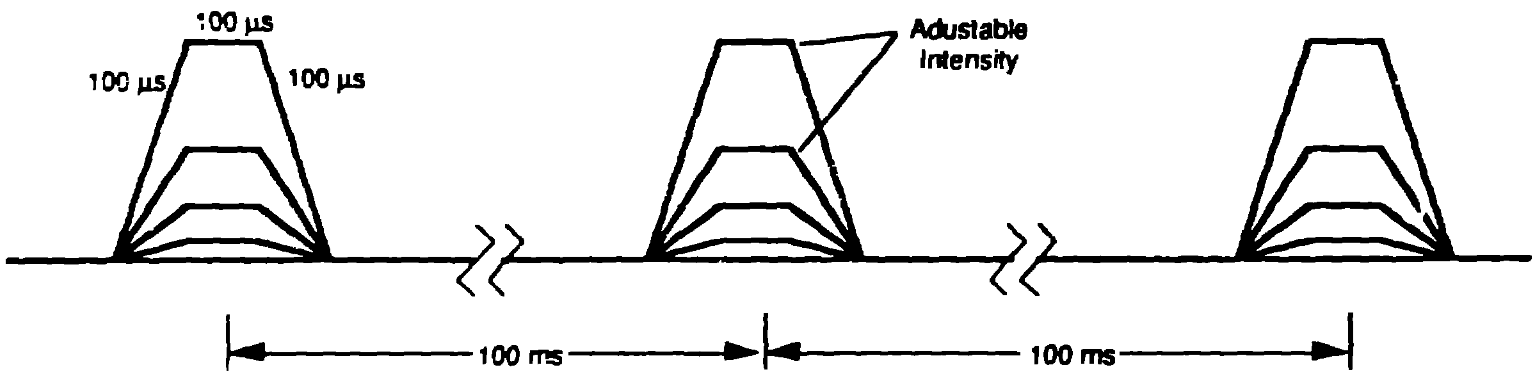
Accelerator Turn-on and Fault Recovery; Operating Modes

- **Variable intensity CW operation (seconds to minutes)**
  - Achieved with adjustable iris in LEBT and/or ion-source modulation
  - Linac focusing lattice nearly independent of input current
- **Long pulse operation (several -100 μs) is practical if rise/fall times are long enough for neutralization and RF feedback loops to follow**
  - Achieved with kicker magnet in LEBT or RFQ modulation
  - Duty factor could be reduced to 0 0002 - 0.002 (40 - 400 μA)
  - Full peak current available for high-current tuning operations
  - Diagnostics should have large dynamic range (10 - 100)



- **Ultra-short pulses (< 100 ns) may be useful for some tuning operations**

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Initial Accelerator Turn-on

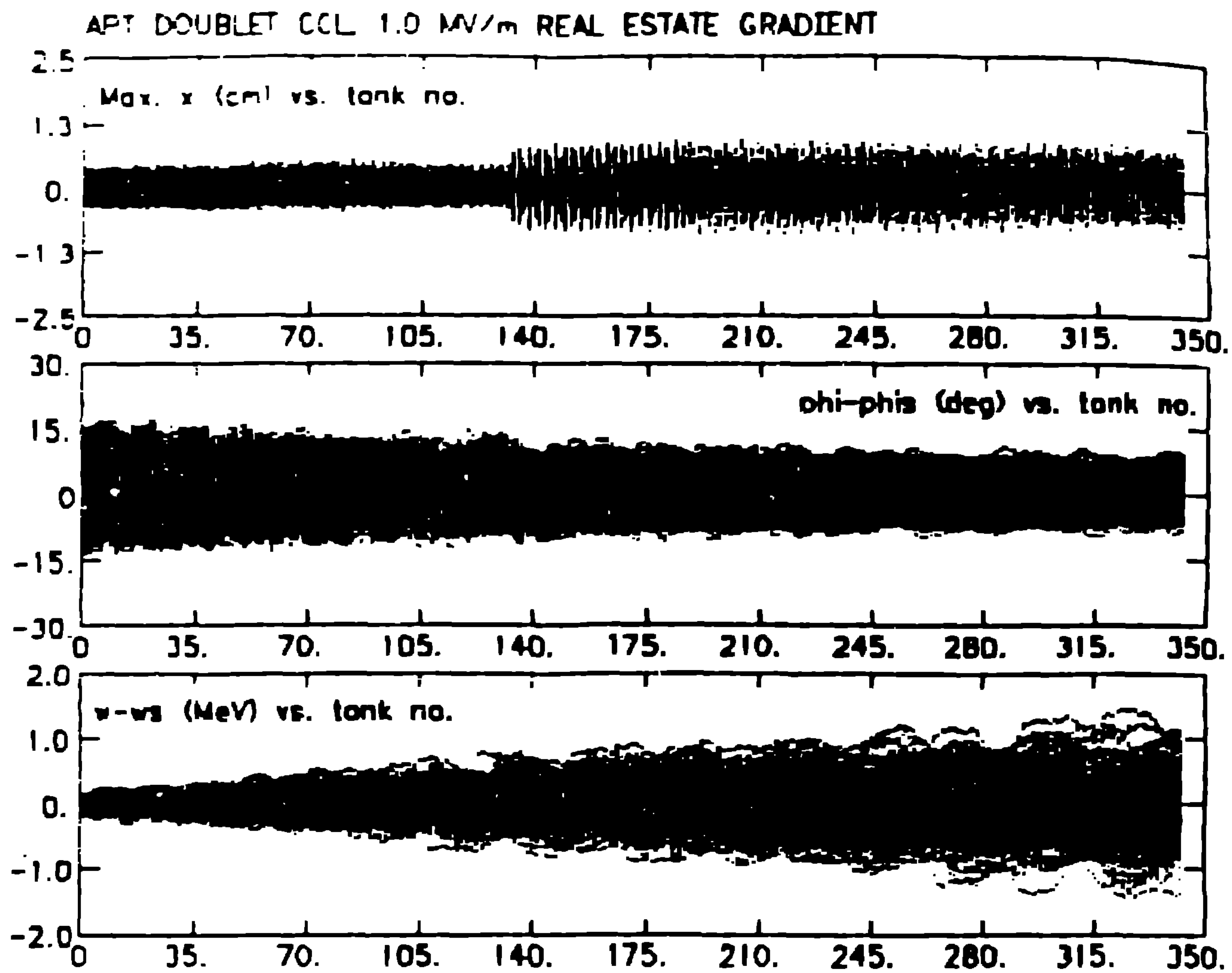
- **Bring up support systems (controls, vacuum, diagnostics, cooling, etc.)**
- **Adjust quadrupole currents to nominal values**
- **Voltage condition RF cavities with short RF pulses (local oscillators)**
- **Adjust RF feeds for nominal cavity amplitudes and phases; no beam**
  - Local oscillators allows klystrons to heat cavities
  - Servo-controlled cooling loops bring cavities to operating frequency
  - RF generators lock to master oscillator frequency
- **Tune linac with beam in sections, using intermediate-energy beam stops**
  - 1) Injector + LEBT; 2) RFQ + DTL + funnel; 3) BCDTL; 4) CCL
- **Start with low average power beam in pulsed mode, 0.1 peak amplitude**
  - Measure and correct beam position errors, RF phase & amplitude errors
  - Peak beam current during this operation is similar to LAMPF
- **Increase peak current gradually to production value and refine tune**
- **Extend pulse width and pulse rate until 200-mA CW operation is attained**

Recovery from Brief Beam or RF-Station Fault

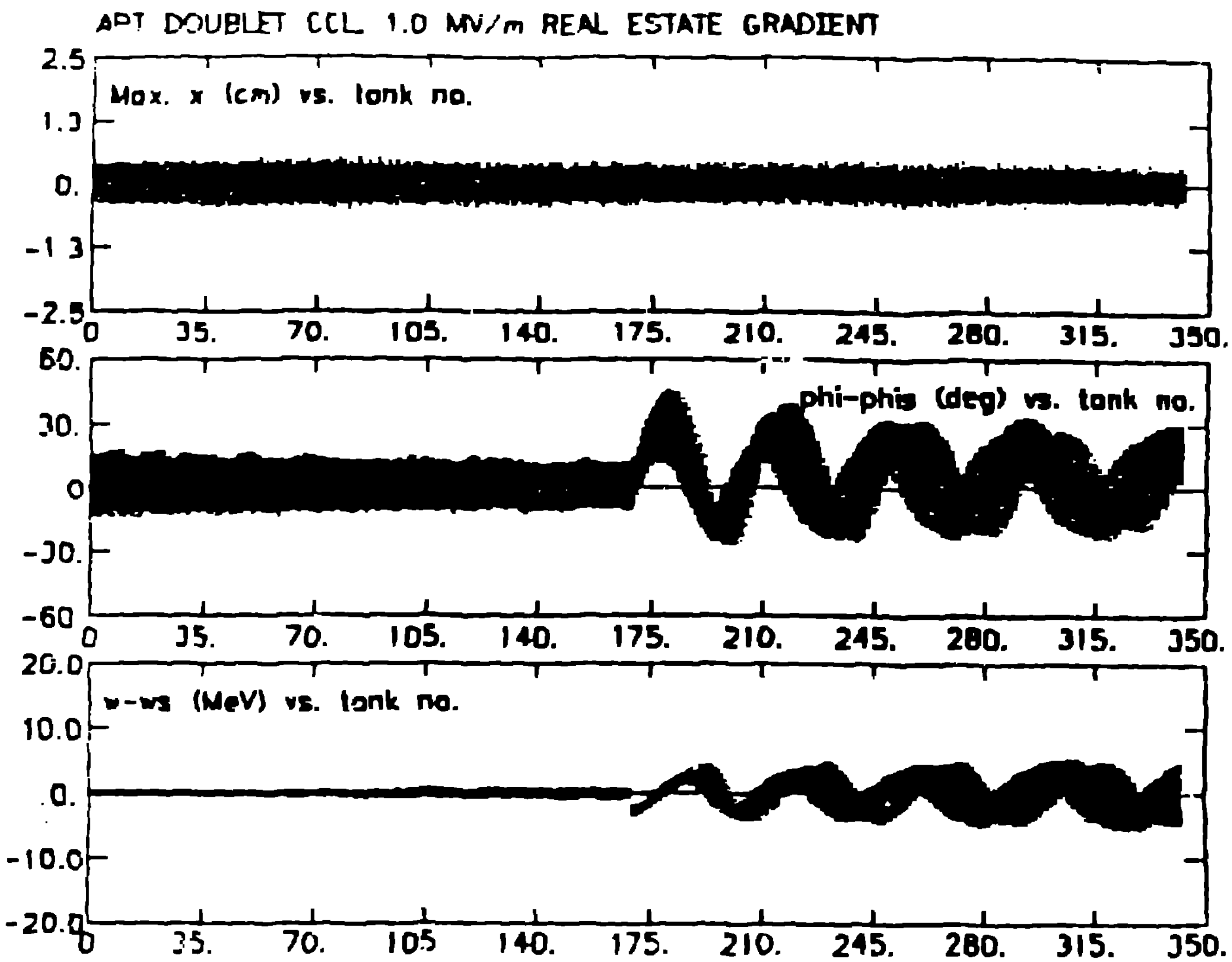
- **Assumptions**
  - RF cavities detuned for optimum match with full beam intensity
  - Beam output insensitive to current level from 0.1 to 1.0 x full intensity
  - Closed loop RF control, with feedforward
- **Beam interrupt (injector arc)**
  - During transient excess RF power reflected through circulator to load
  - RF control circuits reduce generator output to maintain cavity field
  - Excess DC power to klystron collectors; no change in AC grid load
  - Ramp CW beam current to production level over 100-ms to 1-s time period, with RF control circuits holding cavity fields constant
  - Ramp time could be longer following longer beam interrupt
- **RF station interrupt (klystron or cavity arc)**
  - Beam operation may continue if fault is at Ep > 400 MeV
  - If Ep < 400 MeV, then abort beam (< 20 μs)
  - Recover RF module (generator + cavity)
  - Ramp CW beam current to production level as above

