SYNERGY of Irradiation and PIE Facilities at BNL

- **BLAIRR**
- **Tandem van de GRAAFF**

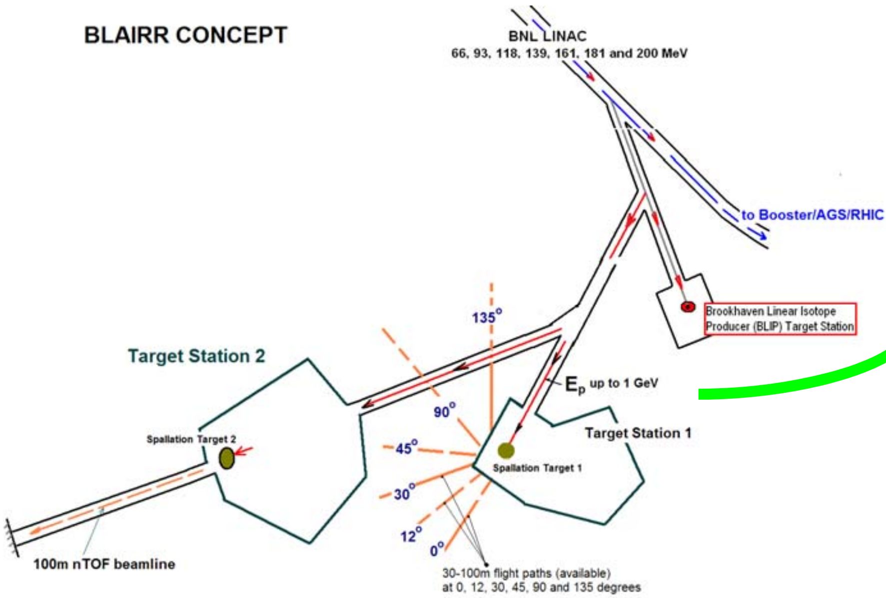
- **NSLS II XPD Beamline (PIE)**

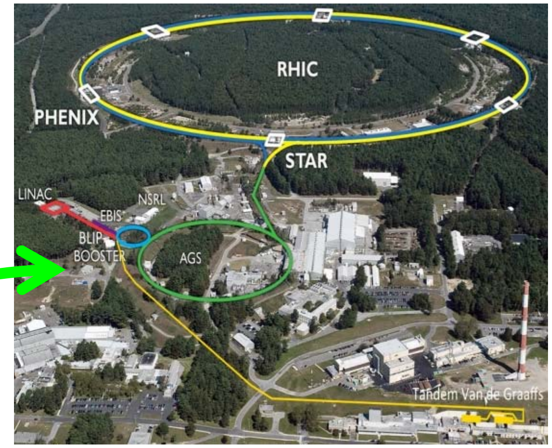
N. Simos

BROOKHAVEN NATIONAL LABORATORY
a passion for discovery

Office of Science
U.S. DEPARTMENT OF ENERGY

RaDiATE Meeting December 12, 2014





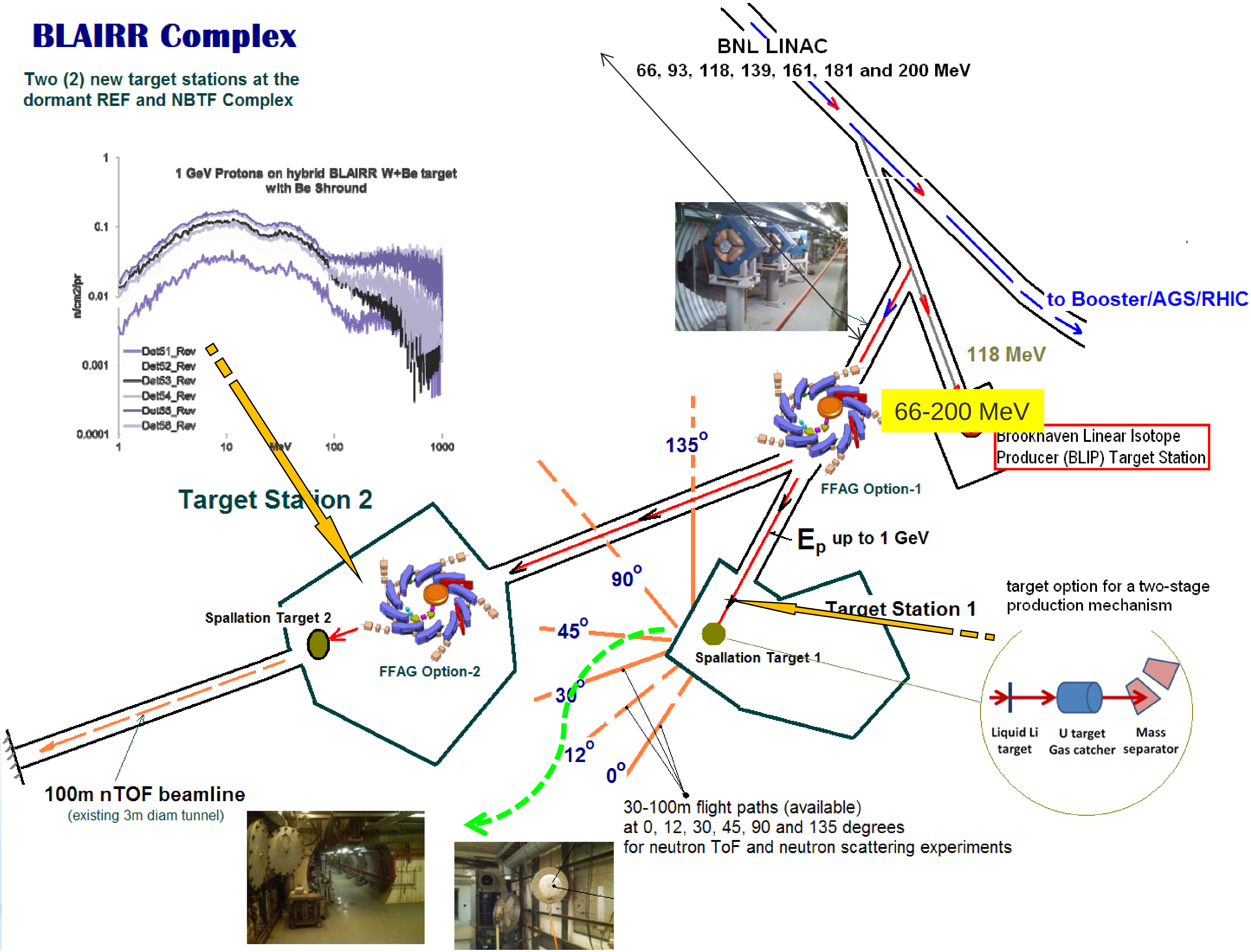
Aim: Capitalize on Complex Unique Features:

- **Multitude of energies the Linac can provide**
- **Polarized H^-**
- **Beam current (140 µA → 2 x in future update of source) enabling spallation-related studies including ADS-relevant experiments**
- **Availability of infrastructure (currently dormant)**
- **Neutron time-of-flight path lengths of 30-100 meters at 0, 12, 30, 45, 90 and 135°**
- **Single micro-pulse selection (<1 ns) with period as low as 400ns**
- **Pulsed Neutron Potential**

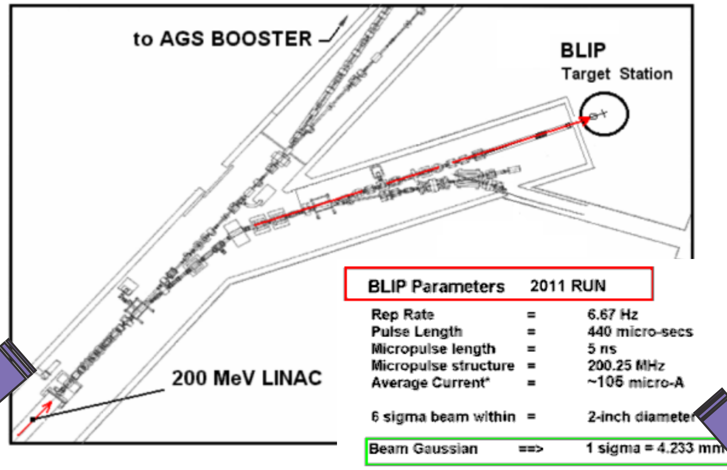
- FAST neutron damage studies of materials for fast neutron and fusion reactors
- Proton irradiation damage of materials for accelerator initiatives as a function of energy
- Validating experiments of neutron flux/reaction rates for accelerator-driven systems
- Blanket, moderator, reflector concept validation/optimization
- Nuclear cross-section data
- Neutron detector studies
- Expansion of the range of isotope generation augmenting BLIP capabilities
- Neutron scattering potential
- Neutron time of flight (nTOF) and nuclear physics experiments

