Argonne Accelerator Driven Systems Activities

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Argonne Accelerator Driven Systems Activities

Argonne has activities (nuclear, chemical, and accelerator engineering) to develop ADS to dispose of the US spent nuclear inventory.

Guidelines

- ***Consider near term deployment as much as possible***
- ***Utilize current technologies as much as possible with minimum extrapolations***
- ***Minimize the required number of the accelerator driven systems to accomplish the objective***
- ***Avoid multi-processing steps of the fuel materials***
- ***Operate the system at the peak power and produce energy to cover the system cost as much as possible***

US Spent Nuclear Fuels Inventory

- At present, ~60,000 metric tons of spent nuclear fuels are stored
- The current accumulation rate is ~2000 metric tons per year
- By the year 2015, the expected inventory is ~70,000 metric tons
- At the end of the lifetimes of the current operating nuclear power plants, the accumulated inventory is ~120,000 metric tons
- The 70,000 metric tons after 25 year of cooling time consists of:
  - ~96% uranium – can be recycled for use in future nuclear power plants
  - ~3% fission products – short lived isotopes can be stored for 300 years to reduce their radiotoxicity by decay to that of the natural uranium ore
  - ~1% transuranics - ~700 metric tons (DOE/EIS-0250 Report)
    - Plutonium is ~585 metric tons – a fraction is used for utilizing the minor actinides in ADS and the balance can be used as MOX fuel for thermal and fast power reactors
    - Minor actinides is utilized in ADS,~115 metric tons (Np, AM, Cm)

Main Parameters of the Accelerator Driven Systems for Disposing of Spent Nuclear Fuels

- *The system power is 3 GW_t, which can produce ~ 1 GW_e similar to a nuclear power plant.*
- *The effective neutron multiplication factor of the subcritical is 0.98, which provides a neutron multiplication factor of ~50.*
- *The required proton beam power for this system is ~25 MW.*
- *Lead bismuth eutectic or liquid lead is the fuel carrier (molten salt is backup option) with transuranics without uranium.*
- *Low plutonium concentration is used with the minor actinides to achieve the required effective neutron multiplication factor.*
- *The physics analyses show the required plutonium concentration in the transuranic is $\leq$ 30%.*
- *For the 70,000 tons of spent nuclear fuels by 2015, the total minor actinides inventory is ~115 tons. Therefore, four accelerator driven systems can consume 150 tons for disposing this inventory.*

Accelerator Driven Systems Development Steps

- System and components characterization
- Design and analyses of main components
- Laboratory characterization and confirmation experiments
- Target and transmutation experiments
- Demonstration system for spent fuel disposition
- First accelerator driven system for spent fuel disposition

Spallation Target Characteristics

- *High Z target material are considered for generating the required neutron source driving the subcritical assembly.*
- *Lead-bismuth eutectic, liquid lead, and tungsten are the considered materials.*
- *Current designs and experiments around the world are using lead-bismuth eutectic as a target material.*
- *Liquid metal target concepts are considered to simplify the target design, to enhance the target performance including its lifetime, and to relax some of the reliability requirements for the accelerator.*
- *Lead is less corrosive and produce less polonium relative to lead-bismuth but it has a higher melting temperature.*

Spallation Target Characteristics (continued)

- *The radiation damage of the target window limits the service lifetime of the target.*
- *The target structure is type 316 stainless steel or HT-9 ferritic steel based on the current material data base and the performed experimental investigations.*
- *Window and windowless target designs are under consideration around the world.*
- *Windowless design eliminates the window problem but create other issues. Control the vacuum quality for the accelerator operation and the stability of the liquid target surface are the main issues.*