Some Representative Off-Normal Conditions Have Been Investigated to Determine Range of Operational Tolerance

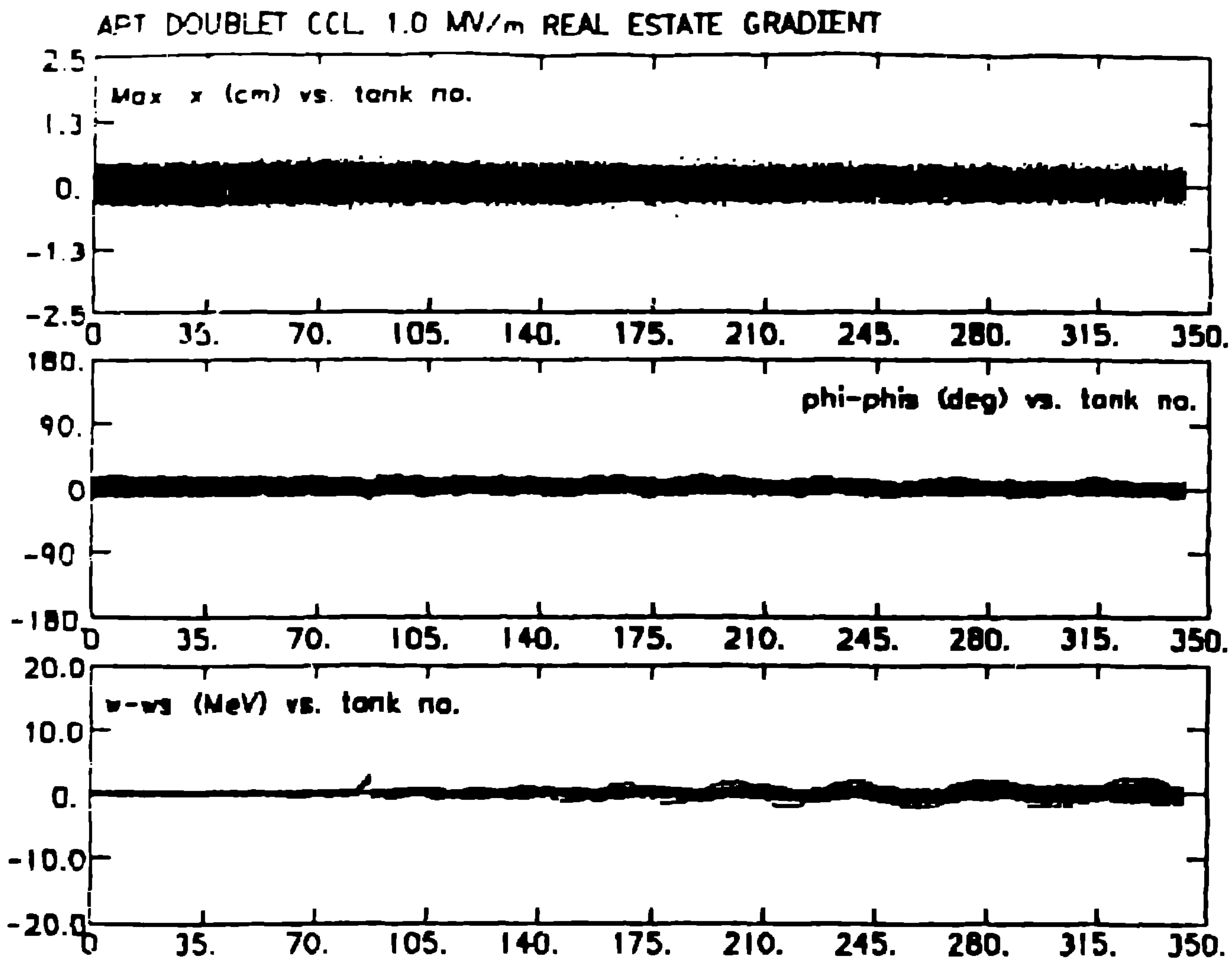
- **Quadrupole doublet failure in CCL**
  - Looked at dependence on energy where failure occurs
  - Some emittance increase, but small effect on overall performance
- **RF station failure in CCL**
  - For Ep < 285 MeV, large fraction of beam lost in linac
  - For 285 MeV < Ep < 400 MeV, some beam is off energy, but is transmitted through rest of linac
  - For Ep > 400 MeV, beam energy spread increases but remains within acceptance of CCL and HEB
- **Is it possible to compensate for a failed station by increasing power from adjacent RF modules?**
- **Increased beam halo production?**



Beam profile plots for a single doublet failure in the APT CCL. Here the Tank 132 doublet has failed.

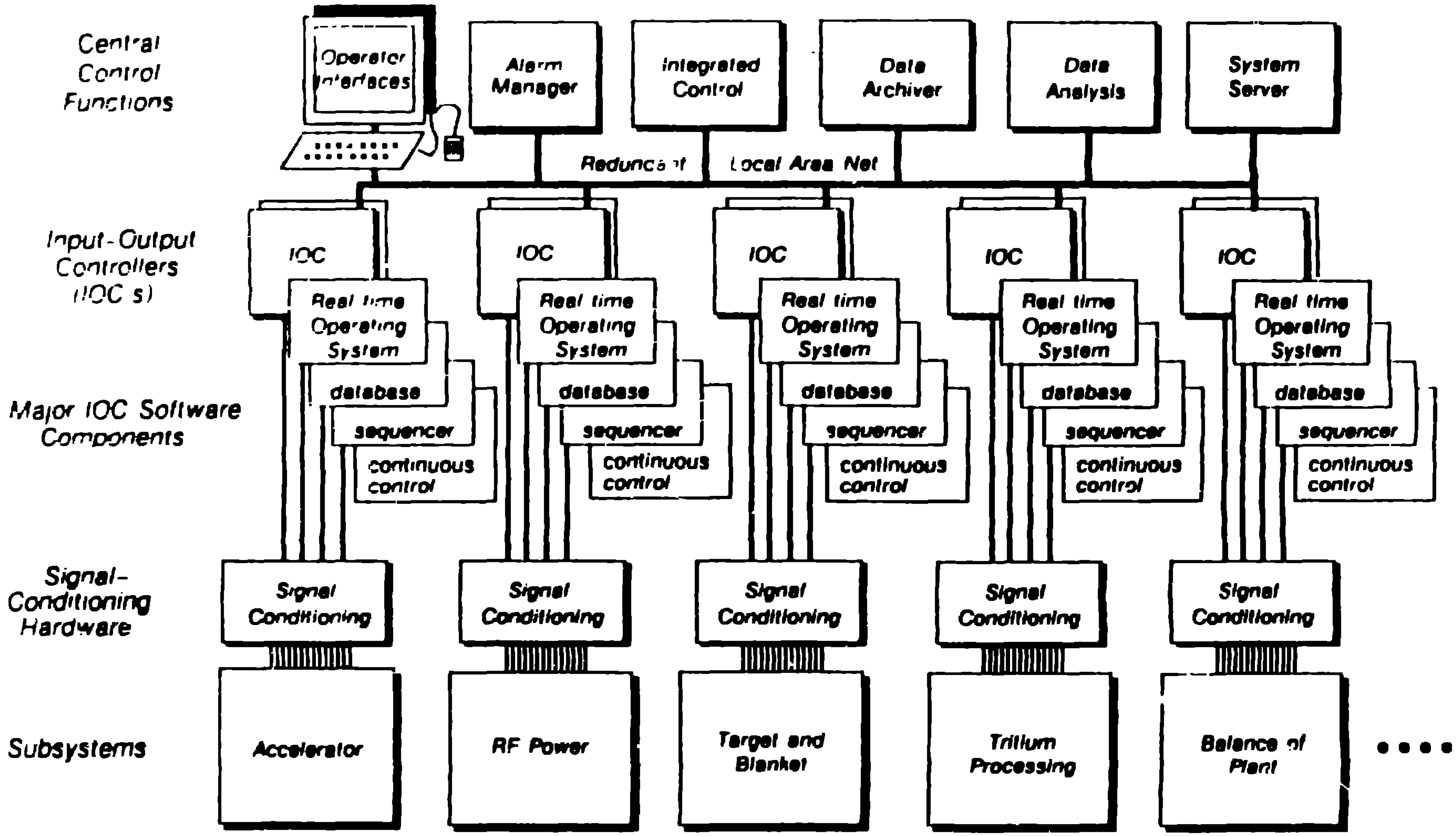


Beam profile plots for a single failed rf module. Here Module 170 has failed. No beam is lost. All particles are captured and accelerated to full energy.



