High-Power Accelerator Technology for ATW Scenarios

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ATW Roadmap Meeting
Washington, DC
February 17-18, 1999

ATW

Outline

- Technology base for high-power linacs
- APT design and ED&D legacy
- Other accelerator programs
- Linac design for ATW systems
- Technical issues and ED&D program

Design Objectives for ATW Accelerator

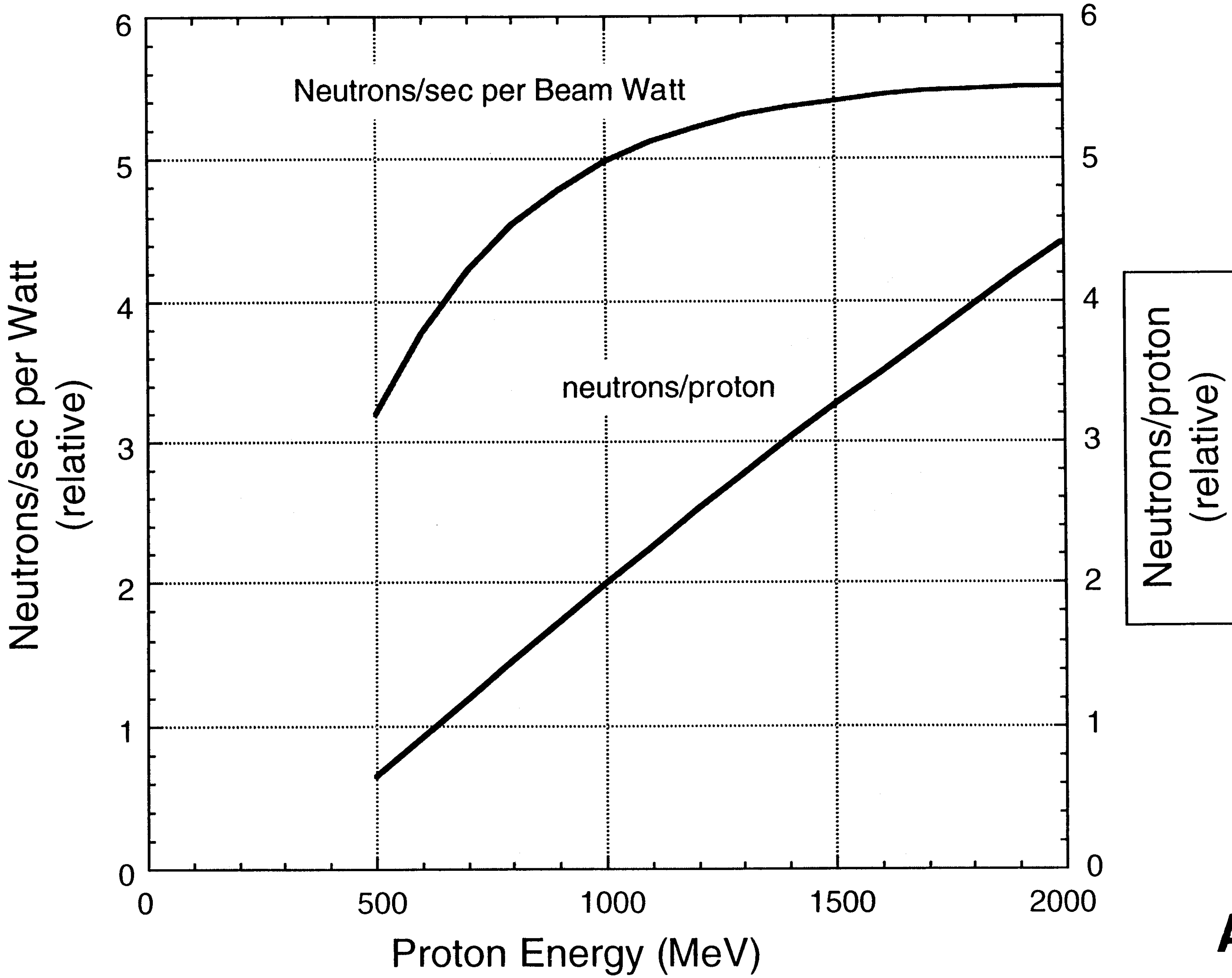
A linac designed to drive an ATW facility should have

- Very high electrical efficiency (ac-power to beam-power)
- Minimum capital and operating costs
- Minimum spatial footprint (short length)
- Capability to adust beam power on target over a wide range
- High availability and operational flexibility
- Employ the best mix of established technology and anticipated technology advances.