BLAIRR Complex

Two (2) new target stations at the dormant REF and NBTF Complex

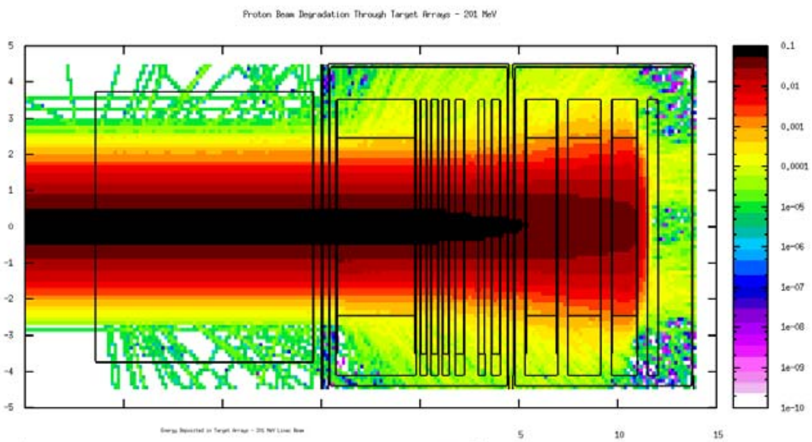


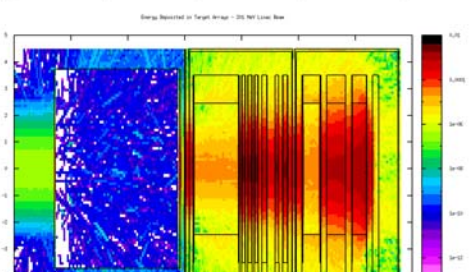
BLAIIR pre-cursor

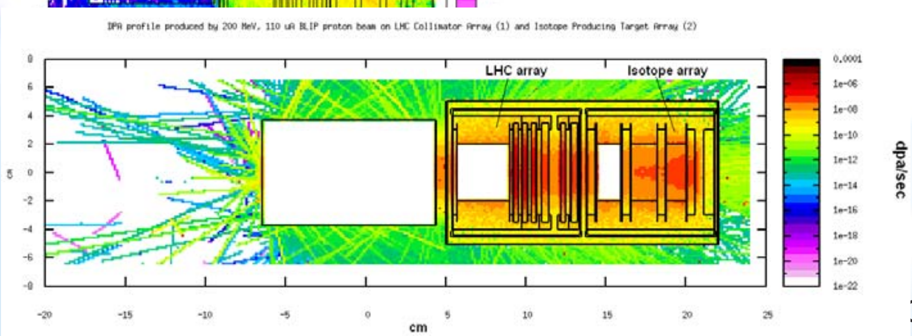


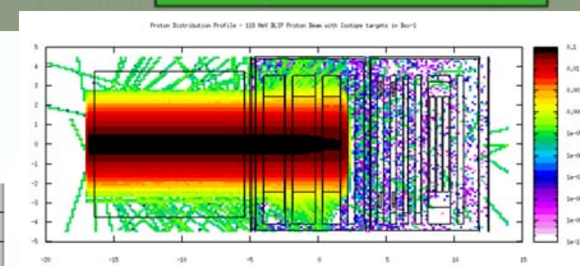
200 MeV proton/target interaction and damage studies

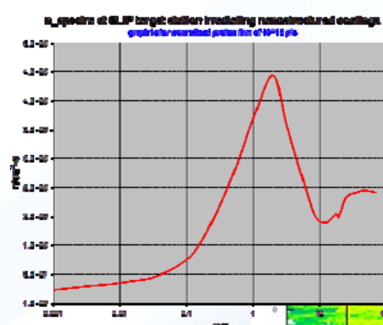
Spallation-induced fast neutron irradiation studies

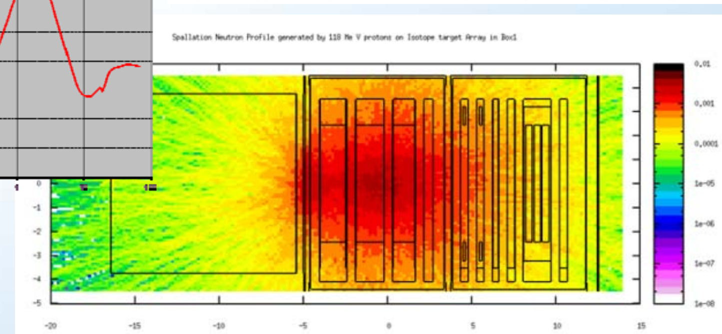












Path Forward

Phase – I BLAIRR-200

Use of existing Source/Linac infrastructure and operate at energies up to 200 MeV and peak current

Consider planned upgrades to the source and Linac leading to 2x the spill and consequently to 2x the accelerator peak power (from 30 kW to 60 kW)

Phase – II BLAIRR-1000

Primary Objective: Integrate into the design a **"tunable"** acceleration system (i.e. FFAG, CCA) to populate energy space up to 1 GeV

- **Linac/TF Upgrade**
- **Booster Use**
- **or possibly FFAG**

BLAIRR STUDY STATUS

Beamline Complex Evaluation/Assessment and Adaptation to the Goals

Facility Radiological Constraints
Large scale analyses of conventional facility and integrated shield (concrete, soil)

Target Optimization and Design:
Beam-target interaction optimization
Hadronic interaction and energy deposition limitations
Single phase and Hybrid target concepts
Irradiation Damage
Thermo-mechanical considerations

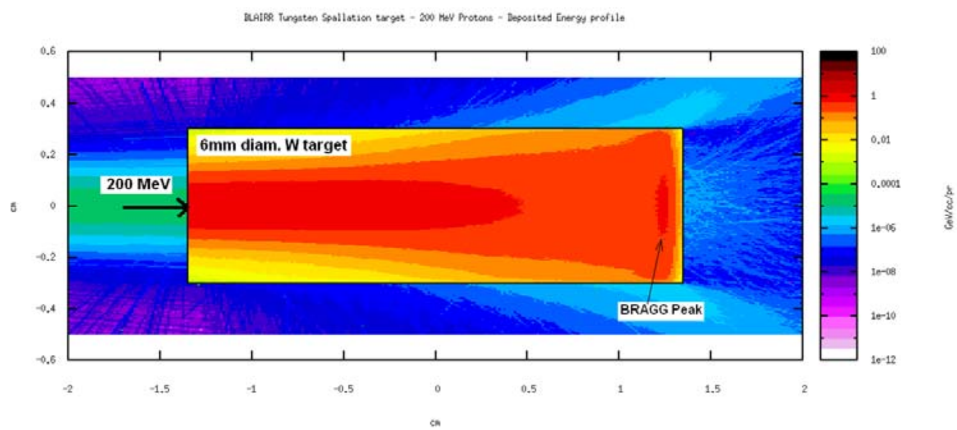
Spallation neutron fluence optimization for
(a) fast neutron irradiation damage
(b) moderator/reflector studies,
© NTOF potential and optimization
(d) mono-energetic neutron beam

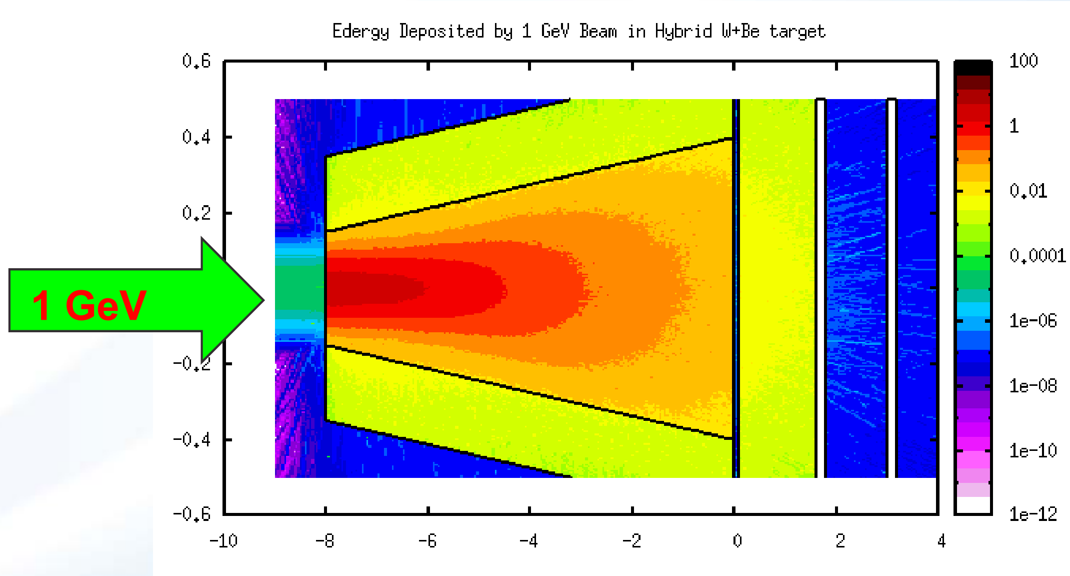
Spallation Target Considerations and Impact to the Facility

