



ISS Partners - Exploration Radiation Health and Protection Meeting
*Radiation Environment and Risk Analysis at and near the Lunar surface:
Cis-lunar Vehicle Requirements*

ESA Permanent Mission in the Russian Federation, Sretensky Blvd., Moscow, Russia
Technical Interchange Meeting (TIM) # 4

SPACE RADIATION TRANSPORT CALCULATIONS

PROGRESS SINCE TECHNICAL INTERCHANGE MEETING (TIM) #3

John Norbury¹, Nikolai Sobolevsky²
Charles Werneth¹, Tony Slaba¹, Brandon Reddell³

¹NASA Langley Research Center, Hampton, Virginia, USA

²Institute for Nuclear Research of the Russian Academy of Sciences

³NASA Johnson Space Center, Houston, Texas, USA

June 13 - 14, 2017

- 1 INTRODUCTION & TIM3 ACTIONS
- 2 ACTION: VERIFY HZETRN2010 TIM2 CALCULATIONS WITH HZETRN2015
- 3 ACTION: CALCULATE PION CROSS SECTIONS
- 4 ACTION: DEVISE OTHER TESTS TO COMPARE SHIELD & HZETRN
- 5 SUMMARY

INTRODUCTION & TIM3 ACTIONS:

Actionees:

- NASA: John Norbury
- INR RAS: Nikolai Sobolevsky

Actions:

- Obtain permission to transfer OLTARIS to ROSCOSMOS
- Calculate SHIELD low energy target fragmentation yields
- Verify HZETRN2010 TIM2 calculations with HZETRN2015
- Calculate pion cross sections
- Improve pion production in HZETRN
- Devise other tests to compare SHIELD & HZETRN

INTRODUCTION & TIM3 ACTIONS:

- Obtain permission to transfer OLTARIS to ROSCOSMOS

Previous TIM3 received permission for HZETRN

Now: Permission obtained for OLTARIS!

(note: permission not to transfer, but to use web site - equally useful)

INTRODUCTION & TIM3 ACTIONS:

- Obtain permission to transfer OLTARIS to ROSCOSMOS

Previous TIM3 received permission for HZETRN

Now: Permission obtained for OLTARIS!

(note: permission not to transfer, but to use web site - equally useful)

- Calculate SHIELD low energy target fragmentation yields

Insufficient time to complete - other tasks higher priority & took longer than expected

INTRODUCTION & TIM3 ACTIONS:

- Obtain permission to transfer OLTARIS to ROSCOSMOS
Previous TIM3 received permission for HZETRN
Now: Permission obtained for OLTARIS!

(note: permission not to transfer, but to use web site - equally useful)

- Calculate SHIELD low energy target fragmentation yields

Insufficient time to complete - other tasks higher priority & took longer than expected

- Verify HZETRN2010 TIM2 calculations with HZETRN2015
Verified extensively
Sample results will be shown today

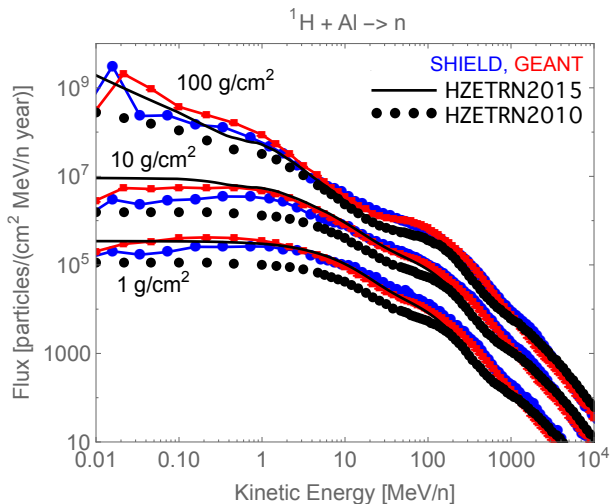
INTRODUCTION & TIM3 ACTIONS:

- Calculate pion cross sections
Comparisons done with NASA models compared to SHIELD

INTRODUCTION & TIM3 ACTIONS:

