U. S. DEPARTMENT OF ENERGY
OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

NUCLEAR WASTE TECHNICAL REVIEW BOARD
PANEL ON THE ENGINEERED BARRIER SYSTEM

SUBJECT: WASTE PACKAGE/EBS DESIGNS

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Outline

Engineered system goals and strategy

Overview of reference design

Thermal considerations

Design approach

Performance assessment implications

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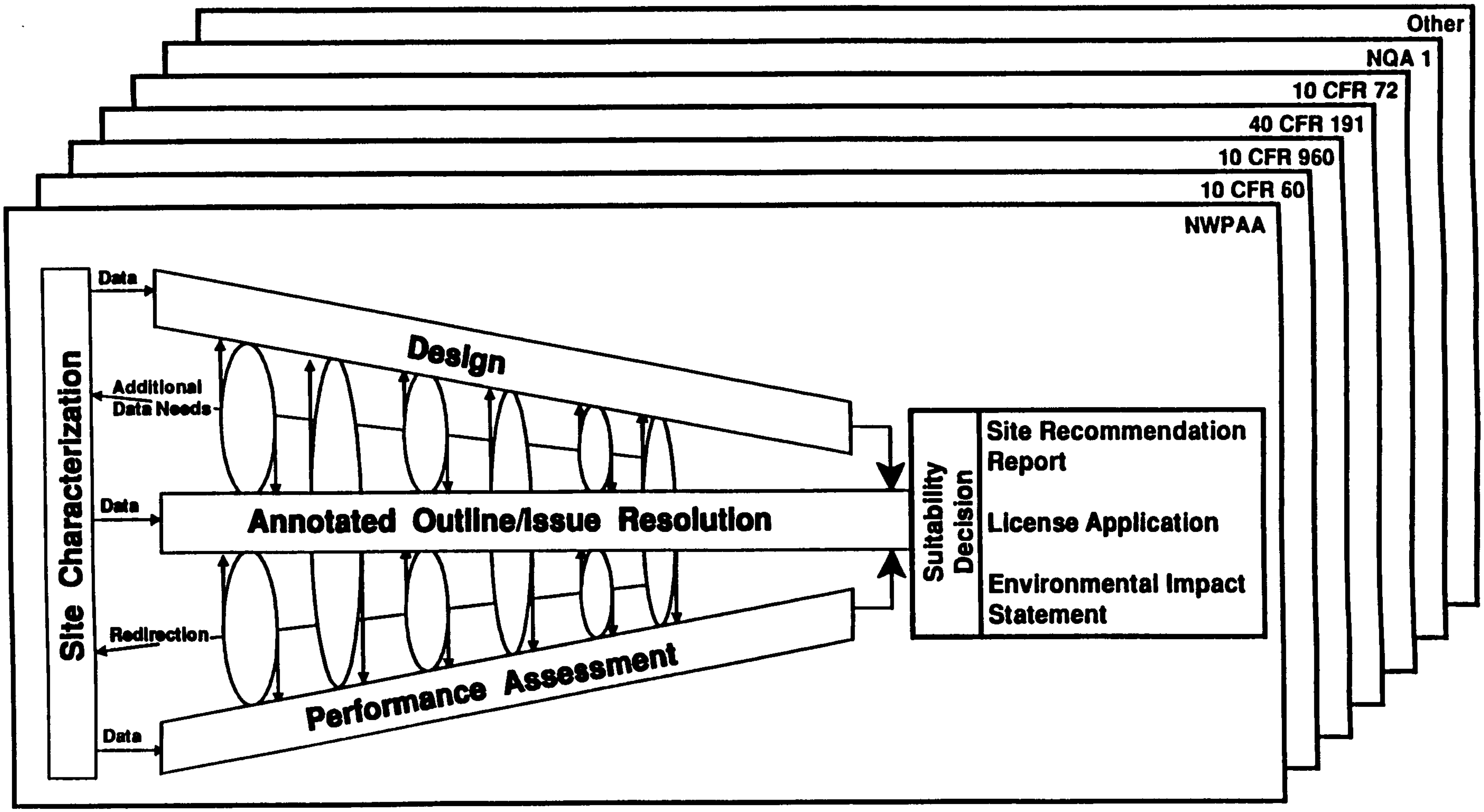
Engineered Barrier System (EBS) Goal

- **Achieve a conservative, licenseable design that meets regulatory requirements with sufficient margin for uncertainty**

Engineered Barrier System Strategy

- The attainment of the goal using an iterative system-engineering approach that relies on
  - A multibarrier approach
  - The unsaturated nature of the Yucca Mountain site
  - Consideration of technical alternatives
  - Sufficient resolution of technical and regulatory uncertainties

Approach to Resolution of Issues



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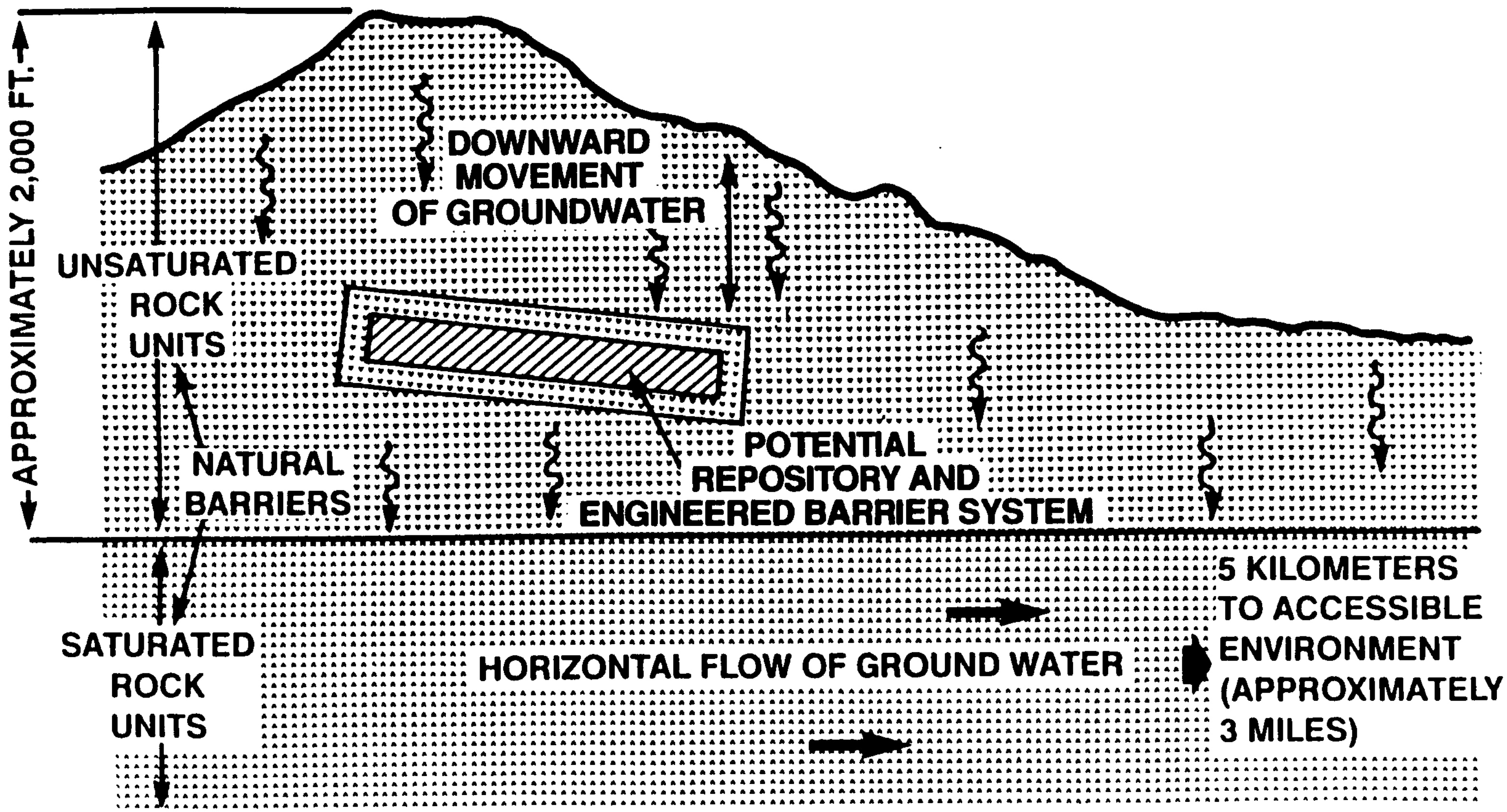
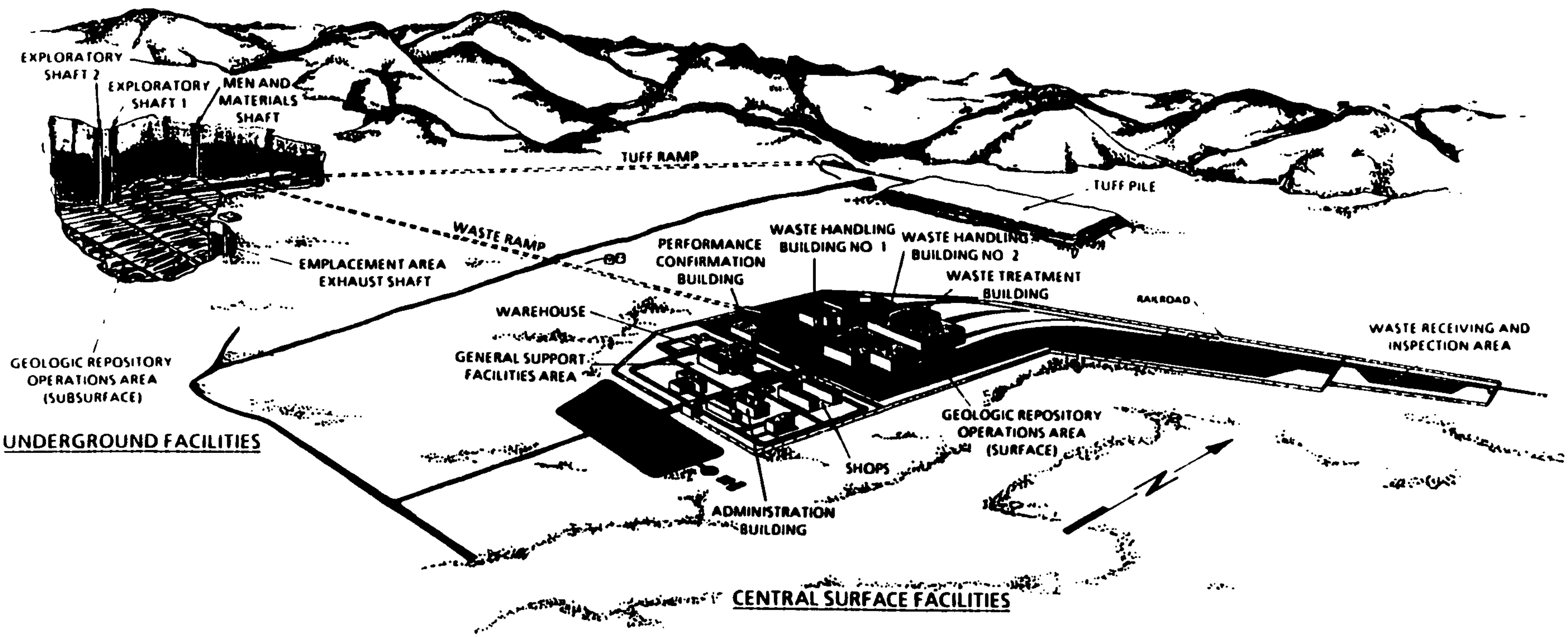
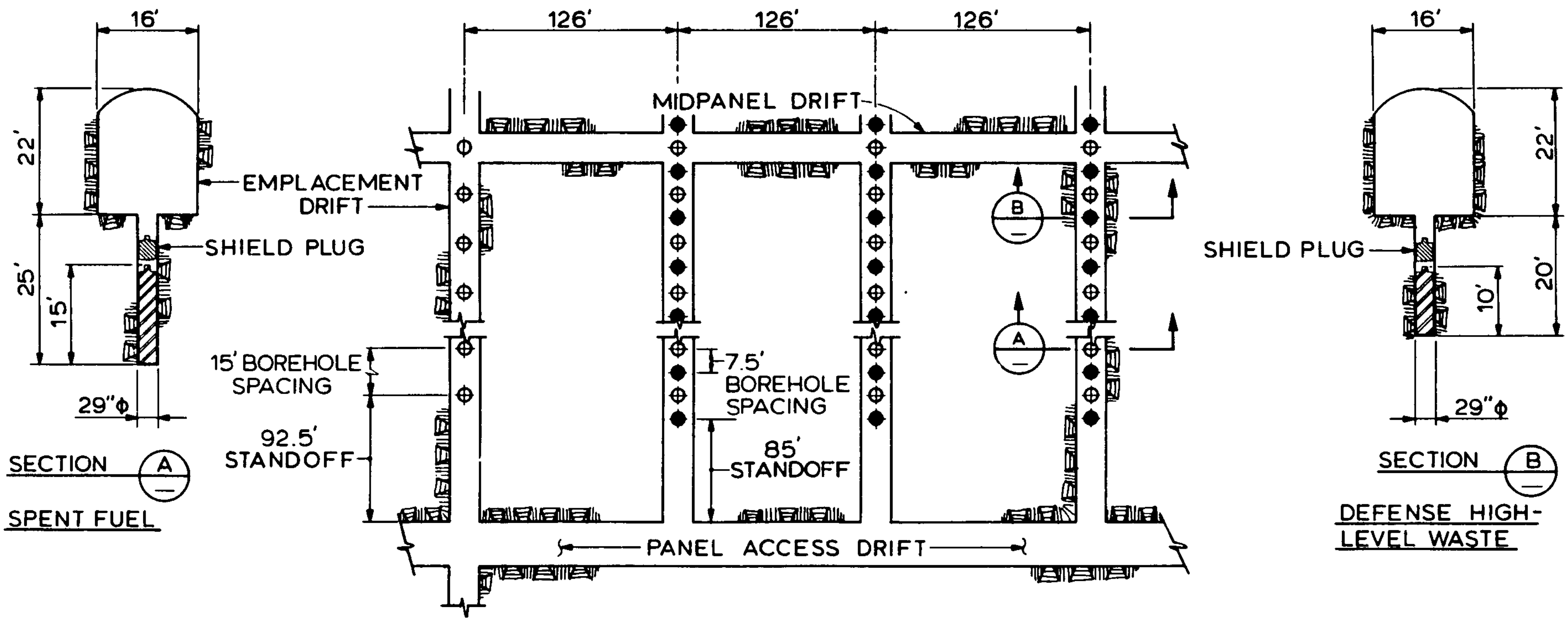
Schematic Representation of Potential Repository at Yucca Mountain that Isolates Radioactive Materials by Using Natural and Engineered Barriers