Nominal beam parameters

- 10 - 40 MW proton beam
- 1000 MeV, 10 - 40 mA, 100% duty

Spallation Neutron Production Physics Determines Optimum Accelerator Energy Range



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Technology Advances That Have Enabled High-Power Proton Linacs (Hardware)

- **Injector (Microwave-Driven Ion Source)**
  - high current, low emittance, high proton fraction
  - space-charge neutralization in low-energy transport; solenoid focusing
- **Radiofrequency Quadrupole (RFQ) for Low-β**
  - dramatic improvement in first acceleration stage
  - high capture efficiency, low emmittance growth
- **Improved Normal-Conducting Structures for Medium-β**
  - coupled-cavity linac (CCL); LANSCE, FNAL
  - CCDTL extends concept to lower β
  - separate focusing and accelerating functions
  - strong RF coupling and field stability
- **Superconducting Accelerating Cavities for High-β**
  - very large apertures; low beam loss
  - very high electrical efficiency; high accelerating gradient
  - wide beam velocity acceptance
- **High Power RF Generators**
  - efficient 1-MW CW klystrons from 350 MHz to 1000 MHz
  - developed and tested in high-energy beam colliders

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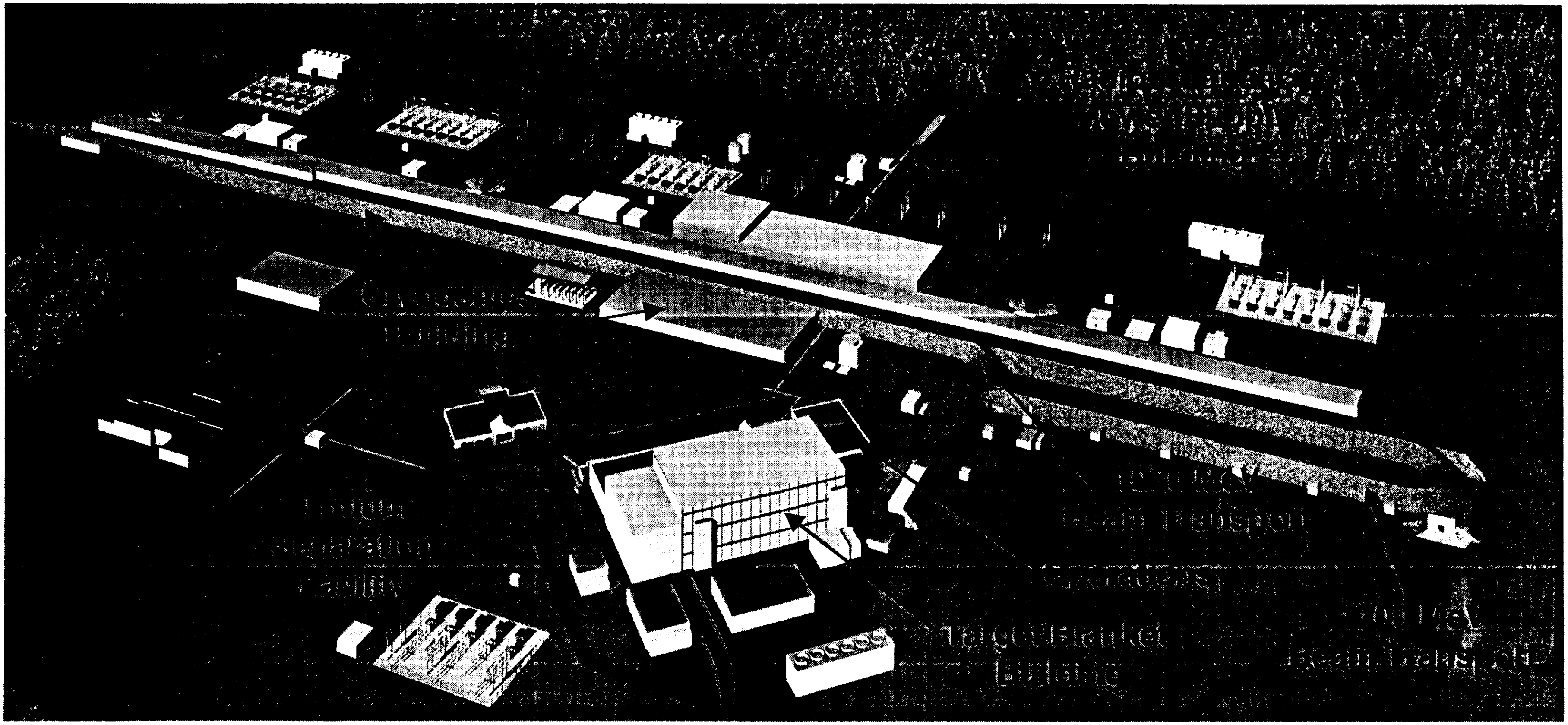
Accelerator Production of Tritium

Beam Physics for High-Power Linacs

- **Advances of past 15 years provide framework for design of high-current linac with very low emittance growth in beam core**
  - high-frequency accelerating structures
  - strong transverse focusing
  - ramped accelerating gradients
  - equipartitioning of thermal energy in beam
  - matching between consecutive accelerator sections
- **Improved understanding of beam halo mechanisms provides guidance for ultra-low beam-loss design.**
  - success of particle-core resonance halo growth models
  - simulation with large numbers of particles (10^6 to 10^7) with MPP computers
- **Design for very low beam loss; low activation of structure**
  - $\leq$ 0.1 nA/m losses, to attain mRem/hr activation levels after shutdown
  - very large aperture-to-beam-size ratios (contain all the beam particles)
  - avoid mismatches and transitions that could produce halo
  - precision RF system control and beam diagnostics