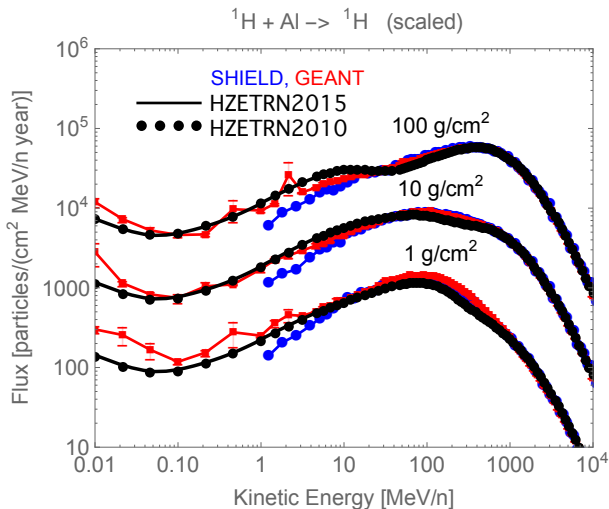
- Calculate pion cross sections
Comparisons done with NASA models compared to SHIELD
- Improve pion production in HZETRN
Insufficient time to complete - other tasks higher priority & took longer than expected
- Devise other tests to compare SHIELD & HZETRN
Extensive light ion comparisons
Previous meetings only a few results
Extensive results today
MSLRAD workshop

ACTION: VERIFY HZETRN2010 TIM2 CALCULATIONS WITH HZETRN2015



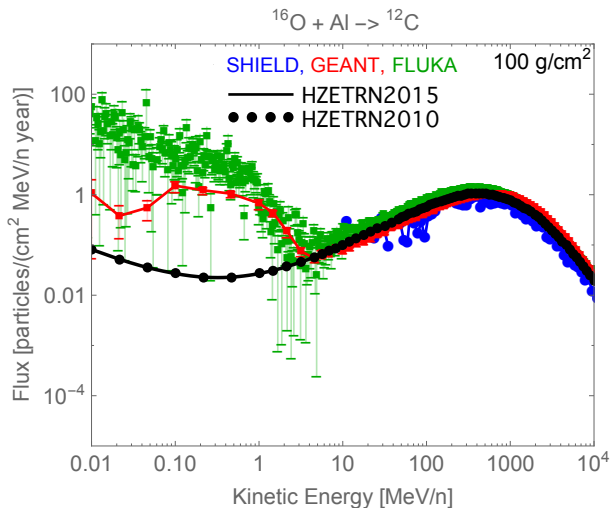
Neutron production shows improved agreement with Monte Carlo codes

ACTION: VERIFY HZETRN2010 TIM2 CALCULATIONS WITH HZETRN2015



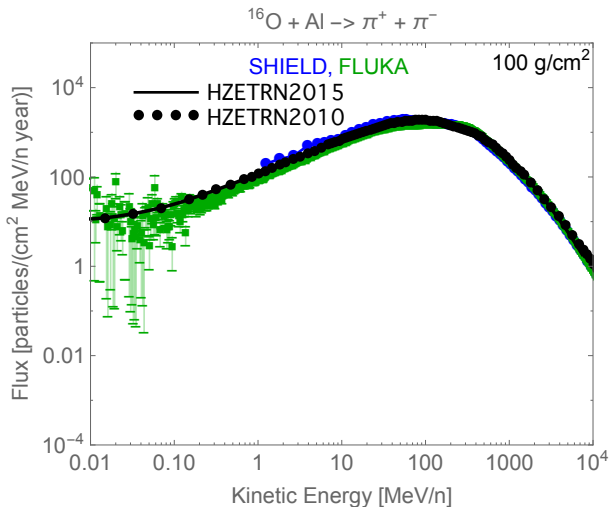
HZETRN2010 = HZETRN2015

ACTION: VERIFY HZETRN2010 TIM2 CALCULATIONS WITH HZETRN2015



HZETRN2010 = HZETRN2015

ACTION: VERIFY HZETRN2010 TIM2 CALCULATIONS WITH HZETRN2015

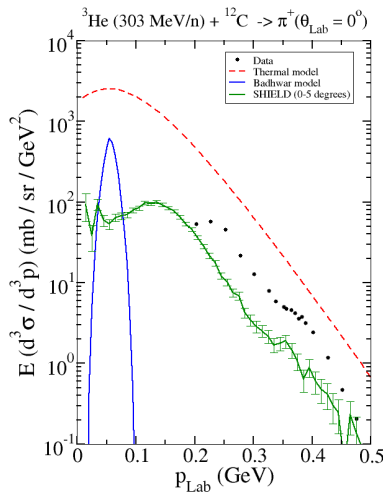
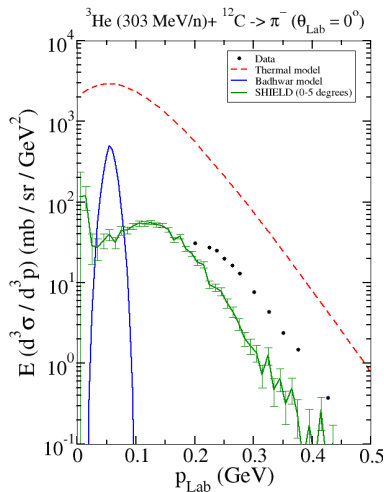