Spallation Target Design Requirements

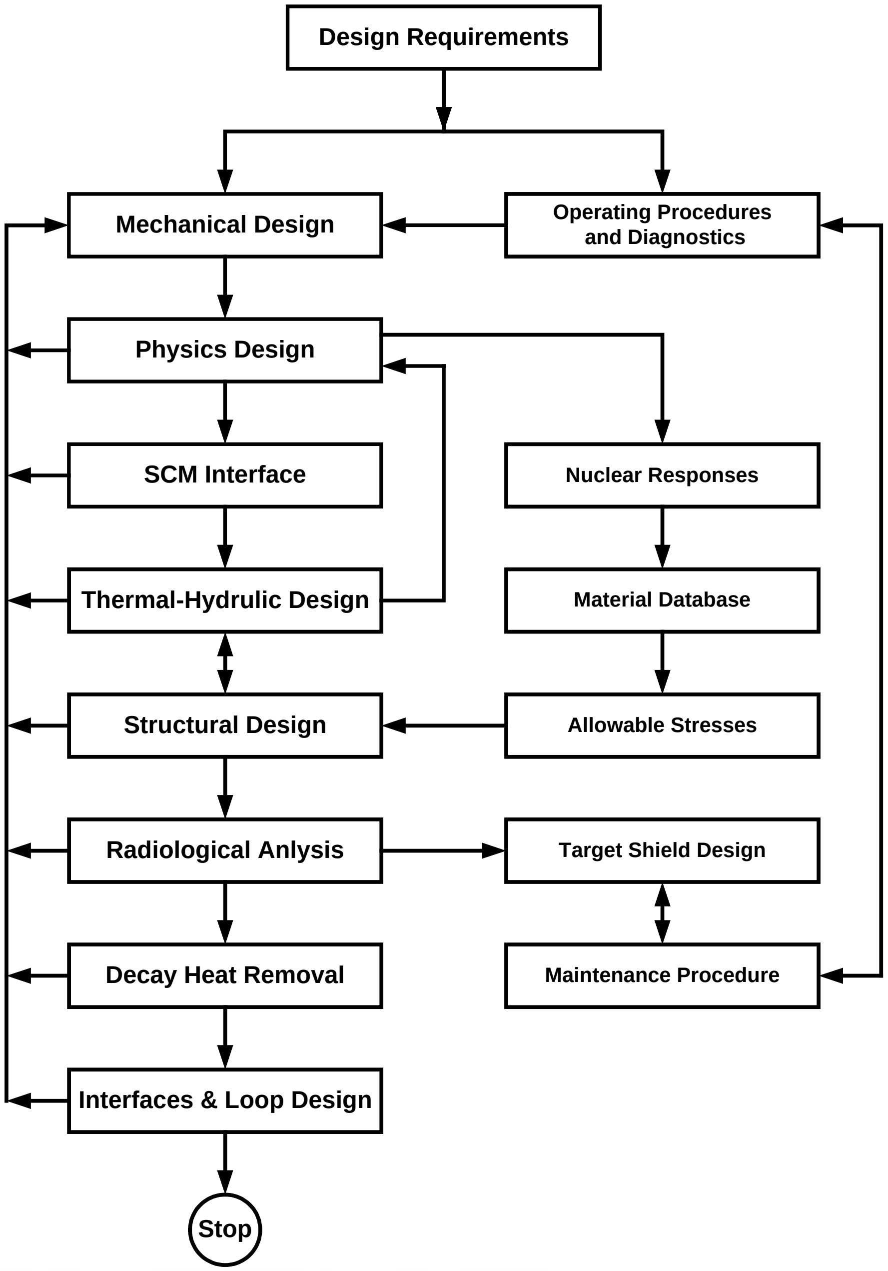
- Produce the required neutron source with the appropriate spatial distribution to drive the subcritical multiplier.
- Protect the subcritical multiplier from the high-energy protons.
- Contain the spallation products during normal and abnormal conditions.
- Achieve a lifetime that satisfies the plant availability goal.
- Utilize a fast replacement procedure for normal and abnormal conditions.
- Operate and fail safely to achieve the required plant performance.
- Communicate with the accelerator and the subcritical, and interface with the plant design.