Target Optimization

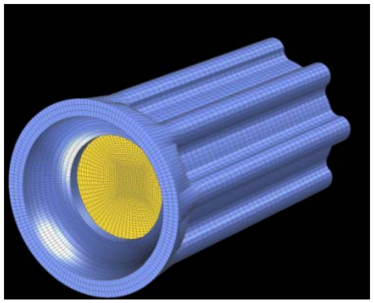
- Optimize for:
- Spallation Neutron YIELD
- Spatial Distribution
- Energy
- Target Longevity

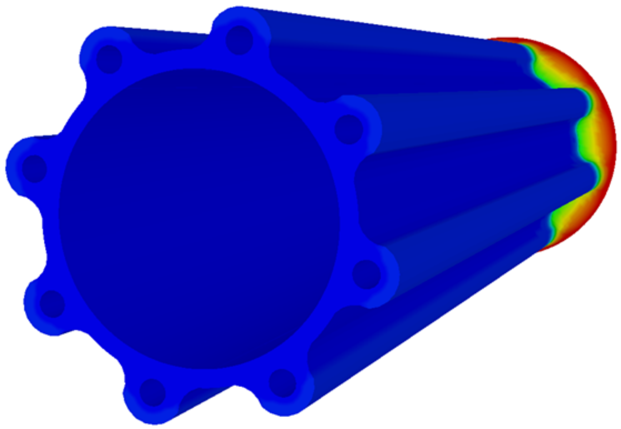
Target Optimization Studies





BLAIRR Target: 200 MeV Protons on W Target with Be Shroud





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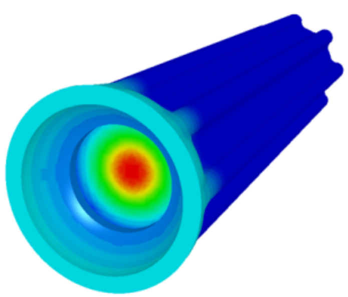

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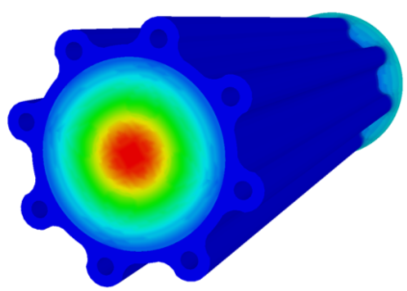
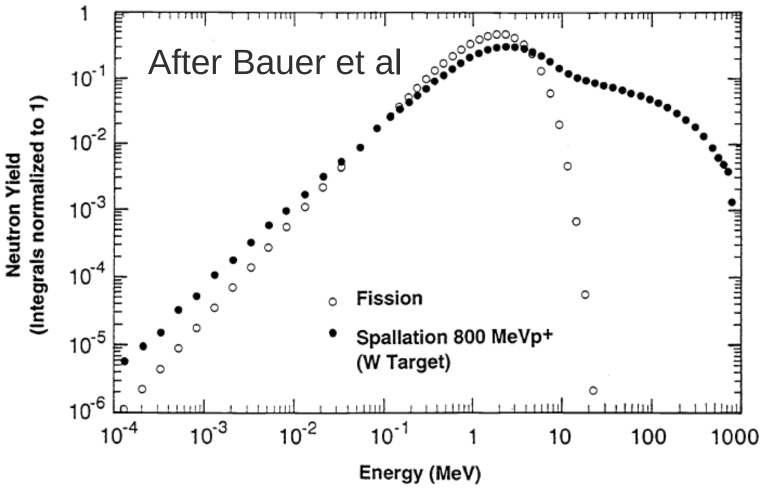
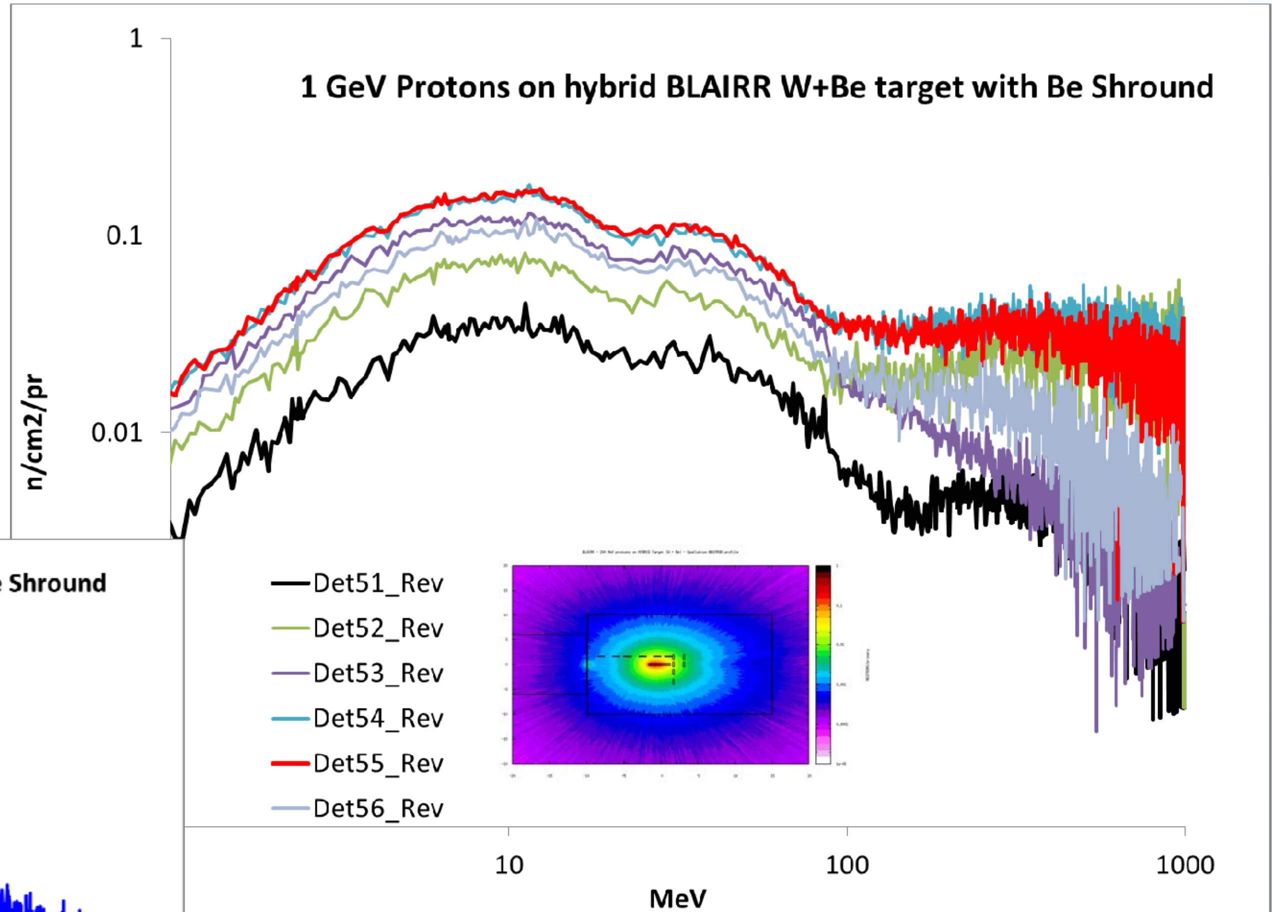
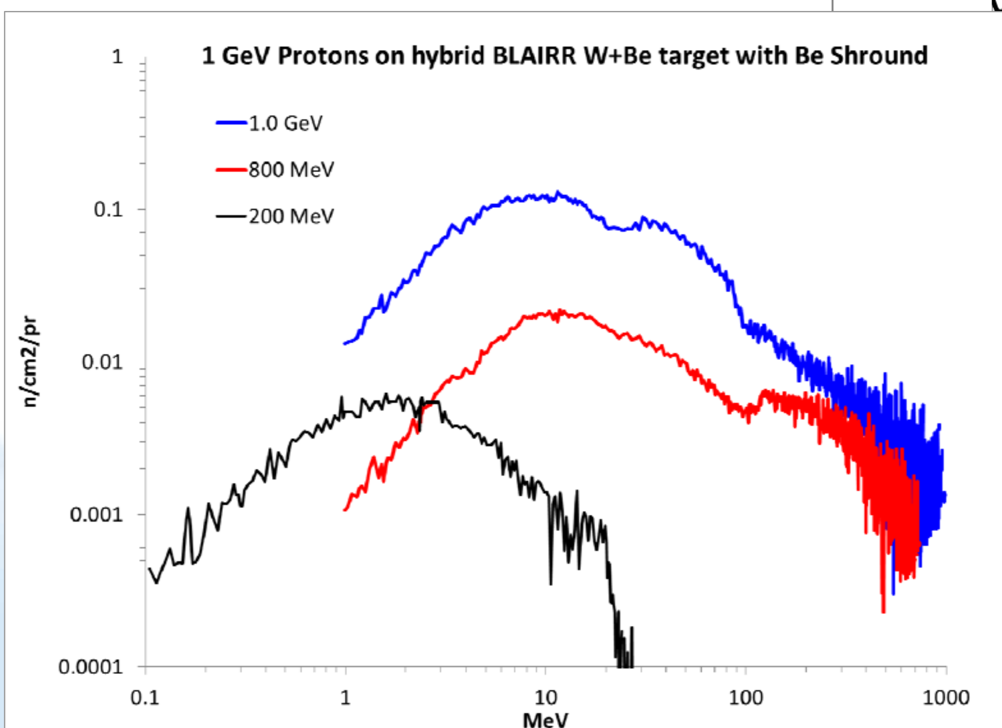