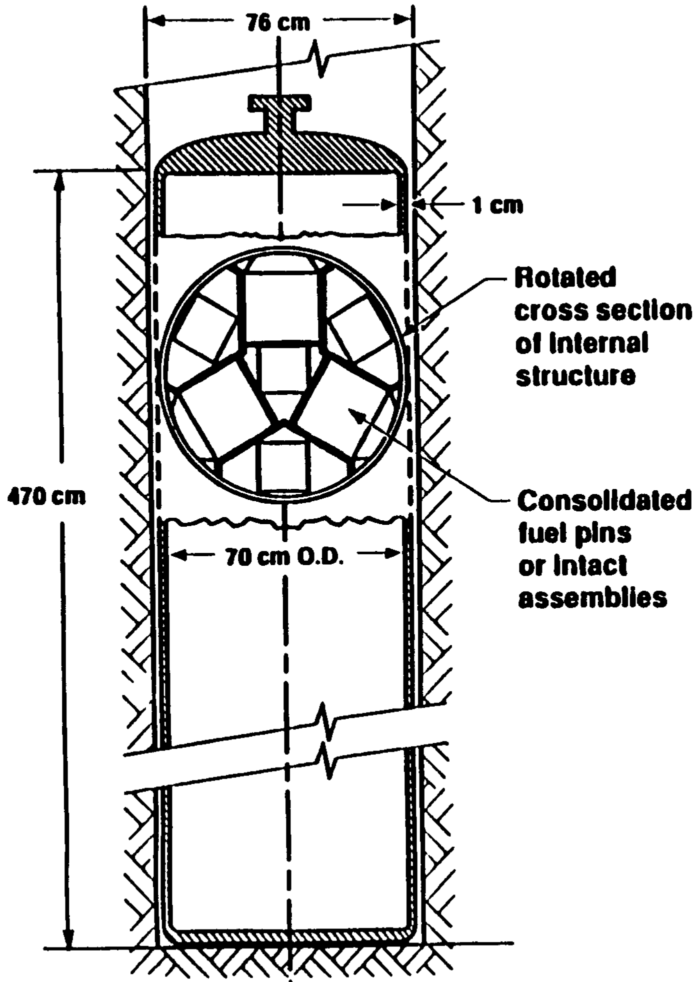
Preliminary Drawing of a Repository Complex



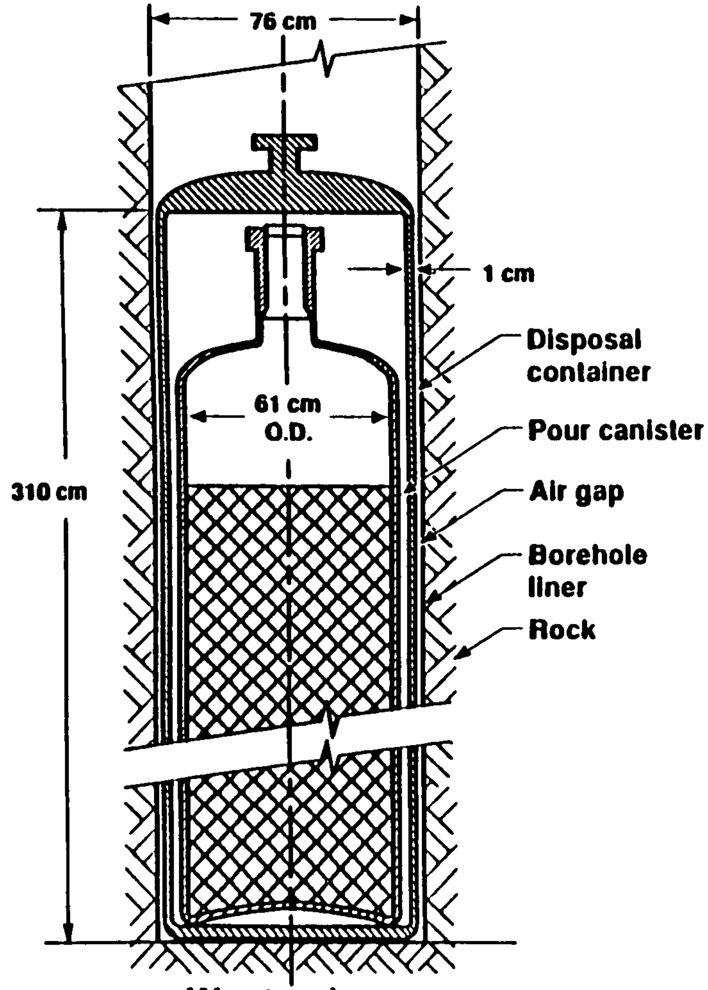
Underground Facility Layout Panel Details For Vertically Emplaced Commingled Waste



Examples of Yucca Mountain Waste Package Designs



Spent fuel containers (25,000 to 35,000)



Waste glass containers (~14,000)

Materials Selection for the SCP Design

- Six candidate alloys extensively studied
  - Austenitic nickel-based alloy 825
  - Austenitic stainless steel AISI 304L
  - Austenitic stainless steel AISI 316L
  - High-purity copper (CDA-102)
  - Copper-nickel alloy (CDA 715)
  - Aluminum bronze (CDA 613)

Materials Selection for the SCP Design (continued)

- Nickel-based Alloy C-4 and titanium alloy Grade 12 also extensively studied

- Materials from earlier (1983) study as well as other suggested material evaluated less riorously

- Selection criteria exercise* yielded the highest scores for
  - Titanium Grade 12
  - Alloy C-4
  - Alloy 835

* R. D. McCright et al, "Candidate Container Materials for Yucca Mountain Waste Package Design, "Proceedings FOCUS '91, Nuclear Waste Packaging, Oct. 1991, Las Vegas, NV, pp 125-135.