Spallation Target Design Constraints

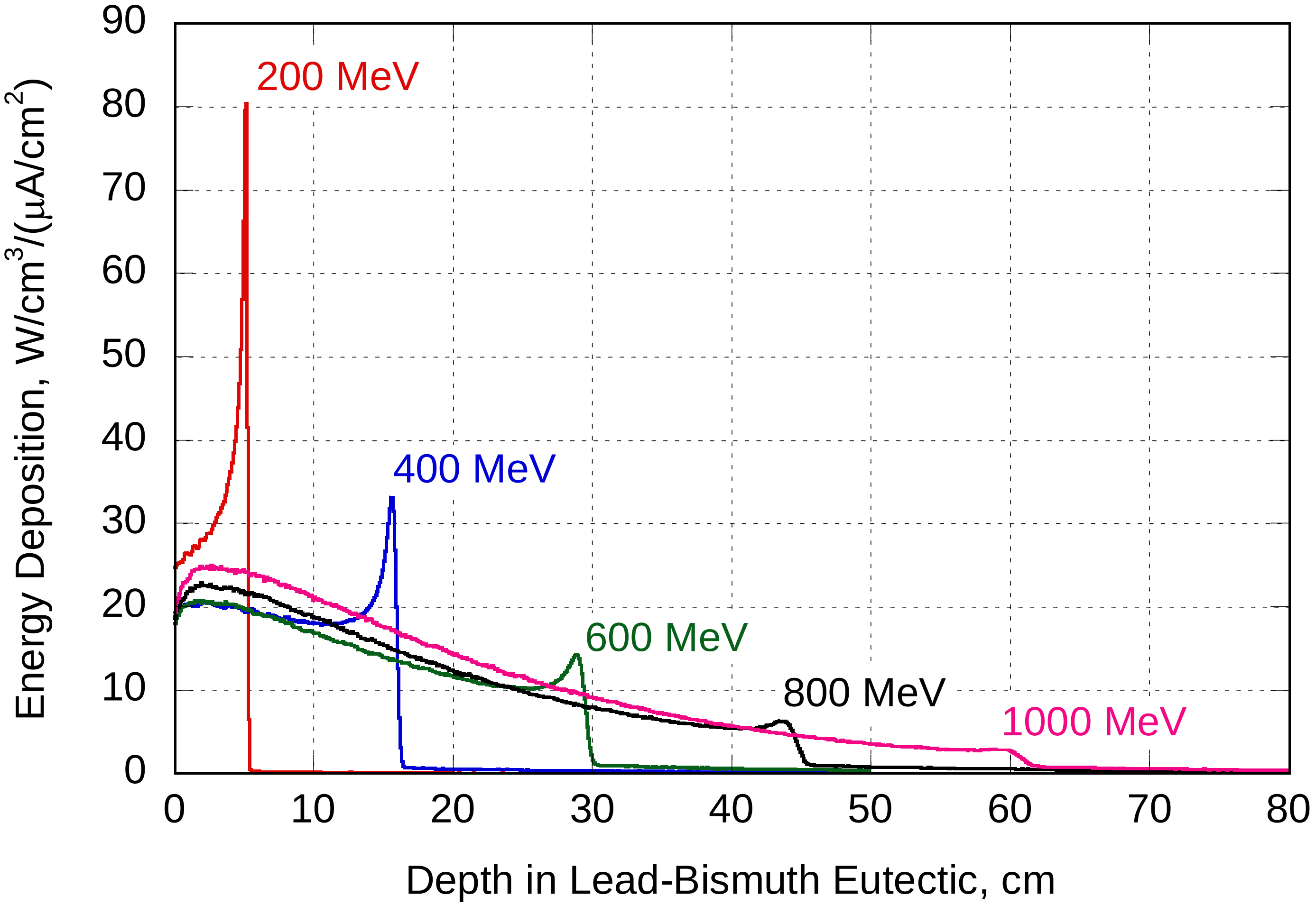
- *The structural material properties limit the maximum power density in the target structure and the target lifetime.*
- *The coolant operating conditions are constrained to satisfy different engineering requirements.*
- *The coolant chemistry is closely controlled to reduce corrosion concerns.*
- *The structure temperature is constrained to insure satisfactory mechanical properties.*
- *The target diameter should be minimized to maximize the utilization of the spallation neutrons, to simplify the target replacement procedures, to reduce the neutron losses in the beam direction, to decrease the shield volume, and to reduce the required fuel inventory.*
- *The target decay heat should be removed by conduction, natural convection, and/or radiation to the surrounding materials.*