Beam profile plots for a Module 88 failure. Here tanks 84-87 have been used to compensate for the energy gain lost in the failed module. Some synchrotron oscillations are observed, however, all the beam remains catured and is accelerated to full energy.

Distributed Instrumentation and Controls for APT



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Types of Safety and Protection Schemes

- **Passive Safety**
  - Conservative shielding
  - Sealed tunnel
  - Physical interlock Personnel Safety System (RPSS)

- **Active Safety**
  - Accelerator shutdown on fault (Fast Protect)
  - Computer-controlled Run Permit
  - Beam diagnostics and feedback
  - Continuous beam loss monitoring

- **Operator training**

- **Formality of Operations**

Run-Permit System

- Computer-controlled shutdown (or prevention of startup)
- All relevant conditions must be satisfied before beam is turned on
- Sensed out-of-range parameters drop run permit
- Redundant sensors and watchdog timers enhance reliability
- Typical inputs include:
  - Magnet currents
  - Vacuum
  - RF system parameters
  - Cooling flows, pressures
  - Beam position
  - Beam transmission
  - Beam profile
  - Target/blanket parameters

Fast Protect System

- **Hardwired, fast-response system**
- **Typical 20 μs response composed of:**
  - Sensor response time (1-5 μs)
  - Electrical signal transmission to injector (< 4 μs)
  - Deflector high-voltage rise time (< 4 μs)
  - Beam transport time for beam in accelerator (< 7 μs)
- **Typical inputs include:**
  - Beam loss monitors
  - RF signal strength
  - Beam edge feelers

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Radiation Exposure Limits

- **Defined by DOE N 5480.5 and adopted by SSC and LAMPF**

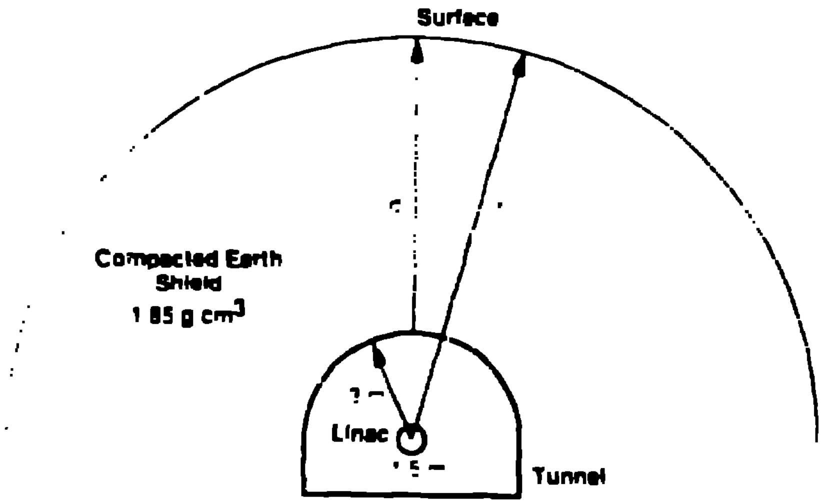
- **Controlled Areas (access only to authorized site workers)**
  - 200 mrem/yr during normal beam operations
  - 100 mrem per beam loss accident

- **Open Areas (access by public)**
  - 20 mrem/yr during normal beam operations
  - 10 mrem per beam loss accident

- **Accident defined as full beam loss for one hour.**

Linac Shielding is Calculated for Worst Case Beam Spill

Geometry for APT Linac Shielding Calculation



Point Source $H(d) = H_0 \dfrac{\exp(-d/\lambda_{eff})}{r^2}$

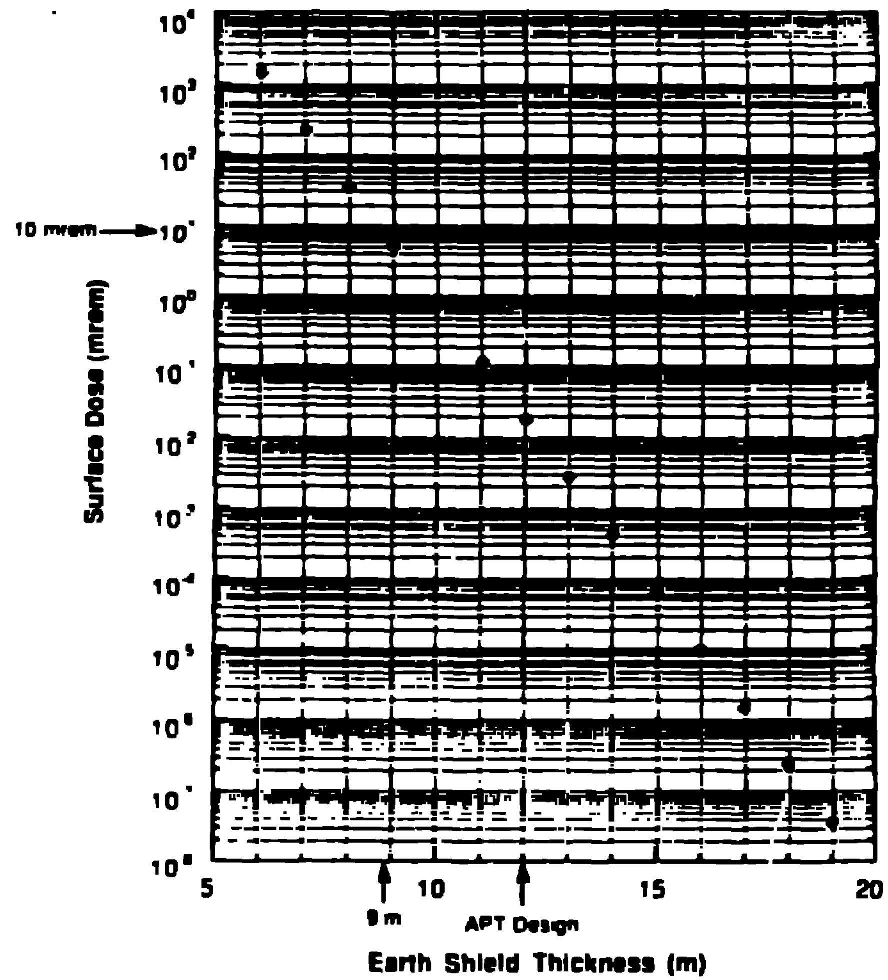
Line Source $H(d) = H_{0,\infty} E_0^{0.8} \dfrac{[0.065 \exp(-1.09 d/\lambda_{eff})]}{r}$

For 1 GeV protons: $H_0 = 7.6 \times 10^{-12}$ mrem m^2

$H_{0,\infty} = 2.8 \times 10^{-12}$ mrem m^2 GeV

$\lambda_{eff} = 117$ g cm^{-2} = 0.6 m

Dose vs Shield Thickness for Full Beam Spill Along 100-m Path for 1 Hour (200 mA at 1 GeV)



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Air Release Calculations

- Isotopic source distribution based on LAMPF experimental data
- Activated air production in APT tunnel based on PSR measurements
  - 1 nA loss at 800 MeV = 9 μCi
- Transport to site boundary calculated by CAP88 as used by LAMPF with conservative factors:
  - 800 m to boundary (LAMPF situation)
  - Factor of 2.5 for ground-level release (no stack)
  - Sealed tunnel leak rate of 2100 cfm (very conservative)

Isotopic Composition of APT Linac Activated Air Source Term

Isotope	Equilib. Isotope Distribution (%)	Activity Distribution (%)	Annual Release (Curies)
10C	0.0	0.8	0.7
11C	52.3	48.4	42.1
13N	9.8	18.6	16.2
16N	0.0	0.2	0.2
14O	0.1	1.1	1.0
15C	2.8	24.8	21.6
41Ar	35.1	6.1	5.3
			87 Ci/yr

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Air Release Calculation Results

- **All calculated levels are well below the present DOE dose limit of 10 mrem/yr for uncontrolled public access areas**

Scenario	Offsite Dose
"Normal" operation with maximum tolerable beam loss (20 nA/m)	0.039 mrem/yr
Tunnel exhaust prior to maintenance (once per day)	0.015 mrem/yr
Maximum credible beam loss accident (200 mA spill at 1 GeV for 1 hour)	0.12 mrem

Summary

- Design features plus LAMPF extrapolations give confidence that ultra-low beam loss is achievable.
- Assessment of machine turn-on and fault recovery methods has been initiated.
- Initial survey of system response to off-normal conditions has been made.
- Controls, safety, and protection systems have been described.
- Accelerator shielding requirements have been estimated.
- Air activation study shows releases can be controlled to well below significant levels.