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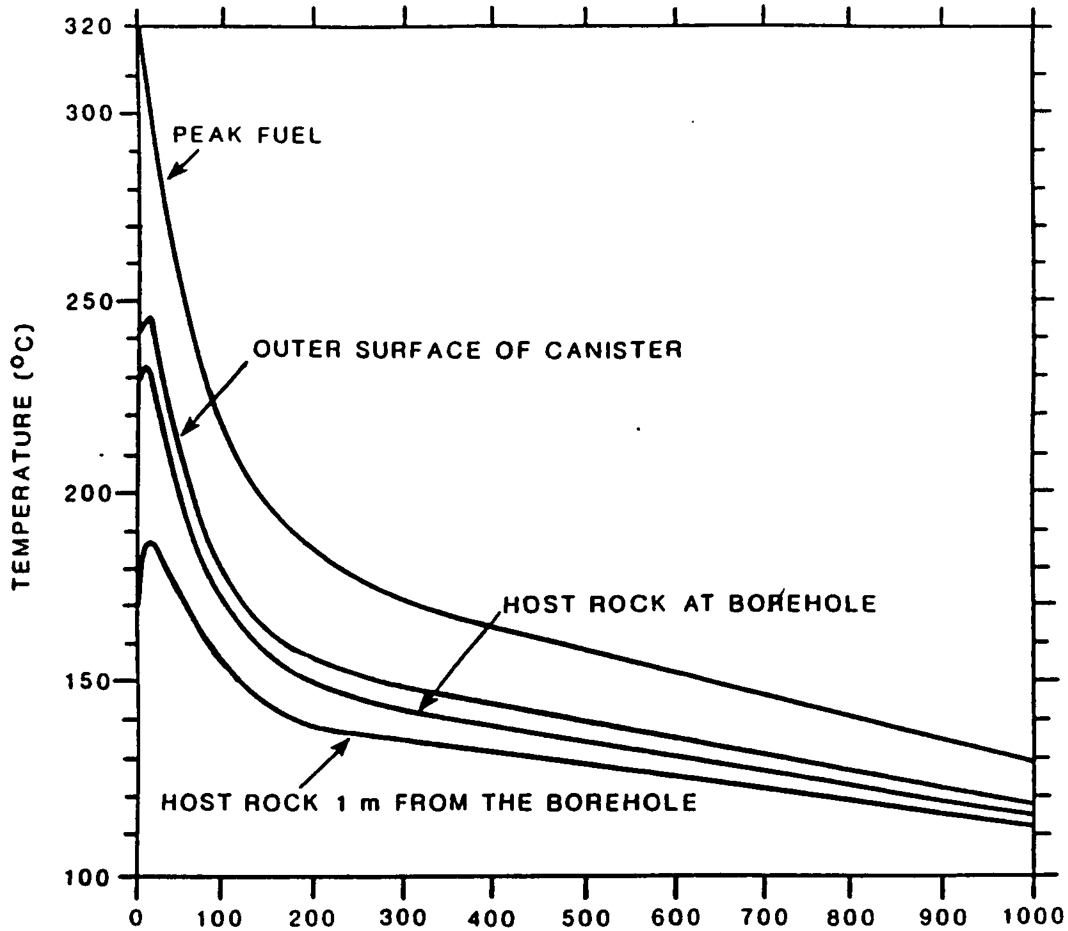
SCP Thermal Goals

Performance Measure	Goal
Cladding integrity	Container centerline $T<350^{\circ}C$ Borehole wall $T<275^{\circ}C$
Near-field rock mass integrity	One meter from borehole $T<200^{\circ}C$
Access drift wall	T wall $<50^{\circ}C$ for 50 years
Temperature change in adjacent strata	TSw2 - TSw3 interface $T<115^{\circ}C$
Surface environment	Temperature change $<6^{\circ}C$
Limit corrosiveness of canister environment	Maximize time spent above boiling in borehole environment

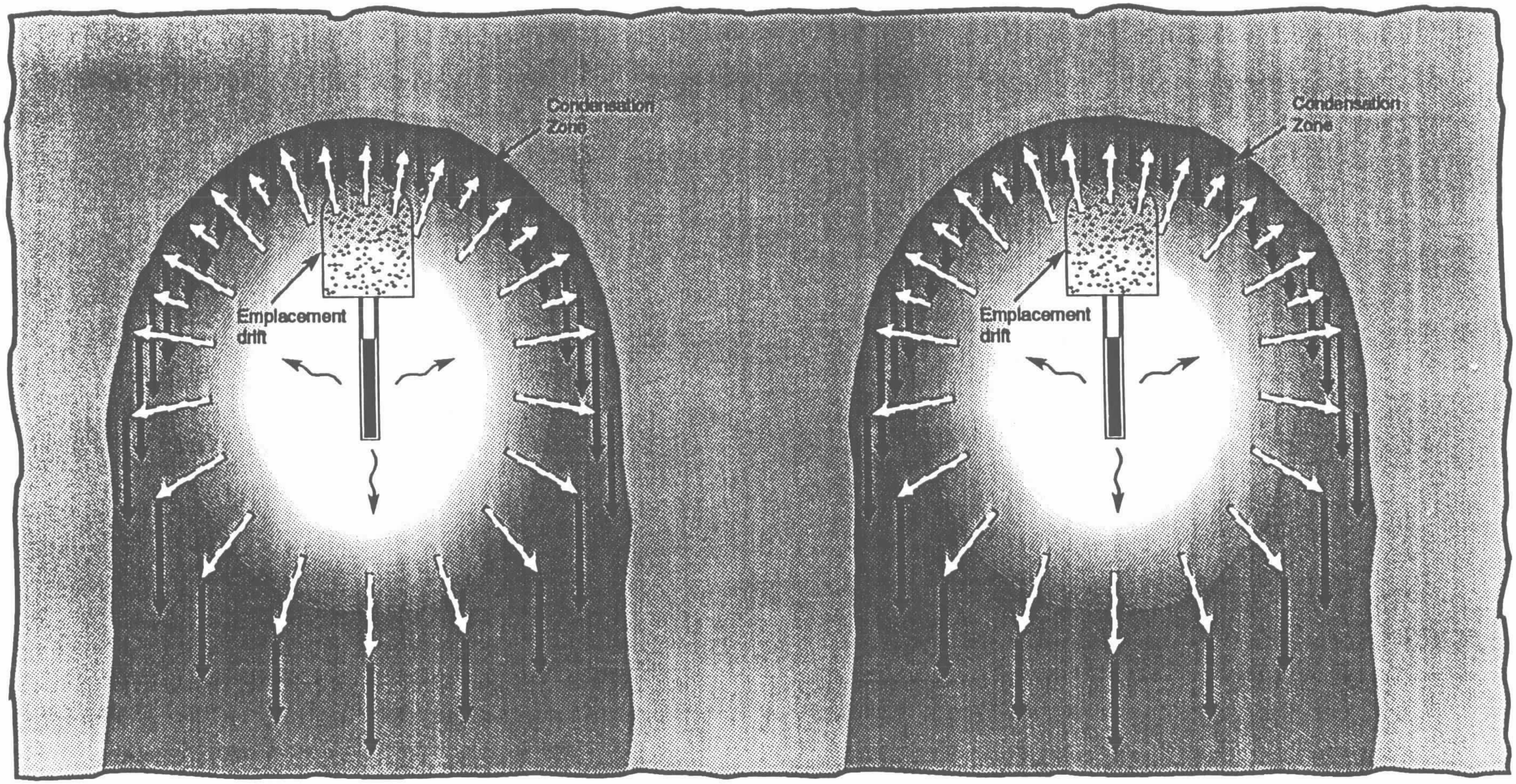


Time after Emplacement (years)

Initial Conditions

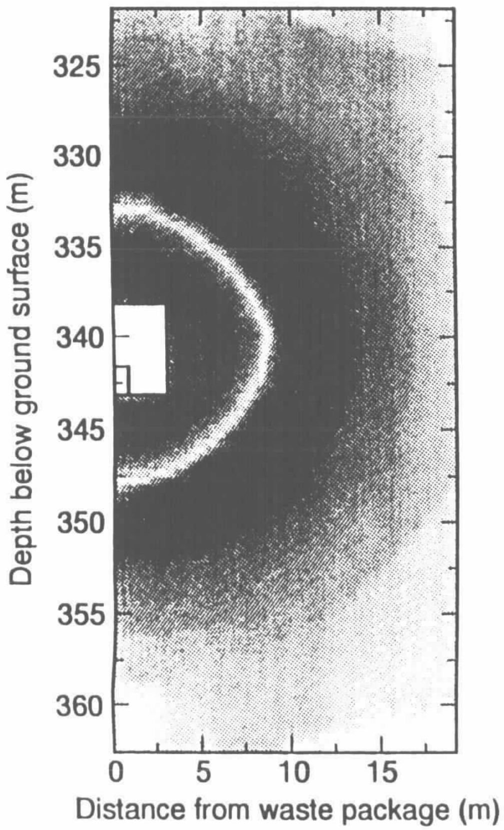
Waste Form	Spent Fuel
Local Power Density	57.0 kW/acre
Areal Power Density	48.4
Heat Output of 10-Yr Old Fuel	3.3 kW