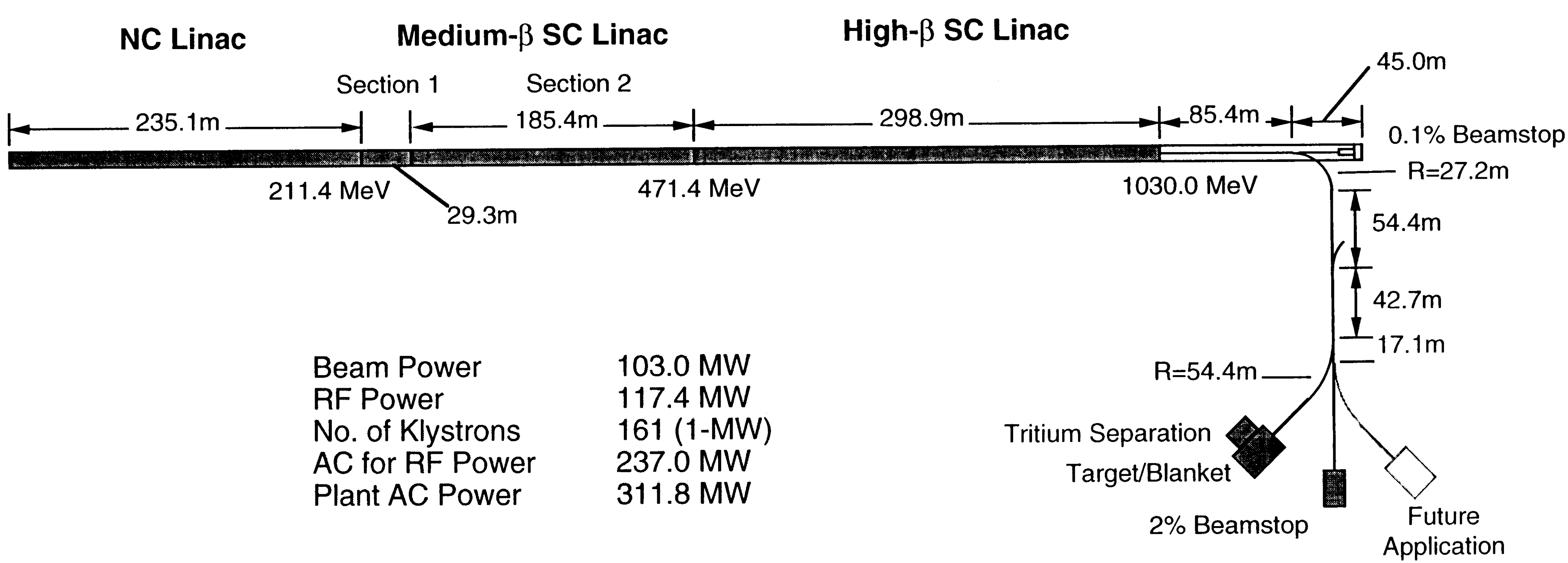
APT Plant has Modular Accelerator Design; Adaptable to Range of Production Requirements