After Bauer et al
Neutron Yield
(Integrals normalized to 1)
Energy (MeV)
Fission
Spallation 800 MeVp+
(W Target)

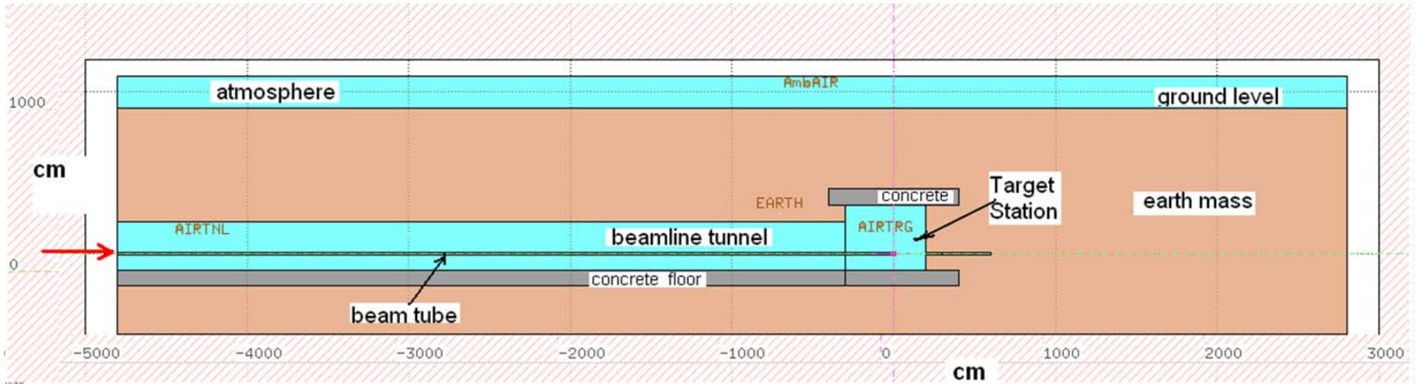

1 GeV Protons on hybrid BLAIRR W+Be target with Be Shround
n/cm2/pr
MeV
Det51_Rev
Det52_Rev
Det53_Rev
Det54_Rev
Det55_Rev
Det56_Rev

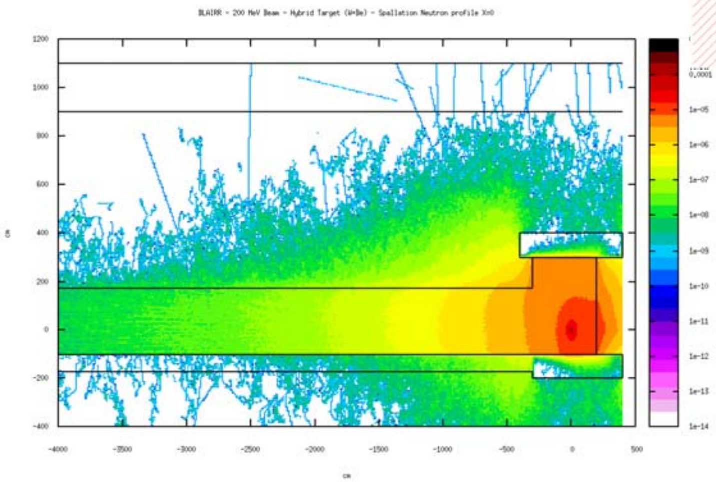

1 GeV Protons on hybrid BLAIRR W+Be target with Be Shround
1.0 GeV
800 MeV
200 MeV
n/cm2/pr
MeV

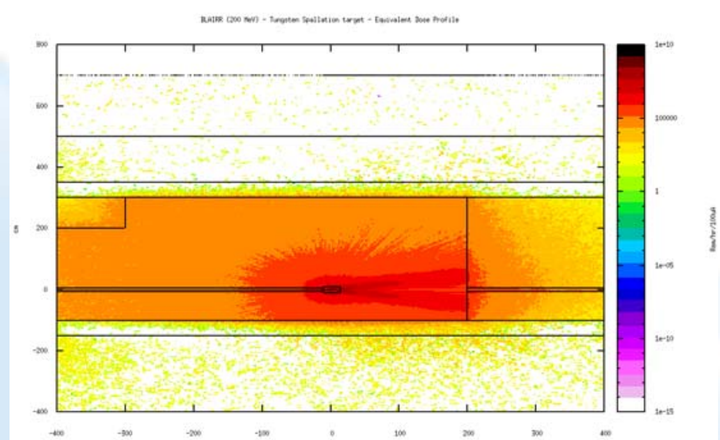
Facility Radiation Protection Consideration and Infrastructure Upgrade

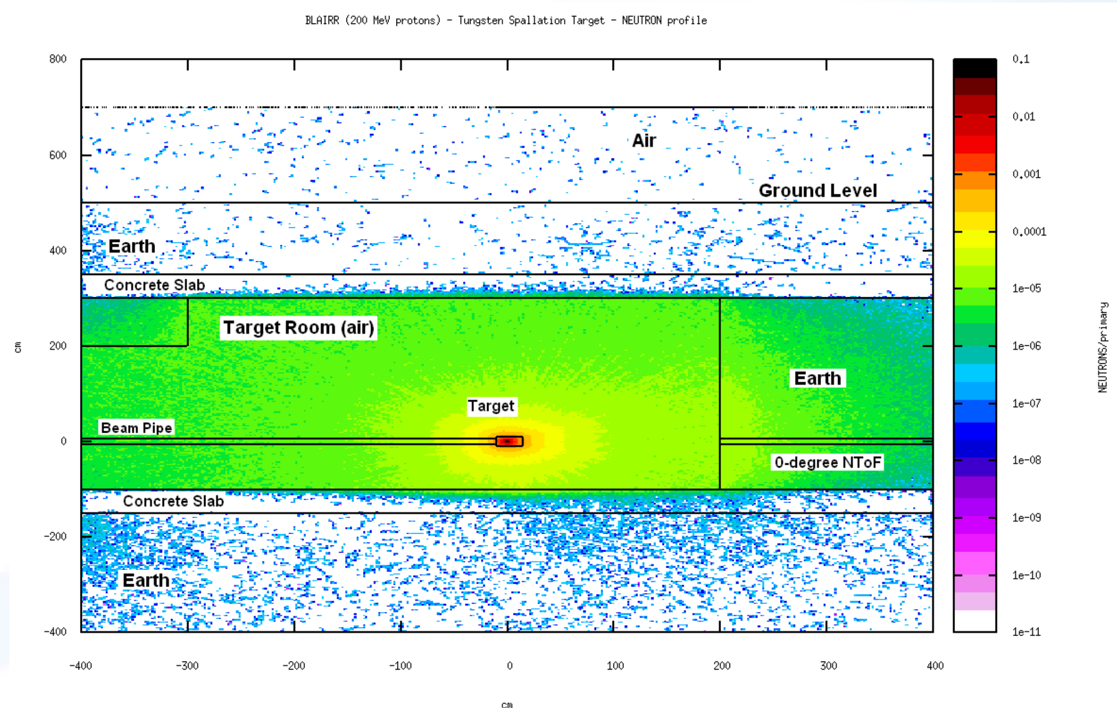
Developed models have been BENCHMARKED against field measurements with exceptional results (BLIP LHC target activation and decay, Tandem Experiment)

Based on the success of these models to predict radiation effects, FULL scale numerical schemes have been developed specifically for BLAIRR studying the radiological IMPACT on the existing facility and the need for infrastructure upgrade









Option-1:

