APT He-3 TARGET LEAD STACKED PLATE CONFIGURATION

Flow Channel Geometry

8mm Thk. Pb Plates

\[ R_{\text{thick}} = 65 \text{cm} \]

1cm Gap

\[ R_{\text{channel}} \]
APT-LANL
D20 Fraction in Target Lead Side

Notes
1. Semi-circular channels, radius = 0.35 cm
2. Total lead thickness = 35 cm

Channel Position

Average w/ 1 cm gap = 9.5%
Average w/o 1 cm gap = 6.8%
## TARGET LEAD

- **Heavy Water Volume Fraction**: 10%
- **Inconel Volume Fraction**: 3%
- **Equivalent Lead Thickness**: 30 cm
- **Peak Operating Power Density**: 48 W/cc
- **Peak Operating Lead Temperature**: 102 °C
- **Peak Decay Heat (1 sec) Lead Temp.**: 84 °C
- **Lead Melt Temperature**: 327 °C
- **Lead Coolant Temperature**:
  - Inlet: 50 °C
  - Outlet: 70 °C
- **Peak Operating Coolant Velocity**: 2 m/sec
- **Pressure Drop**: 35 kPa
- **Max Primary Tensile Stress in Lead**: 175 kPa
- **Lead Mass - Half Section**: 45 MetricTons
- **Coolant pH**: Neutral
MODERATOR TANK & INTERNALS

- Upper Blanket Section
- Head
- Tungsten Coolant Jumpers
- Support Beam
- Moderator Coolant Jumpers
- NSA Remote Lead-In
- Locating Support Pin
- NSA
- Lead Actuator
- Target Lead
- MODERATOR TANK
- He-3 Blankets
REMOTE HANDLING JUMPERS

- Blanket, NSA, Backstop Helium (Not Shown)
- Instrumentation (Not Shown)
REMOTE HANDLING JUMPERS
APT HE-3 REMOTE HANDLING

Hanford - Purex 3
Jaw Connector
RE-TARGETING SEQUENCE

- A step-by-step replacement sequence developed based on current target-facility design
- Equipment, access and laydown requirements identified based on replacement sequence
  - Relatively simple equipment required
  - Next step to coordinate with Bechtel
- Spent target can be transported in air (or water) with heat rejected to ambient
  - Spent target can remain in air indefinitely
  - Utilizes a reusable fin tube coolers(s) connecting target inlet and outlet
  - D20 can be reused; saves $200-300K per target
TARGET DISASSEMBLY SEQUENCE

A step-by-step target disassembly sequence developed based on current target-storage pool design

Equipment, access and laydown requirements identified based on disassembly sequence
- Relatively simple equipment required
  - All cutting / moving equipment are commercial adaptations
  - Next step is to coordinate with Bechtel

Equipment / sequence same with separate or combined disassembly pools
- Combined pool eliminates need to move equipment
SAFETY

The APT System has the following inherent features that contribute significantly to its safety and simplify its design:

- The Target / Blanket Design contains no fissile material. Nuclear criticality and re-criticality are not design concerns
- Beam trip is fast and reliable
- Residual heat is low
- Radioactive inventory is low

The APT System is a high energy system and requires appropriate control and protection systems to maintain its performance and integrity and to protect worker and public personnel.
BEAM TRIP / SFAS OVERVIEW

First Method of Positively Shutting Down the Beam in a Fail-Safe Manner

Beam Injector

Second Method of Positively Shutting Down the Beam in a Fail-Safe Manner

Input/Execute Channels #1 to #4

To Other SFAS Functions

Beam Trip Channel A

Beam Trip Channel B

Input Variables with Four Redundant Sensors, One to Each Input/Execute Channel

Variable A

Variable B

Variable X

Safety Actuation Channel A

Safety Actuation Channel B

#1

#2

#3

#4
SYSTEM SAFETY PHILOSOPHY

- Defense in Depth
  - Active Plus Passive Cooling Systems
  - Diverse, Redundant Backup Systems
  - Multiple Radionuclide Barriers
- System Safety Requirements Document
SYSTEM SAFETY REQUIREMENTS

- Fast and Reliable Beam Trip
- Smooth Transition to Safety Systems
  - Provide Extended Pump Coastdown
  - Flood Heat Source
- Active Residual Heat Removal Systems
  - Use Multiple Loops / Components
  - Maintain Adequate Net Pump Suction Head
  - Provide backup Diesel Power
- Natural Circulation Cooling
  - Specify Component Elevations
  - Preclude Gas Flow Blockage
  - Use Air / Water Heat Exchangers
TARGET/BLANKET/WINDOW HEAT REMOVAL SYSTEMS

TUNGSTEN HEAT 'TRANSPORT' SYSTEMS (THTS)

Tungsten Primary
Coolant System
(TPCS)

Tungsten Heat
Water
Accumulator

Tungsten Secondary
Coolant System
(TSCS)