HZETRN2010 = HZETRN2015

SUMMARY

- Largest differences between HZETRN2010 & HZETRN2015 seen with neutrons

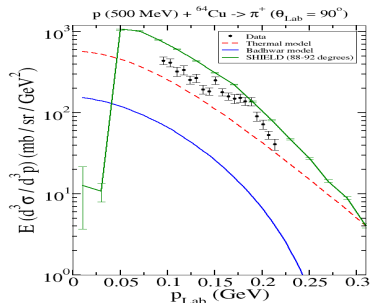
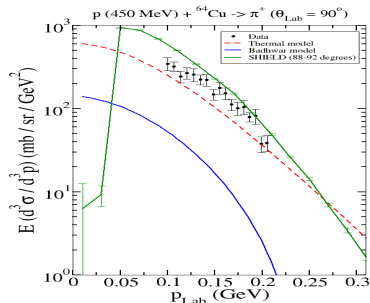
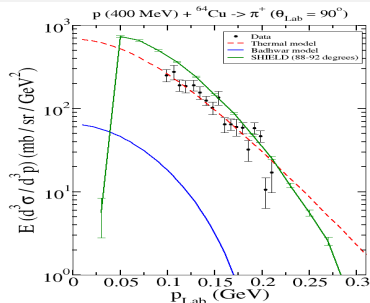
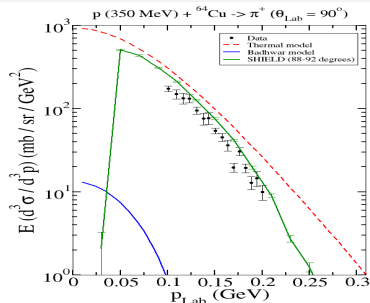
ACTION: CALCULATE PION CROSS SECTIONS



Near threshold - special models needed

SHIELD added to Fig.1 of Werneth, Norbury, Blattnig, NIMB 298, 86, 2013

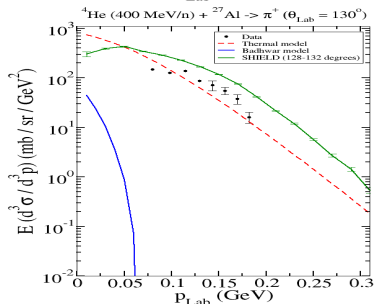
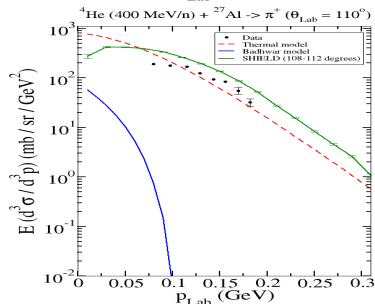
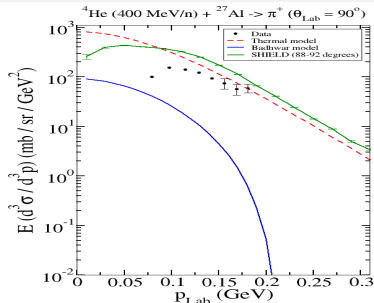
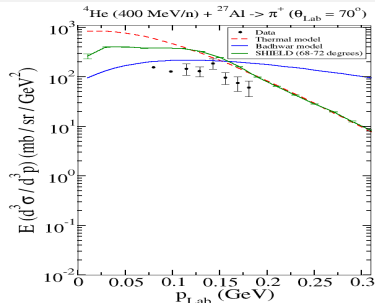
ACTION: CALCULATE PION CROSS SECTIONS