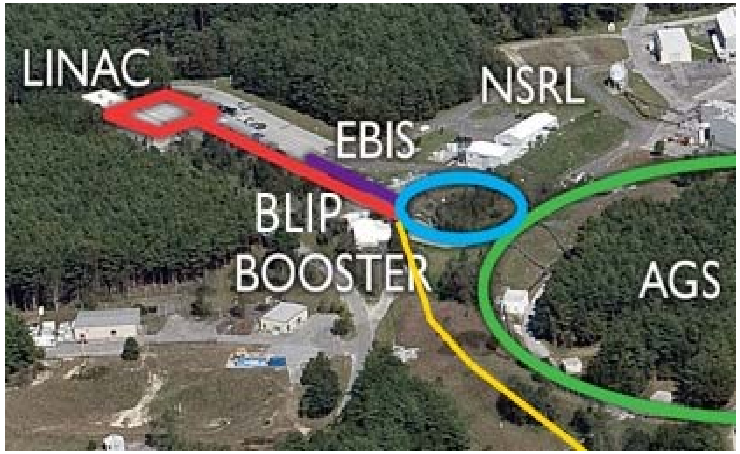
Use Booster to accelerate up to 2 GeV and feed BLAIRR

LINAC: 200MeV/30kW
(200 MeV, 6.67 Hz, 7.0e+14 pps)

Booster: **0.2-1.5 GeV/30kW**
(1.5GeV, 6.67Hz,1.0e14pps)

Assessment:

- Getting DESIRED Energy
- Loosing CURRENT (big time)



Option-2:

Update LINAC and Utilize Transfer Line Straight (~125 m)

LINAC: 200MeV/30kW
(200 MeV, 6.67 Hz, 7.0e+14 pps)

- CCA
- Normal Conducting DTL with high accelerating gradients

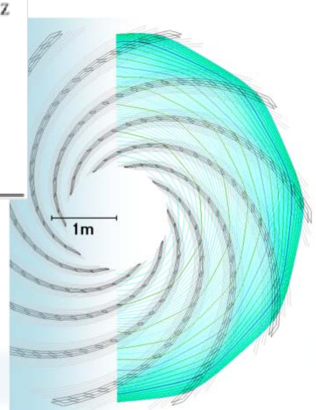
Assessment:

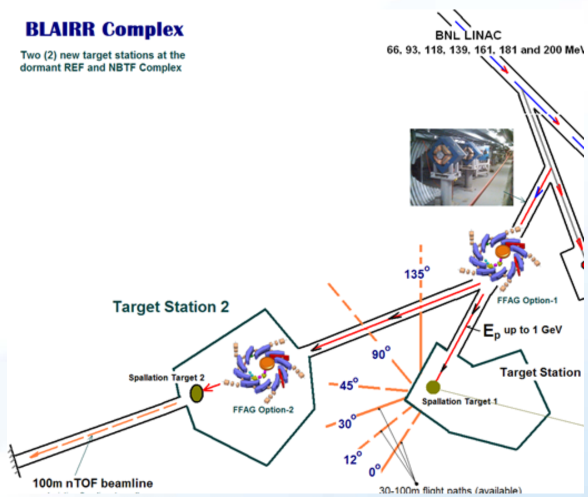
POSSIBLE !!!!

or, look into cyclotrons, FFAG

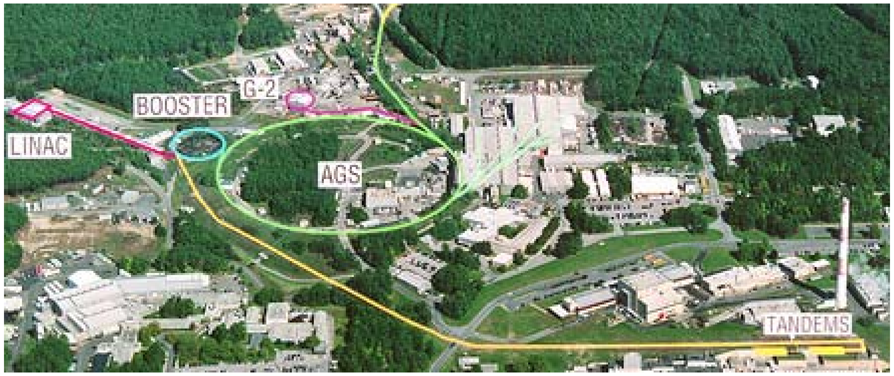
Table 2: Parameters of the Planar Cyclotron

Energy range	40–1500	MeV
Radius range	0.8684–2.9032	m
Maximum field on orbit	6.690	T
Revolution frequency	15.323±0.017	MHz
Sectors	10	
Sector edge angle θ_e	−63.43	°
Packing factor	10.21	%
Fringe extent θ_f	7.04	°
Mean field (γ=1) B_0	−1	T
Asymptotic radius R	3.1297	m





28 MeV Proton & Heavy ion irradiation at Tandem



Target Irradiation Beamline

IONS Available at Tandem

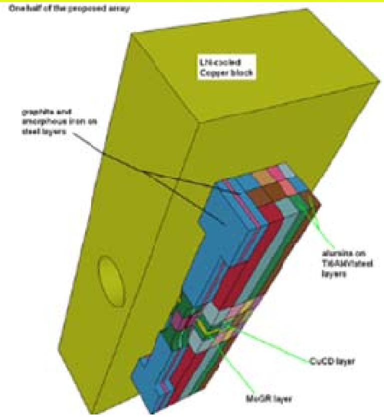
Flux can be in the range of 1 particle/cm^2/sec to greater than 1 · 10^6 particles/cm^2/sec.

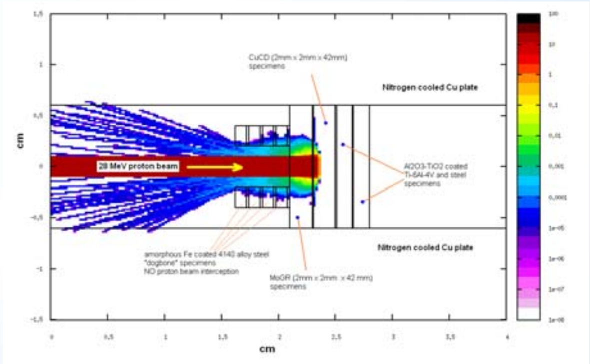
High LET Summary | Low LET Summary | High LET Summary | Low LET Summary

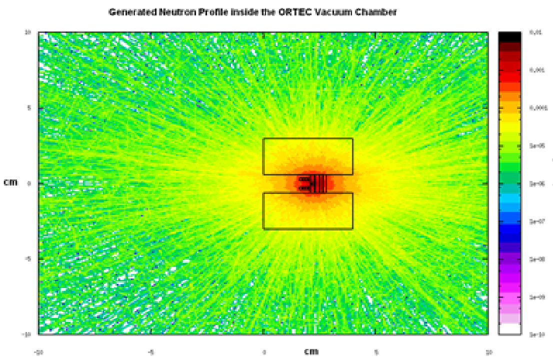
How To Use The Charts Below

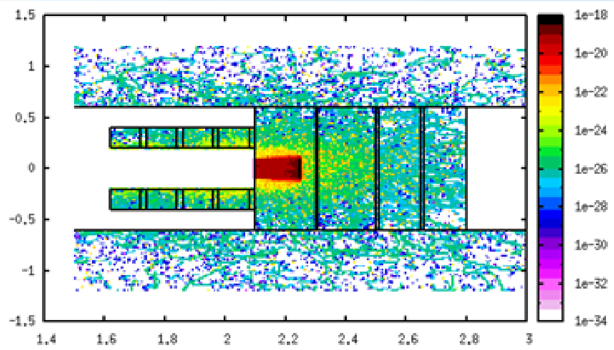
Z	Symbol	Mass AMU	Max Energy MeV	Max Energy MeV/AMU	Surface LET MeV/mg/cm^2	Range Microns	Surface LET MeV/mg/cm^2	Range Microns
1	^{1}H	1.0079	28.75	28.52	0.0153	4550	0.0118	2610
3	^{7}Li	7.0160	57.2	8.15	0.369	390	0.273	240
5	^{11}B	11.0093	85.5	7.77	1.08	206.13	0.754	132.55
6	^{12}C	12.0000	99.6	8.30	1.46	180.43	1.03	115.82
8	^{16}O	15.9994	128	8.00	2.61	137.78	1.83	88.9
9	^{19}F	18.9954	142	7.48	3.51	118.88	2.45	77.12
12	^{24}Mg	23.9927	161	6.71	6.01	84.16	4.17	55.13
14	^{28}Si	28.0855	187	6.66	7.81	77.16	5.42	50.66
17	^{35}Cl	34.9688	212	6.06	11.5	64.41	7.93	42.71
20	^{40}Ca	39.9753	221	5.53	15.8	51.89	10.9	34.7
22	^{48}Ti	47.9479	232	4.84	19.6	47.8	13.4	32.36
24	^{52}Cr	51.9405	245	4.72	22.3	45.86	15.3	31.06
26	^{56}Fe	55.9349	259	4.63	25.1	44.24	17.2	30.09
28	^{58}Ni	57.9353	270	4.66	27.9	44.56	19.1	30.47
29	^{63}Cu	62.9296	277	4.40	30.1	42.06	20.6	28.79
32	^{72}Ge	71.9221	273	3.80	35.9	37.94	24.4	26.25
35	^{81}Br	80.9163	287	3.55	41.3	37.50	28.0	26.11
41	^{93}Nb	92.9060	300	3.23	47.5	36.32	32.1	25.4
47	^{107}Ag	106.9051	313	2.93	59.2	32.48	39.9	22.89
53	^{127}I	126.9045	322	2.54	66.9	32.54	45.0	23.17
79	^{197}Au	196.9665	337	1.71	84.6	29.21	56.2	21.18