Tungsten Passive
Water-to-Air
Heat Exchanger

Tungsten Circulating
Water System
(TCWS)

HEAT TRANSPORT SYSTEMS (MTHTS)

Moderator Primary
Coolant System
(MPCS)

Moderator Secondary
Passive Heat
Removal System
(MSRHRS)

Environment

MODERATOR TANK HEAT TRANSPORT SYSTEMS (MTHTS)

Moderator Primary
Passive Heat
Removal System
(MPRHRS)

Moderator Secondary
Passive Heat
Removal System
(MSRHRS)

Environment

WINDOW HEAT TRANSPORT SYSTEMS (WHTS)

Window Primary
Coolant System
(WPCS)

Window Secondary
Coolant System
(WSCS)

Environment

B&W
Bechtel

Environment
TUNGSTEN HEAT TRANSPORT SYSTEMS (THTS)
TUNGSTEN PRIMARY COOLANT SYSTEM

Accumulator

30 ft
D2O
344 ft³

Pump
29 ft

Heat Exch.
24 ft

Sec. Cool Sys.

140 psia

103 psia

140 F

100 F

2.9E6 lb/hr

2.48E6 lb/hr

265 psia

227 psia

23 ft³

2.2L9

53 W3

Pump
22 ft

Pressurizer

30 ft
D2O
348 ft³

221 F

154 F

48 MWt

Sec. Cool Sys.
WINDOW HEAT TRANSPORT SYSTEMS
CONCLUSIONS

- Design concept is still evolving
- Heat Removal System is safe and uses well-proven technology
- Target/Blanket Assembly concept appears engineerable and producible
- Development Program is needed to provide essential data and to demonstrate performance
- Proceed with Conceptual Design
Tritium Processing Systems
Accelerator Production of Tritium/He-3

Tritium Technology Group
Los Alamos National Laboratory
and
Merrick & Company

Presented by J. W. Barnes

June 1993
Experience Base (LANL-TSTA)

- Tritium Processing System (TPS) design is based upon 10 years experience with operation of the Los Alamos, Tritium Systems Test Assembly (TSTA).
  - $\sim 100$ kg tritium processed to date
  - $\sim 130$ g tritium inventory
  - $\sim 300$ Ci (0.03 g) tritium released to the environment
  - $\sim 3$ mRem/man-year exposure to operations personnel

- TSTA personnel provide design and operational assistance to the Princeton, Japanese and International fusion programs.

- TSTA personnel consult with DCE Defense Facilities on design and operation of tritium processing systems.
Experience Base (Merrick & Company)

- Merrick has extensive Tritium Process and Facility Design experience.
  - Tritium Systems Test Assembly
  - Weapons Subsystems Laboratory (LANL)
  - Replacement Tritium Facility
  - Weapons Complex Reconfiguration
  - Compact Ignition Tokamak (PPPL)
  - International Thermonuclear Experimental Reactor

- Merrick has design experience with DOE and DOE contractors at Argonne (ANL-W), Idaho, Oak Ridge, Rocky Flats, Richland, Savannah River, etc.

- Merrick personnel are familiar with LANL design philosophy and operations.
Design Philosophy

- Conceptual design is based upon a conservative application of demonstrated technology.

- Safety of operating personnel and minimization of environmental releases were the primary objectives during process selection and design (triple containment of tritium will be provided).

- Advanced concepts may be considered as alternatives if they offer potential for significant safety, cost or performance benefits.
APT/He-3 Tritium Processing

- All tritium processing is included within APT/He-3 site boundary.

- Tritium production system inventory is low for APT/He-3 (days) relative to alternative concepts (months to years). However, He-3 inventory is more mobile (gas) than alternative concepts (clad and chemically bound).

- APT/He-3 requires only a gas purification system (cost and safety benefits). Alternative concepts require high-temperature furnace systems for tritium extraction and produce significant quantities of high-level waste (Li/Al melt or graphite "flour").

- Environmental releases will be lower by several orders of magnitude compared with existing tritium processing systems (triple containment will be provided).
Tritium Processing System
Accelerator Production of Tritium/He-3

Tritium Extraction
( High-temperature Furnaces)

High-Level Waste
(Li/Al Melts or Graphite "flour")

Tritium Purification
Flow Schematic
Tritium Processing Facility

Los Alamos
Tritium Process (Primary Systems) Technology

**Tritium Extraction**

- Hydrogen isotope extraction by membrane permeation; impurities removal by molecular sieve sorption.
- Scale-down of proposed fusion breeder technology currently demonstrated at Tritium Systems Test Assembly.

**Isotope Separation**

- Cryodistillation.
- Demonstrated at TSTA, Mound and Savannah River.

**Tritium Storage**

- Metal hydride storage for concentrated tritium.
- Evacuated tank storage for dilute tritium.