APT Accelerator Design Summary

George Lawrence
Accelerator Technology Division
Los Alamos National Laboratory

DOE/DP Quarterly Review
June 7-8, 1993

A Good Baseline Design Has Been Produced

- System architecture and parameters frozen
- First order linac physics design complete
- End-to-end beam simulations run
- Error studies initiated
- Preliminary engineering design of linac complete
- Beam loss, halo growth issues addressed

- Beam transport optical design complete
- Beam transport engineering layout in progress

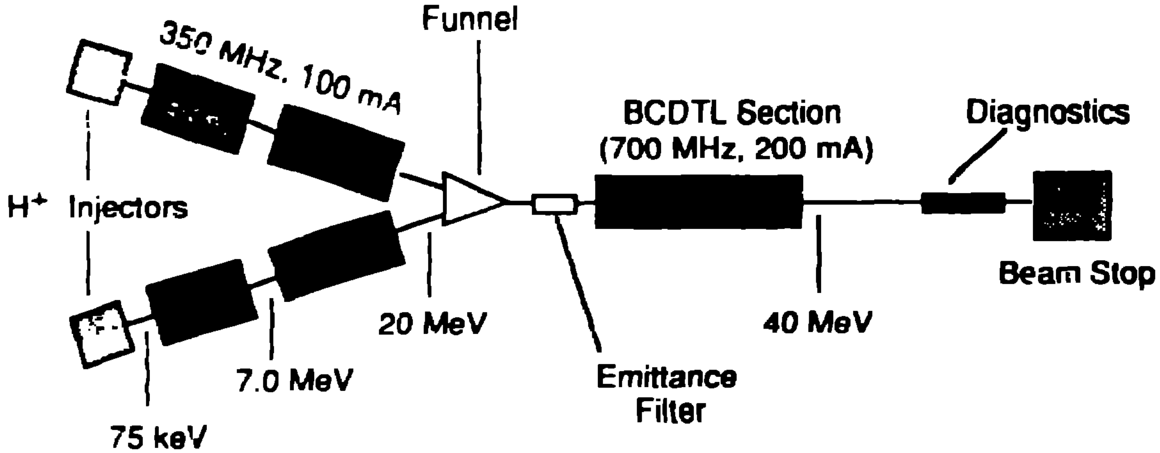
- RF module design established
- RF system control analysis initiated
- Power system design in progress

- Tunnel and infrastructure concepts outlined
- Shielding and air activation estimates made
- Initial outline of turn-on and fault recovery schemes

Operational Issues Need to be Studied in More Depth in FY94

- Error studies
- Beam halo generation and control methods
- Failure-modes analysis
- Beam diagnostics requirements
- RF-generator/cavity/beam system control
- Protection and safety systems
- Accelerator turn-on and fault recovery analysis
- Availability framework and analysis

APDF Addresses Most Critical Accelerator Issue --
Integrated CW High Power Operation of Linac Front End



Accelerator Performance Demonstration Facility

- Demonstrates integrated operation at full CW power
- Evaluates reliability, availability of components & system
- Addresses funnel operation issues
- Establishes beam performance and benchmarks simulations
- Assesses halo production mechanisms and control methods

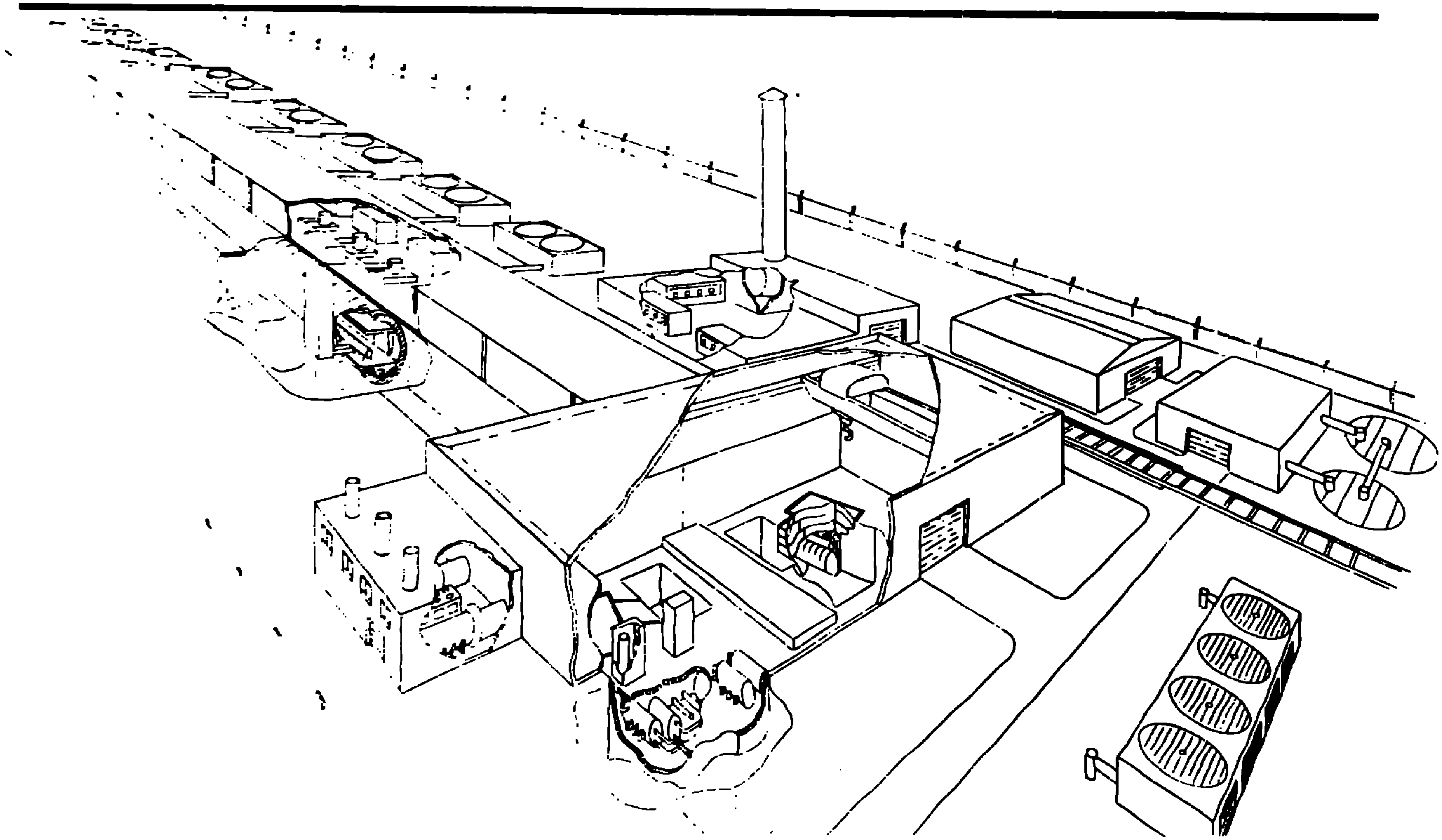
- **Provides assurance for high-energy linac implementation.**
- **First stage (injectors + linac design) proceeding in FY93 with DNA funding**

APT Quarterly Review

June 7-9, 1993

R. Taussig
Bechtel Corporation
San Francisco. CA

APT Perspective View -Artist's Concept



BOP Design Guidelines

1. Develop a comprehensive baseline design which reflects the ES&H advantages of APT [lower residual heat, reduced waste streams, negligable release compared to reactor alternatives] and minimizes cost

2. Optimize Tritium production from a plant-wide perspective

3. Identify future design options to improve baseline design and further reduce construction costs

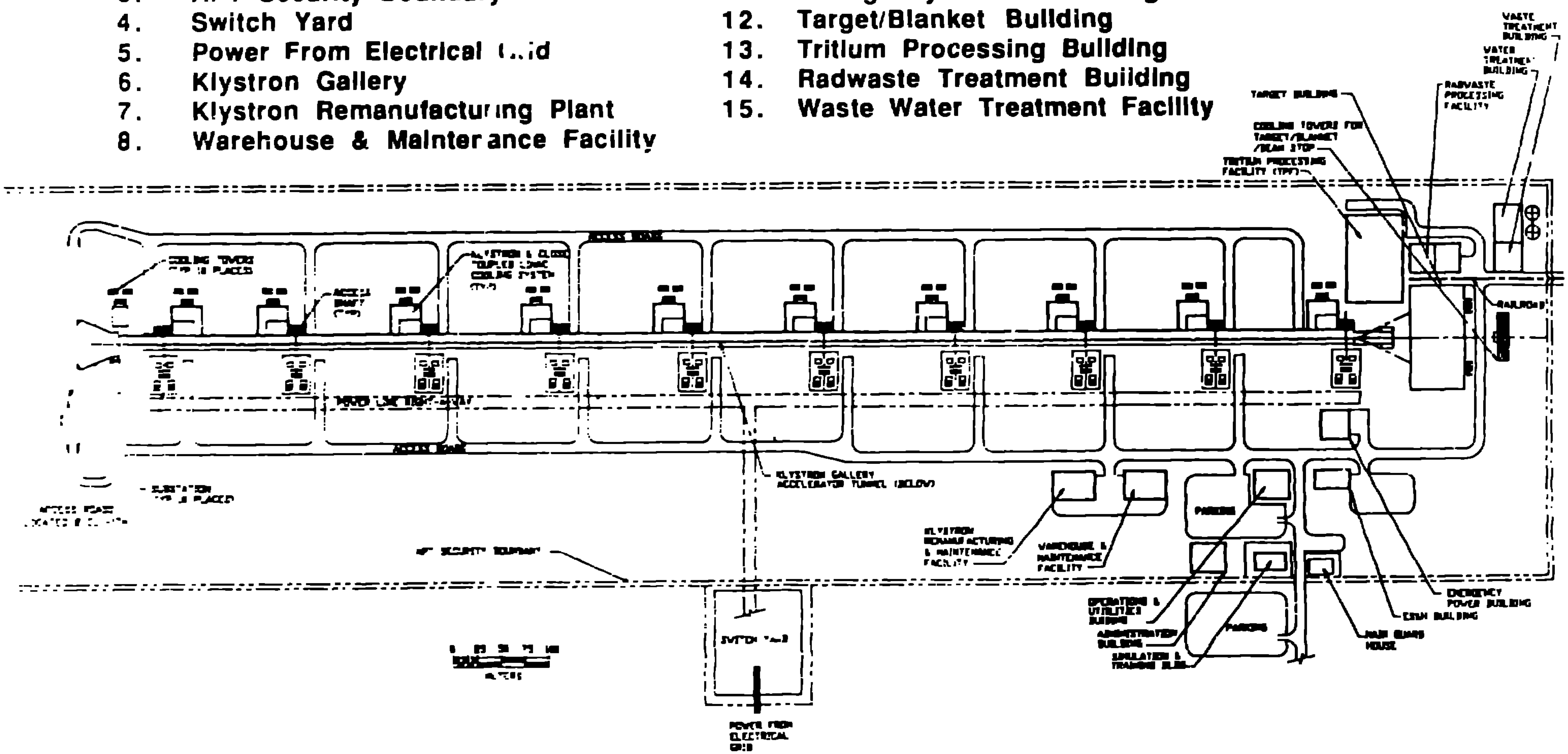
4. Design remote maintenance systems for high plant availability

