localized and stress corrosion concerns.

4. Begin determination of mechanical strength requirements and design analyses for copper canisters.

5. Report on preliminary evaluation of copper as a nuclear waste container material.

FY-86

1. Continue corrosion survey tests to longer exposure periods.

2. Begin specific tests in areas where copper indicates localized or stress-assisted corrosion.

3. Investigate fabrication and welding processes for producing and closing copper containers. Explore feasibility of alternative fabrication techniques. Investigate welding of thick sections, if required.

4. Perform full economic evaluation of copper as a container material: material costs, fabrication and welding costs.

5. Begin study of interaction between copper and other waste package components, including waste forms.

6 Report on corrosion survey test results and recommendation on which copper candidate(s) for further testing.

FY-87

1. Continue corrosion survey and specific form testing, if warranted by previous promising results and as needed

2. Continue interaction study with other waste package components.

3. Make technical and economic comparison between best candidates from the copper alloy system and stainless steel alloy system for final materials selection.

4.0 IDENTIFICATION OF CONTRACTORS

FY-85:

Lawrence Livermore National Laboratory will have primary responsibility for conducting the evaluation of copper as a nuclear waste container materials. This work will be performed along with and parallel to the work directed toward stainless steel as part of the WBS element 2.2.3.2. LLNL will also engage in performing the electrochemical corrosion evaluation of the candidate materials in and out of the presence of a gamma radiation source. They will also initiate the package design concept analysis to support the economic assessment effort.

In order to bring about a timely execution of the proposed work, sub-contracts are contemplated with the following organizations:

CDA and INCRA to defray support of the copper container task group and to defray expenses in activities in gathering information on the supply, availability, and economic projections, and detailed planning of FY-86 program activities.

Westinghouse Hanford for performing exposure tests of copper and copper-base alloys in gamma irradiated environments to survey corrosion performance of these materials in tuff geochemical environments. They will also conduct supporting metallographic and chemical analysis of the materials and environments.

University of Minnesota to conduct general and localized corrosion testing of candidate copper base materials with electrochemical monitoring in a gamma irradiated environment. They will also use impedance measurements to monitor the oxidation rates in moist environments.

SRI-International to continue with the corrosion modeling activities begun on stainless steel and extend these to include copper. The modeling approach is based on environmental changes in the corrosion potentials.

(Contractor to be identified.) Investigate thermodynamic stability of candidate materials in tuff geochemical environments. This investigation may include the nature and properties of protective layers on the copper base materials under these environmental conditions.

(Contractor to be identified.) Conduct survey stress corrosion studies on the proposed candidate materials. The techniques may include slow strain rate, bent beams, U-bends and other configurations.

FY-86:

The corrosion test work will largely continue from FY-85 with possible additional contractors as the nature of the test results indicate and require. The close working relationship with CDA and INCRA will help to identify which organizations are qualified to perform the specific pieces of work.

It is anticipated that localized and/or stress-assisted forms of corrosion will be the principal degradation modes limiting use of copper and its alloys for nuclear waste containers. To a large extent, general corrosion degradation problems can be solved by increasing the thickness of the container wall, while the localized and stress corrosion problems are avoided by use of materials highly resistant to these forms of corrosion. However, these forms of corrosion have a statistical nature and a large data base is needed for adequate prediction of their occurrence. The nature of stress corrosion testing - stress configurations, material variables, environmental variables (including irradiation) require a number of individual tests. A large fraction of the FY-86 resources are planned to be directed toward localized and stress corrosion testing.

5.0 RESOURCE REQUIREMENTS

FY-85:

Contractor	Amount (k$)	Work Content
LLNL	160	Technical cognizance over copper test plan; Conduct electrochemical survey tests on candidate materials to discern localized corrosion susceptibilities; measure corrosion potentials in and out of gamma radiation facility; package design concept evaluation
W-HEDL	170	Perform exposure tests of copper and copper-base alloys in gamma irradiated environments; assess general, localized, and stress corrosion susceptibilities of these materials in gamma irradiated environments; conduct supporting metallographic and chemical analyses of materials and environments.
CDA/INCRA	35	Prepare summary report on availability of copper and associated costs in using Cu for nuclear waste containers in years beyond 2000. Form task group to review test results; work with LLL in developing detailed test plans for FY-86.

Univ. Minn.	80	Conduct general and localized corrosion testing of candidate copper base materials with electrochemical monitoring in a gamma irradiated environment; use impedance techniques to monitor oxidation rates in moist environments.
SRI-International	10	Supplemental work on modelling of corrosion potentials on copper-base materials in the tuff geochemical environment.
(to be determined)	60	Investigate the thermodynamic stability of candidate copper-base materials in the tuff geophysical and geochemical environment; furnish theoretical basis for long-term corrosion performance predictions; determine nature and properties of protective layers on copper-base materials.
(to be determined)	35	Begin stress corrosion cracking susceptibility tests on candidate materials in tuff geochemical environment; develop quantitative techniques for determining SCC susceptibility (e.g. slow strain rate, bent beam, fracture mechanics).
NV/NBS	50	Review and critique corrosion-related test plans and procedures and participate in the assessment of results and draft report.

Total FY-85 Budget	600	

FY-86:

Contractor	Amount (k$)	Work Content
LLNL	350	Technical cognizance over copper test plan; continue general and localized corrosion susceptibility tests with electrochemical measurements and monitoring; conduct electrochemical potential and polarization measurements in gamma field; begin interaction work between copper and other waste package components; work closely with CDA/INCRA on assessment of fabrication and welding processes for container.
W-HEDL	350	Continue the exposure tests in the gamma radiation facility with additional tests under additional environmental conditions; continue supporting analytical work; correlate gamma radiation flux with corrosion rates; perform limited number of quantitatively stressed specimens in gamma field.
Univ. Minn.	120	Continue electrochemical monitoring corrosion tests in gamma irradiated environments; assess role of protective films in providing long-term stability of copper alloys; conduct impedance measurements in gamma facility.

CDA/INCRA	60	Continue industry involvement with the test plan; investigate alternative fabrication and welding processes for copper containers.
SRI-International	20	Continue corrosion modelling activities and incorporate available test results into models.
(to be determined)	300	Continue stress corrosion susceptibility testing; develop statistical base for predicting stress corrosion behavior; assess mechanical strength requirements for copper-base candidates; begin work on high-strength materials, if warranted.
(to be determined)	100	Continue thermodynamic evaluation of copper candidate materials in tuff geochemical environment.
(to be determined)	120	Work closely with CDA/INCRA and LLNL in assessing fabrication and welding processes for producing and closing copper containers.
NV/NBS	80	Review and critique corrosion-related test plans and procedures and participate in the assessment of results and draft report.

Total FY-86 Budget	1500	

6.0 APPENDIX

Attached is a letter from W. Stuart Lyman, Copper Development Association, dated June 15. The letter describes the five copper industry recommended materials and the copper industry suggested research and development approach.

Evaluation of Waste Package Commonality

Task 1 - Develop and Evaluate a Single Waste Package Design Compatible with all Candidate Media

The objective of this task was to develop a single design waste package compatible with all candidate geologic media and to evaluate the impacts of use of the Common Waste Package (CWP) design in place of the site specific designs being developed by the individual projects.

As a result of this limited study, the following conclusions and recommendations are offered:

- Based on consideration of repository factors alone, there is insufficient incentive to pursue a common waste package design for all geologic media. However, overall programmatic and waste management system considerations might provide incentives. These are to be evaluated in the Task 2 evaluation.

- Carbon Steel appears to be a suitable material for development of a waste package overpack which will be suitable at all three first repository sites. Incoloy-825 appears to offer a satisfactory alternative material choice. If a common waste package design is to be pursued, the NNWSI project should confirm the suitability of carbon steel for their environment, and all projects should confirm the viability of Incoloy-825.

- A thick walled overpack design,similar in concept to those being developed for the salt and basalt projects also appears to offer satisfactory performance in an unsaturated zone tuff environment. If a common waste package design is to be pursued, this concept should be thoroughly evaluated by the NNWSI project. Also, CWP concept optimization should be carried out as a high priority task.

- Total Waste Package Cost differentials associated with use of the CWP indicate a slight reduction (7 to 13 %) in tuff, a slight increase (9 to 15 %) in basalt, and a substantial increase (44 to 47 %) in salt.

- The CWP could require increases in package emplacement rates during Phase 1 of up to 4 times the reference cases. In Phase 2, the emplacement rates will range from 1 to 3 times the reference cases.

- Underground mining and borehole emplacement costs will be generally higher as a result of use of a CWP in lieu of the respective reference designs. Overall, the total of the affected costs (i.e., the sum of drift mining and emplacement borehole costs) is increased by 5% in all cases.

- For the reference case scenario (i.e., receipt of intact spent fuel elements at the repository) estimated cost impacts of a CWP on waste handling building and emplacement equipment costs should be on the order of 5 to 15% of the affected costs.

- Should a CWP be pursued, a high priority evaluation of the licensability of such a design should be performed by each of the projects.

1.1 Materials Considerations

In the development of a Common Waste Package (CWP) design, the first question to be addressed is one of the existence of a package material which would be compatible with each of the diverse repository environments. Table 1.1 presents a summary comparison of the repository environments in each of the candidate geologic media for the first repository.

To address the question of material suitability, WESTON conducted a review of materials screening studies conducted by each of the repository projects to determine whether any materials exhibited potentially acceptable levels of performance in all three geologic media. This review is discussed in detail in Appendix A.

Results of the review indicate that low carbon steel (CS) and Incoloy-825 both appear to offer the potential for development of a successful design waste package overpack which would be compatible with each of the geologic media.

CS is the preferred overpack material of two (salt and basalt) of the three first repository projects. Screening studies for an unsaturated tuff environment suggest that the corrosion performance of CS under the oxidizing tuff environment will be somewhat worse than the preferred stainless steels. However, CS is somewhat less susceptible to stress corrosion cracking than stainless steels. Local phenomena, such as stress corrosion cracking, are expected to be the eventual cause of loss of containment boundary integrity for a waste package in a tuff repository.

Table 1.1

Repository Environment Comparison

	BWIP	NNWSI	SRP
SITE CONDITIONS			
• Pressure (MPa)	11 (Hydrostatic)	0.1 (Atmospheric)	16 (Lithostatic)
• Rock Thermal Conductivity (W/mK)	1.7	1.6 to 2.4	4 to 6
• Ambient Temp (°C)	59	26	40
• Max. Rock Temp (°C)	450	>250	250
• Water Chemistry	Reducing Low Ionic Strength	Oxidizing Low Ionic Strength	High Ionic Strength Brine
• Groundwater Availability	Saturated	Unsaturated Arid	Inclusion Pockets

While this literature survey is far from conclusive, it does support the feasibility of developing a single design waste package compatible with all geologic media under consideration. However, should a CWP design be pursued, a thorough evaluation of these alloy selections should be carried out. CS should be thoroughly evaluated by NNWSI. The suitability of Incoloy-825 as a backup material selection should be evaluated by all projects.