**Tritium Load-out**

- DOE "standard" Product Containers (sub-atmos. gas).
- Considering packaging for shipment as solid (hydride).
Tritium Process (Secondary Systems) Technology

**D2O Detritiation**
- Vapor Phase Catalytic Exchange; Cryodistillation.
- Sulzer technology; Selected for HWR.

**Process Containment**
- Catalytic oxidation with molecular sieve sorption of recovered water.
- Oxidation/sorption widely used.

**Gaseous Waste**
- Catalytic oxidation with molecular sieve sorption of recovered water.
- Oxidation/sorption widely used.

**Emergency Clean-up**
- Catalytic oxidation of confined process cell atmosphere with molecular sieve sorption of recovered water.

**Helium-3 Load-in and Storage**
- Gas bottle packaging.
- Tankage with secondary and tertiary containment.

Los Alamos
Moderator Detritation System

Flow: > 30 kg/h
Comp.: > 99% D2O
< 1.5 Ci/t T2

Low Tritium Column (Cryodistillation)
D2 Makeup

High Tritium Column (Cryodistillation)

H2 to Waste

T2 Product

Los Alamos
Gaseous Waste Treatment System

Tritium Processing Building
< 10^-4 Clm^3

Process Gloveboxes
10^-3 to 10^-7 Clm^3

Process Equipment

Target Building

Target Containment

Target Vessel:

Gaseous Waste Cleanup System
Catalytic Oxidation, Mol Sieve Drying and Water Decomposition

Recycle

Waste < 1 kC/yr

Emergency Tritium Cleanup System
Catalytic Oxidation and Mol Sieve Drying

Recycle

Waste

*All process systems and lines are provided with triple containment.

Los Alamos
Annual Tritium Releases
Tritium Systems Test Assembly

Note: TSTA releases are several orders of magnitude lower than those of similar DOE Weapons Facilities.
Tritium Process (Support Systems) Technology

**Measurement & Control**
- Computer-based, Industrial control architecture.
- Fail-to-safe configuration design.
- Redundant safety systems.

**Process Building**
- Tritium areas designed for zone confinement.
- “Hot” shops and storage areas.
- Redundant monitoring in tritium operating areas.

**Ventilation**
- Tritium areas maintained at negative pressure.
- Zoned for isolation if contaminated.

**Services**
- Redundant power and gas supplies to key systems
- In-house backup for critical systems.
- Analytical Laboratory with Raman and mass spectrometer systems.
Summary

- Tritium processing systems will utilize well established, demonstrated technology.

- Safety and environmental features will be significantly improved with respect to current tritium systems.

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FY 94 Design Tasks (Proposed)

- Pre Conceptual Design completion
  - Heavy Water Detritiation
  - Instrumentation and Control
  - Pipe and Instrument Diagrams
  - Process Layout Studies

- Tasks deferred as a result of funding cutbacks.

- Completion needed to verify design concept and to serve as basis for cost estimation.

- Prepare "Budget Grade" cost estimate.
APT Experiments Status

Introduction
Paul Lisowski
Physics Division
Los Alamos National Laboratory

Quarterly Status Review
June 7, 1993

Los Alamos
Outline

- Introduction
- Source Term Experiment
- Materials Safety Experiments
- Thermal Hydraulics Tests

Paul Lisowski

Mike Cappiello

Los Alamos
APT Target/Blanket/Experiment Task Objectives

- Meet 3/8 goal quantity at 75% plant factor with 1000 MeV 200 nA accelerator.
  - Target/Blanket must have high availability, operability, and maintainability.

- Maximize environmental advantages of APT.
  - Protect personnel and environment.
  - Minimal radioactive toxic and mixed waste.
  - Quantify as much as possible those advantages.

- Single Target/Blanket module.
  - Two module system, with a second as spare or in maintenance.

- Utilize existing technology.
  - Choose proven equipment and materials where possible.

- Incorporate safety by design.

Los Alamos
APT Confirmatory Experiments Address Key Issues

**Materials Experiments**

*High neutron and proton fluences dictate careful material choices in design.*

Experiments aid in materials selection and connect proton and spallation neutron data base to fission neutron data base.

**Source Term Experiment**

*Major advantage of APT is low environmental impact.*

Radionuclide production data will bound uncertainty in source term calculation.

**Thermal Hydraulics Experiments**

*Low Pressure, high flow system operates in regime where CHF data is inadequate.*

T:H Experiments verify adequacy of rod bundle cooling under prototypic conditions and allow tests of off-normal conditions.
APT Thermal Hydraulics Experiment

- Experimentally verify target cooling under prototypic operating conditions.

- Perform full scale thermal hydraulic design verification tests.

- Establish damage thresholds under various accident scenarios.

- Identify potential improvements with respect to safety.
APT Materials Safety Experiments

- Provide input to mechanical engineering design on safe stress and ductility levels during and after radiation exposure.