Accelerator Production of Tritium

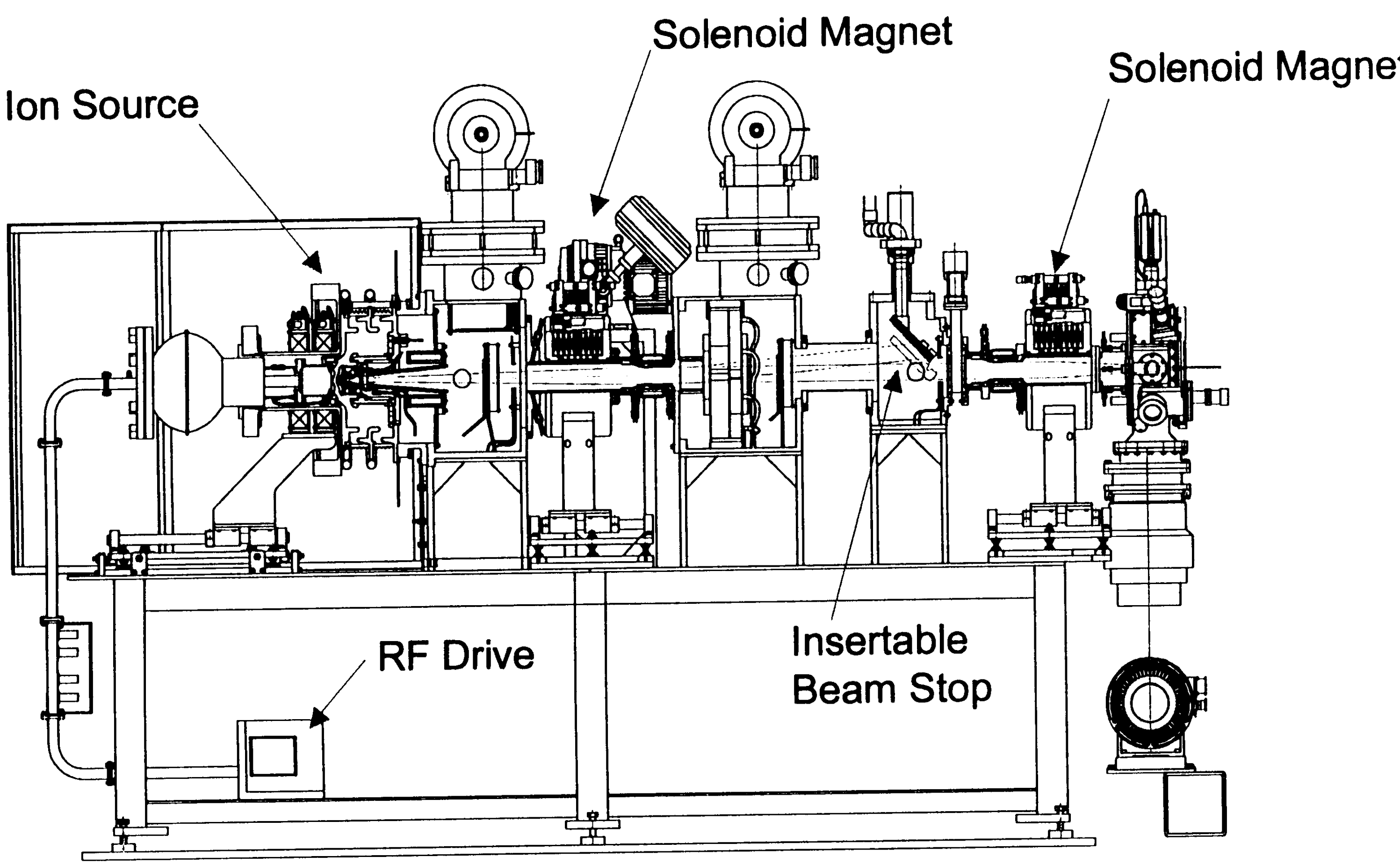
APT Accelerator Design (1.5-kg/yr Plant)

- NC front-end linac for emittance control of high-current beam.
- SC high-beta linac for high efficiency and operational flexibility.
- Architecture emphasizes large apertures, strong focusing, and smooth variation of parameters to achieve very low beam loss.



Beam Power	103.0 MW
RF Power	117.4 MW
No. of Klystrons	161 (1-MW)
AC for RF Power	237.0 MW
Plant AC Power	311.8 MW