1.2 Common Waste Package Design

For purposes of the development of the CWP design, CS was chosen as the reference material, with the Incoloy-825 held in reserve as a backup. This choice was made on the following basis:

a) CS is already the material of choice for two of the three first repository projects (salt and basalt).

b) It was judged that the thick walled overpack necessary to withstand the high external loads in salt and basalt would provide adequate margin for enhanced susceptibility to corrosion in the unsaturated tuff environment (when compared to the reference thin-walled stainless steel alloy container for that project).

c) Incoloy-825 has a substantially higher unit cost than CS.

To size the CWP, limiting factors in the design of each of the project waste packages were reviewed and the most limiting cases were selected to size the overpack. Sizing was performed by scale-up from reference designs. The performance of the resulting "CWP" design was then evaluated by comparison with the project reference designs to confirm design adequacy. Consideration was limited to spent fuel waste packages only. Details of the CWP sizing are summarized in Appendix B.

Figure 1.2 is an illustration of the resulting CWP design. Table 1.2 presents a summary comparison of the CWP design with the reference designs for spent fuel of the three repository projects.

It should be noted that no attempt has been made to "optimize" the CWP in any way. Consequently, the numeric results presented are biased to some extent. The intent here was to scope the magnitude of the impacts and to explore feasibility of the CWP. Should the CWP be pursued, a high priority should be assigned to concept optimization to achieve an even and rational distribution of the compromises necessary to balance the design among the candidate geologic media.

Table 1.2

Spent Fuel Waste Packages

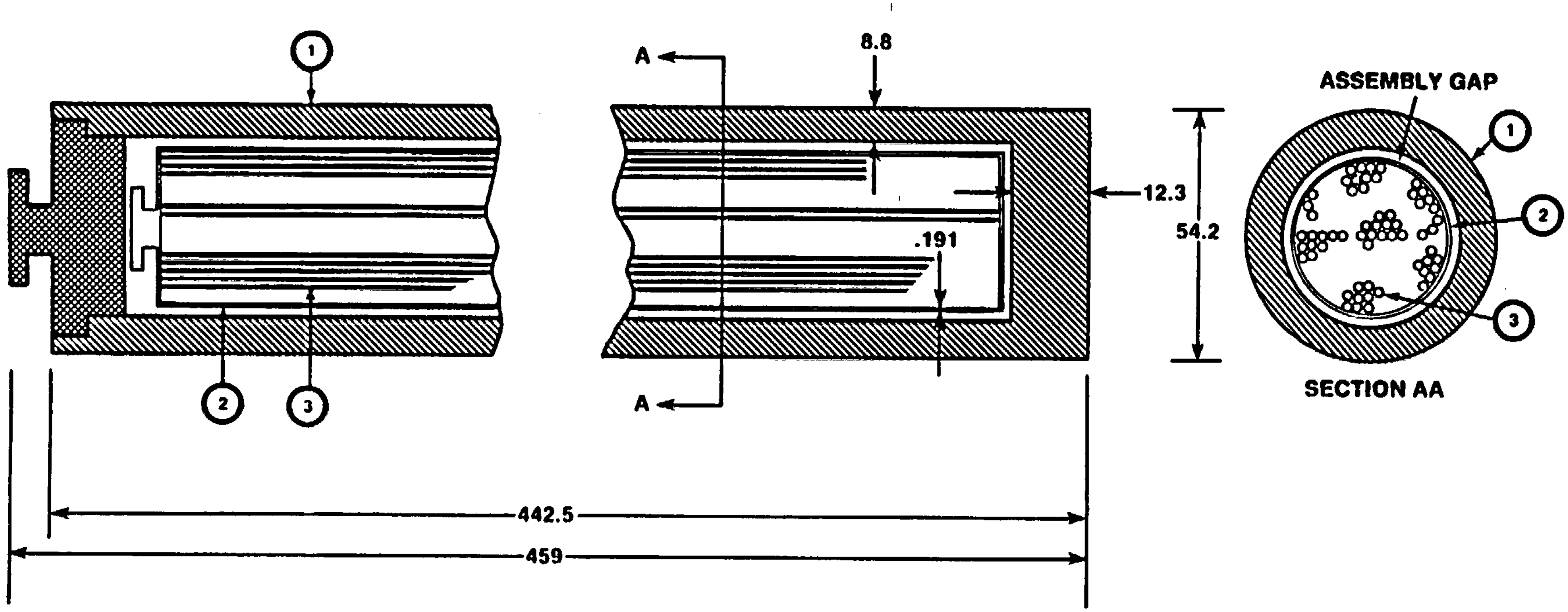
Design Comparison

	SRPO	NNWSI	BWIP	CWP
Waste Form Data				
Configuration	Consolidated Rods	Consolidated Rods	Consolidated Rods	Consolidated Rods
Number of Assemblies	12 PWR 30 BWR	6 PWR 14 BWR	4 PWR 9 BWR	4 PWR 9 BWR
Thermal Output(kw)*	6600	3300	2200	2200
Handling Container				
Diameter - (Cm)	62	50+	-	34
Weight - (kg)	550	1500+	-	68
Overpack				
Diameter - (cm)	84.5	70	50.3	54.2
Wall Thickness-(cm)	10	1	8.3	8.8
Weight (Empty) (kg)	9500	1100	4300	4600
Weight (Loaded) (kg)	17600	6700	7000	7300
Cost (1984 $/pkg)++	35819	29532	18544=	16917** 20262=

** For use in tuff and salt repository
= Includes cost of packing material for basalt repository
+ Space frame - non cylindrical cross section. See Appendix B for details.
* Based on 10 year old fuel with average burnup of 33000 Mwd/MTU
++ Direct Costs not including cost of assembly at Repository.

FIGURE 1.2
COMMON WASTE PACKAGE CONCEPT

ALL DIMENSIONS IN CENTIMETERS



(1) **OVERPACK**
Material - Low Carbon Steel
Empty Container Weight - 4592 kg.

(2) **HANDLING AND STORAGE CONTAINER**
Material - Low Carbon Steel
Body - 33.7 cm ID .191" Wall
Empty Container Weight - 68 kg.

(3) **WASTE FORM**
Consolidated Spent Fuel Rods
4 PWR's (~1.8 MTU)
Max heat Load - 2.2 kw/Package
Weight of Fuel Rods - 2640 kg.

Total Assembly Weight - 7300 kg

Gamma Dose Rate
At Exterior Surface of Overpack
3.3×10^5 mrem/hr

Neutron Dose Rate
At Exterior Surface of Overpack
2.6×10^3 mrem/hr

Gamma Dose Rate
At Exterior Surface of Container
3.2×10^7 mrem/hr

Neutron Dose Rate
At Exterior Surface of Container
6.7×10^3 mrem/hr

9/28/84

1.3 Common Waste Package Performance

Regulatory requirements establish two performance criteria for the waste package:

a) Essentually complete containment for a period from 300 to 1000 years.

b) Gradual release of radionuclides following loss of containment at a rate less than 1×10^{-5}/year.

The waste package is also expected to contribute to compliance with the EPA limits on cumulative radionuclide releases to the environment over 10,000 years. The following summarizes the expected performance of the CWP with respect to each of the reference waste packages in its respective repository environment.

1.3.1 Containment Lifetime

Basalt - From a containment lifetime standpoint, the CWP is very similar to the reference basalt waste package design. This is due to the fact that the CWP is limited by the same consideration which limits the basalt reference design: The maximum heat load of 2200 kw/pkg. In fact, the only differences between the basalt reference overpack design and the CWP are attributable to the incorporation of the handling container in the latter. All of these differences are in a direction which would tend to improve the lifetime performance of the waste package. Because the container material is the same as in the reference design and the waste-induced variations in the emplacement environment are essentially the same as those in the reference case, use of the CWP in a basalt repository would introduce no new technical issues to be addressed during the site characterization program. Thus, it is concluded that containment lifetime performance of the CWP in a basalt repository is essentially the same as that for the reference basalt design.

Salt - Because the total wall thickness of the CWP overpack exceeds that required for structural considerations in a salt environment, the CWP in a salt repository provides additional capability with respect to structural performance compared to the reference salt design. Under-expected conditions, the waste package lifetime prediction in a salt repository is dominated by the relatively low quantity of brine expected to be available; thus, the additional margin would serve no useful function. However, under the unexpected condition of unlimited brine availability, the additional margin could be translated into additional package endurance. Again, because the overpack material is essentially the same in the CWP as in the referencesalt design, use of the CWP in a salt repository would introduce no new technical issues to be addressed during the site characterization program. Thus, it is concluded that containment lifetime performance of the CWP in a salt repository is equal to or slightly better than that of the reference salt package design.

Tuff - In an unsaturated-zone tuff repository, the host medium exerts no external force upon the waste package. Thus, as with the reference package, eventual loss of containment with the CWP in a tuff repository will be caused by corrosion or corrosion related phenomena (e.g. localized corrosion or stress corrosion cracking). The selection of CS (over the more optimal stainless steel being considered for the reference tuff design) prevents an unequivocal statement on CWP lifetime in a tuff repository, simply because it has not been subjected to an in-depth evaluation. However, because the thick walled CWP provides substantial protection against general and localized corrosion, because CS is generally less susceptible to stress corrosion cracking, and because of the minimal quantities of water present in the unsaturated zone repository, the CWP is expected to give satisfactory containment lifetime performance in a tuff repository. However, the change in materials would require a re-orientation of the tuff waste package materials testing program, placing greater emphasis on local and general corrosion of CS (vice stainless steel) in a tuff environment and a comparable program on stress corrosion cracking of CS. Should the CWP be pursued, confirmation of adequate performance in the unsaturated zone tuff environment should be a high priority task for the NNWSI projects.

1.3.2 Radionuclide Release

Use of the CWP in lieu of the reference design is not expected to materially affect the radionuclide release performance in any repository environment. The major implication of this is that use of the CWP in a basalt repository will require use of a packing material (which is a necessary component of the BWIP reference package design to meet the gradual release requirement) as a site specific variation on the CWP design. With this qualification, the gradual release performance of the CWP design would be expected to be comparable to that of each of the reference designs in its respective geologic medium. Although the NNWSI project would be required to substitute CS for stainless steel in many of its release rate tests, use of the CWP design should have minimal impact on the site characterization programs of the respective projects with respect to release performance.

1.4 Repository Effects and Costs

The use of a CWP has effects on the repository design, both in the underground and surface facilities. To quantify some of these effects, the impact of using the CWP design on each project's repository design was assessed. The reference repository designs used in these assessments were those described in each repository project's Two Phase Repository Feasibility Study. This allows consideration of the differing impacts during Phase 1, while the Phase 2 effects alone are suggestive of the impacts on a single phase design. Results of the assessment are summarized below. Details are included in Appendix C.

1.4.1. Total Package Requirements

The most obvious effects of using the CWP are associated with the numbers of packages required for a 70000 MTU repository. Table 1.4.1.A summarizes the total numbers of packages required and the approximate total waste package costs for using the CWP vs. the reference design in each candidate geologic medium.