Recent 28 MeV proton irradiation experiment at Tandem



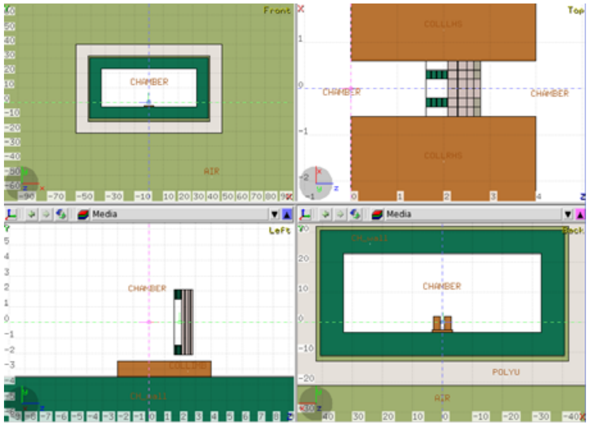


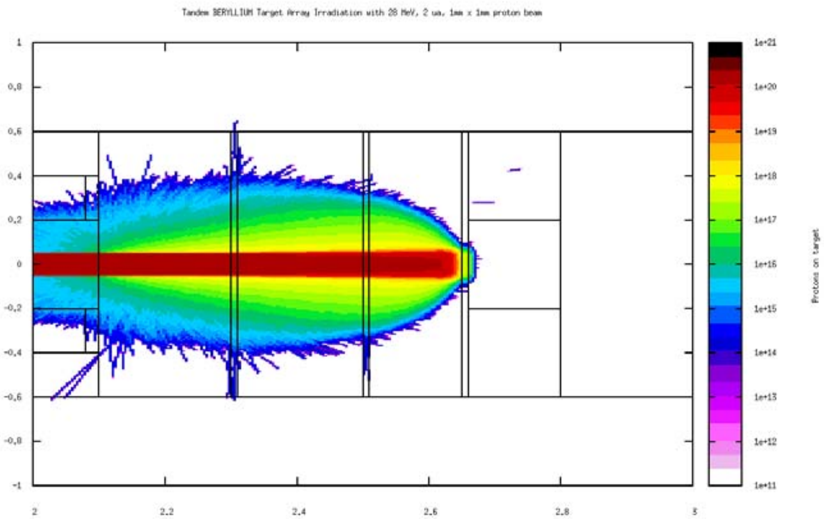


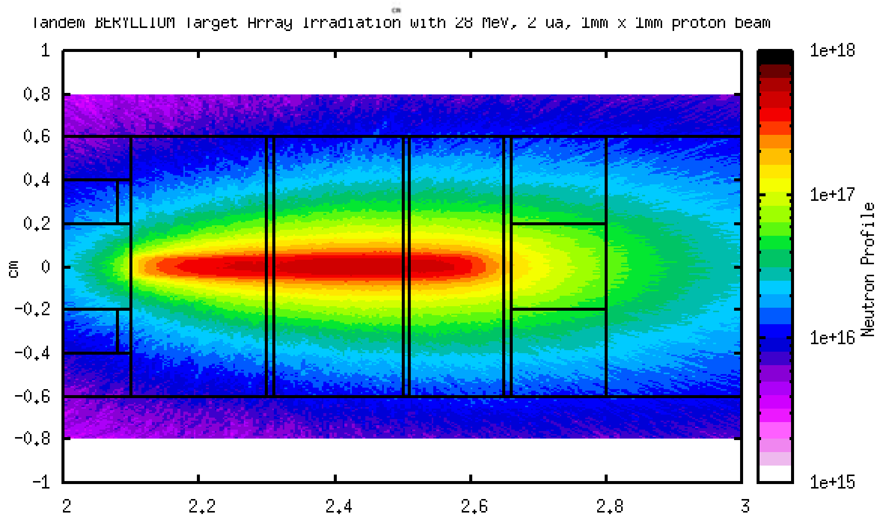


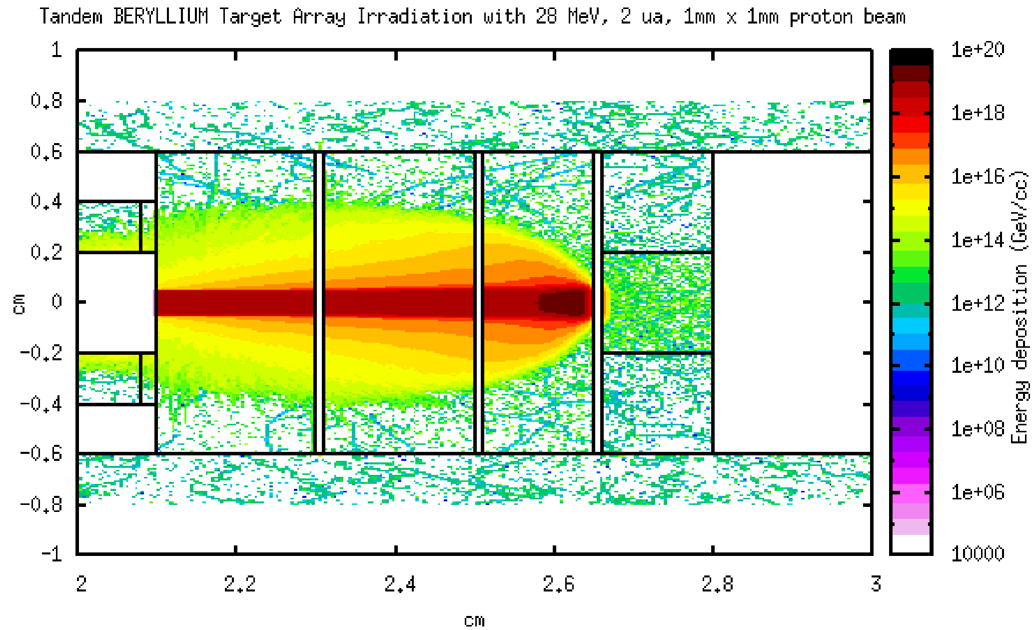
What Damage Can One Achieve at Tandem?

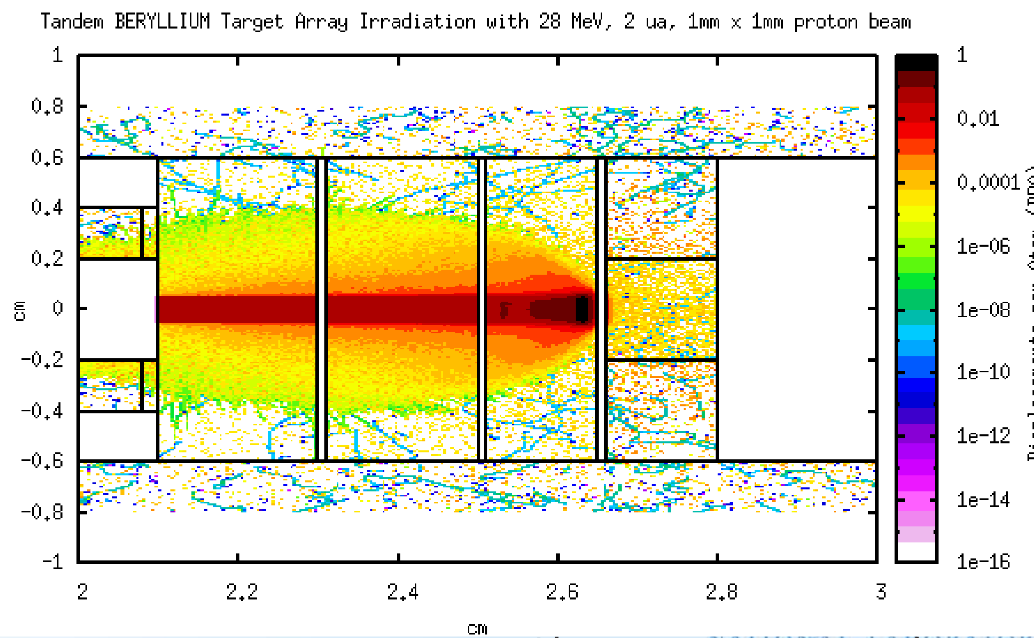
28 MeV protons on BERYLLIUM target array



