Advances in High-Power Targets

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Harold G. Kirk
Brookhaven National Laboratory
The Drive for Intense (MW Class) Sources

In Operation:
LANSCE: 0.8 MW -- 0.8 GeV Protons
PSI: 1.2 MW -- 0.6 GeV Protons
CERN SPS: 0.5 MW -- 400 GeV Protons

Under Construction:
SNS: 1.4 MW – 1 GeV Protons
JPARC: 0.75 MW -- 50 GeV Protons

Under Consideration:
BNL AGS: 2 MW -- 30 GeV Protons
ISIS: 1 MW -- 0.8 GeV Protons
FNAL Main Injector: 2 MW -- 120 GeV Protons
JPARC: 4 MW -- 50 GeV Protons
SNS: 2 MW -- 1 GeV Protons
SPL: 4 MW -- 3.5 GeV Protons
The Challenge: Convert to Secondaries

Secondary Beams for New Physics
- Neutrons (e.g. for neutron sources)
- $\pi$’s (e.g. for Super $\nu$ Beams)
- $\mu$’s (e.g. for Muon Colliders, Neutrino Factories)
- Kaons (e.g. for rare physics processes)
- $\gamma$’s (e.g. for positron production)
- Ion Beams (e.g. RIA, EURISOL, $\beta$-Beams)
Facilities with High-Power Target Interest

| AGS         | ESS       |
| EURISOL     | IFMIF     |
| ISIS        | JPARC     |
| LANCE       | Muon Collider |
| Neutrino Factory | NUMI   |
| ILC         | RIA       |
| SINQ        | SNS       |

High-power Targetry Challenges

High-average power and high-peak power issues

- Thermal management
  - Target melting
  - Target vaporization
- Radiation
  - Radiation protection
  - Radioactivity inventory
  - Remote handling
- Thermal shock
  - Beam-induced pressure waves
- Material properties
Choices of Target Material

- **Solid**
  - Fixed
  - Moving
  - Particle Beds
- **Liquid**
- **Hybrid**
  - Particle Beds in Liquids
  - Pneumatically driven Particles
Desirable Attributes for High-Power Targets

- High heat capacity, \( C_V \) (to reduce thermal load)
- Low thermal expansion, \( \alpha_T \) (especially for pulsed beams)
- Low bulk modulus, \( Y \) (to reduce stress)
- High yield strength, \( \sigma_Y \) (for solids to resist fracturing)
- Good diffusivity (to quickly move the heat away)
- Resistance to irradiation damage (to retain the beneficial properties)

\[
\text{Stress} = Y \alpha_T \frac{U}{C_V}
\]

Where \( U \) is energy deposition

(> 100 J/g is Considered Aggressive)
Static Solid Target Examples

A. CERN CNGS
   Carbon 750 J/g
   He Gas Cooled

B. FNAL NUMI
   Carbon 350 J/g
   Water Cooled

C. JPARC T2K
   Carbon 170 J/g
   He Gas Cooled

D. Los Alamos NS
   Tungsten 100 J/g

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Moving Solid Target Examples

A. KEK Kaon Target-Ni Pulsed 600 J/g Water Cooled
B. PSI Target-M- Carbon CW 30 J/g Radiation Cooled
C. FNAL Pbar Target-Various materials Pulsed 800 J/g Air Cooled
Liquid Target Examples

A. ORNL SNS  Pulsed 1J/g
B. PSI MEGAPIE  CW 125W/g
C. U.S. Neutrino Factory  Pulsed 160J/g
High-Power Targetry R&D

Key Target Issues for high-power targets

- What are the power limits for solid targets?
- Search for suitable target materials (solid and liquid) for primary beams > 1MW
- Optimal configurations for solid and liquid targets
- Effects of radiation on material properties
  - Target materials
  - Target infrastructure
- Material limits due to fatigue
- Design of reliable remote control systems
Fatigue Testing

R. Bennett, et al  Rutherford Appelton Lab

The test concept:
Pulse the wire “target” with equivalent energy and pulse structure.