Although in every case, the total number of CWP required exceeds the number of reference waste packages required, the use of the CWP in the tuff repository appears to offer a small cost reduction in total waste package costs. This is

Table 1.4.1.A

Waste Package Quantity and

Cost Comparison

	Number of Packages		Package Cost* (M $)		Cost Difference (M $)	
	Ref Design	CWP	Ref Design	CWP	(CWP-Ref)	(/Ref)
Tuff Repository						
Phase 1	1,355	4,650	40.0	78.7	+38.7	+97
Phase 2	24,946	37,893	736.7	641.0	-95.7	-13
	26,301	42,543	776.7	719.7	-57.0	- 7
Basalt Repository						
Phase 1	1,110	4,650	45.6	94.2	+48.6	+85
Phase 2	37,893	37,893	702.7	767.8	+65.1	+ 9
	39,003	42,543	748.3	862.0	+113.7	+15
Salt Repository						
Phase 1	4,650	4,650	63.6+	78.7+	15.1+	+24+
Phase 2	12,189	37,893	436.6	641.0	+204.4	+47
	16,839	42,543	500.2	719.7	+219.5	+44

* Direct costs, 1984 dollars, including contingency and quality assurance during fabrication, but not including cost of waste handling, final closure, and emplacement.

\+ differences between Phase 1 Ref cost and CWP are due to differences in the way in which package unit costs were estimated and are not necessarily indicative of any significant physical difference.

due to the high unit cost of the tuff waste package which is, in turn, due in part to the high cost of the space frame+ used in that design.

In the cases of the salt and basalt repositories, use of the CWP results in increased waste package costs compared to use of the reference design: 15% for basalt and 44% for salt. In the case of Basalt, most of the difference is due to the Phase 1 effect, where the reference case uses a larger diameter package to maintain a constant per-package heat load of 2,200 kw/package with intact fuel assemblies. The cost differences associated with package dimensional differences in basalt during Phase 2 are only 9 percent.

Another effect related to the number of waste packages is the emplacement rate. This is the number of packages which must be emplaced per day in order to achieve the design annual throughput (400 MTU/year in Phase 1; 3000 MTU/yr in Phase 2). Table 1.4.1.B compares required emplacement rates with CWP and reference waste packages.

+Consideration of the merits of the space frame design is beyond the scope of this evaluation.

Table 1.4.1.B
Required Emplacement Rates
(Packages/Day)

	Ref. Package	CWP Package
Tuff Repository		
Phase 1	1.1	3.6
Phase 2	4.3	6.6
Basalt Repository		
Phase 1	0.9	3.6
Phase 2	6.6	6.6
Salt Repository		
Phase 1	3.6	3.6
Phase 2	2.1	6.6

With the tuff and basalt repositories, the required emplacement rate of 3.6 packages per day with the CWP during Phase 1 is nearly 4 times that required using the reference package designs. This could have a serious impact on Phase 1 repository operation, requiring emplacement during additional daily shifts and substantial improvement in average productivity during Phase 1. A similar situation would prevail during Phase 2 operations for tuff and salt repositories, where use of the CWP would require improvement in the daily emplacement rate of 50% for tuff and more than 200% for salt. The repository design and cost impacts of this are potentially very large, if for example, an additional waste handling shaft were required to maintain the necessary emplacement rates.

1.4.2 Repository Underground Effects

The use of the CWP design in lieu of the reference design will have impacts on the underground repository layouts. The most significant effects are evident in the emplacement drift mining requirements, in emplacement borehole drilling requirements and in the operating costs of handling and emplacement of wastes. Table 1.4.2 summarizes these effects and the incremental costs associated with them. Methods used to estimate these effects and costs are described in Appendix C.

Table 1.4.2
Repository Underground Effects and
Costs Comparisons

	Volume (m^3)		Estimated Cost		△	△%
	Reference	CWP	Reference	CWP	(CWP-Ref)	(△/Ref)
1. Tuff Repository						
Drift Mining -						
Phase 1	108,600	223,000	27.1	55.6	28.5	105
Phase 2	2,889,300	2,925,900	720.3	729.5	9.2	1
Total	2,997,900	3,148,900	747.4	785.1	37.7	5
Emplacement Boreholes-						
Phase 1	6,100	13,900	16.5	37.4	21.2	128
Phase 2	111,400	113,000	303.2	307.5	4.3	1
Total	117,500	126,900	319.7	345.2	25.5	8
2. Basalt Repository						
Drift Mining -						
Phase 1	85,000	141,900	64.0	106.8	42.8	67
Phase 2	2,901,100	2,901,100	2184.4	2,184.4	0	0
Total	2,986,100	3,043,000	2,248.4	2,291.2	42.8	2
Emplacement Boreholes -						
Phase 1	8,600	20,200	30.0	70.8	40.8	136
Phase 2	143,800	157,000	503.3	549.6	46.3	9
Total	152,400	177,200	533.3	620.4	87.1	16
3. Salt Repository						
Drift Mining -						
Phase 1	324,500	186,400	23.3	13.4	-9.9	-42.
Phase 2	7,017,600	7,272,100	505.2	523.5	18.3	4
Total	7,342,200	7,342,200	528.5	536.9	8.4	2
Emplacement Boreholes -						
Phase 1	8,600	8,600	10.6	10.6	0	0
Phase 2	48,200	65,900	59.6	81.5	21.9	37
Total	56,800	74,500	70.2	92.1	21.9	31

Several conclusions can be drawn from Table 1.4.2. The most obvious is that the overall cost of the underground workings of the repository will most likely increase over the reference case if the CWP design is substituted for the reference design.

For the tuff repository with the reference vertical borehole design, a large portion of the increment is associated with Phase 1 of the two phase concept. This is due to the lower efficiency of the CWP design to accommodate intact fuel assemblies compared to the reference design. To partially offset this effect, the Phase 1 design had to be modified to incorporate a double row of emplacement holes at the minimum spacing and the emplacement drift pitch was reduced to maintain the areal heat load. The combination of these effects results in an increase in the local extraction ratio. Elimination of the two phase concept would result in the differences being smaller, although they would still evidently favor the reference concept.

For the Basalt repository, there is again a significant difference between Phase 1 operations with the reference design and the CWP. This is due to the fact that the reference design employs a larger waste package in Phase 1 to accommodate the same number of intact assemblies (4) as the smaller Phase 2 package of consolidated rods. With the CWP on the other hand, individual package heat loads for Phase 1 are so low that emplacement spacing is limited by the minimum borehole pitch and it is not possible to maintain the local area thermal loading at the reference value. The result is a substantial increase in emplacement drift mining cost to accompany the larger cost of borehole drilling. As might be expected, due to the similarity of the reference Basalt design to the CWP design, the Phase 2 difference in emplacement drift costs are virtually nil. The small difference in borehole drilling in Phase 2 is entirely attributable to the difference in package outside diameters.

For the salt repository, the Phase effects are not so evident. Differences are due more to the treatment of the first Phase waste package by Fluor (who simply assumed emplacement of single intact PWR assemblies within the waste package). The cost reduction in Phase 1 is due to a reduction in the amount of mining required by employing a double row of CWP's in the emplacement drift, a more efficient arrangement which might also have been employed by Fluor.

The difference in mining costs for Phase 2 in the salt repository is due to the slightly reduced areal efficiency of the CWP for disassembled BWR rods compared to PWR rods. It is expected that this could be largely offset in practice by reducing the borehole pitch for BWR packages commensurate with their expected lower heat output, essentially eliminating the mining cost difference. However, the increase in borehole drilling costs in Phase 2 is due to the larger number of CWP's required and is considered to be indicative of the expected cost differential.

Overall, considering all three media, affected underground costs (i.e., the sum of emplacement drift mining and borehole drilling costs) will be increased on the order of approximately five percent as a result of using the CWP in lieu of the reference design, regardless of the geologic medium.

1.4.3 Surface Facility Effects

The impact of a CWP on the Surface Facility Design depends to a large extent on the Waste Management System scenario being considered. The reference scenario, which is taken to be a 2 Phase repository where intact spent fuel assemblies are received and prepared for emplacement (i.e., packaged during Phase 1 and consolidated and packaged for Phase 2) can be expected to exhibit the most significant impact. Other scenaria which involve receipt of spent fuel in other configurations (e.g., consolidated and canistered, and even overpacked) will exhibit other effects. Only the reference case is discussed here. Other scenarios are to be considered under Task 2 of this effort.

Most of the surface facility effects which accrue from use of the CWP are attributable to the differences in emplacement rate previously discussed. The increased capability could be achieved by working additional shifts, by adding additional processing capacity, and by improved productivity. For purposes of this evaluation the additional throughput has been assumed to be achieved by addition of processing lines alone, although in practise, it is likely that a combination of the three methods might be employed.

Estimated cost increments associated with these modifications to the reference designs are summarized in Table 1.4.3. For the basalt repository, the impacts are entirely in the Phase 1 facilities; for salt, they are entirely within Phase 2; while for tuff, they are spread over both Phases.

When compared on the basis of the total of affected costs, it can be seen that surface facility impacts due to the CWP are increases of from 5 to 15 percent: $103.6M for tuff, 41.5M for basalt,and 117.4M in salt.

Table 1.4.3
Repository Surface Facility
Cost Comparison

	Est. Cost Ref.	CWP	Δ (CWP-REF)	Δ% (Δ/Ref)
1. Tuff Repository				
WHB-1	110.6	136.9	26.3	24
WHB-2	600.4	621.3	20.9	3
Emplacement Equip.	78.9	135.3	56.4	72
Total	789.9	893.5	103.6	13
2. Basalt Repository				
WHB-1	106.6	136.9	30.3	28
WHB-2	621.3	621.3	0	0
Emplacement Equip.	124.1	135.3	11.2	9
Total	852.0	893.5	41.5	5
3. Salt Repository				
WHB-1	136.9	136.9	0	0
WHB-2	541.2	621.3	80.1	15
Emplacement Equip.	98.0	135.3	37.3	38
Total	776.1	893.5	117.4	15

1.4.4 Overall Repository Cost Comparison

Table 1.4.4 presents a summary of the overall repository cost impacts from use of the CWP in place of the reference designs. Entries in the estimated cost column are totals of the affected costs from the preceding tables, not the total repository costs. It can be seen that the impact of the CWP on the affected costs is from 8 to 20 percent of the totals. This represents individual cost increments of from $109.8M to $367.5M. It is considered likely, however, that optimization of the CWP and repository designs could substantially reduce these impacts.

Table 1.4.4

Overall Repository Cost Comparisons

	Est. Cost		Δ	Δ%
	Ref.	CWP	(CWP-REF)	(Δ/Ref)
1. Tuff Repository				
Waste Packages	776.7	719.7	-57.	-7
Underground	1067.1	1,130.3	63.2	6
Surface Facilities	789.9	893.5	103.6	13
Totals	2,633.7	2,743.5	109.8	4
2. Basalt Repository				
Waste Packages	748.3	862.0	113.7	15
Underground	2,781.7	2,911.6	129.9	5
Surface Facilities	852.0	893.5	41.5	5
Totals	4,382.0	4,667.1	285.1	7
3. Salt Repository				
Waste Packages	500.2	719.7	219.5	44
Underground	598.4	629.0	30.6	5
Surface Facilities	776.1	893.5	117.4	15
Totals	1,874.7	2,242.2	367.5	20

1.5 Site Selection/Licensing Impacts

Use of a CWP design could impact the repository site selection and licensing process. Consider that, although the thick walled Carbon Steel overpack concept is very similar in principle to the reference designs for the salt and the basalt repositories, it is very different from the reference tuff design. The NNWSI project considers the thin walled stainless steel overpack (as in their reference design) to be near optimum choice for the unsaturated zone tuff repository. Consequently there is concern that the selection of a less-than-optimum material and design concept will make licensing more difficult. While there is some merit to this argument, it is extremely subjective. However, the important point to note is that the waste package licensing decisions, in the final analysis, are to be based on the adequacy of the design with respect to the criteria specified in 10 CFR 60 (i.e., containment lifetime and gradual release). Thus, the NRC in the end will not consider whether there possibly exist better choices of materials and design concepts, but rather, whether the design actually presented is adequate with respect to the criteria in the regulation.