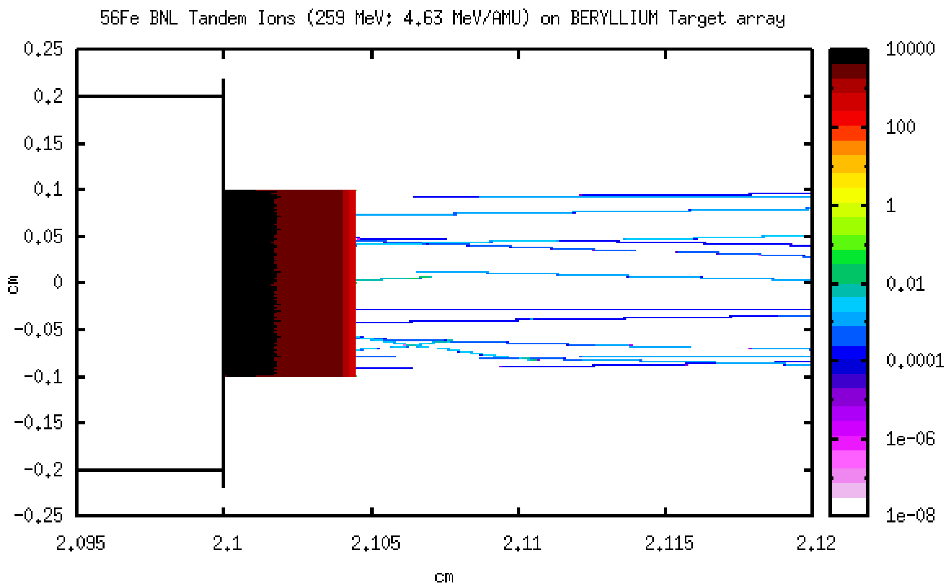


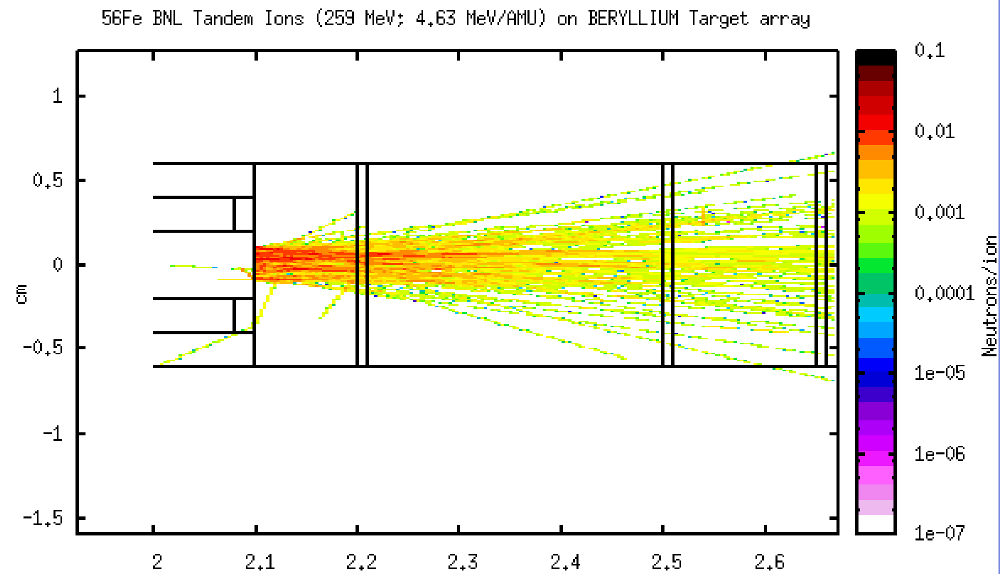


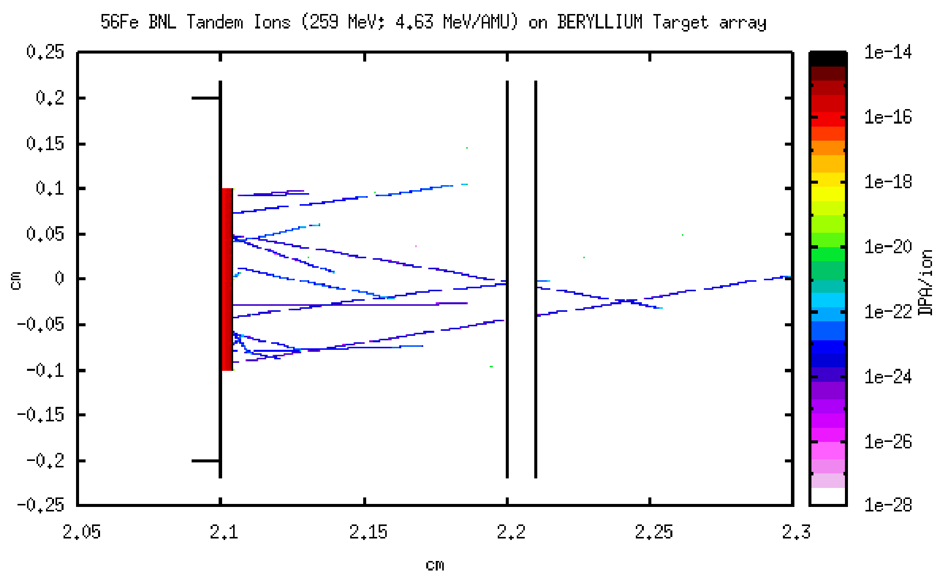


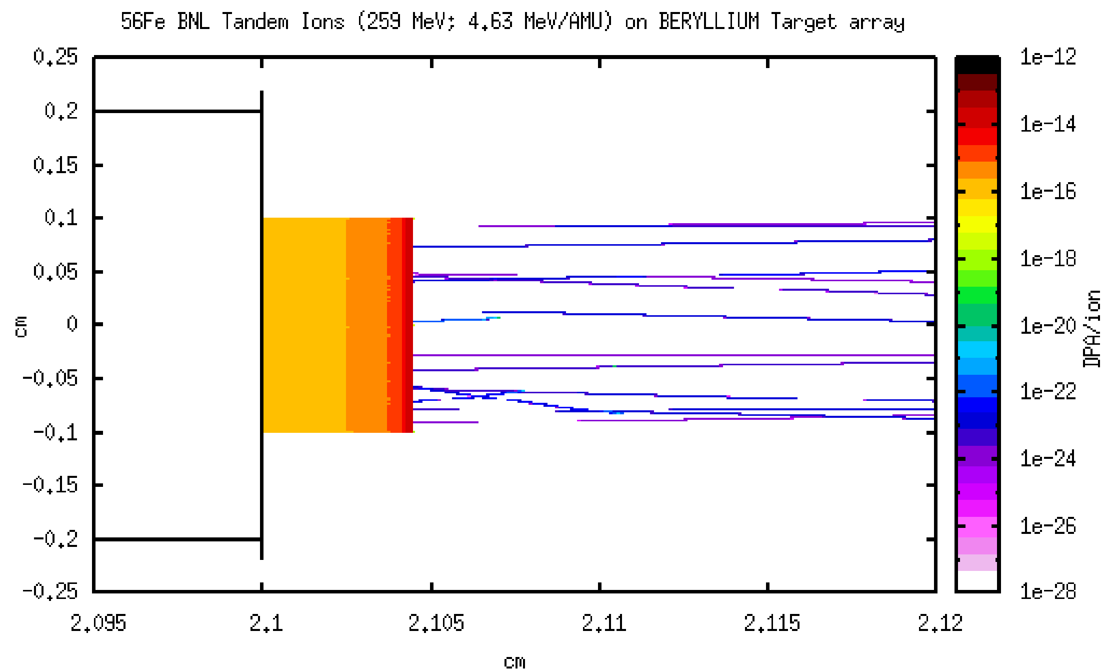


^{56}Fe ion on Be target Array



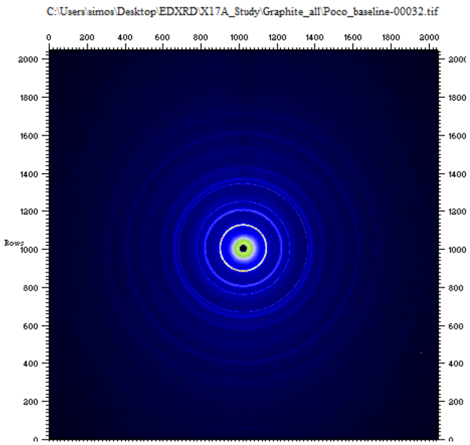


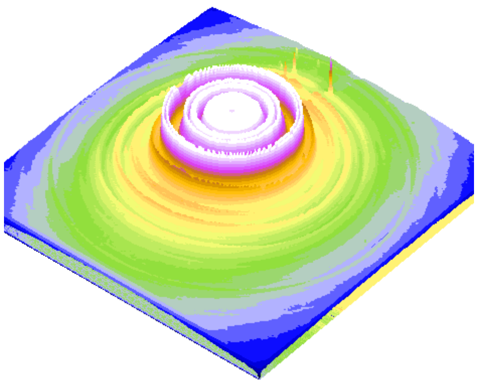


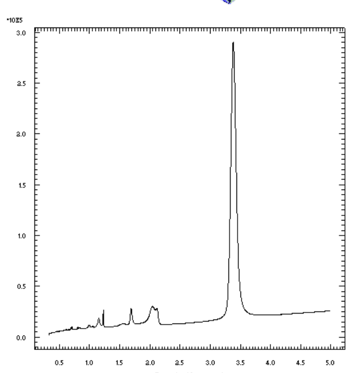


PIE assessment using X-ray diffraction at Synchrotron and macroscopic analysis in Isotope Extraction Hot Cell Facility

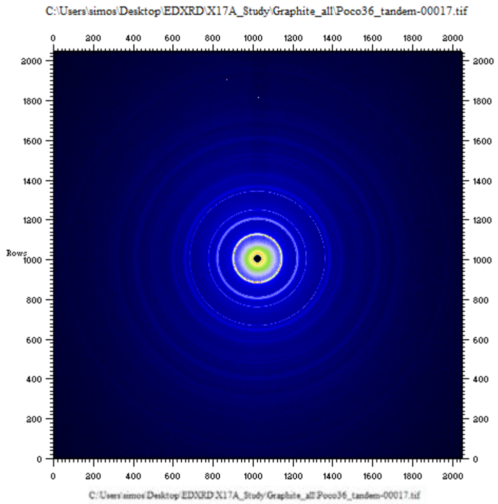