Performance Specs for Microwave-Driven H^+ Injector Have Been Demonstrated



Proton current: 110 mA

Beam energy: 75 keV

H2 gas flow: 2-5 sccm

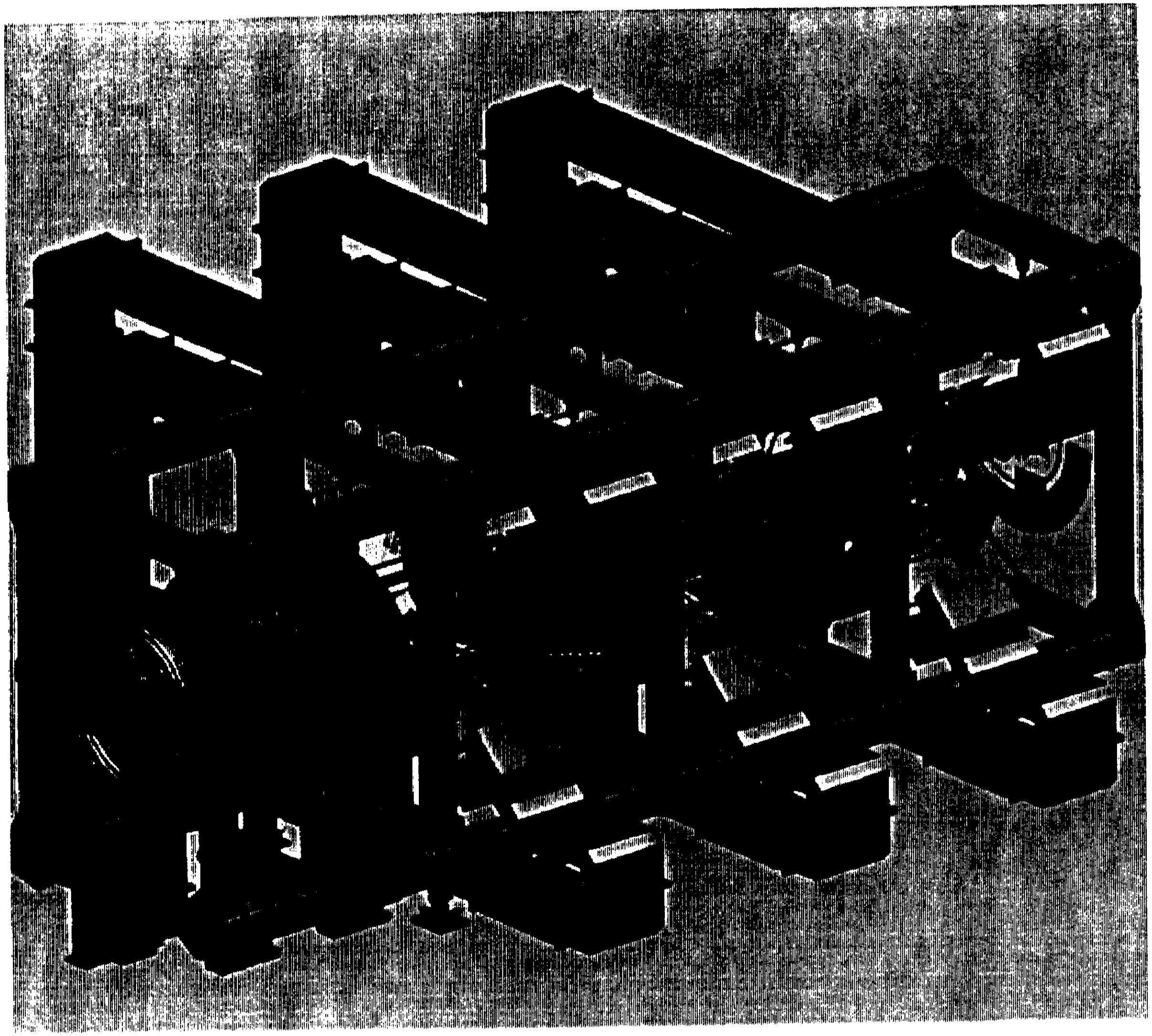
Proton fraction: > 90%

Emittance: < 0.20 π mm-mrad

Availability: 96-98%

APT Accelerator Production of Tritium

First-Stage Accelerating System is 6.7-MeV RFQ