Tantalum wire broke after $3 \times 10^6$ pulses.

Tungsten wire has survived $>19 \times 10^6$ pulses

1 Year at 50 Hz is $\sim 10^9$ pulses

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SNS Target: The Pitting Issue

Effect has been identified as resulting from cavitation development within the Hg followed by violent collapsing of the bubbles near the Stainless Steel surface.

SNS Team has been pursuing several options:
- Gas layer near container surface
- Kolsterizing the SS surface
- Bubble injection

Further R&D is ongoing
The Neutrino Factory Target Concept

Maximize Pion/Muon Production
- Soft-pion Production
- High-Z materials
- High Magnetic Field

Meson Production - 16 GeV $p + W$

Pion Kinetic Energy, GeV

$dN/dKE$ (1/GeV/interacting proton)
MERIT Experiment at CERN
Installed in the CERN TT2a Line

Before Mating

After Mating and Tilting
MERIT Scientific Goals

Milestone towards demonstration of a 4MW target concept

Study MHD effects of pion capture scheme with Hg-jet and 15T solenoid

Study jet disruption and cavitation by varying the PS spill structure

**MERIT: 180 J/g**

- 30TP@24GeV protons
- 1cm diam. 20m/s Hg-jet
- 1.2×1.2 mm² beam size rms

Jet dispersal at t=100μs with magnetic field varying from 0 to 10 Tesla

Pump-Probe with Particle Detectors

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Material Properties R&D

Irradiation studies are being undertaken at many facilities:

- BNL BLIP
- Los Alamos Lance
- RAL ISIS
- CERN ISOLDE
- PSI
- Triumf

New facilities are being proposed:

- IFMIF
Strain Gauge Measurements

BNL E951: 24 GeV, 3 x 10^{12} protons/pulse

Stress = Y \alpha T U / C_V

Carbon-Carbon Composite

ATJ Graphite
Super-Invar CTE measurements

BNL BLIP

Peak Proton fluence
1.3 x 10^{20} protons/cm^2

Non-irradiated sample B6
Irradiated sample S42
Irradiated sample S46

Temperature, deg C

Average CTE, 10^{-6}/K

Thermal Expansion (dL), microns

Average Displacements per Atom

Non-irradiated sample B6
Irradiated sample S42
Irradiated sample S46

Plane 1
Plane 4
Base

Original Document

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Carbon-Carbon Composite

Average Proton Fluence

\( (10^{20} \text{ protons/cm}^2) \)

0.76

\{ 0.52 and 0.36 \}

0.13

green}

none
Recovery of low $\alpha_T$

Carbon-Carbon anneals at $\sim200^0\text{C}$

Super-Invar anneals at $\sim600^0\text{C}$
Degradation of Carbon-Carbon

Carbon-Carbon Composite before irradiation

Carbon-Carbon Composite after exposure to fluence of $10^{21}$ protons/cm²

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Tensile testing shows that Super-Invar strengthens while remaining ductile (at the 0.25 dpa level)
A New Approach I

Fluid Cooled Particle Bed

Advantages for a granular approach

- Reduced sample volume results in reduced sample thermal gradient
- Large surface/volume ratio leads to better heat removal
- Better liquid or gas conduction through the target
- Simpler stationary solid target approach
- Could utilize high-Z target material

Peter Sievers, CERN
New Approach II

O. Carletta, C. Densham  RAL
A pneumatically driven slurry

Particles jet He flow

beam

solenoid

Pion shower

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Summary

The R&D Program for the development of high-power targets is diverse and includes exciting new ideas—but:

- Solutions for >1MW primary beam targets are still unproven
- Target test facilities are lacking – more in beam experiments like MERIT are needed
- Search for suitable target materials is an important ongoing effort with wide reaching impact
- More irradiation experiments are needed