SHIELD & Thermal models reasonable agreement with data

SHIELD added to Fig.3 of Werneth, Norbury, Blattinig, NIMB 298, 86, 2013

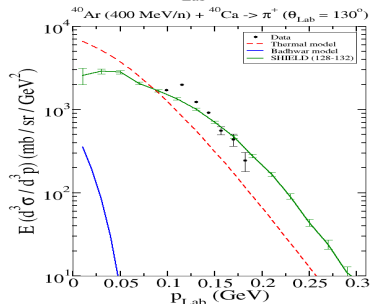
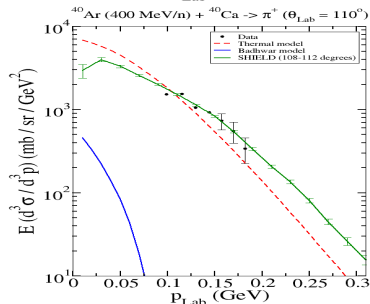
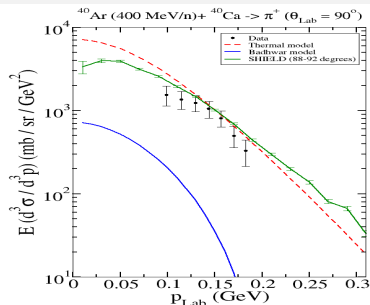
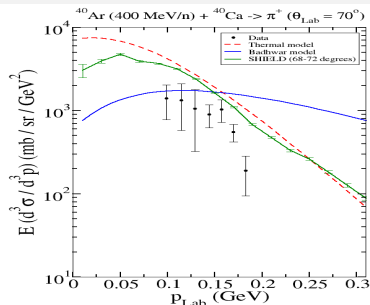
ACTION: CALCULATE PION CROSS SECTIONS



SHIELD & Thermal models reasonable agreement with data

SHIELD added to Fig.4 of Werneth, Norbury, Blattinig, NIMB 298, 86, 2013

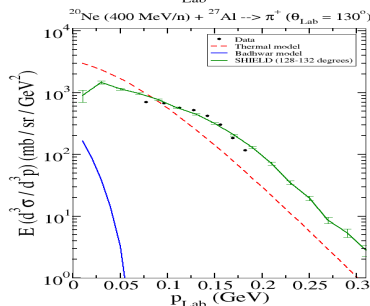
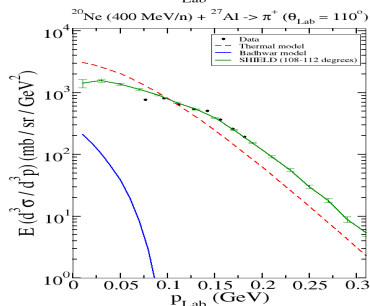
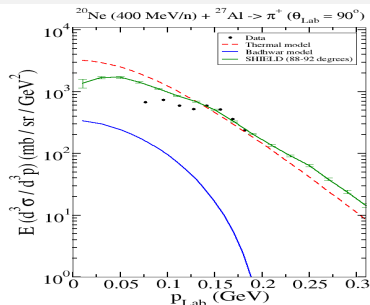
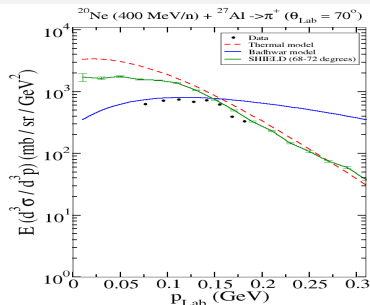
ACTION: CALCULATE PION CROSS SECTIONS



SHIELD & Thermal models reasonable agreement with data

SHIELD added to Fig.5 of Werneth, Norbury, Blattinig, NIMB 298, 86, 2013

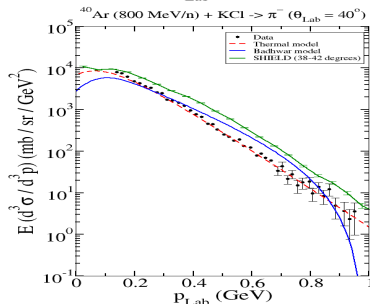
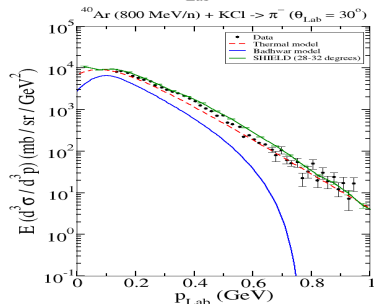
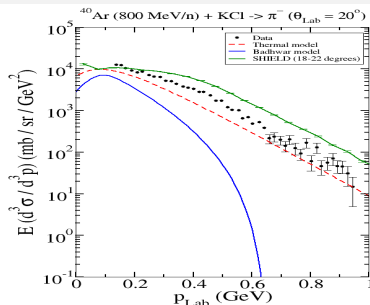
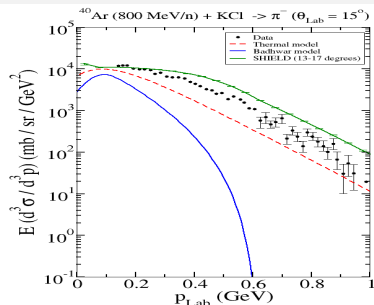
ACTION: CALCULATE PION CROSS SECTIONS