"Hydrothermal Umbrella" Established Along Each Emplacement Drift due to Condensate Shedding off Sides of Boiling Zone

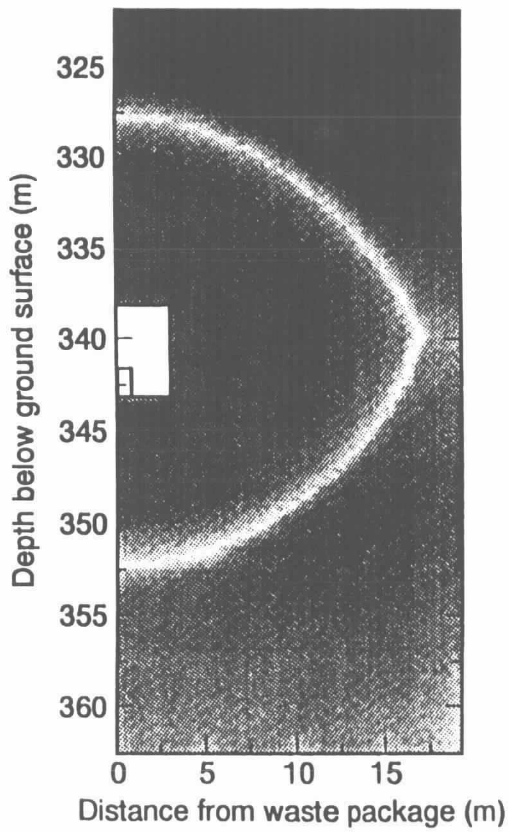


Condensate Shedding Between Emplacement Drifts will Continue Until Boiling Zones Coalesce, About 80 Years After Emplacement

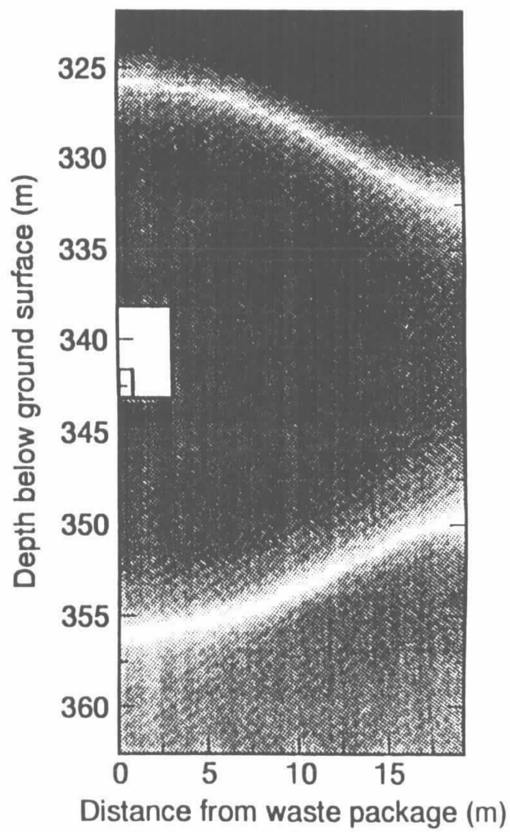
Dimensionless liquid saturation for 30-yr-old fuel, an APD of 57 kW/acre, a drift spacing of 38.4 m, and a recharge flux of 0.0 mm/yr



t = 30 yr



t = 60 yr



t = 100 yr

Normalized area required for repository, as a function of initial APD and spent fuel age (areas are divided by area for the reference SCP-CDR design)

	20 kW/acre	36 kW/acre	57 kW/acre	80 kW/acre	100 kW/acre
10-yr-old fuel	2.85	1.57	1.00	0.71	0.57
30-yr-old fuel	1.81	1.00	0.64	0.45	0.36
60-yr-old fuel	1.14	0.63	0.40	0.29	0.23
100-yr-old fuel	0.73	0.40	0.25	0.18	0.15

Effects of Thermal Loading on EBS

- Effects on EBS Environment
  - Geomechanical
  - Geochemical
  - Hydrogeological

- Effects on EBS components
  - Containers
  - Waste form
  - Other EBS components

Potential Effects of Repository Thermal Loading on Container Degradation

- Defines temperature and exposure time for general corrosion of containers
- Defines exposure time for potential onset of localized corrosion of containers
- Establishes conditions that could lead to gaseous and aqueous release of radionuclides
- Established conditions that could lead to mechanical loads from changes to borehole/drift walls
- Not strongly coupled to the heat output and size of an individual waste package

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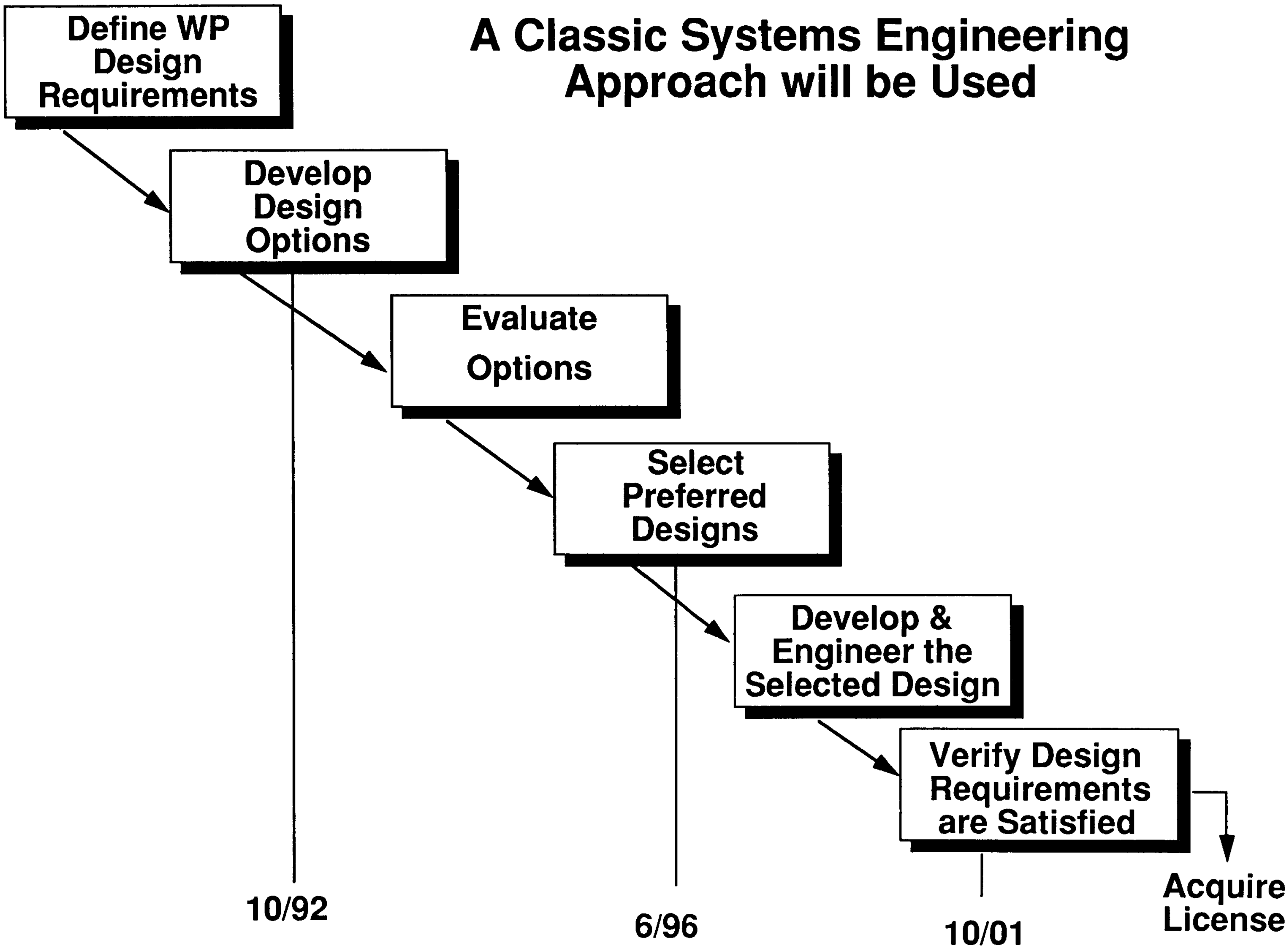
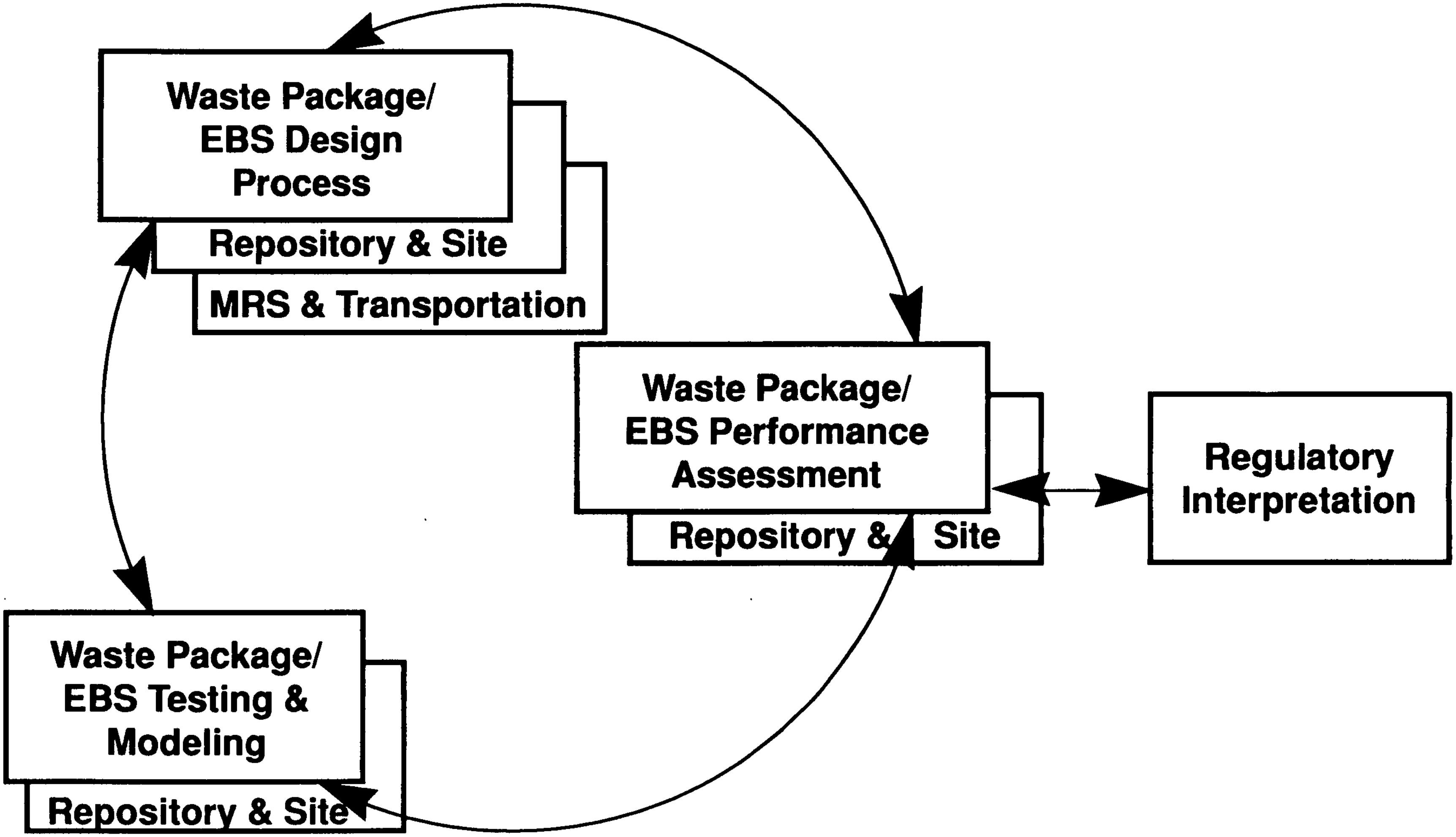
A Classic Systems Engineering Approach will be Used