- Compare mechanical property response after radiation exposure for Medium energy protons and spallation neutrons in order to determine extrapolation limits from fission neutron irradiated material.

- Investigate the role of transmutation-generated impurities on possible early-fracture mechanisms.

- Identify potential improvements with respect to safety.
APT Source Term Experiment

- Measure radionuclide production for thick targets of W and Pb in order to benchmark calculations and bound the source term and total radioactivity calculations.

- Collaborate with BNL in measurements at the AGS in 1993.
Source Term Experiment

Presented by:
Paul Lisowski,
Los Alamos National Laboratory

Collaborators:

<table>
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Los Alamos
Outline

- Motivation for Experiment
- Experimental Procedure
- Status
Motivation for Experiment

- Measure radionuclide production in target materials (Tungsten and Lead)
  - Quantify radionuclides produced for safety and engineering
  - Set bounds on calculated “source term”
  - Study short half-life isotopes that may contribute to decay heat

- Test our ability to calculate radionuclide production
  - Must understand production over wide energy range
  - No experimental data exists for thick tungsten targets (A principle element in Los Alamos design)
Calculation of Radionuclide Yield

- **Cascade Models**
  - Best nuclear physics
  - Monte-Carlo model
  - Gross nuclear properties well predicted
  - Yield of individual radionuclides uncertain by factors of 2 to 3 in best cases

- **Secondary production and transport complicated**

- **Few experiments on “thick targets”**
  (SNQ data at 600,1100 MeV on lead)
Calculational Questions

- Production of isotopes for p+A as a function of incoming proton energy.

- Production of secondary particles (primarily neutrons) in the process.

- Transport of the secondaries in the bulk target assembly.

- Interaction of secondaries with the target material.

- Needed "systems test" - thick target experiment to test our ability to integrate all elements of this complex problem.
Overview of Experiment

- **Use thick targets of $^{\text{Nat}}$Pb, $^{\text{Nat}}$W**
  Sample at various locations in target with 0.020” and 0.040” thick foils

- **Irradiate at 800 MeV**
  - Few seconds, to study short half lives
  - 1 hr, 8 hr irradiation to study longer-lived isotopes

- **Identify isotopes by their gamma ray decay spectrum**
  - Each isotope emits several characteristic gamma-rays
  - Use high resolution Ge detectors
  - Measure spectrum several times to determine half-life
  - Foils from short irradiations counted at WNR with 5 Ge detectors

- **Foils from long irradiations counted at Nuclear Chemistry facility**
  - Automated foil changing detectors
Tungsten Irradiation Assembly

Tungsten samples were placed at locations 'A - E.' 'A' was on-beam-axis.

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Summary of APT Tungsten Irradiations

- **14 “Short” Irradiations**
  5 foils each, foils counted immediately at WNR
  500 pulses (2 sec) to 100,000 pulses (156 sec)
  $1.5 \times 10^{11}$ protons to $3.45 \times 10^{14}$ protons

- **1 medium irradiation**: $1.1 \times 10^6$ pulses in 3900 sec
  $3.5 \times 10^{14}$ protons
  24 foils counted at Nuclear Chemistry Facility

- **1 long irradiation**: $4.4 \times 10^6$ pulses in 21945 sec
  $1.3 \times 10^{15}$ protons
  30 foils, counted at Nuclear Chemistry Facility
Samples were placed at locations 'A - E.' 'A' was on-beam-axis.
Summary of APT Lead Irradiations

- 9 “Short” Irradiations
  5 foils each, counted immediately at WNR
  200 to 200,000 beam pulses, 3 sec to 367 sec
  $6 \times 10^{11}$ protons to $6 \times 10^{13}$ protons

- 1 “medium” irradiation
  $1 \times 10^6$ beam pulses in 1352 seconds
  $3 \times 10^{14}$ protons
  24 foils, counted at Nuclear Chemistry Facility

- 1 “long” irradiation: $5.5 \times 10^6$ beam pulses in 4265 seconds
  $1.6 \times 10^{15}$ protons
  29 foils, counted at Nuclear Chemistry Facility

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Typical Results

- Spectrum from tungsten irradiation designed to get short half-life activity

- First results ever for isotopes with $t_{1/2} < 30$ minutes.

- Data at 50-minutes after exposure, 3-minute count
Stages of Analysis

I. Calibrations: Energy and efficiency standards traceable to NIST
   - Energy Calibration
     Fast ADC's introduced slight non-linearity
     1 part in 10000 precision required
   - Detector efficiency
     "Thick" targets have 10% transmission for low-energy gamma rays
     - accurate corrections needed.

II. Data Processing (Peak identification)

III. Understand complicated decay schemes to determine primary spallation products
Summary and Status

- Thick-target radionuclide production experiment at 800 MeV completed. Foils have been counted.

- Calibrations have been completed.