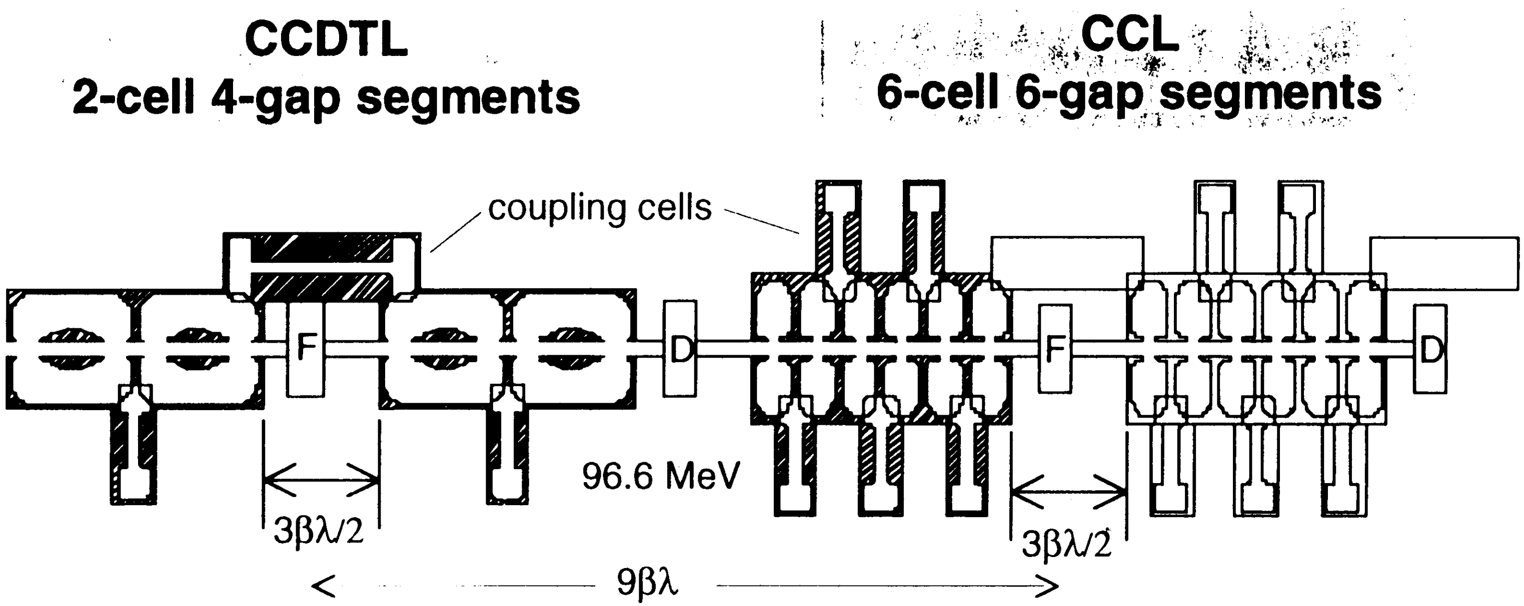


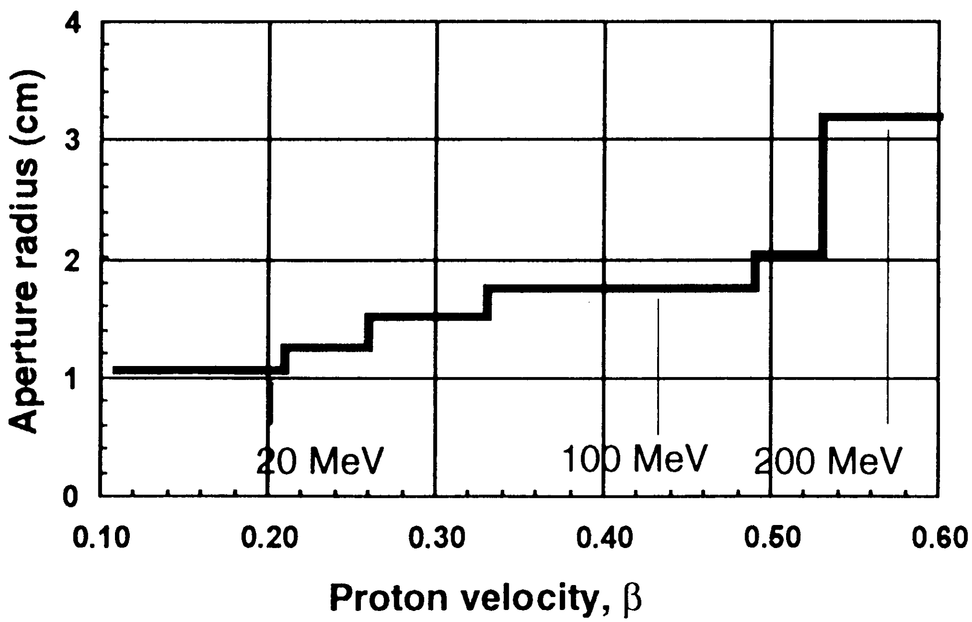
- 4-vane structure
- Four 2-m-long sections, resonantly coupled
- Driven by three 350-MHz 1.2-MW klystrons
- Gradient: 1.38 MV/m
- Wall losses: 1.26 MW
- Current-independent match to 8-βλ CCDTL

Depiction of LEDA RFQ mounted inside waveguide, vacuum, and water-cooling connections