The above notwithstanding, DOE must consider whether a practical waste package development program based on a "non-optimum" design such as the CWP is likely to lead to a licensable design at the time of license application within the real budget and schedular considerations. Should the CWP idea be pursued, this determination should be a high priority task of the NNWSI project.

Another concern with selection of a CWP is that the non-optimum nature of the CWP could bias the selection of a site. This argument also has some merit. Assuming that all other things were equal at the time of site selection, economic factors such as those discussed in Section 1.4 of the report could not be ignored. It is possible that residual effects of the CWP after optimization could change the economic balance in favor of one site or another. However, again in the final analysis, there is no intrinsic evil in choosing among otherwise equal sites on the basis of economic differences if those differences are a result of well-reasoned decisions on a programmatic level. Thus, even though repository economics and technical considerations may not support a decision to pursue a common waste package design strategy, waste management system economics and schedule considerations may override.

A related concern to those above is that, once the site is selected, the CWP would retain some compromises to make it suitable for the sites which were not selected, and that it would not be possible to "optimize" the design for the site selected. Again, there is some merit to this concern. At the time of site selection, the license applications and the Title 1 repository designs will all be firmly based on the waste package design and test program results and it will be difficult to make any significant change to the waste package design (e.g., alternate materials selection) at that time, unless a parallel development program had been carried out. Again, however, if the "compromises" are results of carefully reasoned decisions and if they are consistent with an adequate design, there is nothing wrong with this situation.

1.6 Development and Test Program Impacts

A decision to pursue a CWP would have broad impacts on the repository project waste package test and development efforts. Some insights into the magnitude of the potential effects can be gained by considering the selection of the CWP described earlier.

1.6.1 Materials Test Programs

The selection of CS as the CWP overpack material of choice would have little impact on the salt and basalt materials programs. As pointed out earlier, CS is already the preferred material for these two projects.

For tuff, on the other hand, the selection of CS would have a drastic impact on the program. The present materials testing program emphasizes stainless steel with heavier emphasis on localized effects such as stress corrosion cracking. The selection of CS would require a shift in emphasis as well as a change in materials being studied. NNWSI is already studying corrosion performance of CS in a tuff environment for possible application as an emplacement borehole liner material. This work would require a significant expansion in intensity to provide the data necessary to show compliance with the regulatory lifetime criterion for the waste package and to confirm expected adequacy of CS. The new program would emphasize corrosion phenomena, both general and pitting, with lesser emphasis than at present (although still significant) on stress corrosion cracking.

The selection of Incoloy-825 as a common alternate material would require test program modifications in all three programs, since none of the repository projects is actively considering this alloy at this time. It might also be prudent to test site-specific back-up materials to address the contingency that a CWP may prove to be infeasible. (At present, the three repository project test programs include only limited consideration of alternate materials due to funding limitations.)

Inasmuch as the material questions being addressed are site dependent, the testing program must be carried out on a site specific basis. Thus, it is clear that the selection of a CWP will most likely result in an increased level of activity in the materials testing programs of the individual projects.

A major near-term impact of a decision to pursue a CWP could be a significant delay in issue of the SCP's. The SCP's are required to include (among other things) descriptions of the conceptual waste package designs, repository design, and the waste package test program to be pursued to address site-specific waste package issues. Thus, a change to a CWP would substantially delay issue of SCP's while conceptual designs are developed, test plans are revised, and the SCP's rewritten. The delay could be on the order of a year or more.

1.6.2 Design and Development Programs

Selection of a CWP program strategy would be expected to have a significant impact on the waste package and repository design and development programs. A CWP design strategy would allow consolidation of the waste package design effort at a single contractor in lieu of the three independent efforts currently being pursued. However, the benefits of such an arrangement are not clear-cut.

On the positive side, there should be a net reduction in the amount of management and administrative overhead required, although this would be partially offset by the need for the single agency to coordinate his efforts with each of the projects.

There could also be some savings in cost associated with the development of analytical models and methods for such items as structural, thermal, and radiation shielding analyses through centralization of these efforts. However, much of these same savings can be achieved with the present arrangement by integration of the individual project efforts in these areas. There will also likely be some savings involved in the actual analyses to be performed, although the most detailed and costly analyses will have site-specific inputs and will have to be performed on a site-specific basis in any event.

The number of design drawings necessary could be expected to be reduced, although not by the full 2/3 which might otherwise be expected. Site-specific details associated with handling and emplacement would continue to require a small number of site specific waste package drawings; however, these also could be minimized by proper integration of activities among the projects.

Some savings could also be expected in development program costs. Included among these are programs to resolve development issues such as developing a remote welding, stress relief and leak test process for final closure of the waste package, fabrication of full scale prototype packages, and the "heat and beat" testing necessary to demonstrate package capabilities under accident conditions. Because of their parallel interest in Carbon Steel, the BWIP and SRP projects share common concerns in the development of remote welding capabilities. Thus, assuming proper integration of these efforts under the current program, the potential savings in this area would be reduced due to the elimination of the currently divergent efforts of NNWSI. On the other hand, prototype fabrication and "heat and beat" test activities can be expected to yield a 2/3 reduction by following a CWP program approach. Overall then, some savings in development program costs could be expected from pursuing a CWP course.

A final area where savings might result from pursuit of a CWP is in the design of the WHB and the development of equipment for it. In practice, the selection of a single CWP would allow the development of a single set of rod consolidation equipment based on a single waste package capacity. It would also allow development of a single WHB layout and equipment arrangement, allowing a small (but significant) portion of the building design to proceed independently of site-specific waste package design considerations. However, it is unlikely that a CWP approach is sufficient to allow significant progress in the design of the WHB without early consideration of site-specific factors such as seismic conditions, wind loads, snow loads, soil bearing conditions, drainage, etc. Thus, even though the building design would be very similar from site to site, the use of a CWP alone does not provide sufficient incentive for a single A/E for the WHB design.

1.6.3 Development and Test Program Savings

All the potential savings associated with the CWP would be achieved in the pre-CAA period prior to 1990. During this period, the total Waste Package Development Program Cost (From FY 83 thru FY 90) is $190M. Of this, 40% ($76M) is associated with test program costs, and 18% ($34M) is design and development costs. The remainder is associated with management integration, package environment, and performance analysis activities, which would be unaffected. Based on the preceeding discussion, the following changes in these levels are expected to result from selection of a CWP:

Materials Test Program:	$+ 9M
Development Program:	$- 21M
Net*	$- 12M

These cost savings are clearly insufficient on their own to offset the substantial cost increases from the CWP discussed in earlier sections. Thus, it is concluded that economic considerations alone are insufficient to justify pursuit of a CWP.

*Not including WHB savings.

1.7 Schedular Considerations

Pursuit of a CWP does not appear to offer any significant schedular benefits when compared to the reference cases. In fact, because of the need to redo some work (especially in the NNWSI project) and the shift of emphasis in test program work in all projects, there is very likely to be a net schedular delay in pursuing a common design.

1.8 Summary

The development of a Common Waste Package Design, suitable for disposal at any of the first repository sites appears to be feasible from the standpoint of materials compatibility and overall performance. However, when considering repository impacts alone, there does not appear to be any positive programmatic benefit which provides sufficient incentive to pursue such a course.

APPENDIX A

MATERIALS CONSIDERATIONS

A.1 Materials Screening for Common Waste Package Design

Ideally, the material chosen to provide satisfactory performance in all geologic media should conform to the following guidelines [1]:

1. A simple matrix microstructure so that complicating effects due to precipitation hardening, tempering treatments, etc. are not introduced into the fabrication process. These would include the single phase pure metals and solid solution alloys.

2. Strength and impact resistance to support the waste form, withstand handling, and resist buckling under hydrostatic or lithostatic pressure. There will be some flexibility for selecting different materials with different strengths to give a range of container thicknesses with the same overall strength.

3. Good weldability with, preferably, no need for pre- or post-weld heat treatment.

4. High toughness and cracking resistance to delayed fracture mechanisms such as stress corrosion cracking and hydrogen embrittlement under expected repository environmental conditions.

5. Generally low rates of uniform corrosion and immunity to localized attack such as pitting and crevice corrosion under expected repository environmental conditions.

6. A relatively stable microstructure, to avoid adverse metallurgical changes during long periods at high temperature.

7. Reasonable assurance of an adequate supply at an acceptable cost.

The range of commercially available metals used for structural and containment applications can be categorized as:

1. Low melting point alloys such as aluminum base and magnesium base.

2. Plain carbon and low alloy ferritic steels.

3. Stainless steels:

   - ferritic
   - austenitic
   - martensitic
   - precipitation hardened
   - austenitic/ferritic

4. Superalloys and high alloy austenitics

- nickel-chromium
- iron-nickel-chromium
- monels
- Inconels, Hastelloys
- Incoloys

5. Titanium and its alloys.

6. Copper and its alloys.

7. Zirconium and its alloys.

Screening studies in salt and basalt groundwaters have been the most extensive. [2, 3]. Specimens of the following materials have been examined in these two media:

- <u>Stainless Steels</u>

  304 SS
  304 L SS
  316 SS
  321 SS
  405 SS
  410 SS

- <u>Nickel-Base Alloys</u>

  Inconel 600
  Inconel 625
  Incoloy 800
  Hastelloy C-276
  Ni-200

- <u>Cast Irons</u>

  ductile cast iron

  ductile cast iron with 0.73% Cu

  gray iron

  gray iron with 3.05% Ni

  gray iron with 0.18% Cr, 1.34% Cu

- <u>Titanium-Base Alloys</u>

  Titanium Grade 12

  Titanium Grade 2

- <u>Copper-Base Alloys</u>

  Copper

  Copper-nickel 70-30

- <u>Zirconium Base Alloys</u>

  Zircaloy-2

Materials considered for tuff environments have received relatively little laboratory analysis compared to the salt and basalt screening studies. Three classes of materials have been considered [4]:

1. Iron-base alloys with a ferritic structure

   - AISI 1020 carbon steel
   - AISI A537B carbon steel

2. Iron base to nickel base alloys with an austenitic structure

- 409 SS
- 304L SS
- 316L SS
- Nitronic 33 SS
- Ferralium 255 SS
- Inconel 625
- 2Cr-1Mo SS
- 321 SS
- 317L SS
- JS 700 SS
- Incoloy 825

3. Copper, Titanium, and Zirconium-base alloys

- Ti Grade 2
- Ti Grade 12
- Zr 702
- Copper-nickel 70-30

A.2 Summary of the Materials Screening Studies

Ranking of the service performance of the materials undergoing the screening studies should be made only from tests performed under repository relevant conditions, or those conditions directly identifiable as accelerating the degradation modes in the repository. In fact, repository conditions have been impossible to identify exactly, owing to such complicating effects as radiolysis, heat, groundwater migration, and materials interactions. Nonetheless, a pattern of corrosion resistance emerges from tests that approximates repository conditions. The following table summarizes the materials that have shown promise as container materials on the basis of general corrosion resistance.