- Data processing is under way

- Spallation radionuclide decay library update in progress

- Predictions of yield completed, awaiting comparison to data.
Materials Safety Experiments

Presented by:
Paul Lisowski,
Los Alamos National Laboratory

Walt Sommer, Los Alamos National Laboratory, P.I.

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M. Borden, Los Alamos National Laboratory

APT Quarterly Review
June 7, 1993
LAMPF Experiments are Needed to Connect Low and High Energy Material Damage Results
Aluminum Alloys offer high efficiency relative to other structural materials due to a low thermal neutron absorption cross section. They have been considered prime candidates for all facilities where high thermal neutron fluxes are required.

A limited experience base for the use of aluminum Alloys exists for APT-Relevant proton and neutron spectra [LAMPF, LANSCE, SIN]; Some Alloys have performed well.

Extrapolation to APT target and blanket conditions involves uncertainties as demonstrated by differences seen between performance in fission reactor environments and in an 800 MeV proton beam.

Using material already irradiated, or scheduled to be irradiated, this test plan was designed to remove uncertainties associated with the use of aluminum alloys for APT, to develop a more sound data base and to establish safe stress levels for design.

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Testing Methods

- Microhardness - Los Alamos

- Tensile Properties - University of Illinois

- Disc-Shear tests - Battelle - Pacific Northwest Laboratories

- Scanning Electron Microscopy - Sandia National Laboratory
Preliminary Test Results

- **Samples Irradiated with 800 MeV protons at $10^{20} \cdot 10^{21}$**
  - AlMgSi and AlMg alloys at $>200^\circ C$ - loss of tensile strength $\sim 10^{20}/cm^2$
  - AlMgSi and AlMg alloys at $\sim 50^\circ C$ - little effect on mechanical properties
    $\sim 2 \times 10^{21}/cm^2$
  - AlCu 2219 alloy at $\sim 120^\circ C$ - Microhardness tests show little effect after a fluence of $\sim 10^{21}/cm^2$.

- **Irradiated with spallation neutrons at 2 - 5 $\times 10^{20}/cm^2$**
  - AlMgSi and AlMg alloys at 90 - 120$^\circ C$ - little effect on mechanical properties
Long Range Materials Test Plan

- **Features:**
  - Prototypic radiation environment
  - Prototypic stress states including cyclic variations
  - Prototypic corrosion conditions
  - Uses materials from controlled lots

- **Facilities:** LAMPF AGS HFBR HFIR ACRR ATR EBR II

- **Special tests - materials already on hand**
  - Irradiated properties of W and Alloys
    Irradiated at LAMPF in 1992 to $> 10^{21}/\text{cm}^2$
    Test mechanical properties with microhardness
    Determine product release as a function of temperature
  - Irradiated properties on beam-entry windows
    LAMPF Inconel 718 windows
    PSI/SIN Fe-10.5% Cr windows
Experiment Status

- Testing is complete
- Topical Report has been initiated
- Scanning electron microscopy at SNL continues
APT DESIGN REVIEW

APT THERMAL HYDRAULIC EXPERIMENT

PRESENTED BY

MIKE CAPPIELLO
APT THERMAL HYDRAULIC EXPERIMENT

OBJECTIVE:

- VERIFY ADEQUACY OF COOLING TARGET UNDEP. PROTOTYPIC CONDITIONS.
- PRESSURE, TEMPERATURE, FLOW.
- CRITICAL HEAT FLUX (CHF) UNDER LOW PRESSURE, HIGH VELOCITY, HIGH L/D COND.
- LOSS OF PRESS/TEMP/FLOW RESPONSE/LIMITS
APT THERMAL HYDRAULIC EXPERIMENT

RATIONALE:

• SCARCITY OF CHF DATA IN 0.1 TO 2.0 KW/SQ.CM. RANGE.

• SCARCITY OF CHF DATA IN 50 TO 600 L/D RANGE.

• CHF CORRELATIONS FOR SUB-COOLED FLOW HAVE ERROR BARS TO ± 50%.

• LITTLE WORK HAS BEEN DONE ON PARALLEL CHANNEL AND INTERCONNECTED CHANNEL INSTABILITIES.

TESTING OF PROTOTYPIC CONFIGURATION, TEMPERATURE, PRESSURE, MASS FLOW IS NECESSARY FOR DESIGN ASSURANCE.