Target Design Steps

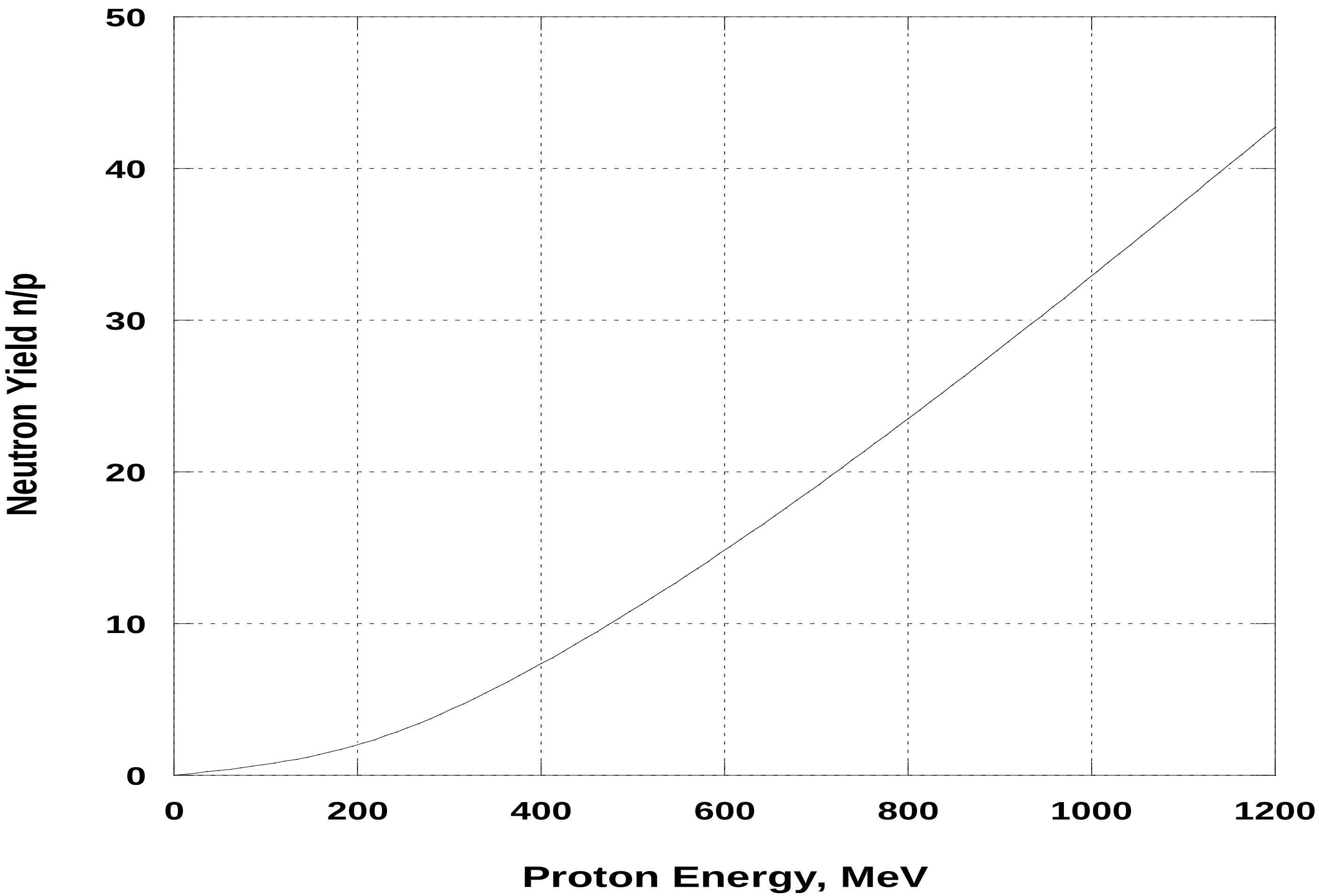
- *Design tools are available to develop the target design.*
- *The current worldwide engineering experience and data base for designing and operating ADS targets are very limited.*
- *Irradiated structure design criteria need standardization, some effort is underway.*
- *The engineering material data base for the expected irradiation conditions of ADS is very limited and incomplete.*
- *The current state of the art are adequate to perform the design process but design validation is required.*