	Salt	Basalt	Tuff
1.	Ti-12	Ti-12	Ti-12
2.	304L SS	304L SS	304L SS
3.	321 SS	316 SS	321 SS
4.	Incoloy 825	Incoloy 800	316L SS
5.	316 SS	Copper	Incoloy 825

These lists represent a cross-section of the materials tested in screening studies that appear to exhibit acceptably low general corrosion rates. Little account has been taken for localized failure modes and mechanical properties.

Titanium and its alloys are at the top of all lists for general corrosion resistance. Of the titanium base alloys, the greatest resistance to uniform corrosion, stress corrosion cracking and hydrogen embrittlement is found in the very dilute alpha-titanium alloys, that is, commercially pure titanium, Ti-0.2% Pd and Titanium Grade 12. The dilute alloys also have greater ductility and are less notch sensitive than the more highly alloyed materials, but they have lower strength and creep resistance. Titanium is one of the most expensive materials on a unit weight basis, but when the strength and density are taken into account the effective costs are at least comparable to the intermediate and high nickel austentic alloys. Titanium can be readily welded using inert gas techniques, but its high affinity for interstitial impurities which can cause embrittlement means the welding procedure is more complex than for most materials. The hydrogen embrittlement problem has been of significant concern in recent years, even though no studies have reported failures of Ti Code 12 due to stress corrosion cracking or hydrogen embrittlement. All studies have, however, noted significant hydrogen pickup in all alloys. It may be possible that titanium alloys could be utilized under certain conditions of perhaps a self shielded package, or after elucidation of the long-term rate of hydrogen pickup under repository conditions.

The 300 series stainless steels are essentially solid solution strengthened alloys with moderate strength and excellent ductility. Their principal drawback is a susceptibility to transgranular and intergranular stress corrosion cracking in chloride environments. However, the use of low carbon alloys practically eliminates sensitization and hence intergranular stress corrosion cracking. This concern over cracking in chloride containing environments has eliminated the stainless steels from serious consideration from all but the relatively benign tuff repository conditions. If long term repository-relevant tests could show that stabilized low carbon stainless steels would not undergo cracking, they could be considered for use in all repository environments.

Considering the corrosion resistant nickel base alloys, Inconel 600 is probably the most widely used for general applications because it is virtually immune to classical transgranular stress corrosion cracking in chloride environments. However, it is very susceptible to intergranular stress corrosion cracking even in pure water and in the absence of sensitization. The only solution strengthened nickel base alloys which offer significant benefits over the 300 series stainless steels are those containing molybdenum, such as Incoloy 825. This nickel-iron-chromium-molybdenum-copper austenitic alloy is designed for extremely corrosive environments. It is stabilized with titanium to resist intergranular corrosion and intergranular stress corrosion cracking. The nickel content makes it very resistant to transgranular stress corrosion cracking. The molybdenum and copper give this alloy resistance to pitting and crevice corrosion. The high chromium content gives it resistance to various types of oxidizing environments. Incoloy 825 appears to be a reasonable candidate for a container material in all repository environments.

The suitability of copper or copper base alloys for a universally applicable corrosion resistant container is questionable. A low sulphate to chloride ratio in the groundwater would favor resistance to normal pitting. However, the combination of oxygen, chloride, sulphide and high surface temperature of the container does raise the question of dealloying and sulphide induced pitting, particularly where crevices are present. For pure copper, of course, dealloying is not a problem. Moreover, the Swedish KBS assessment concluded that, in the absence of gamma irradiation effects, a 200 mm thick copper container would have a lifetime of hundreds of thousands of years. Certainly there is considerable historical and archeological evidence to indicate that copper would be acceptable in some environments for at least 500 years.

Plain carbon steels were not identified by any of the screening studies as particularly corrosion resistant materials for waste containers, but they have been carried through for consideration because of their availability, low cost and adequate mechanical properties. It is felt that satisfactory protection against loss of containment can be obtained by increased thickness of the metal.

The table below attempts a summary ranking of the candidate alloys identified by screening studies as potentially suitable for use in any of the repositories currently under consideration.

Material	Corrosion resistance*	Mechanical Properties*	Weldability*	Cost*	Score**	Rank***
Carbon Steel	0	1	2	2	5	2
Copper	0	1	1	0	2	3
Ticode-12	2	0	0	0	2	3
304L SS	0	1	2	2	5	2
321 SS	0	1	2	2	5	2
316 SS	0	1	2	2	5	2
Incoloy 825	1	2	2	1	6	1

* 0 = some disadvantages; 1 = suitable; 2 = superior; for all repository environments

** 0 = lowest; 6 = highest

*** 1 = highest; 3 = lowest

The general waste package will have to withstand the failure modes of all of the repositories under consideration. In the salt and basalt repositories under consideration, the predicted end of the containment period arrives when the uniformly corroding waste container eventually succumbs to lithostatic or hydrostatic pressure. It is considered that even though corrosion rates are not well characterized on the basis of short term corrosion studies, the addition of metal will overcome the accelerated corrosion rates of carbon steel to a sufficient degree to be competitive with the higher priced alloys.

It should be noted that low carbon steel is currently the reference material for two of the three repository projects, with long-term testing underway. The salt repository studies have reported that carbon steel is undergoing unexpectedly severe pitting attack in a high magnesium brine (the so-called, "Brine A"). This pitting has caused significant delay in the development of carbon steel as the salt reference material. Testing in high magnesium containing brines is considered important because it is believed that brine solutions will enrich in magnesium (due to solubility effects) as they migrate toward the heat of the waste package.

A.3 Conclusions From the Materials Screening Studies

The review of the materials considerations for a common waste package indicates that there may be a number of materials suitable for this purpose. The broad class of low carbon steels could be "optimized" by modest additions of chromium or molybdenum to improve general corrosion resistance with only small impacts on cost. Virtually any of the austenitic chromium-nickel alloys such as Inco'oy 825 or 304L stainless steel could conceivably perform satisfactorily in an engineered barrier system. Also, the alloys of titanium and ziroconimum show promise in repository environments if the need for performance outweighs cost considerations.

For purposes of this study, low carbon AISI 1020 carbon steel appears appropriate for the CWP, as well as the Incoloy 825 designed for extremely corrosive environments. Pursuit of the CWP concept with these materials would require that the tuff repository project begin an intensive test program on carbon steel to verify its feasibility. Incoloy 825 would be included as a back-up material in the test programs of all of the repository projects.

Appendix B

Common Waste Package Sizing and Performance Evaluation

This Appendix describes the basis for the Common Waste Package (CWP) Design developed to assess the feasibility of a single design compatible with each of the three geologic media under consideration for the first repository and to assess the impacts on the repository system of choosing such a course. For purposes of this evaluation, only spent fuel waste packages are considered.

B.1 Repository Project Reference Designs

Each of the repository projects has completed a waste package conceptual design and is pursuing advanced conceptual design work based on selected reference concepts. The material which follows presents a brief summary description of each project's reference concept. Figure B.1.1 through B.1.3 and Table B.1 provide summary comparisons of the reference designs.

B.1.1 Basalt Reference Design

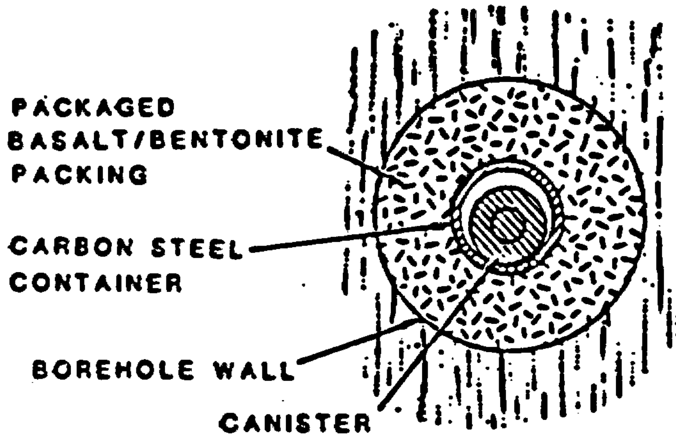
The basalt reference waste package design for spent fuel (Figure B.1.1) employs a thick walled container of Carbon Steel. It is sized to accommodate consolidated spent fuel rods from 4 PWR assemblies or 9 BWR assemblies. For 10 year old spent fuel with an average burnup, this converts to an average heat output of 2200 kw/package. The BWIP project has indicated that this is the maximum allowable package thermal loading because of rock stress considerations for a basalt repository. The basalt design does not include any additional containers for the spent fuel waste form.

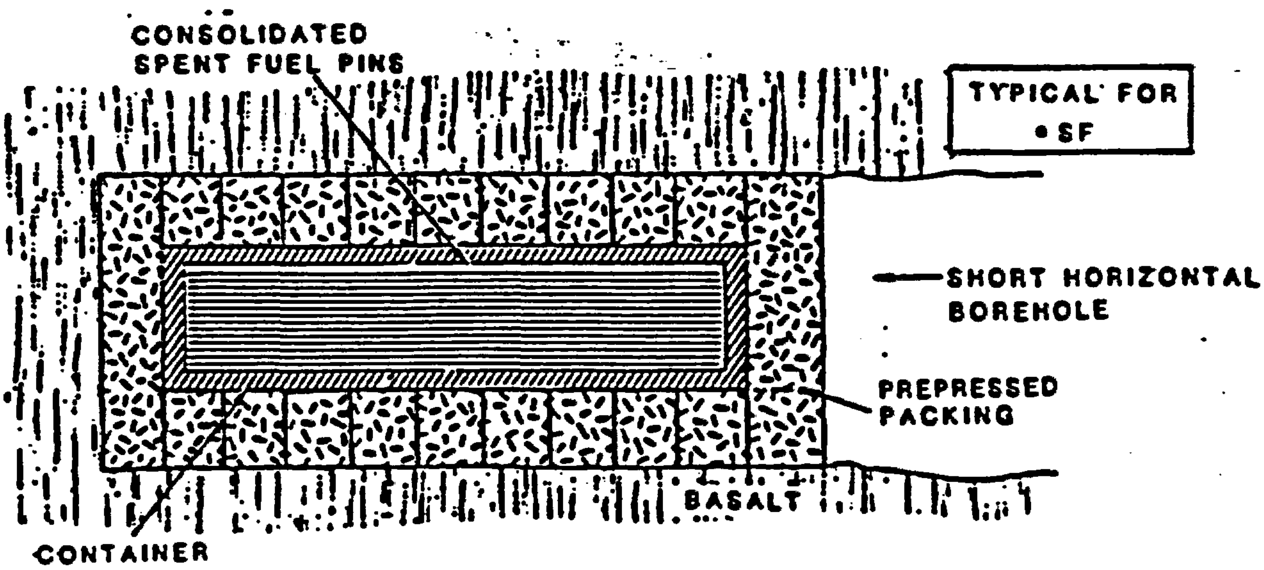
Table B.1
Repository Project Reference
Spent Fuel Waste Package Design Comparison

	Tuff	Salt	Basalt
Number of Assemblies (PWR/BWR)	6/14	12/30	4/9
Thermal Output (DLW)	3300	6600	2200
Internal Container	Space Frame	Segmented Cylinder	None
Overpack Material	Stainless Steel	Carbon Steel	Carbon Steel
Overpack ID (cm)	68.0	64.5	33.7
Overpack OD (cm)	70.0	84.5	50.3
Overpack Thickness (cm)	1.0	10.0	8.3
Packing Material	None	None	80% Basalt 20% Bentonite
Thickness	N/A	N/A	15 cm (min)

Figure B.1.1

BASALT REFERENCE WASTE PACKAGE DESIGN FOR SPENT FUEL





The thick walled container is necessary to withstand the hydrostatic pressure at the repository depth. Additional wall thickness is provided to allow for corrosion for the duration of the waste package containment lifetime, required by regulation to be from 300 to 1000 years. The basalt design includes a packing material, composed of an 80/20 mixture of crushed basalt and bentonite. The primary purpose of the packing is to ensure compliance with regulatory requirements for gradual release of radionuclides in the saturated basalt repository, following loss of containment. BWIP studies have indicated a minimum packing thickness of 15 cm is required.