Major Process Interfaces



Waste Package Design Options

- Barrier Types
- Material Options
- Canisterization
- Emplacement Modes
- Waste Package Capacity

Design Approach

- Start ACD with range of concepts including
  - Small, thin-wall borehole emplaced
  - Robust, small, drift emplaced
  - Robust, higher capacity, drift emplaced
    - Partially self-shielded
    - Self-shielded to personnel exposure limits

- Evaluate corrosion-resistant plus corrosion-allowance materials

- Accommodate ranges of burnup and fuel age

- Retrieve single waste package from any location

- Variable thermal loading capability
  - Adjust waste package locations prior to backfill to optimize thermal loading

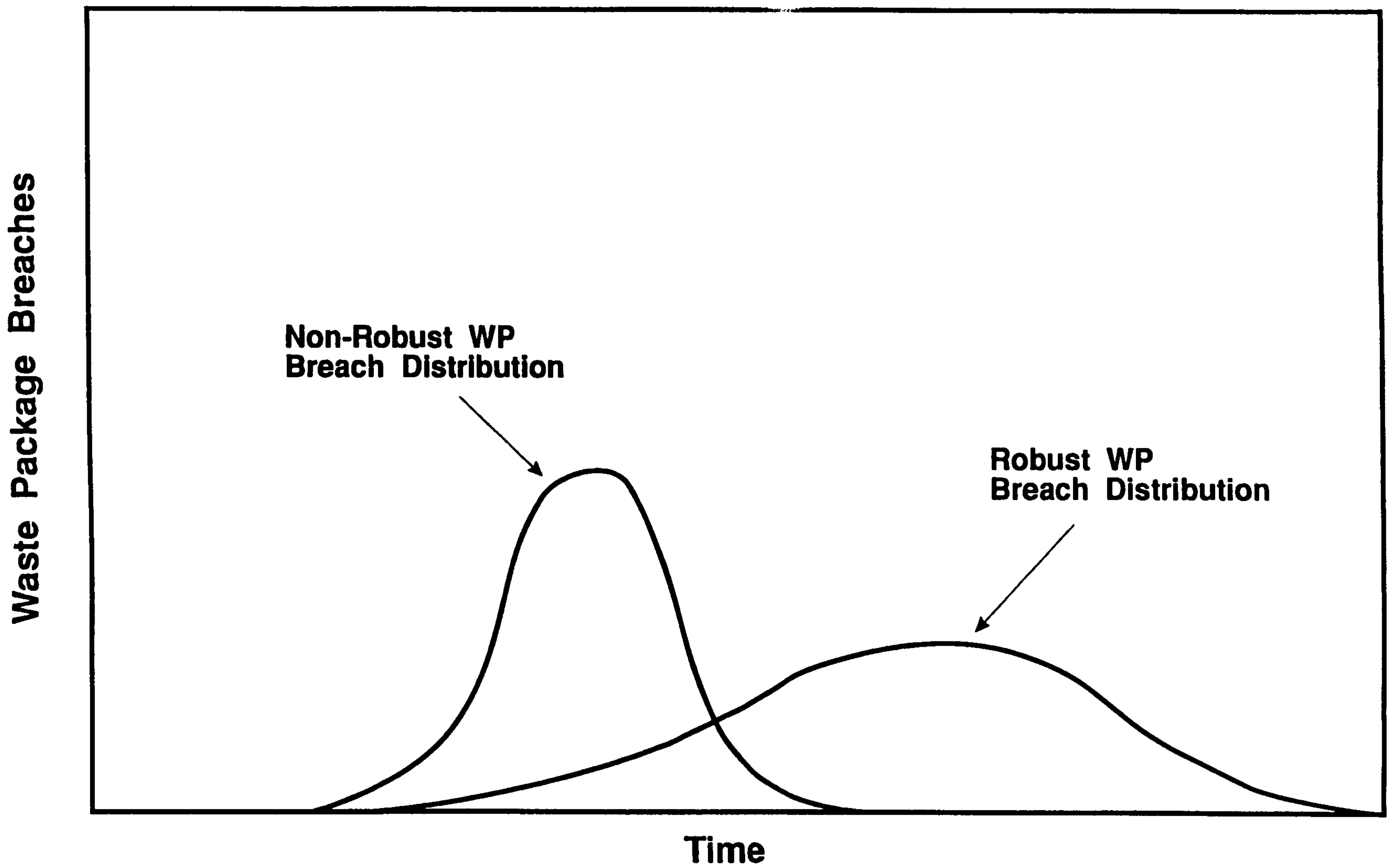
- Reduce concepts during ACD and LAD to one reference and one alternative desing for detailed evaluation

Robust Waste Package

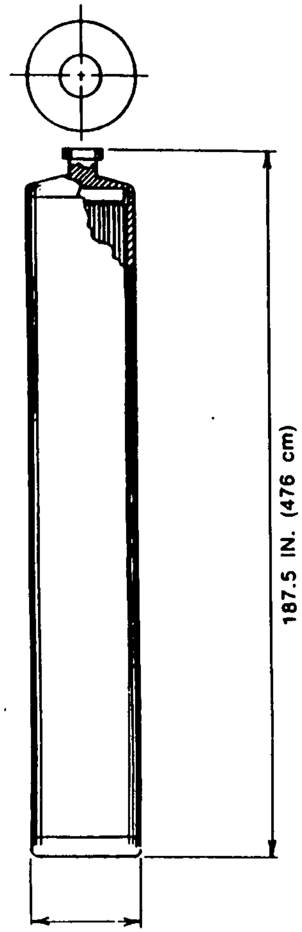
A robust waste package

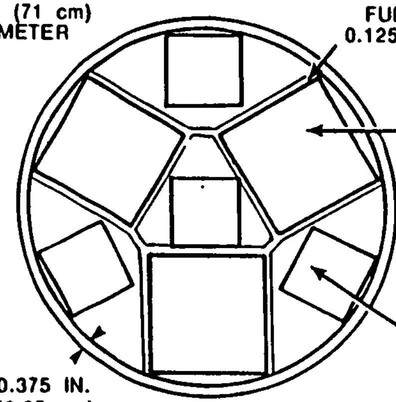
- Increases certainty of meeting containment requirements
- Is tolerant to a wide range of repository conditions
- Is a multibarrier WP/EBS concept
- Uses a defense-in-depth approach
- Is partly or fully self-shielded
- Lends itself to drift emplacements