5. Develop a controls scheme and plant design to maximize personnel safety, protect plant equipment and minimize environmental impact

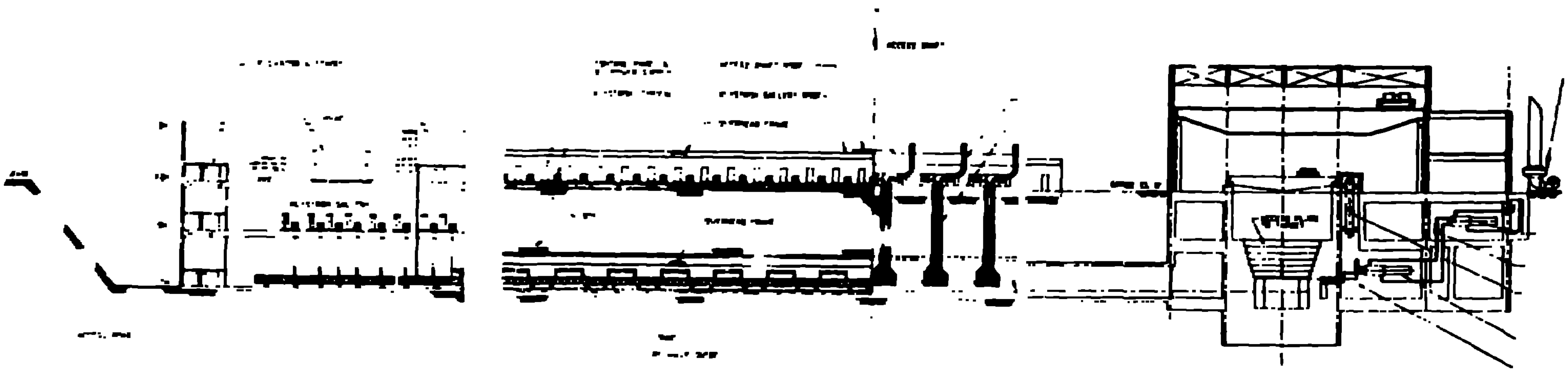
APT Site Layout

Key:

1. Substation
2. Cooling Towers
3. APT Security Boundary
4. Switch Yard
5. Power From Electrical Grid
6. Klystron Gallery
7. Klystron Remanufacturing Plant
8. Warehouse & Maintenance Facility
9. Operations & Utilities Building
10. Admin and ES&H Building
11. Emergency Power Building
12. Target/Blanket Building
13. Tritium Processing Building
14. Radwaste Treatment Building
15. Waste Water Treatment Facility



APT Facilities - Longitudinal Cross-section



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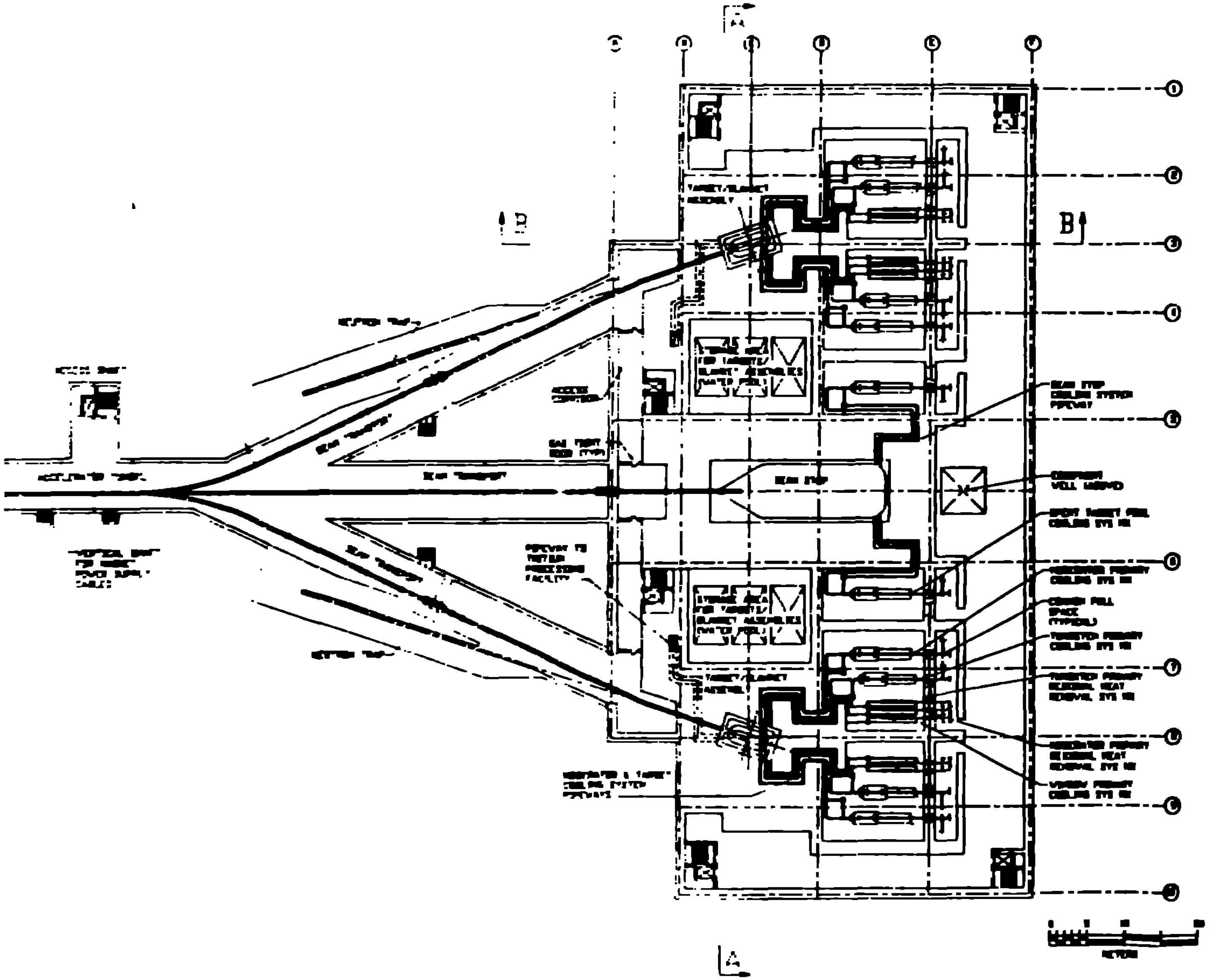
Target/Blanket Building Layout



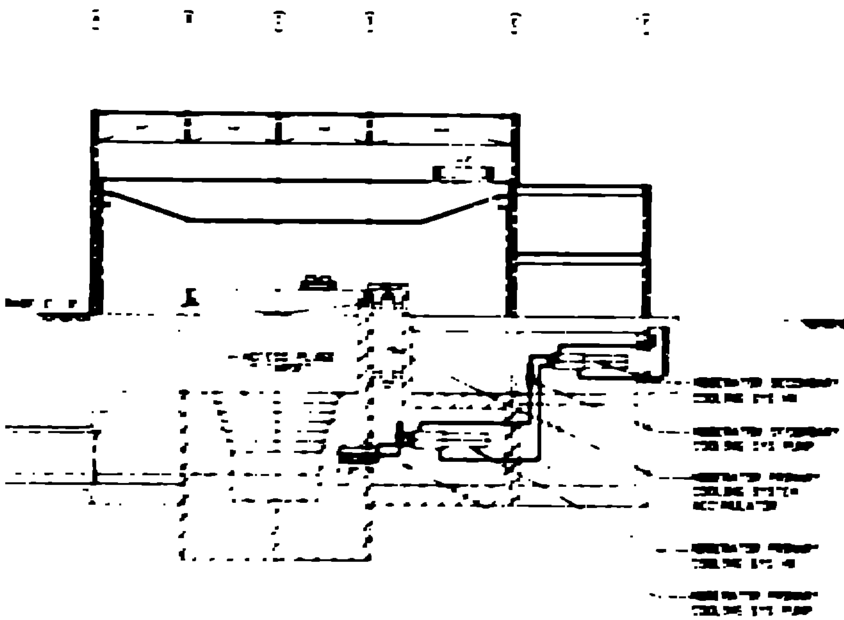
APT

Containment Design Approach

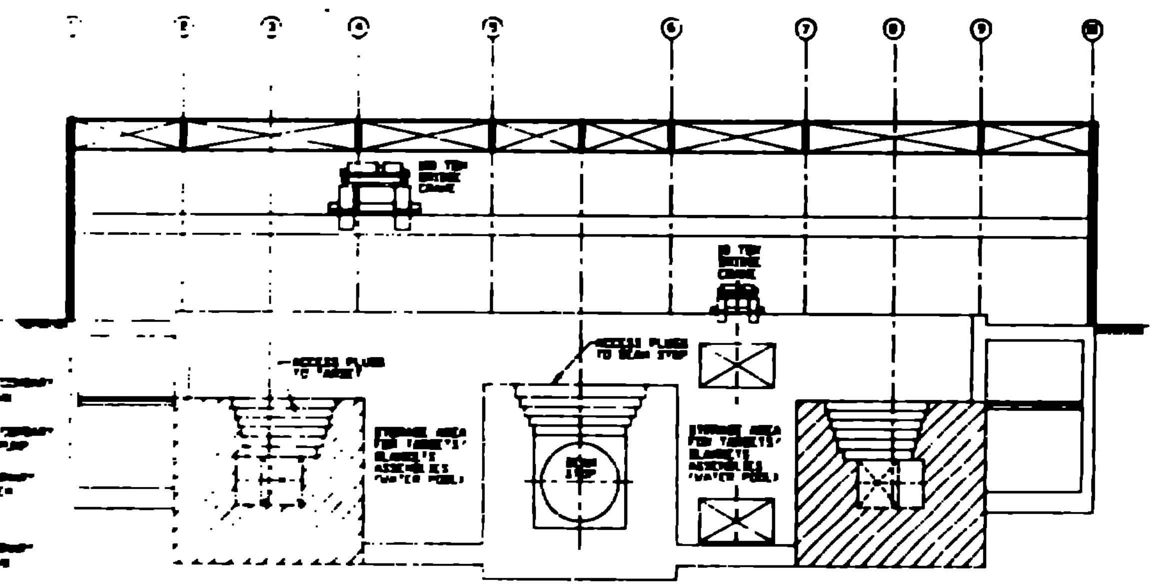
- **APT GSRD and RD prescribe a target containment which:**
  - is essentially a leaktight barrier to uncontrolled radionuclide release
  - provides functional protection level comparable to that of commercial reactors
  - will enclose target handling activities
  - will have other specifically prescribed characteristics