The basalt design does not incorporate any special features to facilitate retrievability. Retrieval in the reference emplacement made (short horizontal boreholes) is to be accomplished by simply extracting the package from the borehole using the grappling fixture on the closure head of the container.

B.1.2 Salt Reference Design

The salt reference waste package design (Figure B.1.2) for spent fuel also employs a thick walled container of Carbon Steel. It is sized to accommodate consolidated spent fuel rods from 12 PWR assemblies or 30 BWR assemblies. The high thermal conductivity of the salt medium provides excellent heat dissipation, which allows must higher waste loadings before temperature limits are reached. In the case of the salt reference design, the applicable temperature limit is the 375°C limitation placed on spent fuel to ensure continued integrity of the cladding (also based on 10 year old, average burnup spent fuel).

The salt design employs a segmented internal container for spent fuel rods which serves two functions:

a. It facilitates loading of spent fuel rods from dissassembled fuel bundles.

b. It facilitate retrieval (see below)

The thick walled overpack is necessary to withstand the loads imposed by the lithostatic pressure in the salt medium. A sacrificial corrosion allowance is also provided to ensure adequate structural capability throughout the regulatory containment period. The salt design does not use any external packing material.

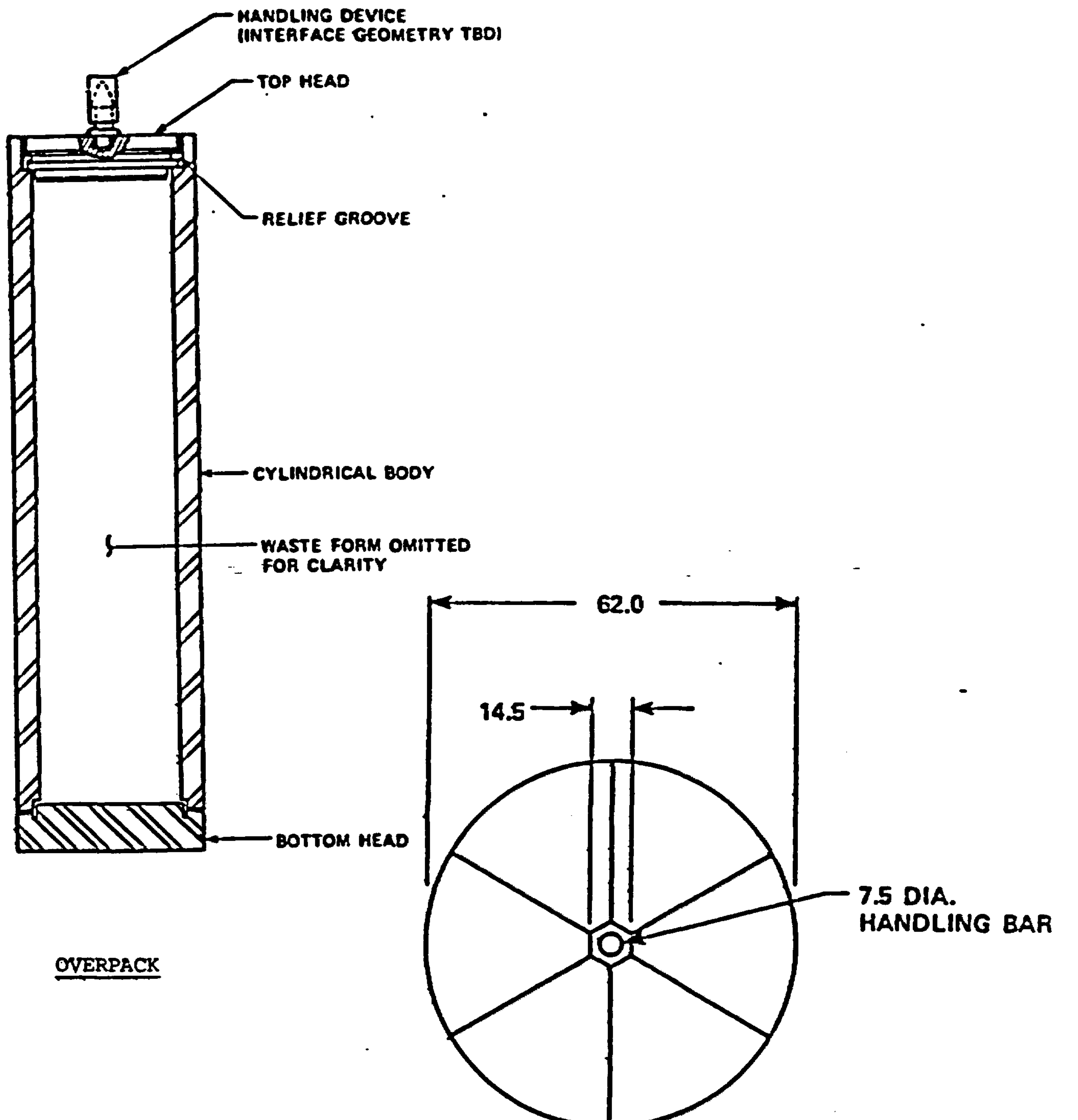
Retrieval in the reference vertical emplacement made is envisioned to be accomplished by overcoring the overpack and extracting the entire emplacement package or by excavation to the top closure level, cutting through the closure weld, removing the head, and extracting the internal handling container from the overpack.

B.1.3 Tuff Reference Design

The tuff reference design (Figure B.1.3) employs a thin walled, stainless steel overpack. An internal space frame is used to accommodate either intact spent fuel assemblies or rods consolidated in canisters with a square cross section of the same exterior dimension as an intact spent fuel assembly. The

Figure B.1.2

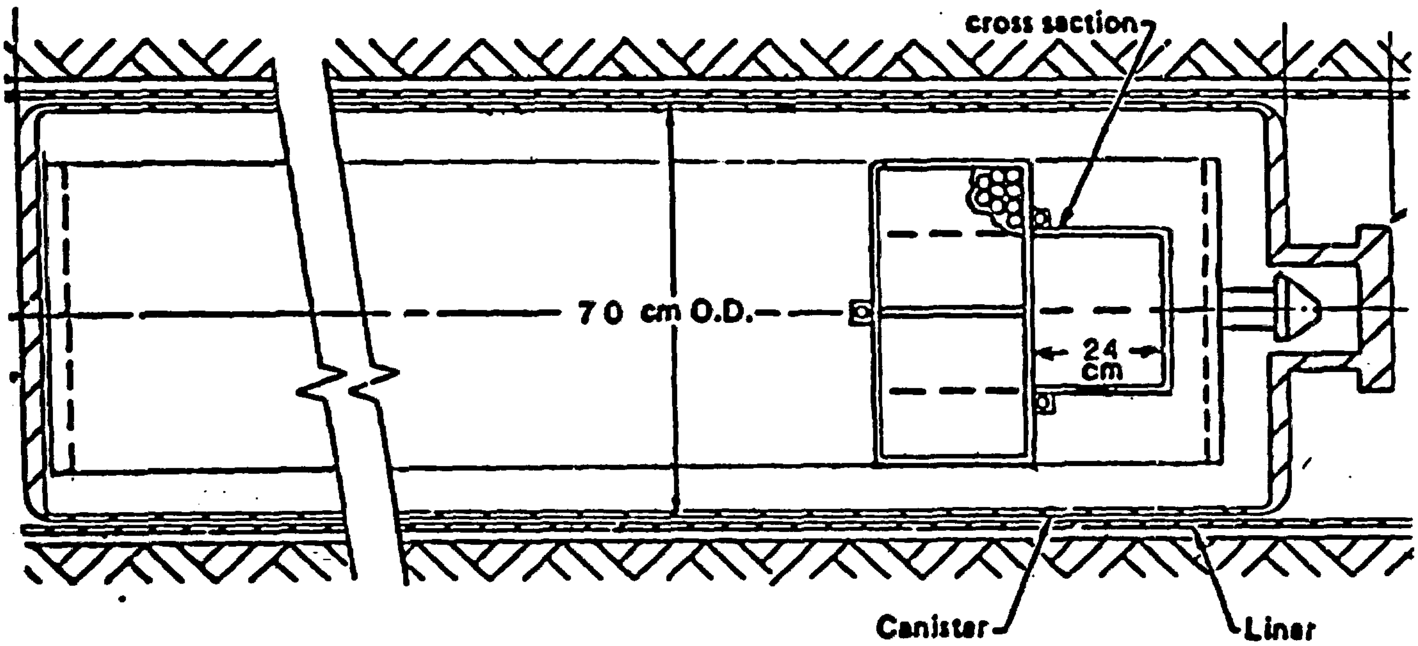
SALT REFERENCE WASTE PACKAGE DESIGN FOR SPENT FUEL



INTERNAL CONTAINER
CROSS SECTION

Figure B.1.3

TUFF REFERENCE WASTE PACKAGE DESIGN FOR SPENT FUEL



reference design concept can accommodate either 3 intact PWR assemblies or 3 canisters of consolidated rods from 6 PWR assemblies and either seven intact BWR assemblies or 7 canisters of consolidated rods from 14 BWR assemblies. Based on 10-year-old, average burnup spent fuel, the heat load of 3300 kw is the maximum consistent with the spent fuel temperature limit in a tuff repository.

Inasmuch as the tuff environment does not exert any external force on the waste package, a thin walled overpack, with thickness sufficient to withstand loads encountered during normal handling and emplacement operations is expected to be adequate. Eventual loss of containment is expected to result from local phenomena such as pitting corrosion or stress corrosion cracking. The selection of a stainles steel alloy is expected to provide excellent resistance to general and pitting corrosion which, coupled with the limited amount of water expected in the unsaturated tuff site, should provide adequate performance with respect to these degradation mechanisms. Minimization of the potential for sensitization to stress corrosion cracking and the levels of residual stresses are guiding the design effort and alloy selection.

The tuff reference design does not employ a packing material; however, an alternative design does provide for packing in the event that the rate of release of radionuclides to the tuff environment from spent fuel exceeds regulatory limits.

At present, retrieval from the reference vertical emplacement configuration does not require any special waste package design features. The alternate emplacement scheme (long horizontal boreholes) may require some additional design features to facilitate both emplacement and retrieval. However, details on these have not been developed.