Breach Distribution

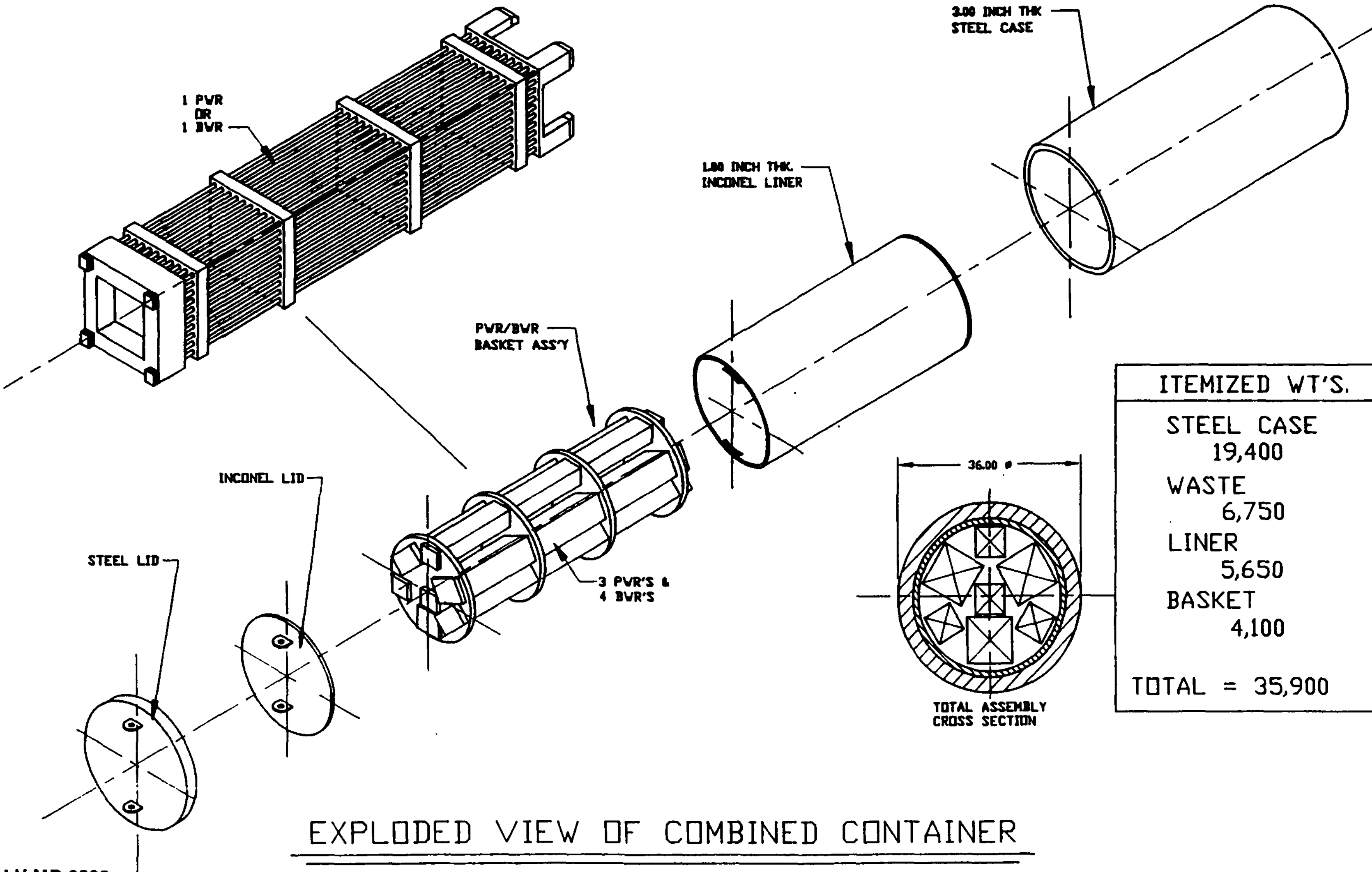


SCP Hybrid Design





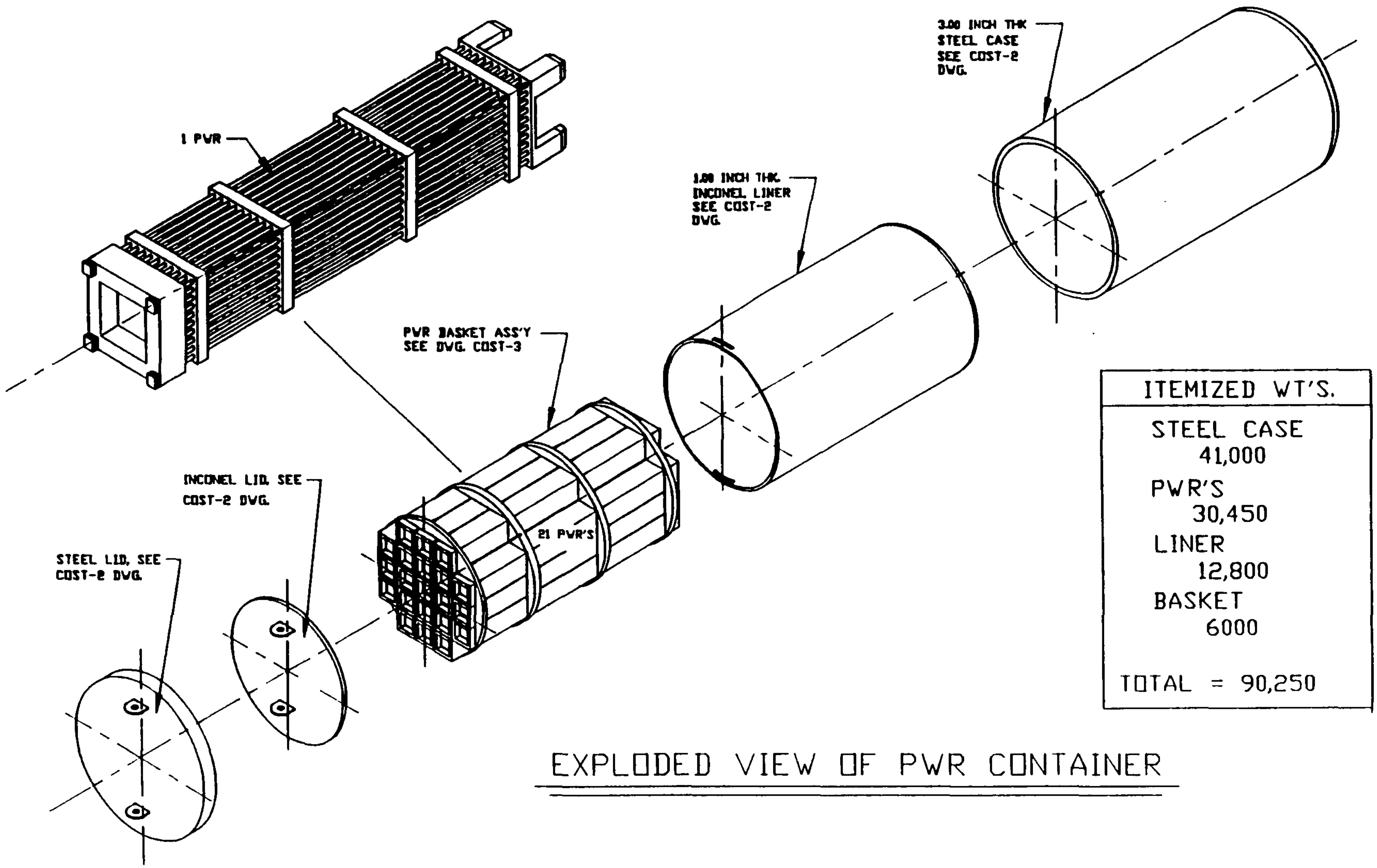
Multibarrier Candidate Waste Package
(SCP Hybrid Design)



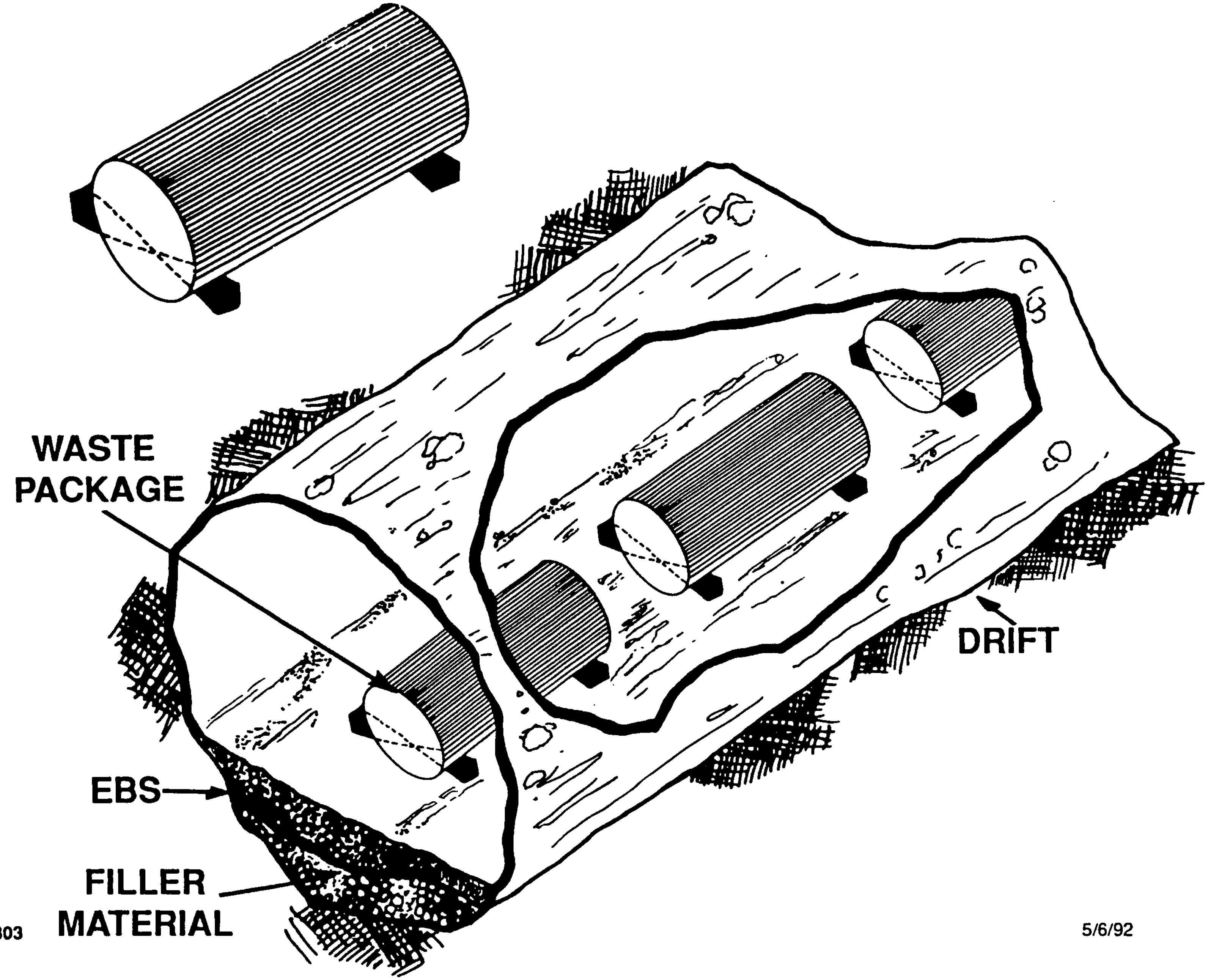
ITEMIZED WT'S.	
STEEL CASE	19,400
WASTE	6,750
LINER	5,650
BASKET	4,100
TOTAL =	35,900