APT Accelerator Production of Tritium

NC Linac is CCDTL to 96.6 MeV and CCL to 211.4 MeV



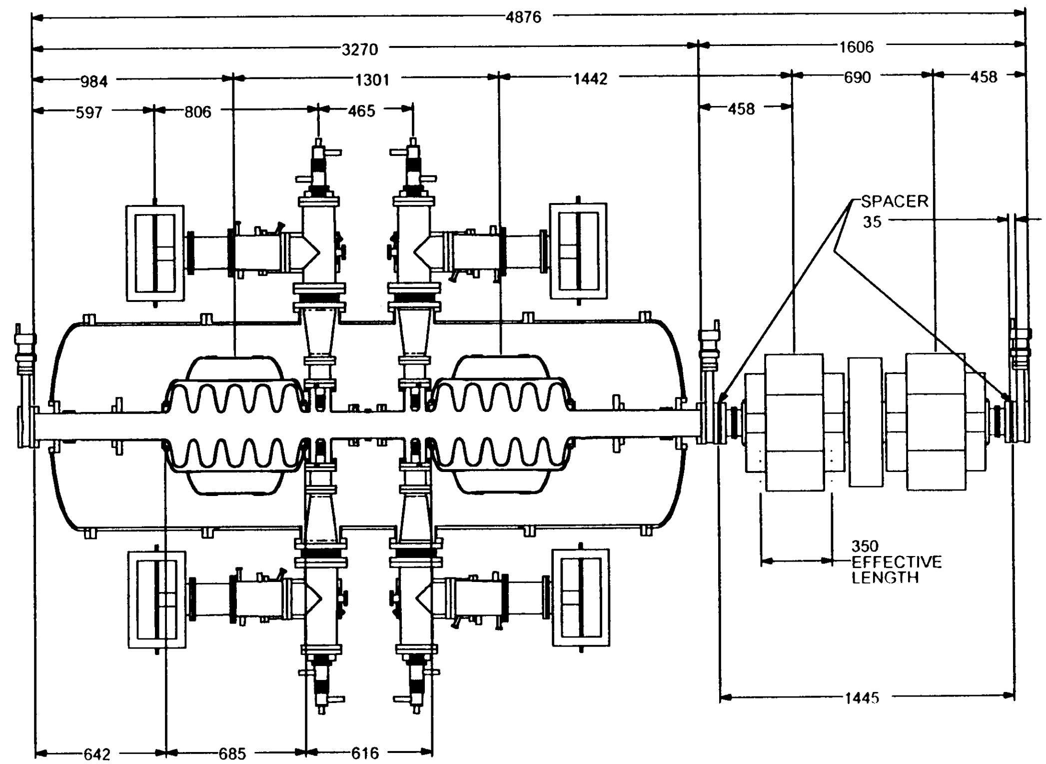


- Aperture increases with energy
- Focusing lattice lengthens in proportion to velocity (β)
- Longitudinal focusing strength changes smoothly
- Quadrupoles are external to accelerating structures

APT Accelerator Production of Tritium

Accelerating Units in APT SC Linac Contain a Cryomodule (2, 3, or 4 Cavities) + NC Quadrupoles

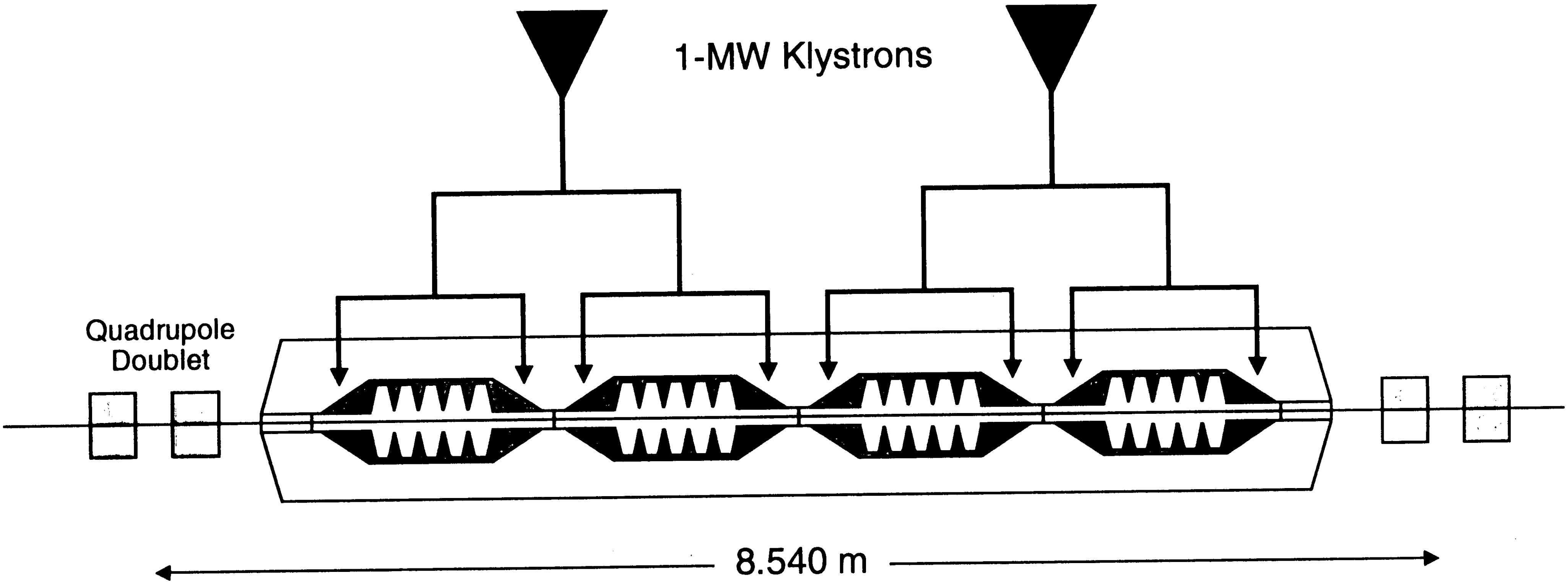
- **5-cell 700-MHz Nb cavities operate in π mode (TM_{010})**
- **Peak surface field requirement**
  - medium-β: 14.1 - 17.7 MV/m
  - high-β: 13.1 - 17.5 MV/m
- **Nominal Q_0 is 5×10^9 at 2 K**
- **Power couplers require up to 210-kW capability; coaxial**
- **Beam-induced power transported to ambient through HOM couplers**
- **Cryostat design based on proven concepts from CERN and JLAB**



2-cavity β = 0.64 cryomodule and NC quad doublet

Accelerator Production of Tritium

High-β Superconducting Linac Architecture ($\beta = 0.82$)
Doublet Lattice, 4 Cavities per Cryomodule