B.2 Common Waste Package Concept

To develop the common waste package (CWP) design, a "lowest common denominator," approach was used. This method was selected to demonstrate feasibility only, and may not lead to an "optimum" configuration in any sense. Concept features and dimensional sizing were based on providing performance equal to or better than each of the reference designs in its respective medium with the minimum necessary departure from established project test and development plans. Should the CWP concept be pursued by the OCRWM, a much more detailed concept optimization study should be performed.

B.2.1 Material Selection for CWP

Appendix A derives the relevant factors in selection of an overpack material. Appendix A suggests that there are several viable candidate materials which might result in a single overpack design suitable for each of the three media. Appendix A concludes that based on cost and availability, low carbon steel (CS) appears to be a good material choice for a CWP. Although any of several other materials appears to offer comparable potential for a CWP, Incoloy 825 is selected as a backup material.

In that CS is the material of choice for two of the three projects (basalt and salt), its selection would result in the introduction of few new issues to be evaluated by the repository projects. However, the NNWSI project would have to confirm its adequacy in the tuff environment.

B.2.2 CWP Design Concept

The basalt repository's identified limit of 2200 kw/package is the most limiting consideration in selection of a package heat output. This results in a maximum of 4 PWR or 9 BWR assemblies per package (based on 10-year-old, average burnup). The spent fuel waste form was assumed to be consolidated rods.

An internal handling container was selected primarily to provide comparable retrieval capability to the salt design.

A thick walled overpack concept was selected to provide the necessary structural strength and sacrificial corrosion allowance for the salt and basalt repositories; it is expected that the thick walled CS container would provide adequate corrosion allowance to offset the greater corrosion rates of CS in the oxidizing tuff environment. Moreover, CS is expected to be less susceptible to stress corrosion cracking than the reference stainless steel material for the tuff design.

To ensure adequate spent fuel radionuclide release performance, a packing material is used in the basalt repository as a site-specific variation on the CWP design. No packing material is used in salt and tuff repositories.

B.2.3 CWP Sizing

The internal handling container size was selected to accommodate the quantities of spent fuel rods from 4 PWRs and 9 BWRs in a "close packed" cylindrical array. The handling container is a section of standard 16" OD pipe with suitable top and bottom heads. The selection of the 16" OD pipe size was confirmed by PNL during the course of recent MRS studies.

A nominal diametral assembly gap of 2.6 cm (1 in) was allowed to set the overpack internal diameter at 36.6 cm.

The following procedure was used to establish the overpack wall thickness required:

- The wall thickness for structural adequacy assumed to be proportional to the inside diameter.

- The corrosion allowances required were assumed to be the same as those in the reference designs.

	Salt	Basalt
Overpack O.D. (cm)	84.5	50.3
Overpack I.D. (cm)	64.5	33.7
Total Wall Thickness (cm)	10.0	8.3
Corrosion Allowance (cm)	2.3	2.0
Structural Wall Thickness (cm)	7.7	6.3
Structural Wall Thickness required for CWP(cm)	4.4	6.8
Total Wall Thickness required for CWP (cm)	6.7	8.8
CWP Overpack OD		54.2

A similar procedure was used to establish head thickness requirements for the CWP. The CWP length was selected to accommodate the longest of the range of spent fuel rods of current spent fuel designs with appropriate allowances for the handling container lifting fixture and the overpack lifting fixture.

B.3 CWP Performance Confirmation

To confirm the adequacy of the CWP design, the structural, thermal and radiation effects were evaluated and compared with those of the reference designs.

B.3.1 Structural Adequacy

The ability of the CWP to withstand the external forces improved in he salt and basalt media, the CWP was subjected to an ASME-III structural evaluation similar to that described in Appendix E of WTSD-TME-001. Results of those calculations confirm adequate structural performance in both salt and basalt environments.

B.3.2 Thermal Performance

The thermal performance of the CWP in each medium was checked using the following procedures:

1) The peak temperature of the host medium was assumed to be constant at values as follows:

Salt: 175° (From WTSD-TME-001-Fig 5-3)

Basalt: 208° (From AESD-TME 3142-Table 1-2 - Peak Backfill Temp.)

Tuff: 183° (From UCID-20091, Table 1, Case 21)

2) The temperature increase across the container wall was assumed to be represented by the steady state radial conduction solution for an annulus without internal heat generation:

$$q' = k \Delta T / \ln (D_o/D_i)$$

The linear heat conduction rate, q^1 is proportional to the number of assemblies and the container inner Diameter, which results in the following proportionality for the temperature rise in the canister:

$$Tc \; 2 \; \frac{Nassy's}{Di} \; X \; \ln (D_o/D_i)$$

Using this propostionality and the following reference information from the sources cited above, the temperature rise across the containers was estimated

Parameters	Salt	Basalt	Tuff	CWP
Do (cm)	84.5	41.7	68	54.2
Di (cm)	64.5	30.5	66	36.6
Nassy's	12	3	6	4
ΔTc (°c)	93	56	5	-
ΔTc^{CWP} (°C)	79	78	79	-

Additions of this temperature differential to each of the media temperatures results in a maximum temperature for the Carbon Steel material of 286°which is slightly higher than maximum value cited for basalt in the reference above, but less than the limit of 430° identified by BWIP at the recent Waste Package Coordination Group Meeting.

Finally, the temperature rise of the waste form was estimated by assuming that it was adequately represented by the conduction solution for a cylinder with internal heat generation:

$\Delta T \propto q''' \propto$ Nassy's/A cross section

For this calculation, it was assumed that the basalt waste form configuration (bundled rods) is most representative of the bundled and canistered rods of the CWP configuration.

Using these approximations, the following result is obtained:

$$\Delta T_{wf} = 39\ C^\circ \times \frac{4}{3} \times \frac{30.5}{36.6} \approx 36^\circ\ C.$$

Combining this with the previously determined values for the container and the geologic medium results in the following estimates for the peak waste form temperature using the CWP in each medium:

Salt:	290° C
Basalt:	322° C
Tuff:	298° C

These are all less than the identified limits for spent fuel of from 350° C to 400° C. However, because these simplifying assumptions are crude and not necessarily conservative, a detailed thermal analysis in each geologic medium is necessary to confirm adequacy of thermal performance margins for the CWP.

B.3.3 Radiation Levels

The radiation intensity at the exterior of the package could potentially impact the corrosion performance of the waste package through radiolysis. The radiation levels on the exterior of the waste packages were estimated using techniques described in "Reactor Shielding Design Manual" by Rockwell. Results below show the ratio of the calculated gamma dose rate for the CWP to those calculated by the same techniques for the reference designs:

	CWP Dose Rate/Ref Dose Rate
Salt:	1.164
Basalt:	.869
Tuff:	.0134

While the estimated dose value for the CWP is slightly higher than that of the reference design in Salt, it is esentially the same with respect to the potential for inducing radiolytic effects on corrosion processes based on data presented by D. Clark, ONWI at the recent WPCG meeting. The substantially lower dose rate for the CWP compared to the reference tuff design is due to the substantially greater wall thickness of the former. The actual magnitude of the radiolysis effect on Carbon Steel corrosion in tuff must be determined by experiment.

B.3.4 Containment Lifetime

Because the CWP is of the same material as the reference waste package in Salt and Basalt, because the thermal and radiation conditions are substantially the same as for the reference cases in these two media, and because CWP was sized to accomodate the "worst case" conditions for these two media, the CWP containment lifetime is expected to be comparable to that of the reference design for each medium.

For tuff however, the CWP involves a change of material and substantially different conditions compared to the reference case. Therefore, a different approach is necessary to estimate the adequacy of the CWP in a tuff environment. With respect to corrosion performance, UCRL-53449 states that the temperature of the emplacement borehole wall will be $< 100^\circ$ C for 770 years. The temperature of the waste canister itself will be $< 100^\circ$ C for at least the subsequent 230 years. These conditions are assumed to be dependent only on the areal heat loading as long as the volumetric heat generation rate in each package is constant. [In actual fact, the CWP volumetric heat generation rate is slightly more than twice as high as that for the reference package in tuff so that the actual can temperatures will be somewhat higher in the CWP and remain that way for somewhat longer].

Using the information in UCRC-53449:

Time Space	Package Environment	CWP Corrosion Penetration	Ref Tuff Pkg Corrosion Pen.
770 years	Steam	.05 mpy x 770 yrs. .098 cm	.02 mpy x 770 yrs. .039 cm
230 years	Moist Air	2 mpy x 230 yrs 1.168 cm	-0-
Total Corrosion for 1000 yrs. (tc)		1.266 cm	.039 cm
Total Wall Thickness (tw)		8.8 cm	1 cm
Ratio (tw/tc)		6.95	25.6

From this, it can be seen that the thick walled carbon steel canister appears to provide adequate margin against uniform corrosion for the 1000 year containment period in tuff. Moreover, nonuniform corrosion can proceed at a rate of up to 7 times the uniform corrosion while maintaining containment integrity for 1000 yrs. Because Carbon steel is known to be less susceptible to stress corrosion cracking than the reference stainless steel materials, the expected lifetime with respect to this failure mode is expected to be at least as good as those of the reference tuff package, assuming that satisfactory procedures are developed to keep residual stresses to a minimum.

B.3.5 Summary

A common waste package (CWP) concept using a thick walled, carbon steel overpack has been developed. Preliminary simplified calculations and assessments suggest that the performance of the CWP in each of the first repository geologic media is expected to be comparable to that of each of the reference waste package designs in its respective medium.

Appendix C

Common Waste Package - Cost Estimation Basis

This Appendix provides a summary of the basis for the waste package and repository cost comparisons discussed in the main body of the report.

C.1 Waste Package Costs

Waste package cost estimates (Table C.1) for the reference waste package designs are those which were developed by WESTON during their current effort to estimate the overall construction, operation, and decommissioning costs for repositories in each of the geologic media. Costs for the Common Waste Packages were estimated by extension of the data for the reference packages to the CWP design described in Appendix B.

C.2 Repository Underground Effects:

Repository underground cost differentials associated with the CWP were estimated as follows.