EXPLODED VIEW OF COMBINED CONTAINER

Multibarrier Candidate Waste Package
(21 PWR Assemblies)



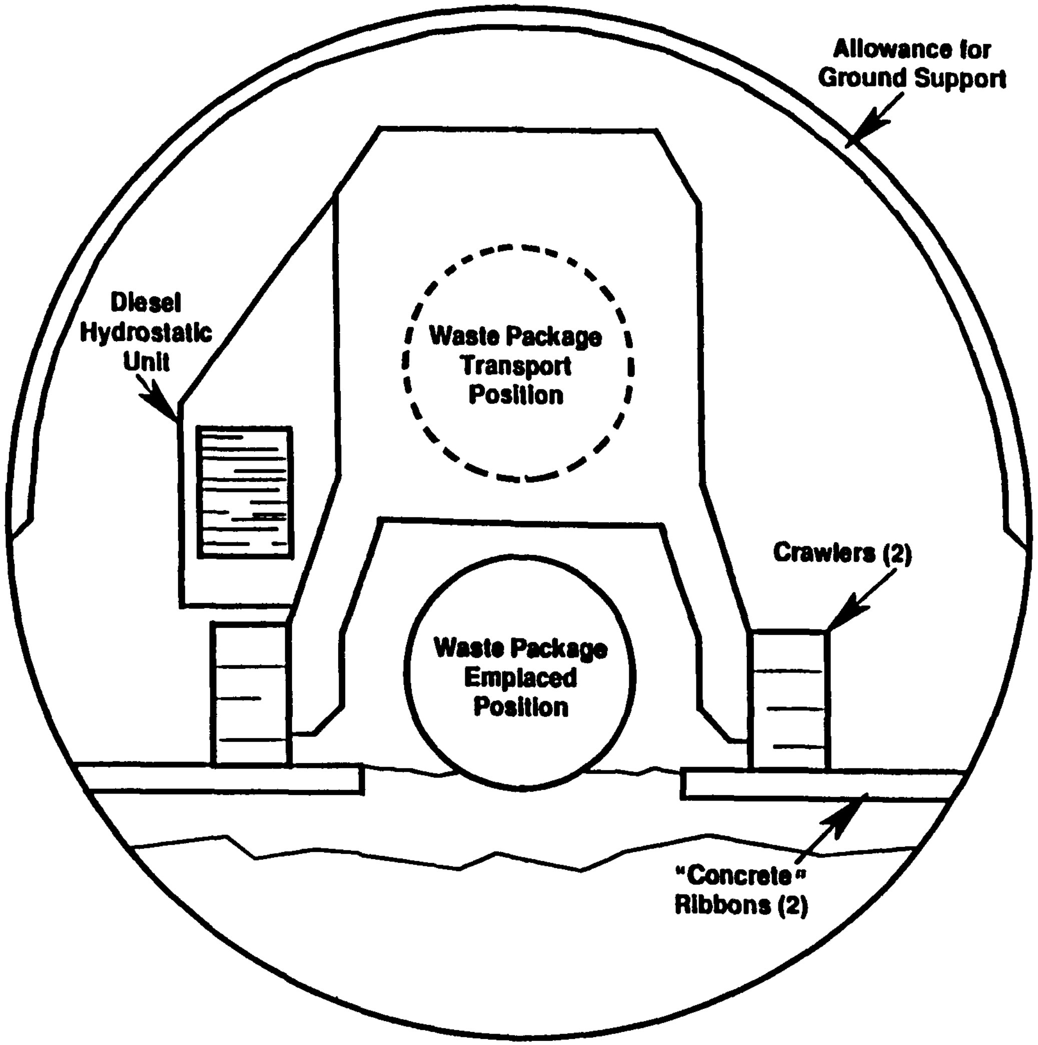
Waste Package Drift Emplacement



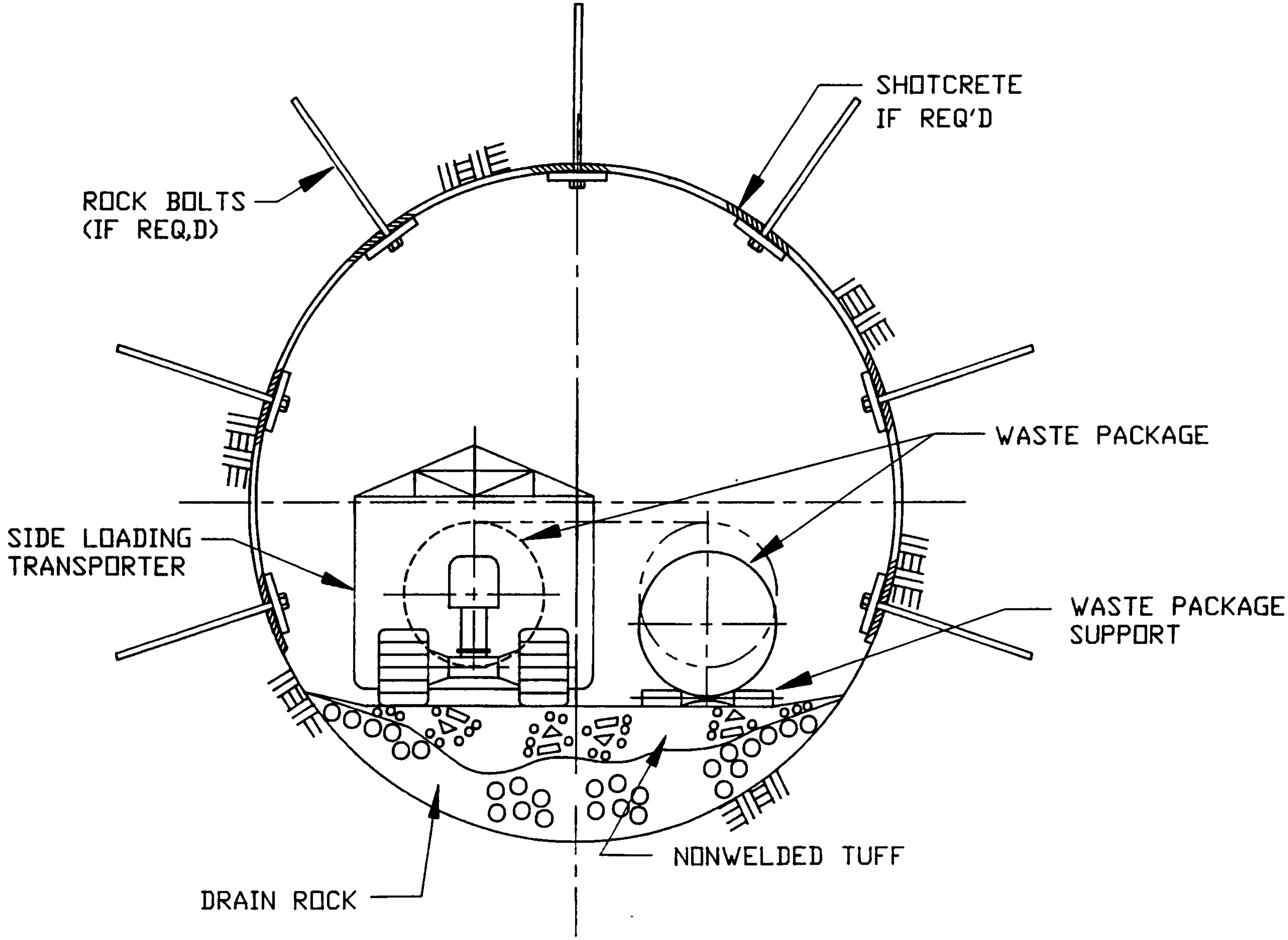
Drift Emplacement Alternative

- Improves heat dissipation from waste package
- Permits management of thermal loading to increase time waste package will stay dry
- Permits relocation of waste packages up to closure to adjust thermal loading
- Considers robust waste package including corrosion allowance and/or corrosion resistant materials
- Accommodates larger waste packages holding more assemblies than SCP design
- Permits easier retrieval
- Reduces potential for damage due to seismic events

Waste Package Transporter/Emplacement Unit



Side Load Emplacement



Near-Term Container Materials Effort

- Perform degradation mode survey of iron-based corrosion allowance materials
- Identify gaps in information for iron-based materials and perform prototypic scoping tests
- Restart degradation model development effort
- Identify parametric testing program needed to support model development and initiate testing
- Develop long-term materials test matrix and plan and initiate testing

Near-Term Waste Package/EBS Design Effort

- Evaluate and select candidate design concepts for ACD based on preliminary analysis of
  - Containment capability
  - Radionuclide release performance
  - Thermal performance
  - Subcriticality margin
  - Handling and emplacement
  - Retrievability
  - Fabricability and structural integrity
  - Worker exposure
- Initiate detailed evaluation of selected concepts as part of ACD

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Implications of New Waste Package Designs on Performance Assessment

- Degradation modes must be defined for iron-based corrosion allowance materials
- Materials testing must be performed to fill information gaps
- Materials interactions must be evaluated
- Predictive models must be developed for
  - Outer containment barrier breach
  - Inner containment barrier breach
  - Waste package gaseous and aqueous radionuclide releases

Basis for Material Assessment

- Assumes that inner containment material will be one of the candidate alloys selected by LLNL: Alloy 825, Alloy C-4, or Titanium Grade 12

- Outer containment material can be either corrosion-allowance or corrosion-resistant material

- For corrosion-allowance materials, the dominant degradation mode is general corrosion (atmospheric and aqueous)
  - Permits performance prediction
  - Rates are usually parabolic (protective)
  - some rates are linear (non-protective)