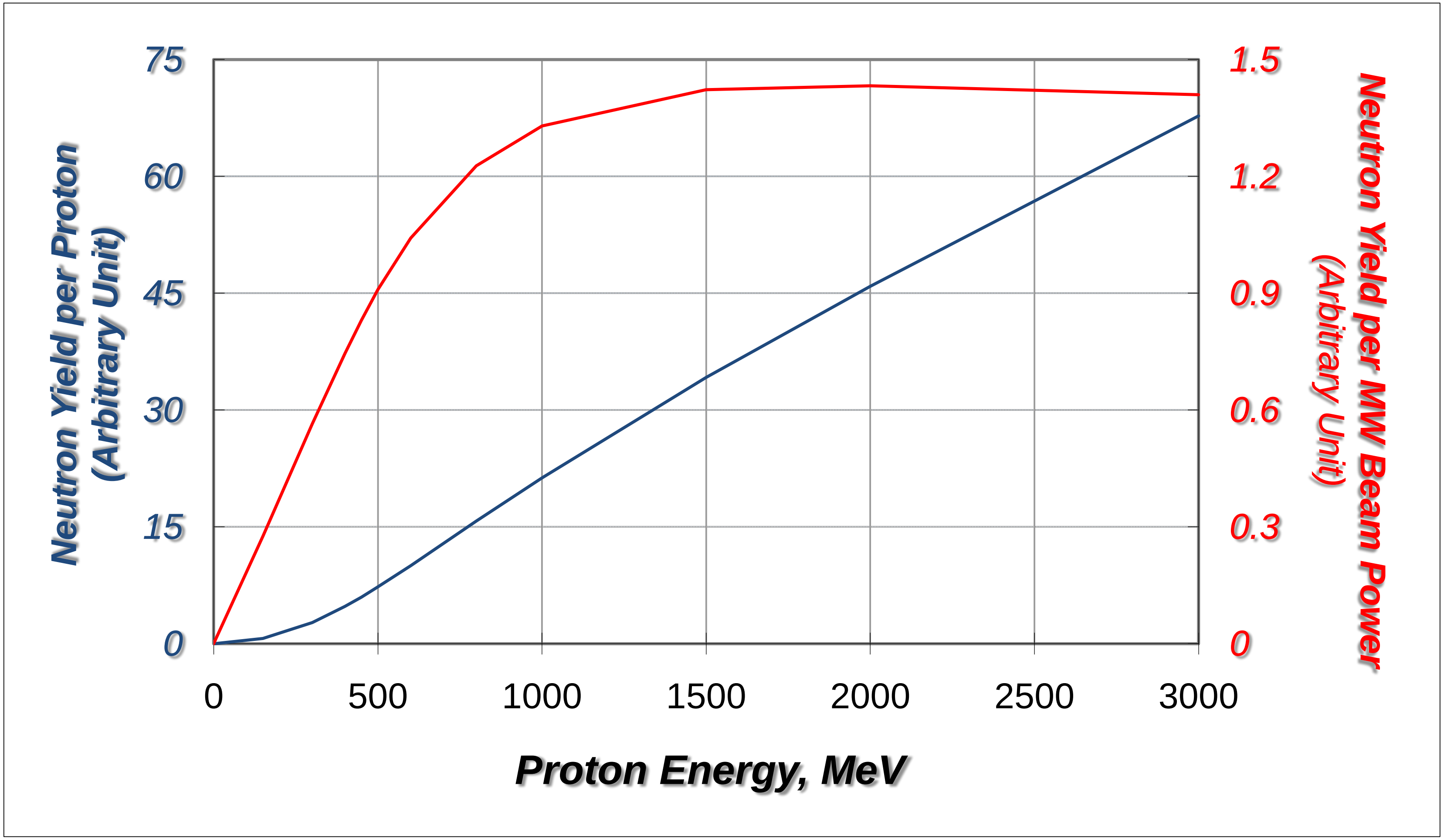
Lead-bismuth Eutectic Spatial Energy Deposition for Different Proton Energies with a Uniform Proton Beam Distribution



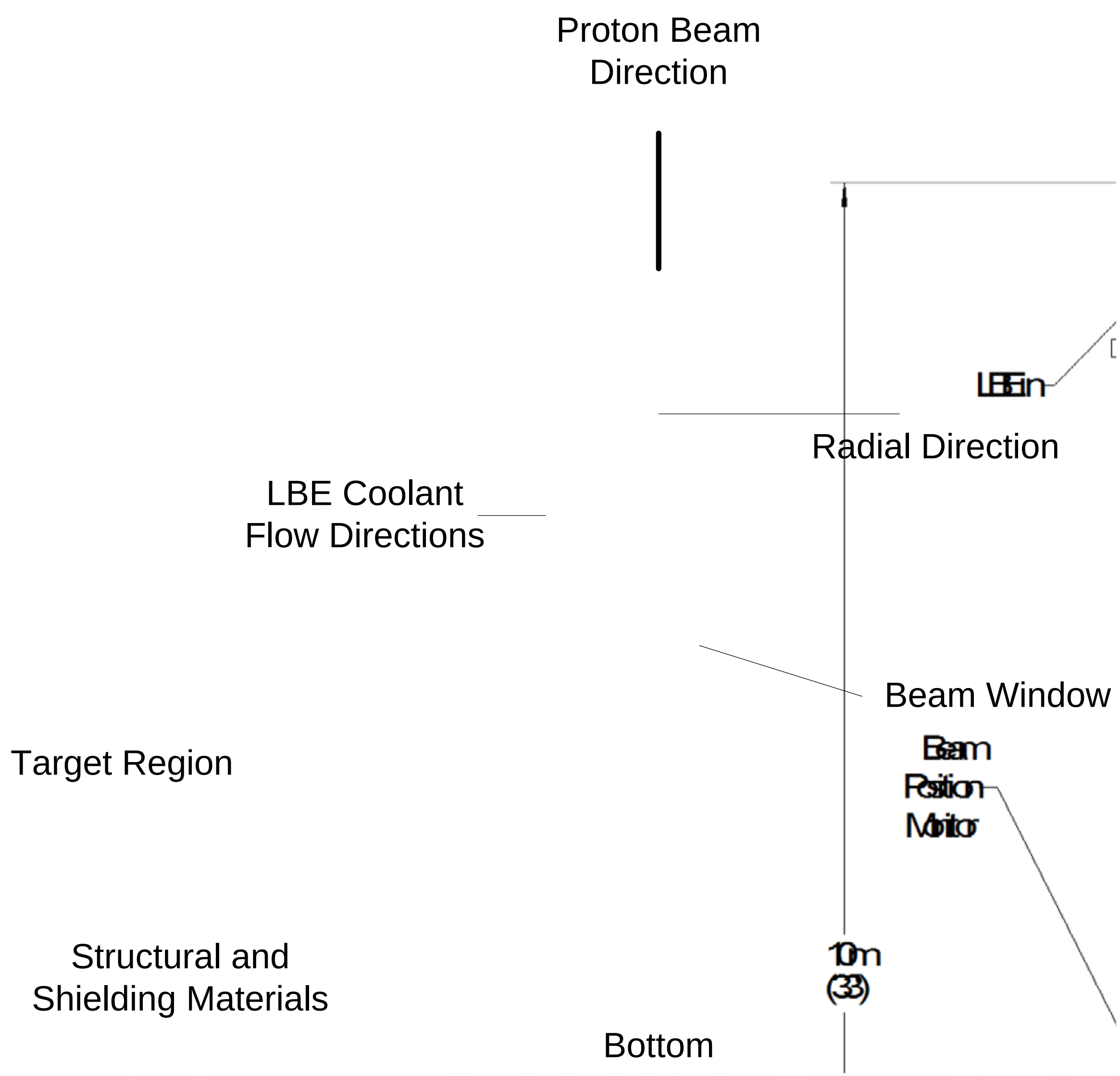
Lead-Bismuth Neutron Yield per Proton as a Function of the Proton Energy