Table C.1
Waste Package Cost Estimate Basis

	Tuff-Ref.	Basalt - Ref.	Salt - Ref	CWP
Repository Phase 1				
Number of Assemblies (PWR/BWR)	3/7	4/9	1/2	1/2
Assembly Configuration	Intact	Intact	Intact	Intact
Overpack Material	SS	CS	CS	CS
Internals	Space Frame	Frame Structure	Canister	Canister
Weight (lbs., ea.)	3314	705	145	143
Unit Cost ($1b)	4.39	1.10	1.10	1.10
Cost ($/package)	14,555	776	160	157.
Container	Thin Wall	Thick Wall	Thick Wall	Thick Wall
Weight (lbs. ea.)	2,426	21,400	8,180	10,100
Unit Cost ($/lb.)	3.72	1.10	1.10	1.10
Cost ($pkg)	9,014	23,540	8,998	11,110
External Packing	N/A	Basalt/Bentonite	N/A	Basalt/Bentonite*
Weights (lbs. ea.)	--	11.118	--	7,458
Unit Cost ($/lb.)	--	0.30	--	0.30
Cost ($/Package)	--	3,293	--	2,230
Subtotal ($/Package)	23,569	27,608	9,158	11,267 (13,497*)
QA Cost ($/Package)	5,963	13,494	4,515	5,634 (6,749*)
Total ($/Package)	29,532	41,103	13,672	16,901 (20,246*)

Table C.1 (Cont.)
Waste Package Cost Estimate Basis

Repository Phase 2				
Number of Assemblies (PWR/BWR)	6/14	4/9	12/30	4/9
Assembly Configuration	Consol.	Consol.	Consol.	Consol.
Overpack Material	SS	CS	CS	CS
Internals	Space Frame	N/A	Canister	Canister
Weights (lbs. ea)	3,314	--	1,213	143
Unit Cost ($/lb)	4.39	--	1.10	1.10
Cost ($/Package)	14,555	--	1,334	157
Container	Thin Wall	Thick Wall	Thick Wall	Thick Wall
Weights (lbs. ea.)	2,426	9,300	20,819	10,100
Unit Cost ($/lb.)	3.72	1.10	1.10	1.10
Cost ($/Package)	9,014	10,230	22,901	11,110
External Packing	N/A	Basalt/Bentonite	N/A	Basalt/Bentonite*
Weights (lbs, ea)	--	7,130	--	7,458
Unit Cost ($/lb)	--	0.30	--	0.30
Cost ($/Package)	--	2,133	--	2,230
Subtotal ($/Package)	23,569	12,363	24,235	11,267 (13,497*)
QA Cost ($ Package)	5,963	6,181	11,584	5,634 (6,749*)
Total ($/Package)	29,532	18,544	35,819	16,901 (20,246*)

*In Basalt repository only

Note: Costs are in 1984 dollars; Direct Costs only with no contingency; Cost are "FOB Repository" and do not include cost of waste form, final assembly, closure, and emplacement.

C.2.1 Emplacement Drift Mining

Two factors were considered in evaluating the impact of the CWP on the repository emplacement drift mining: the local area power density and a minimum borehole pitch (BHP) for borehole stability. The waste package pitch which results in the same local area power density as the reference waste package was estimated. This pitch was then checked against the "minimum" borehole pitch and the larger of the two was selected. If the minimum BHP pitch were selected, (which occurs for very low package heat outputs), either

1. a double row of emplacement boreholes of the minimum pitch was assumed and the emplacement drift pitch was re-estimated to give an equivalent local areal power density (vertical boreholes, tuff and salt - Phase 1)).

2. the minimum borehole spacing was assumed and the local areal power density was allowed to decrease. (short horizontal boreholes basalt-Phase 1).

Emplacement drift (ED) dimensions were then adjusted as necessary from those in the 2 Phase repository study an the emplacement drift mining volume was calculated as follows:

$$\text{ED Mining Vol.} = \text{ED Width} \times \text{ED Height} \times \text{BHP} \times \frac{\text{Npackages}}{\text{Nrows}}$$

Table C.2.1
CWP - Repository Emplacement Drift Mining Impacts

	Tuff		Basalt		Salt	
	Ref.	CWP	Ref.	CWP	Ref.	CWP
Ref. Cost-ED Mining ($M)	747.4	--	2248.4	--	528.5	--
Phase 1						
Waste Package Design (cm)	70.0	54.2	85.2	54.2	54.2	54.2
Heat Load/Package (kw)	1650	550	2250	550	550	550
Spent Fuel Form	Intact	Intact	Intact	Intact	Intact	Intact
Number of Assemblies (PWR/BWR	3/7	1/2	4/9	1/2	1/2	1/2
Total No. of Packages	1355	4650	1110	4650	4650	4650
Emplacement Made	V	V	SMB	SMB	V	V
Local Areal Power Density (kw/ocr)	57	57	50	31.5	60	60
Minimum Borehole Pitch (m)	2.74	2.21	7.0	2.79	2.44	1.87
Borehole Pitch (m)	2.74	2.21	7.0	2.79	2.44	1.87
Number of Rows/Drift	1	2	2	2	1	2
Emplacement Drift Spacing (m)	35.35	29.31	14.91	14.91	22.55	77.60
ED Width (m)	4.57	6.78	6.71	6.71	4.27	6.14
ED Heights (m)	6.40	6.40	3.26	3.26	6.70	6.70
ED Mining (m^3)	108,589	222,959	84,983	141,895	324,598	186,431
ED Mining Cost ($M)	27.1	55.6	64.0	106.8	23.3	13.4
Phase 2						
Waste Package Design (cm)	70.0	54.2	50.3	54.2	84.5	54.2
Heat Load/Package (kw)	3300.	2200	2200	2200	6600	2200
Spent Fuel Form	Consol.	Consol.	Consol.	Consol.	Consol.	Consol.
Number of Assemblies (PWR/BWR)	6/14	4/9	4/9	4/9	12/30	4/9
Total No. of Packages	24,946	37,893	37,893	37,893	12,189	37,893
Emplacement Mode	V	V	SMB	SMB	V	V
Local Areal Power Sens. (kw/m)	57	57	50	50	60	60
Min. Borehole Pitch (m)	2.36	2.21	2.67	2.79	2.70	1.87
Borehole Pitch (m)	3.96	2.64	7.0	7.0	22.14	7.38
Number of Raws/Drift	1	1	2	2	1	1
Emplacement Drift Spacing (m)	45.71	45.71	14.96	14.96	26.23	26.23
ED Width (m)	4.57	4.57	6.71	6.71	4.27	4.27
ED Height (m)	6.40	6.30	3.26	3.26	6.09	6.09
ED Mining Voc (m^3)	2,889,298	2,925,897	2,901,130	2,901,130	7,017,636	7,272,111
ED Mining Costs ($M)	720.3	729.5	2184.4	2184.4	505.2	523.5
Total ED Mining cost ($M)	747.4	785.1	2248.4	2291.2	528.5	536.9

The numbers of Packages required was determined by assuming a 2/3 PWR - 1/3 BWR split in both Phase 1 and Phase 2. Phase 1 was assumed to involve 400 MTU/yr for 5 years. Phase 2 was the balance to a total 70,000 MTU capacity.

Cost factors were obtained for the 2 Phase repository concepts for each project from the ongoing WESTON efforts to determine repositry construction, operation, and decommissioning costs. To estimate cost differentials, costs were assumed to be proportional to the ED mining volumes calculated by the procedures above. Table C.2.1 is a summary of the results of these calculations.

C.2.2 Borehole Drilling Costs

Borehole drilling cost impacts were estimated using the following procedure:

1. Borehole diameters were estimated for the CWP in each geologic medium by maintaining the same differential between the borehole diameter and the waste package OD as in the reference case. For basalt, the diameter was set so as to allow the same thickness of packing material as in the reference case. Borehole depths in each case were assumed to be the same as those in the reference cases. Total borehole volumes were then calculated assuming right circular cylinders, 1 package per borehole.

2. Borehole costs were obtained from the WESTON studies of construction, operation, and decommissioning costs of repositories and were assumed to be proportional to the borehole volumes estimated above.

Table C.2.2 summarizes these evaluations.

C.3 Repository Surface Facility Costs

Repository surface facility effects of the CWP for the reference case (i.e., intact spent fuel assemblies received at the repository) will be primarily seen in the following areas:

- Waste Handling buildings, especially in the hot cells.
- Hot cell equipment for disassembly of fuel bundles (Phase 2 only) and for packaging.
- Emplacement Equipment.

The principal factor affected by the CWP which influences the costs of these facilities is the emplacement rate, i.e., the number of waste packages per day which must be processed to achieve the desired annual emplacement rate. Necessary emplacement rates for each of the reference waste package designs and for the CWP are summarized in Table C.3.1. It is noted that emplacement rates for the CWP are identical to that for the salt repository during Phase 1 and to that for the Basalt repository during Phase 2.

Table C.2.2
CWP - Repository Emplacement Drift Mining Impacts

	Tuff		Basalt		Salt	
	Ref.	CWP	Ref.	CWP	Ref.	CWP
Ref. Cost-ED Mining ($M)	747.4	--	2248.4	--	528.5	--
Phase 1						
Borehole Diameter (m)	.864	.706	1.24	.93	.597	.597
Total No. of Boreholes	1355	4650	1110	4650	4650	4650
Borehole Depth (m)	7.62	7.62	6.40	6.40	6.57	6.57
Total Borehole Vol. (m3)	6054	13,871	8,579	20,216	8,552	8,552
Borehole Drilling Cost ($M)	16.5	37.7	30.0	70.8	10.6	10.6
Phase 2						
Borehole Diameter (m)	.864	.706	.89	.93	.90	.597
Borehole Depth (m)	7.62	7.62	6.10	6.10	6.21	6.21
Total No. of Boreholes	24,946	37,893	37,893	37,893	12,189	37,893
Total Borehole Vol (m3)	111,448	113,035	143,800	157,016	48,154	65,870
Borehole Drilling Cost ($M)	303.2	307.5	503.3	549.6	59.6	81.5
Total Borehole Drilling Cost ($M) [Phase 1 and 2]	319.7	345.2	533.3	620.4	70.2	92.1

Table C.3.0

Required Emplacement Rates

	Phase 1	Phase 2
Annual Emplacement (MTU/yr)	400	3000
Tuff Repository (Packages/Day)	1.1	4.3
Basalt Repository (Packages/Day)	0.9	6.6
Salt Repository (Packages/Day)	3.6	2.1
Common Waste Package (Packages/Day)	3.6	6.6

C.3.1 Waste Handling Building Costs

The following preliminary cost estimates for the waste handling buildings and hot cell equipment were developed by WESTON to represent the waste handling buildings at each of the repository sites. The estimates were developed during the course of parametric studies to determine the overall costs of construction, operating, and decommissioning of a repository in each geologic medium. For the CWP, the waste handling building costs were assumed to depend only on the emplacement rates and to be independent of the actual site under consideration. Thus, for Phase 1, the estimated costs were taken to be the same as those for WHB-1 the Salt Repository and for Phase 2, the WHB-2 costs were assumed to be the same as those for the Basalt Repository Table C.3.1 Summarizes WHB (including hot cell equipment) costs.

Waste Handling Building Cost Estimates ($M-1984)

	WHB-1	WHB-2
Tuff Repository	100.6	600.4
Basalt Repository	106.6	621.3
Salt Repository	136.9	541.2
CWP (Any Repository)	136.9	621.3

C.3.2 Emplacement Equipment

Reference costs for emplacement equipment were also taken from the WESTON studies to estimate the cost of construction, operation, and decommissioning, of a repository. The total number of CWP's to be emplaced is very nearly the same as for BWIP. Thus, the BWIP case was taken to be the reference case and the cost for all repositories was assumed to be directly proportional to the total number of packages emplaced. This is probably an oversimplification since the cost are probably also dependent on the mode of emplacement (short horizontal, long horizontal, or vertical) and on the waste package size. However, these results are judged to be adequate for the present study. Table C.3.2 summarizes the estimates used.

Table C.3.2

Emplacement Equipment Cost Summary

	Total Packages (For 70,000 MTU)	Est. Cost ($M-1984)
Tuff Repository	26,301	78.9
Basalt Repository	38,870	124.1
Salt Repository	16,845	98.0
CWP (Any Repository)	42,543	135.3