Basis for Materials Assessment (continued)

- For corrosion-resistant materials, the dominant degradation mode is localized corrosion
  - Initiation is usually a random process
  - Performance prediction is difficult
  - Rates are usually rapid after the process is initiated
  - Degradation mode surveys have been performed for the six candidate alloys plus titanium alloys

Expected Performance of Iron-Based Barriers

- Potential material choices:
  - Low-carbon structural steels
  - Weathering (low-copper) steels
  - Low alloy steels
  - Cast irons
  - Coated (aluminized, galvanized) steels
- Natural analogues exist that can support model validation
- Degradation mode surveys are required to confirm anticipated mechanisms and suggest the testing program

Expected Performance of Iron-Based Barriers (continued)

- Atmospheric corrosion of steels at ambient temperatures is well documented
  - Rates are dependent on humidity and amount of pollutants
  - Rates for structural steels are generally above 20 micrometers/year
  - Rates for weathering steels are much lower (<3 micrometers/year), if proper patina is established
  - Data for elevated temperatures are not as readily available
- Data on wet-dry cycling are not available for conditions expected at Yucca Mountain
- Effects of microbes need evaluation

Expected Performance of Iron-Based Barriers (continued)

- Aqueous corrosion of steels is well documented
  - Rates are dependent on pH, Eh, and flow rate
  - Neutral to mildly alkaline conditions preferred
  - Rates for structural steels are generally above 50 micrometers/year
  - Rates for weathering and low alloy steels are somewhat lower
  - Pitting corrosion of steels is possible, but pits are usually of low aspect ratio

- Data on wet-dry cycling are not available for conditions expected at Yucca Mountain

- Effects of microbes need evaluation

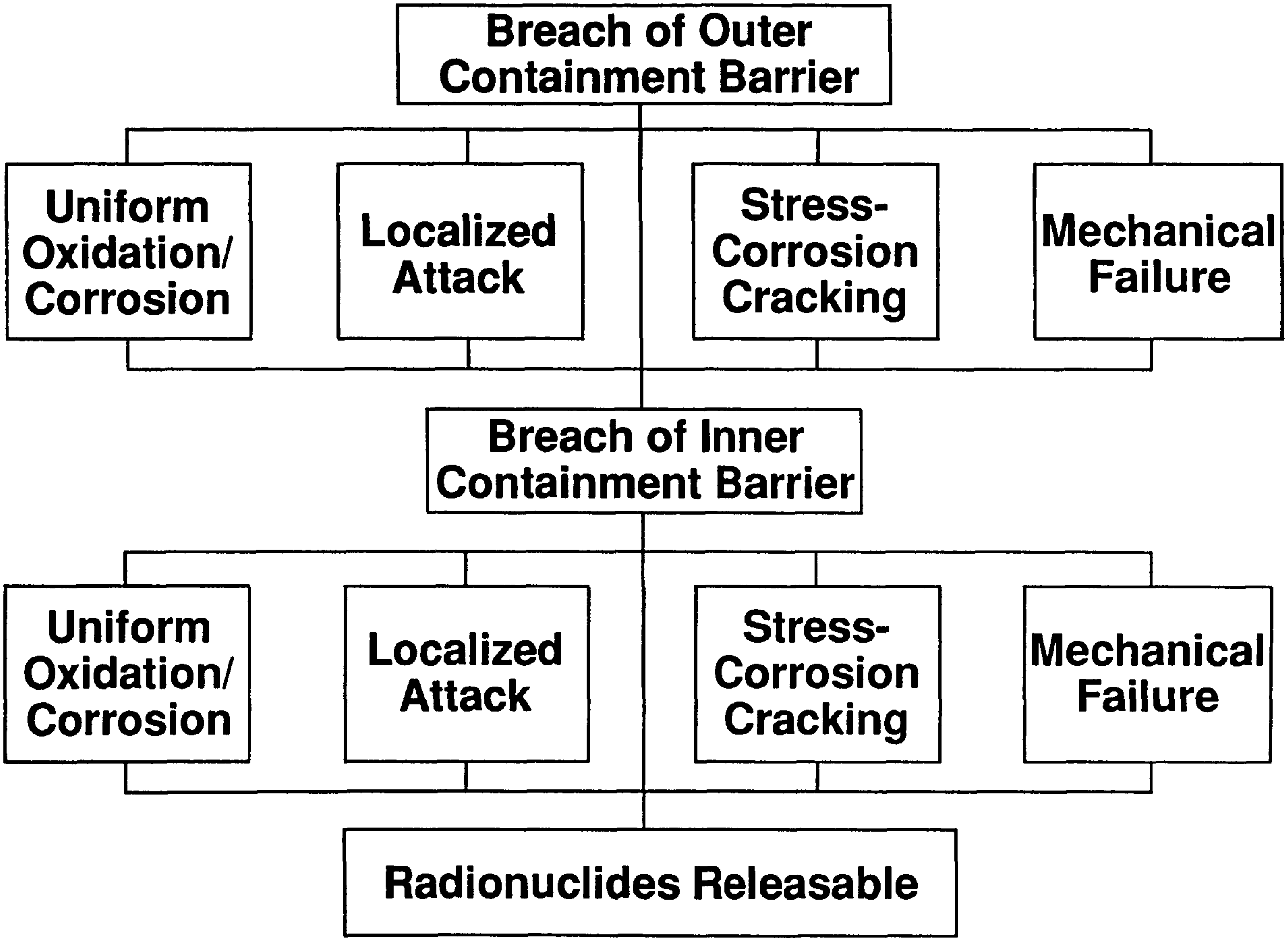
Expected Performance of Copper-Based Barriers

- Degradation mode survey performed by LLNL
  - Atmospheric corrosion rate low ($\leq$1 micrometers/year)
  - Elevated temperature oxidation possible for some copper alloys: aluminum bronze behaves best because of alumina film
  - Aqueous corrosion good, generally 5-25 micrometers/year
  - Stress-corrosion cracking can occur, if nitrites etc. are present
  - Pitting corrosion not likely, but can occur under some conditions

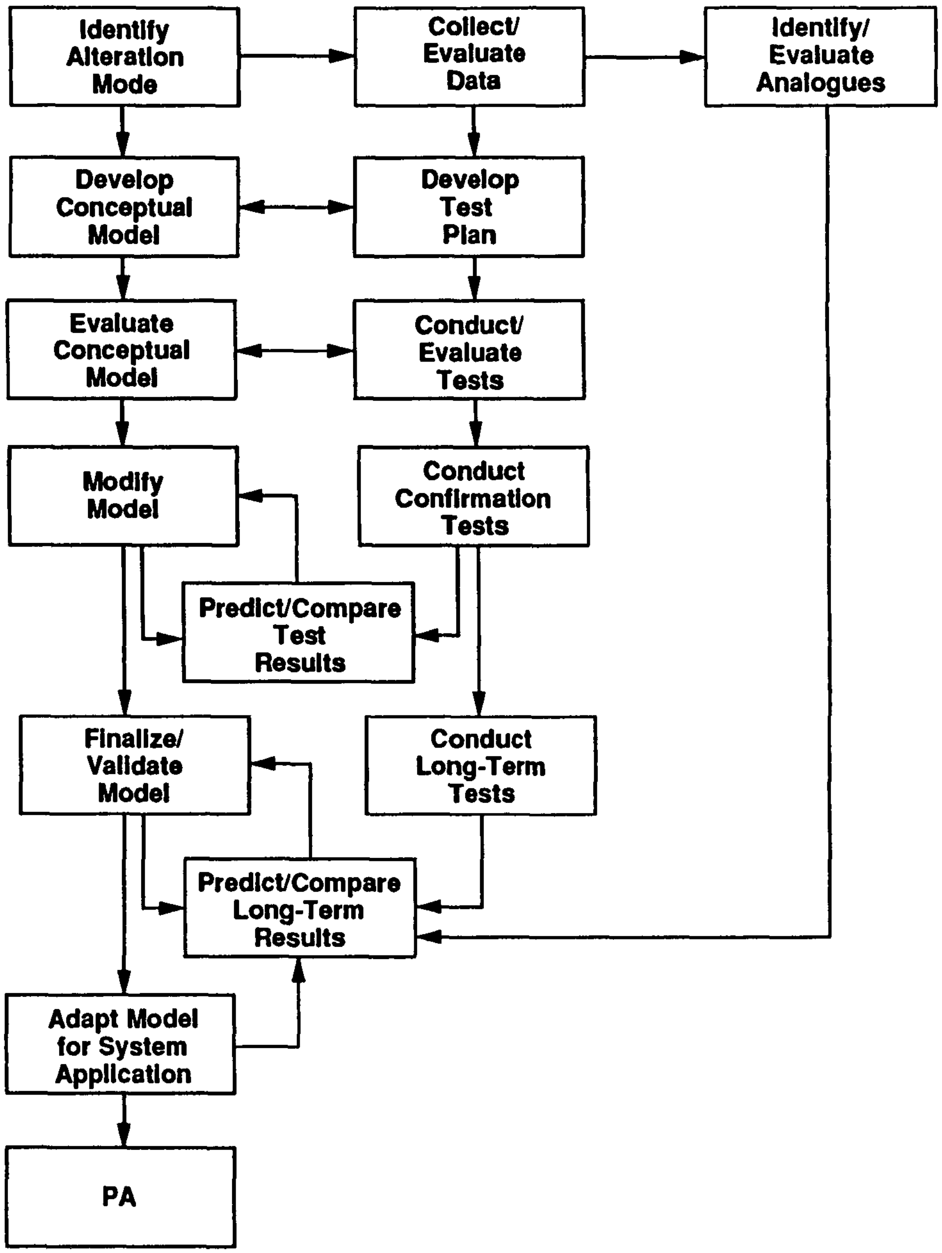
- Natural analogues exist that can support model validation

- Copper and copper alloys are known to be immune to some but not all microbes

Waste Package Breach Model Hierarchy



Coupled Model Development Material Testing Program



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