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Thermal Hydraulic Experiment
APT THERMAL HYDRAULIC EXPERIMENT

EXPERIMENTAL METHODS:

- COLD FLOW TEST.
- ELECTRICALLY HEATED HOT TEST.
APT THERMAL HYDRAULIC EXPERIMENT (COLD TEST)

- TEST BUNDLE
- WATER OUTLET
- FLOW METER
- REMOTE CONTROL
- MOTOR SPEED CONTROL
- PUMP
- FILTER
- WATER INLET

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APT THERMAL HYDRAULIC EXPERIMENT (COLD TEST)

Thermal Hydraulic Experiment

Los Alamos
APT THERMAL HYDRAULIC EXPERIMENT (HOT TEST)

FLOW METER

TEST BUNDLE

PRESSURE

PRESSURE & TEMPERATURE

POWER SUPPLY

HEAT EXCHANGER

THROTTLE VALVE

PUMP

FILTER

Los Alamos
APT THERMAL HYDRAULIC EXPERIMENT (HOT TEST)

1. STEADY STATE FULL POWER TESTS.
   - HEAT TRANSFER COEFFICIENT.
   - BUNDLE PRESSURE DROP.

2. CRITICAL HEAT FLUX TEST.

3. LOSS OF HEAT SINK TRANSIENT (T-IN INCREASE)

4. LOSS OF PUMP ACCIDENT (FLOW REDUCTION, BEAM TRIP).

5. LOSS OF POWER ACCIDENT (LOSS OF FLOW, BEAM TRIP, LOSS OF PRESSURE).

Initial tests with 7-pin bundle, subsequent test with 19 pin bundle.

Thermal Hydraulic Experiment

Los Alamos
APT THERMAL HYDRAULIC EXPERIMENT TEST FACILITIES

- 2.5 MW D.C. POWER SUPPLY.
- RECTIFIED A.C. & RF POWER SUPPLIES AVAILABLE.
- POWER DISTRIBUTION SYSTEM IN PLACE TO TEST CELL.
- DEDICATED 5 MW COOLING TOWER.
- 8 MW TOTAL POWER ON SITE (TA-46).
- DATA ACQUISITION SYSTEM IN PLACE.
- HIGH BAY CONTAINMENT VESSEL AREA AVAILABLE

Los Alamos
APT THERMAL HYDRAULIC EXPERIMENT

HOT TEST

Stainless Steel Plenum

Copper Feedthru

Interface block 1/2" dia.
200 p.s.i
125 g.p.m.

Water cooling Feedthru

Brazed

Electrical insulator

1/8" Tungsten rods x 7
Bundle Container w/External Surface Heaters

Los Alamos
API THERMAL HYDRAULIC EXPERIMENT

TEST STATUS:

- COLD FLOW TEST COMPLETED.
- HOT TEST SYSTEM DESIGN COMPLETE.
- 1.25 MW POWER SUPPLY AND DISTRIBUTION NETWORK SWITCHING OPERATION VERIFIED.
- MOTOR GENERATOR ENERGIZED, VOLTAGE APPLIED TO DUMMY LOAD.
- 7-PIN TEST BUNDLE BEING INSTALLED.
APT Accelerator Design Overview

George Lawrence

Accelerator Technology Division
Los Alamos National Laboratory

DOE/DP Quarterly Review
June 7-8, 1993

Los Alamos APT Team
# Accelerator Design Agenda

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LANL APT Accelerator Design Team

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Los Alamos APT Team
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Los Alamos APT Team
Outline

- Performance requirements
- Reference accelerator concept
- Key parameter selection
- Beam transport concept
- Technology base maturity
- Technical issues
- Design status
Linac Design Requirements

- 3/8-Goal tritium production at 75% plant factor
- High availability and operability
- Minimum life cycle cost
- High electrical efficiency
- Machine, personnel, and environment protection
As Proton Energy Increases Different Accelerating Structures are Used

RFQ (Radiofrequency Quadrupole)
Low Energy

DTL (Drift-Tube Linac)
Medium Energy

CCL (Coupled-Cavity Linac)
High Energy

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Introduction to APT Accelerator Design

- Linac design is based on conventional technology approach
  - Room-temperature copper accelerating structures
  - Performance levels demonstrated or within technology base

- Key parameters justified by limited cost/performance trades

- Conservative overall accelerator design framework
  - Low-energy section derived from NPB/SDI technology advances
  - High-energy section based on proven LAMPF technology
  - RF power system uses CW klystrons developed for colliders

- Linac design has evolved to stable, self-consistent solution
Reference AP1 Accelerator
1000-MeV, 200-mA CW Proton Linac

- Beam power: 200 MW
- Total RF power to linac: 254 MW
- RF to beam efficiency: 0.787
- AC to RF efficiency: 0.582
- RF transport efficiency: 0.950
- AC to beam efficiency: 0.435
- AC power requirement: 485 MW
- Average CCL gradient: 1.0 MV/m
- Transverse output emittance: 0.04 π cm·mrad
- CCL aperture/beam-size ratio: 13–26

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## APT Reference Accelerator Parameters (2/3/93)