Neutron Yield as a Function of the Proton Energy



Lead-Bismuth Target Design for 5 MW Proton Beam Power Demonstration Experiment



Main Parameters of the Target Design Example

Proton Beam

Power	5 MW
Current	8.33 mA
Proton Energy	600 MeV
Current Distribution	Uniform
Current Density	40 μA/cm^2

Engineering Parameters

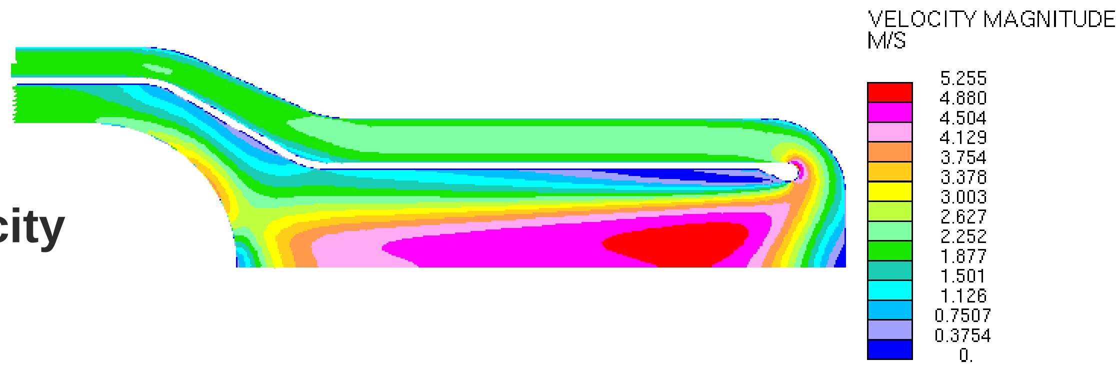
Steel Structural Material	HT9 or 316SS
Lead-Bismuth Inlet/Outlet Temperature	200/280 C
Average Lead-Bismuth Velocity	2 m/s
Maximum Steel Surface Temperature	550 C
Maximum Steel Temperature:	
HT9 Steel	550 C
Type 316 Stainless Steel	600 C
Leakage Detection Capability	
Passive Decay Heat Removal	

Beam Window Nuclear Responses of the Target Design Example

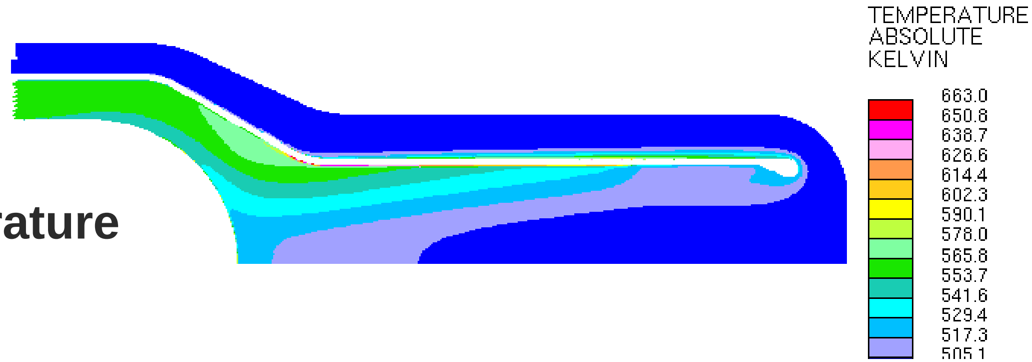
Energy deposition	766.5 W/cm3
Atomic Displacement	
Neutrons	46.2 dpa/fpy
Protons	21.1 dpa/fpy
Total	67.4 dpa/fpy
Helium Production	
Low energy neutrons < 20 MeV	6 appm/fpy
High energy neutrons > 20 MeV	50 appm/fpy
Protons	1437 appm/fpy
Total	1493 appm/fpy
Hydrogen production	
Low energy neutrons < 20 MeV	6 appm/fpy
High-energy neutrons > 20 MeV	1010 appm/fpy
Protons	26753 appm/fpy
Total	27769 appm/fpy