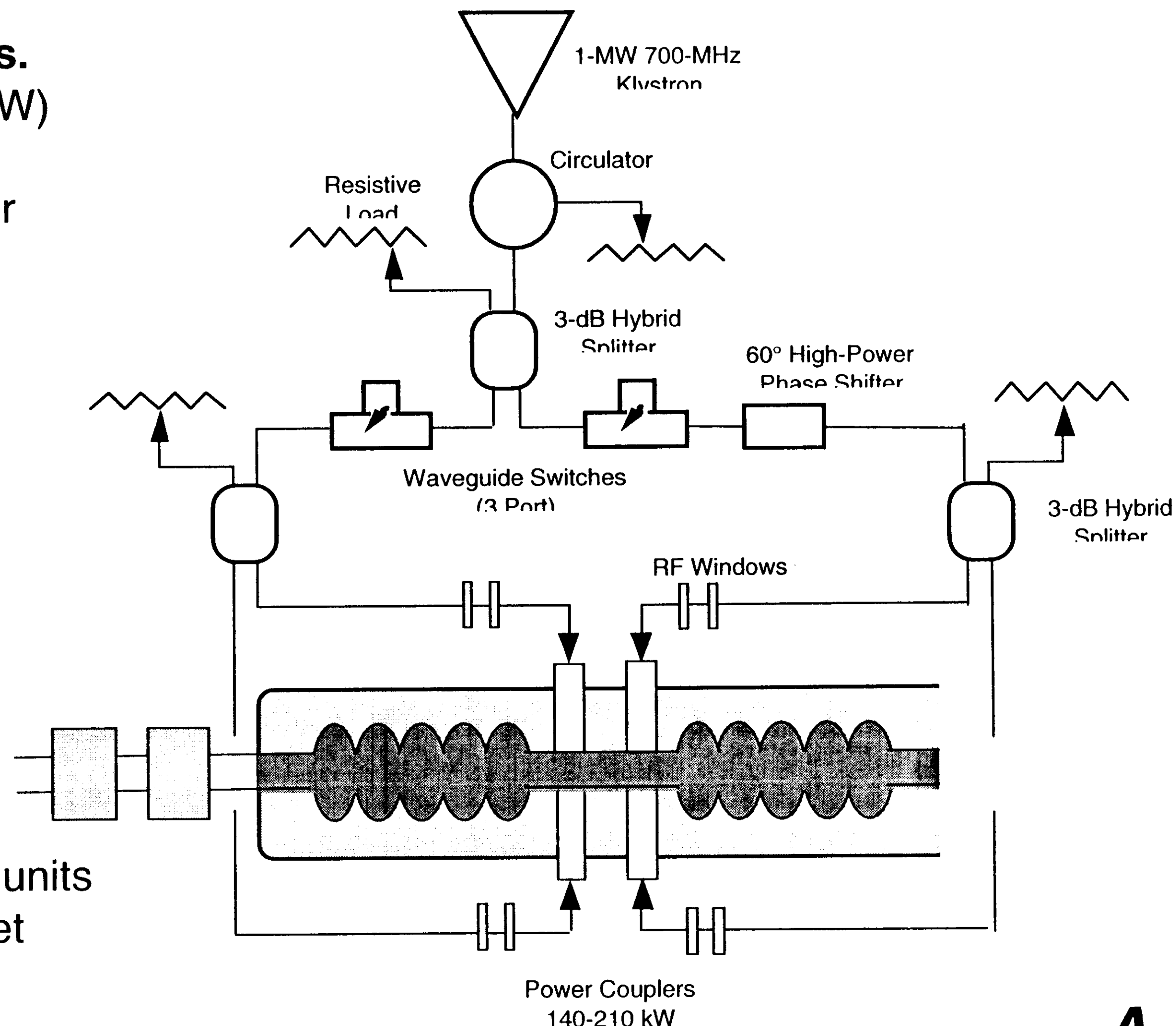
Energy span	471 - 1700 MeV	Section length	657.6 m
Gradient (E_0T)	5.25 MV/m	Klystrons	154
$E_{peak\text{-}surface}$	13.1 - 17.5 MV/m	Power/coupler	200 - 210 kW
Cryomodules	77	Power/klystron	798 - 840 kW
5-cell cavities	308	NC quadrupoles	154
ΔW per cavity	4.0 - 4.2 MeV	Quad gradient	5.6 - 9.8 T/m

APT Accelerator

RF Power System is Major Design Driver in Terms of Costs, Operability, and Availability

- **RF power dominates accelerator construction and operating costs.**
  - use high-power generators (1 MW)
  - make full use of klystron output
  - choose largest practical value for cavity power couplers
- **RF power system summary**
  - RFQ: 3 350-MHz
  - NC linac: 52 700-MHz
  - SC linac: 190 (106) 700-MHz
  - power efficiencies:
    - > AC to DC: 95.0%
    - > DC to RF: 58.5%
    - > RF Xmission: 94.0%
- **System includes redundancy in both NC and SC linacs**
  - production continues with failed units
  - allows availability goals to be met

RF Module in High-Beta SC Linac



Accelerator Production of Tritium

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