<table>
<thead>
<tr>
<th>parameter</th>
<th>RFQ (2)</th>
<th>DTL (2)</th>
<th>BCDTL</th>
<th>CCL</th>
<th>Totals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structure Type</td>
<td>4-vane</td>
<td>1βλ.</td>
<td>1βλ.</td>
<td>side-coupled</td>
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<tr>
<td>Frequency (MHz)</td>
<td>350</td>
<td>350</td>
<td>700</td>
<td>700</td>
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</tr>
<tr>
<td>Energy (MeV)</td>
<td>0.075 to 7.0</td>
<td>7.0 to 20</td>
<td>20 to 100</td>
<td>100 to 1000</td>
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<tr>
<td>Output Current (mA)</td>
<td>100</td>
<td>100</td>
<td>200</td>
<td>200</td>
<td></td>
</tr>
<tr>
<td>Avg Gradient $E_g T$ (MV/m)</td>
<td>0 to 1.75</td>
<td>0.83 to 2.24</td>
<td>1.7, 1.5</td>
<td>1.50, 1.30, 1.38</td>
<td></td>
</tr>
<tr>
<td>Struct Gradient, $E_g T$ (MV/m)</td>
<td>-90 to -30</td>
<td>-35 to -25</td>
<td>-40 to -30</td>
<td>-30</td>
<td></td>
</tr>
<tr>
<td>Synchronous Phase (deg)</td>
<td>90 to -30</td>
<td>23.0 to 24.3</td>
<td>23.0 to 37.4</td>
<td></td>
<td></td>
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<tr>
<td>Shunt Impedance (Max)</td>
<td>1.9</td>
<td>1.29 to 2.62</td>
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<td></td>
<td></td>
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<tr>
<td>Total Length (m)</td>
<td>8.1</td>
<td>8.0</td>
<td>93.6</td>
<td>1039</td>
<td>1180 a</td>
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<tr>
<td>Tank Length (m)</td>
<td>2.5</td>
<td>0.61 to 1.27</td>
<td>1.29 to 2.62</td>
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<td></td>
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<tr>
<td>Cells per Tank</td>
<td>433</td>
<td>22 to 15</td>
<td>7</td>
<td>14</td>
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<tr>
<td>Radial Aperture (cm)</td>
<td>0.235 (min)</td>
<td>1.0</td>
<td>2 to 2.25</td>
<td>2.5</td>
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<tr>
<td>Aperture Beam-Size Ratio</td>
<td>6.5</td>
<td>8 to 13</td>
<td>13 to 26</td>
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<tr>
<td>RF Power</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cooper (MW)</td>
<td>1.12x2</td>
<td>1.15x2</td>
<td>6.5</td>
<td>43.2</td>
<td>54.2</td>
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<tr>
<td>Beam (MW)</td>
<td>0.70x2</td>
<td>1.30x2</td>
<td>16.0</td>
<td>180.0</td>
<td>200.0</td>
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<tr>
<td>Total (MW)</td>
<td>1.82x2</td>
<td>2.45x2</td>
<td>22.5</td>
<td>223.2</td>
<td>254.2</td>
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<tr>
<td>Efficiency</td>
<td>0.385</td>
<td>0.530</td>
<td>0.711</td>
<td>0.806</td>
<td>0.787</td>
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<tr>
<td>Focusing</td>
<td></td>
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</tr>
<tr>
<td>Quadrupole Lattice</td>
<td>FD</td>
<td>FOFOFOFO</td>
<td>FDO</td>
<td>FDO</td>
<td></td>
</tr>
<tr>
<td>Phase-Adv. Period (deg)</td>
<td>80 to 70</td>
<td>80</td>
<td>70</td>
<td></td>
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<tr>
<td>Eff. Quad Length (m)</td>
<td>5.7</td>
<td>5 to 6</td>
<td>7 to 11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quad Spacing (m)</td>
<td>0.01 to 0.17</td>
<td>1.04 to 1.93</td>
<td>1.93 to 3.56</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quad. Gradient (T/m)</td>
<td>35 to 30</td>
<td>49 to 57</td>
<td>46 to 61</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Emittance (normalized, rms)</td>
<td>0.02 to 0.022</td>
<td>0.023 to 0.025</td>
<td>0.031 to 0.035</td>
<td>0.035 to 0.038</td>
<td></td>
</tr>
<tr>
<td>Transverse (x cm-mrad)</td>
<td>0 to 2.34</td>
<td>0.220 to 0.235</td>
<td>0.275 to 0.272</td>
<td>0.272 to 0.309</td>
<td></td>
</tr>
<tr>
<td>Longitudinal (x MeV-deg.)</td>
<td>0 to 0.31</td>
<td>0.031 to 0.035</td>
<td>0.035 to 0.038</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a Includes tunnel & matching sectors
b Normalized to 350 MHz RF cycle

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Design Framework for APT Linac

- Low energy design (< 20 MeV) emphasizes emittance control.

- Beam funneling at 20 MeV is a conservative design feature.

- High energy design (> 20 MeV) balances low beam loss & high RF efficiency.

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**Basis for Selection of Key Parameters**

- **Energy, Current**
  - 1000 MeV, 200 mA
  - Meets 3/8-G production requirement at minimum cost with conservative design.