Operating Conditions of the Target Design Example

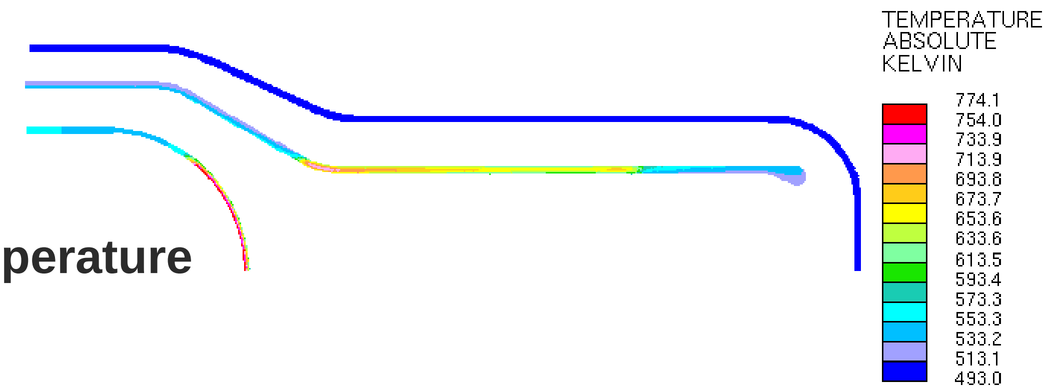
Fluid Velocity



Fluid Temperature



Structure Temperature



Proposed Target Experiments for Project - X

Demonstrate and confirm technical approach and the proposed technologies:

- Neutron yield, spectra, and spatial distribution.
- Control and recovery of the spallation products.
- Chemistry control of the lead bismuth eutectic or the liquid lead to protect the structural material.
- Thermal hydraulics parameters of the target design including the velocity and the temperature distributions, and the pressure drop.
- Structural material performance including radiation damage and liquid metal effects.
- Target operation and handling procedures
- The operation and the maintenance of auxiliary systems

Subcritical Assembly Characteristics

- *Subcritical assemblies with solid fuel materials are considered to utilize the gained experience from the operating fission power reactors. Such choice requires:*
  - *Development of new fuel materials and designs,*
  - *Multi reprocessing steps, and*
  - *Additional fuel reprocessing plants.*

  These issues translate to more R&D, development time, cost, and long time to dispose of the spent nuclear fuels.

- *Mobile fuel forms with transuranic materials and without uranium are under consideration to avoid the issues of the solid fuel forms and to achieve the objective of eliminating the transuranics and most of the long-lived fission products.*