- **Design approach taken to satisfy these requirements:**
  - intended to provided responsive yet cost-effective compliance
  - leverages off of commercial BWR precedent
  - provides separation and isolation as well as radionuclide retention
  - provides external hazard protection

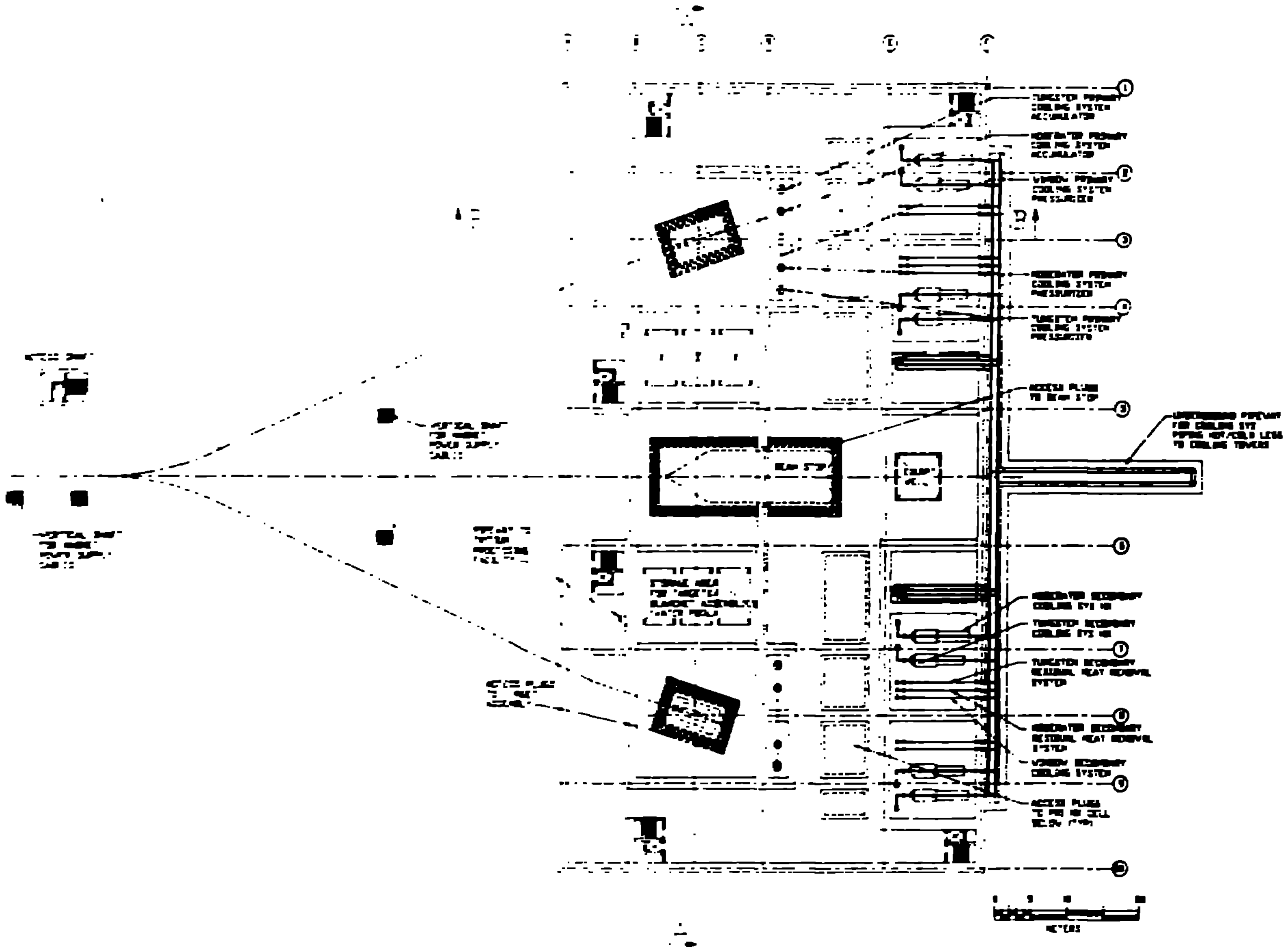
Containment Concept



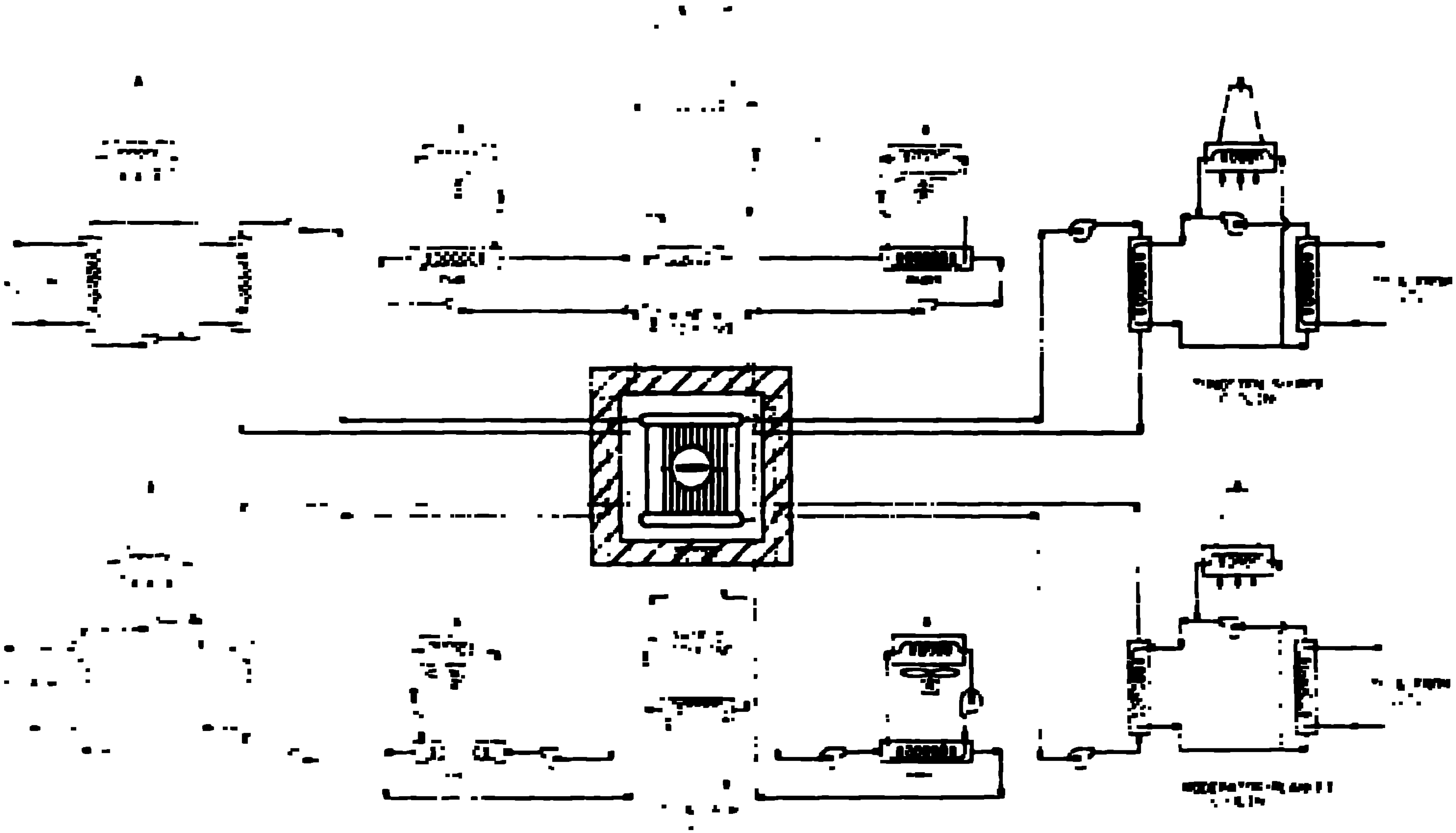
SECTION B-B



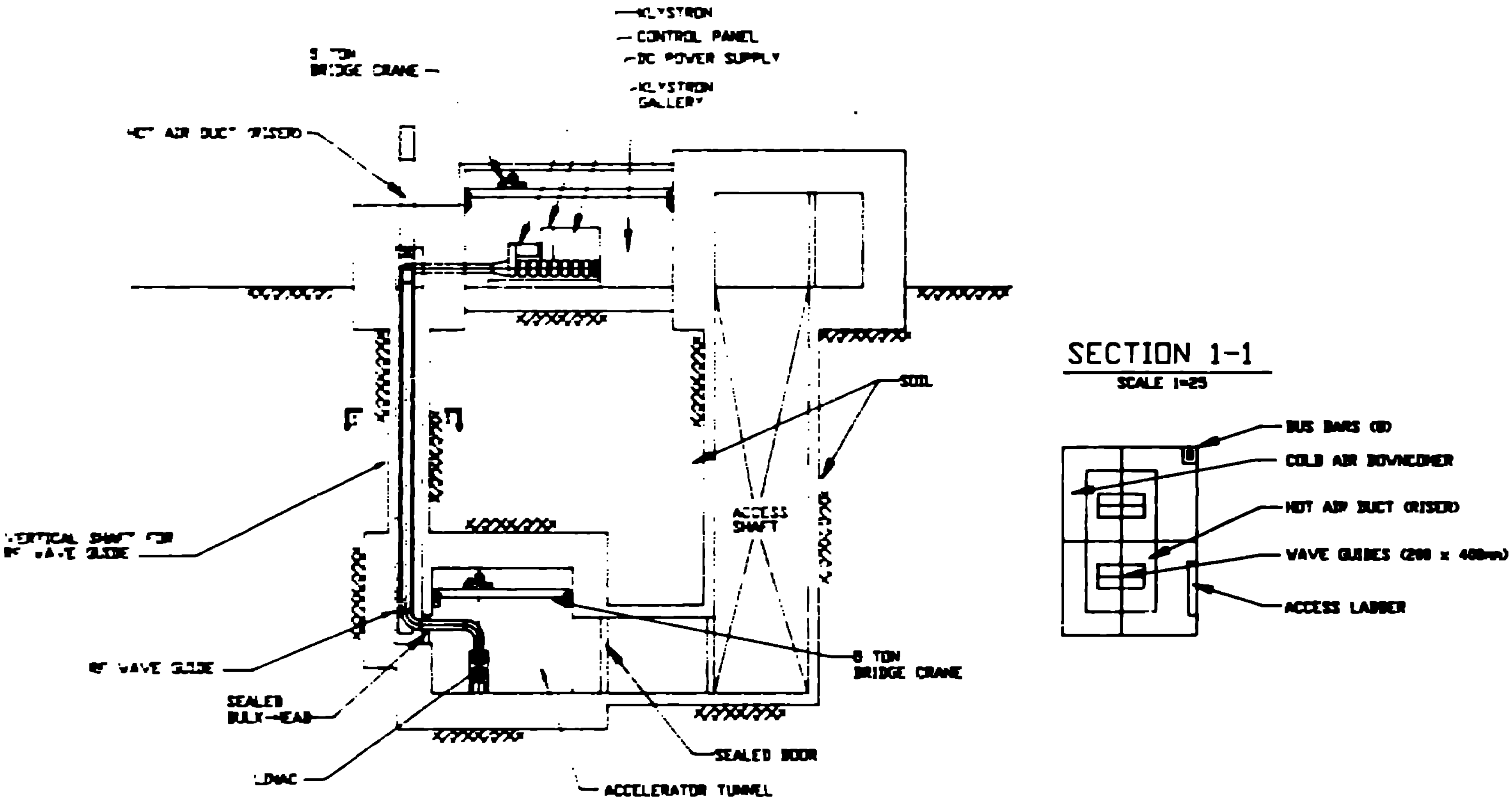
SECTION A-A



Target/Blanket Heat Removal System

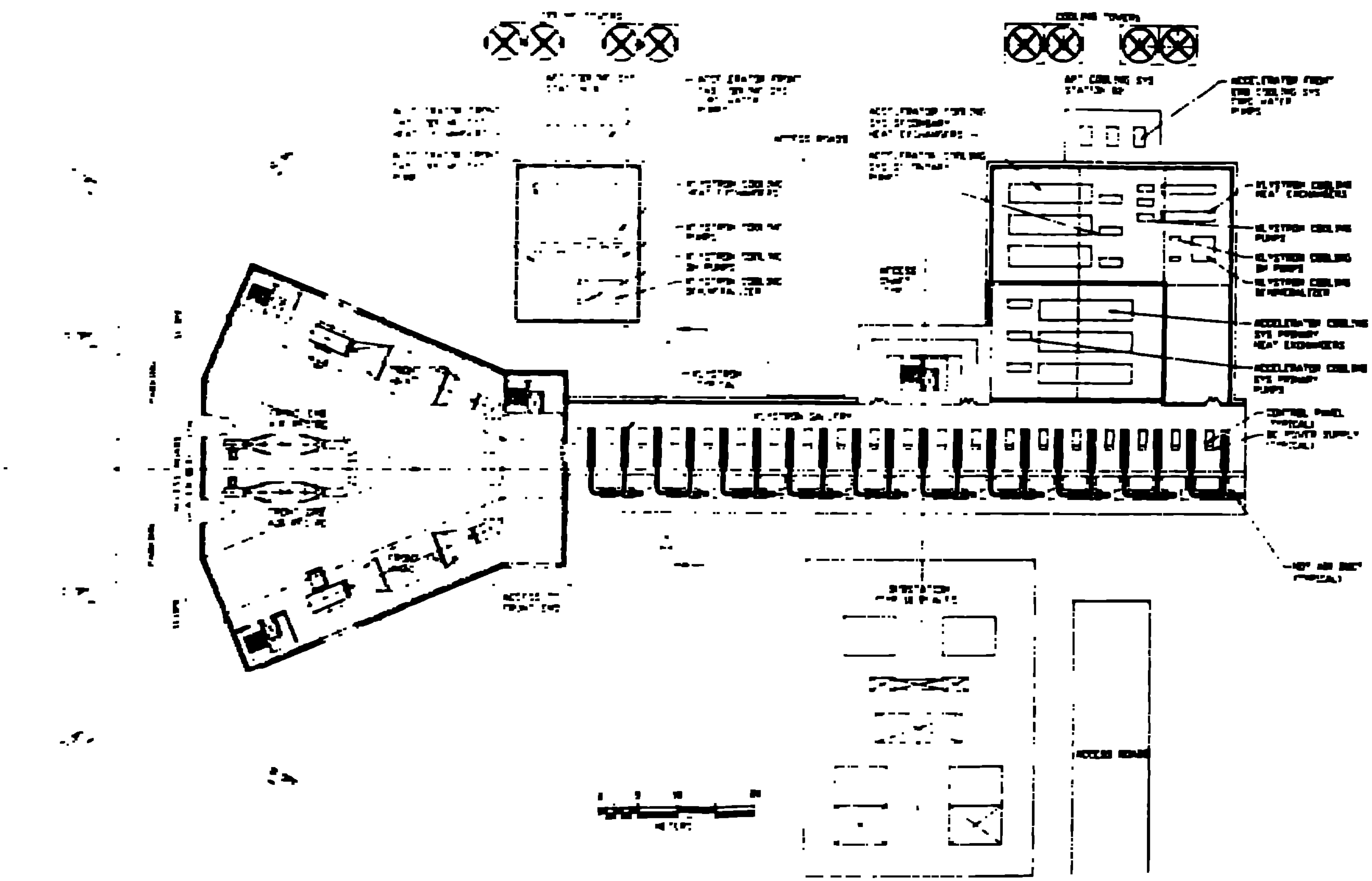


Traversal of Accelerator Tunnel and Klystron Gallery

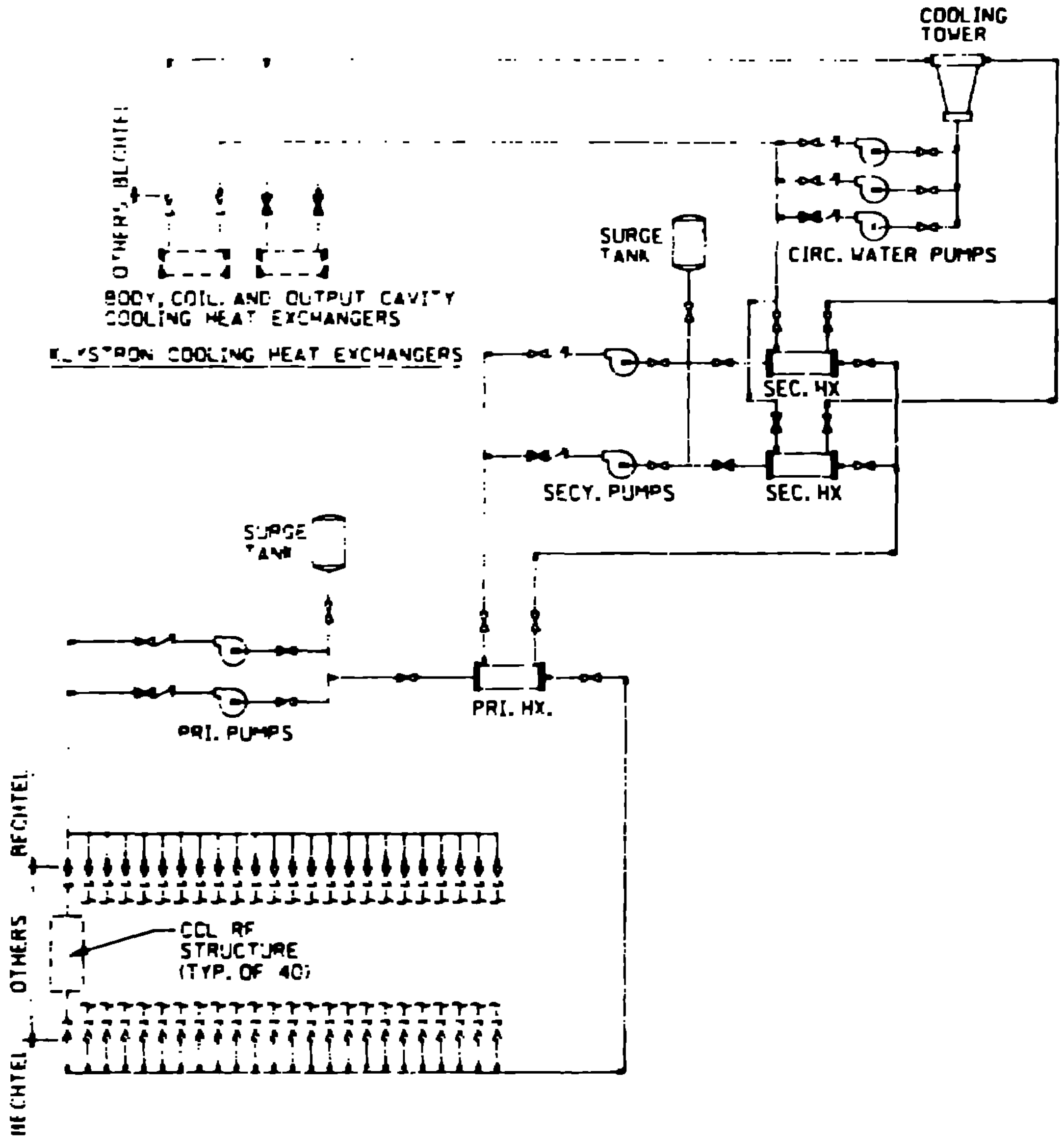


APT

Plan View of Injector Facilities

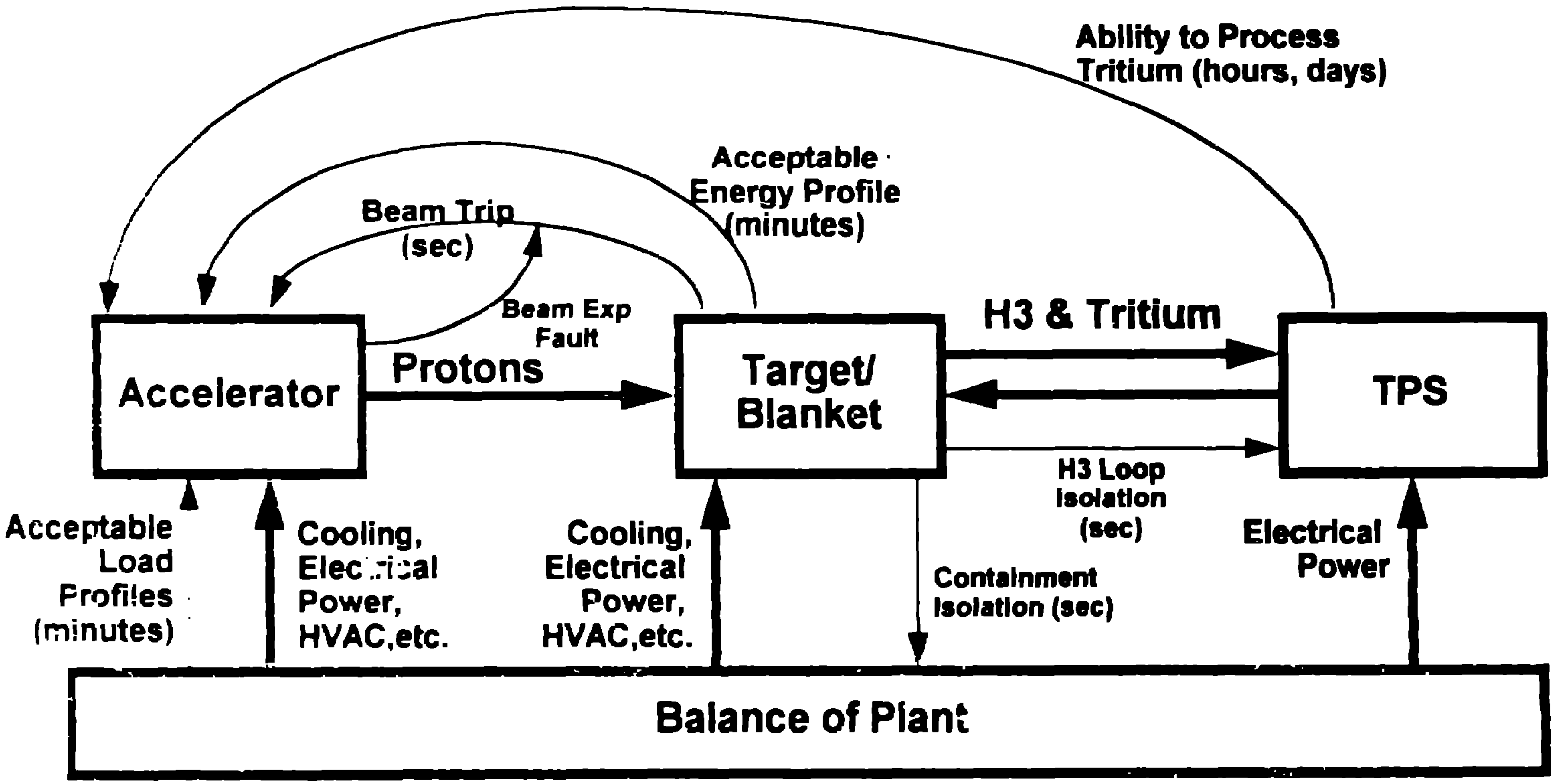


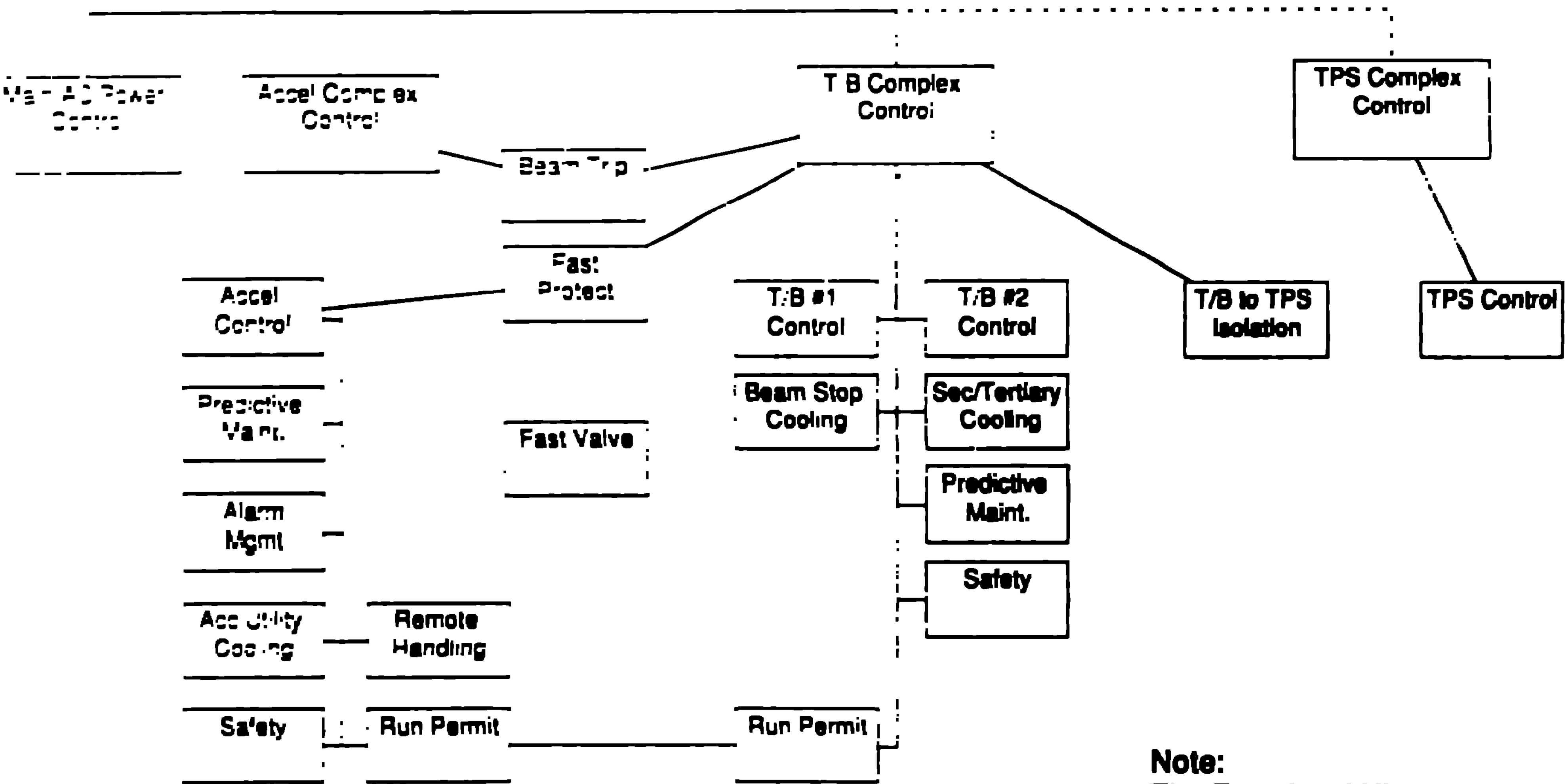
Heat Removal from the Accelerator



APT

Overview of Control





Note:
The Functional Hierarchy shows control signals from the perspective of the operators.

Remote Maintenance