- **Frequencies**
  - 350 MHz
  - High enough for good emittance control;
  - Low enough for EM quads in DTL drift tubes.
  - Proven 1-MW CW klystron from industry.

  - 700 MHz
  - Minimum frequency for funneled system.
  - High shunt impedance for CCL, BCDTL.
  - Reasonable-diameter structure; fabricability.
  - Klystron within familiar design space.

- **CCL gradient**
  - 1.0 MV/m
  - Low RF losses, with minimal thermal management stress in CW operation.
  - High RF-to-beam conversion efficiency.

- **CCL aperture to beam size**
  - 13 - 26
  - Assures < $10^{-8}$/m losses in CCL, while still providing reasonable RF efficiency.

- **CCL focusing lattice**
  - Doublet
  - Provides higher aperture/beam-size ratio; some penalty in magnet power.

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Average Current in APT Linac is 200 x LAMPF but Charge per Bunch is Only 3.4 x Greater

**LAMPF**

- Injector
- DTL: 200 MHz
- CCL: 800 MHz, 1 mA avg

CCL current 6% Duty Factor
- 16.7 mA
- 500 μs
- 0.52x10^9 ppb

1/4 of CCL RF cycles contain bunches

**APT**

- Injector
- RFQ: 350 MHz, 100 mA
- DTL
- CCL: 700 MHz, 200 mA avg

CCL Current 100% Duty Factor
- 1.78x10^9 ppb

All CCL RF cycles contain bunches

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Top Level Accelerator Issues

- Beam loss in accelerator and transport system
- RF power system electrical efficiency
- RF generator-cavity-beam system control
- High power CW operation of RF components (windows, couplers)
- Transport/target interface; target protection
- Turn-on and fault handling; off-normal conditions
- Component reliability; maintenance

Integrated system operability
Overall system availability
Cost, performance, risk tradeoff

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Demonstrated Accelerator-Technology Base

**RFO Linac**
- 70-mA, 600-keV CW proton beam (CRNL)

**Funnel**
- LANL 5-MeV single-leg funnel demonstration (425 MHz)

**Drift-Tube Linac**
- LANL 7-MeV DTL: 100-mA pulsed current (425 MHz)
- CERN 100-MeV DTL: 250-mA pulsed current (201 MHz)

**Coupled-Cavity Linac**
- LAMPF: 17 mA peak, up to 12% duty (805 MHz)
- CRNL: CW operation at 1.8-MV/m gradient (804 MHz)

**Beam Transport**
- Straightforward engineering; standard beam optics and magnets

**RF Generators**
- 1-MW CW klystrons available from Industry (350 MHz, 500 MHz)
- 700-MHz 1-MW klystron is within developed design space

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Design Summary

- Linac, HEBT architecture and parameters frozen
- First-order physics design complete
- End-to-end beam simulations run
- Engineering design to PDR stage
- RF module design established
- Power system concept established
- Tunnel and infrastructure concepts outlined
- Initial exploration of operations issues
- Shielding and air activation estimates made

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Accelerator Physics Design

George Lawrence
Accelerator Technology Division
Los Alamos National Laboratory

DOE/DP Quarterly Review
June 7-8, 1993
Outline

- LE and HE linac design principles
- Accelerating structure physics
- Beam simulations
- Error studies
- Funnel design
Low Energy Linac Design (< 20 MeV)
Emphasizes Preservation of Beam Quality (Emittance)

- ECR ion source for high DC current with good emittance
- Low injection energy (75 keV) for high injector reliability
- High-energy RFQs for bunching & initial acceleration stage
- High structure frequency (350 MHz) reduces charge/bunch and provides strong transverse focusing
- Ramped accelerating field in DTL provides strong longitudinal focusing
- Precise matching between structures reduces beam heating shocks

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High Energy Linac Design (> 20 MeV)
Balances Low Beam Loss With High RF Efficiency

- Very large ratio of accelerating structure aperture to rms beam size
- Strong transverse focusing (short accelerator tanks)
- No significant transitions in transverse or longitudinal acceptance
- Low accelerating gradient (1.0 MV/m)
- Doublet (FD) focusing minimizes beam transverse dimensions
- Bridge-coupled DTL is efficient structure for 20 - 100 MeV region
- 700 MHz frequency choice provides close to maximum RF efficiency

Coupled Cavity Linac (CCL)
(700 MHz, 200 mA)

BCDTL (700 MHz) 100 MeV 14-Cell Tanks Doublet Focusing 1000 MeV

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Ion Source Options

- Electron Cyclotron Resonance (ECR) source
  - Most promising candidate
  - Proven, reliable cw operation
- RF driven volume source with magnetic filter
  - Proven concept, scalable design
  - Requires high power and large gas flow
- Viable "standby" candidates
  - Filament-driven multicusp source
  - Single ring cusp field source
  - Duopigatron source

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