Subcritical Assembly Characteristics

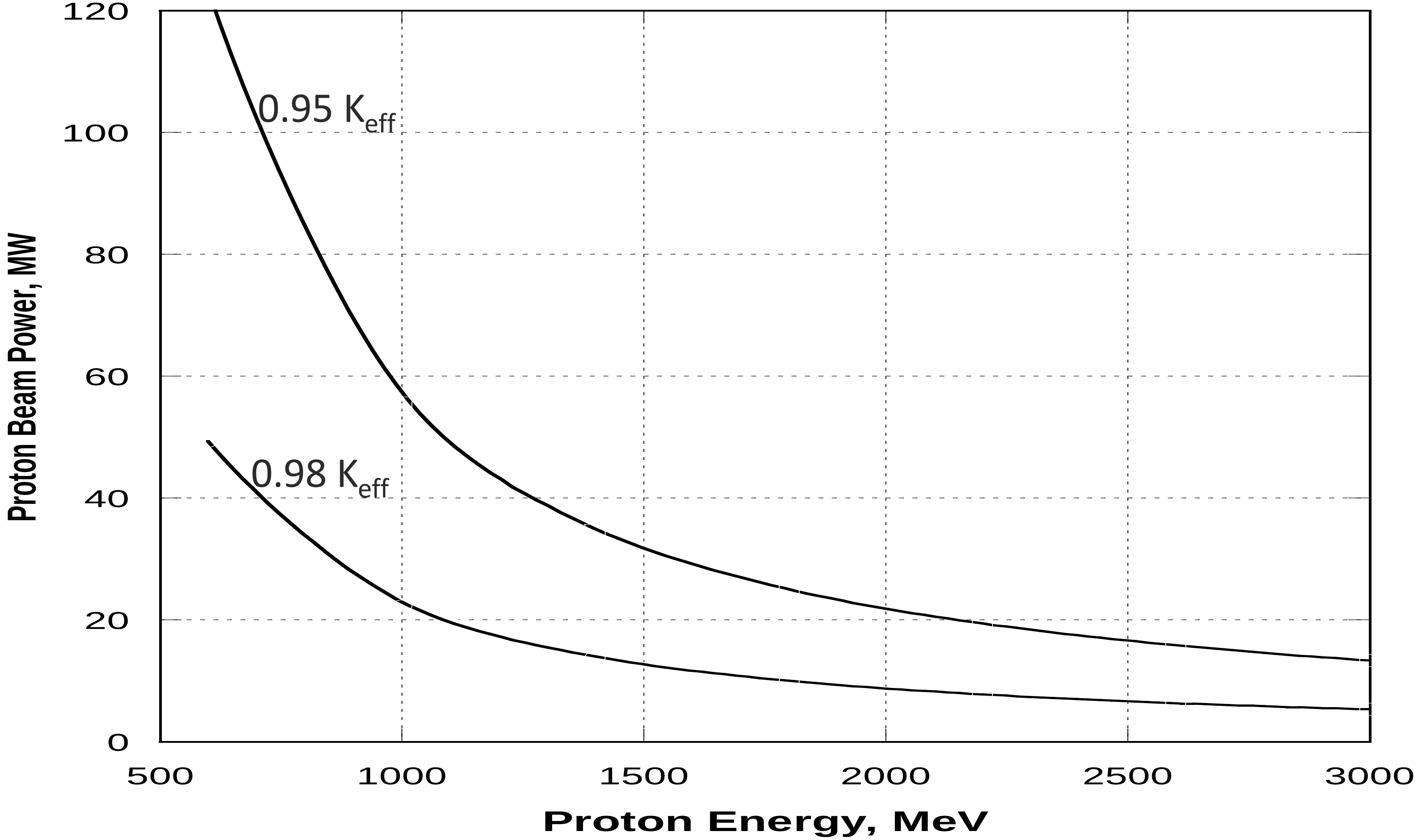
(Continued)

- Mobile fuel forms:
  - Eliminates the minor actinides without the need for extra fuel processing steps.
  - Relaxes some of the reliability requirements for the accelerators,
  - Reduces the required R&D, the deployment time, and the total cost.
  - Operate with a fast neutron spectrum, which have neutronics advantages relative to thermal systems:
    - Efficient neutron multiplication and utilization,
    - Good neutron economy in the presence of fission products,
    - Remove fission gases during operation,
    - Lower probabilities for generating higher actinides.
  - Liquid metals carriers achieve the proposed objective and permit controlling the output power without changing the proton beam power.

Accelerator Driven System Characteristics with Mobile Fuels

- ***The system has a closed material cycle, which is highly proliferation resistance. The liquid carrier has the fission products mixed with the transuranics all the time.***
- ***A significant fraction of the long-lived fission products are transmuted during the power generation process.***
- ***The continuous feed of the transuranics during the operation reduces significantly the produced radioactive waste and the needed capacity for a long-term geological storage.***
- ***The successful operation of fission reactors with lead bismuth eutectic, spallation targets, and different lead-bismuth eutectic loops in Russia, Europe, Korea, and USA provides the technical experiences to proceed with such material.***
- ***MYRRHA ADS system (56 MW_t) utilizes lead bismuth eutectic as the target material and the coolant for the subcritical.***

Beam Power Requirements as a Function of the Proton Energy with Lead Bismuth Target for 3 GW_{th} System



Proposed Transmutation Experiments for Project – X

Demonstrate and verify the following aspects for the subcritical:

- The thermal hydraulics parameters including the velocity and the temperature distributions, and the pressure drop
- The chemistry control of the fuel carrier to protect the structure material
- The removal of the short lived fission products from the mobile fuel carrier
- The online measurements of the mobile fuel composition
- The operation of the continuous fed of the transuranic materials to control the composition of the mobile fuel carrier
- The start up, the operation, and the shutdown procedures of the transmutation experiment
- The operation and the maintenance procedures of the auxiliary systems
- Decay heat removal approach