Un-irradiated

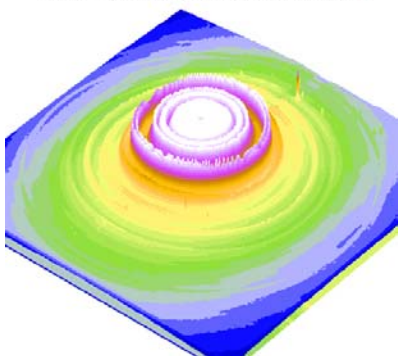


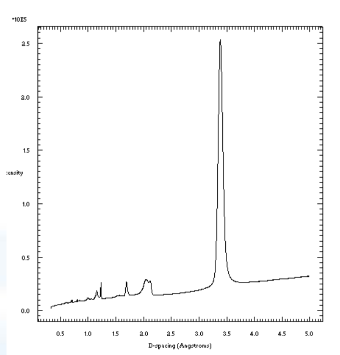




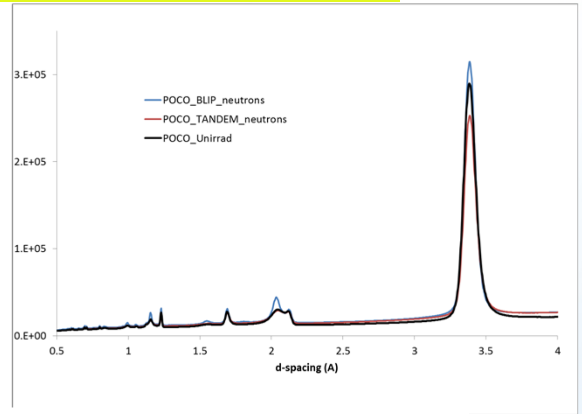
TANDEM irradiated

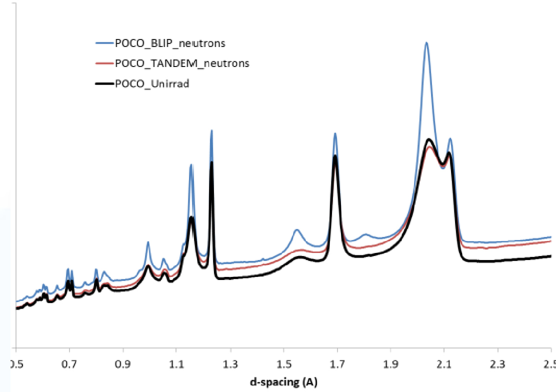


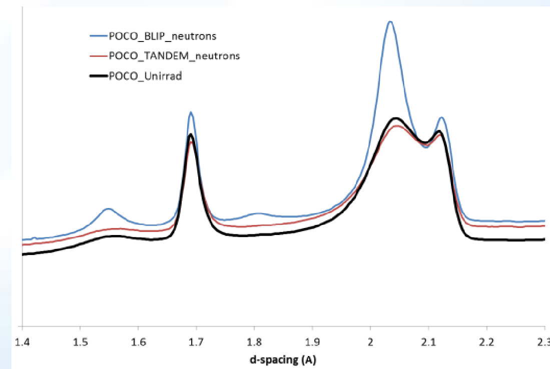




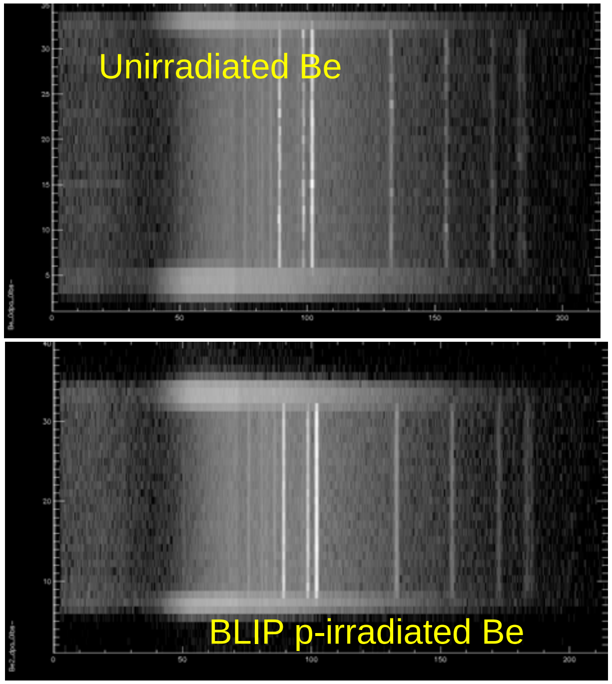
Study of Irradiated Graphite

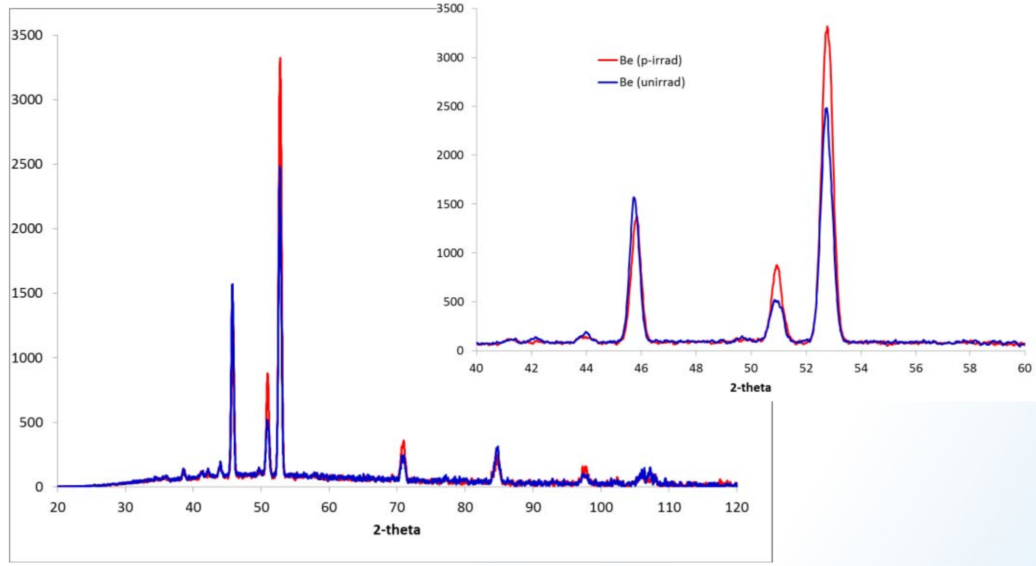






Proton Irradiated Be – EDXRD with high energy White X-ray Beam





Proton Irradiated Be

XRD with
High Energy X-rays
Monochromatic Beam