- Define components needing remote handling
- Determine physical and radiological characteristics of these components
- Estimate frequency of access required, weight, size, attachments, controls required for component removal, repair and reinsertion
- Develop top level RME (remote maintenance equipment) architecture for plant-wide parts and controls compatibility
- Initiate concepts for materials handling sequences for normal and off-normal operation of the various facilities needing RME
- Determine sizes, types and main equipment features for highest priority RME applications [e.g., target change-out, accelerator repair, radwaste handling and storage/disposal]

- BOP PEIS inputs - Draft submittal completed
- Site Layout and Preliminary General Arrangement Drawings (SL/PGADs)
  - Draft submitted for review to LANL
- Reference preconceptual designs for heat removal systems have been prepared
- HVAC, water treatment and gas clean-up/handling facilities - Designs are nearing completion
- Single line electrical designs - draft completed
- Top level control system architecture - Preconceptual Design established
- Remote handling conceptual designs are in progress
- Structural Design in Progress

Items Needing Further Work

- Systematic analysis of materials throughput
  - Need to optimize the design for tritium production
  - Consider target design in conjunction with neutronics, assembly & disassembly sequences, remote handling requirements, tritium extraction processes, waste stream production, etc.
  - Analysis will trade off design elements for cost-effective, safe tritium production
- Target/blanket facility safety criteria and associated evaluation approach
- Functional design criteria and systems design descriptions
- Site factors evaluation [available power, water; soils conditions, pre-existing contamination, site access, size, etc.]
- Cost/design trade studies
- Completion of conceptual design