SHIELD & Thermal models reasonable agreement with data

SHIELD added to Fig.6 of Werneth, Norbury, Blattinig, NIMB 298, 86, 2013

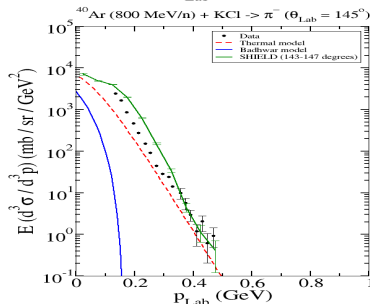
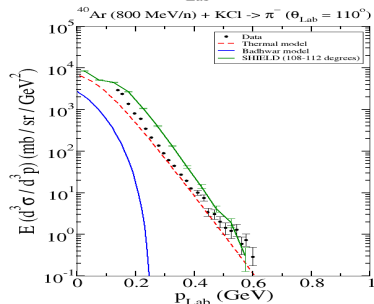
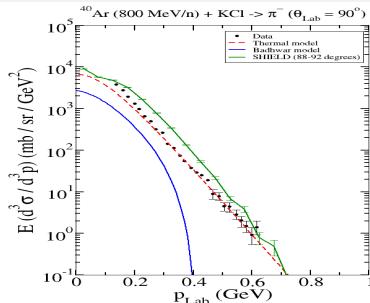
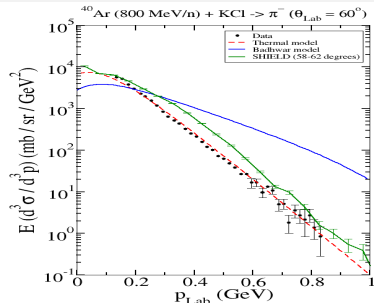
ACTION: CALCULATE PION CROSS SECTIONS



SHIELD & Thermal models reasonable agreement with data

SHIELD added to Fig.7 of Werneth, Norbury, Blattinig, NIMB 298, 86, 2013

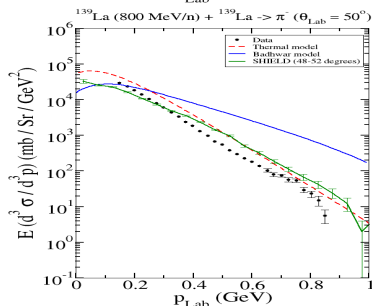
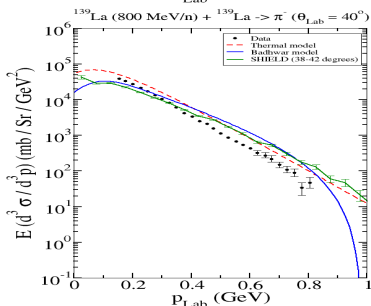
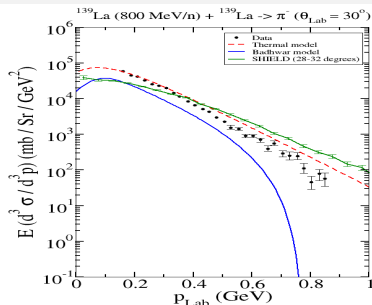
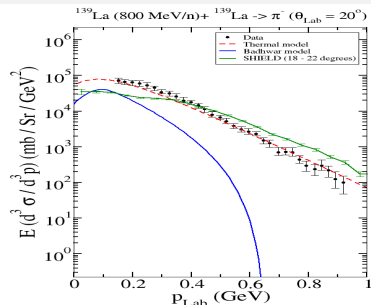
ACTION: CALCULATE PION CROSS SECTIONS



SHIELD & Thermal models reasonable agreement with data

SHIELD added to Fig.8 of Werneth, Norbury, Blattinig, NIMB 298, 86, 2013

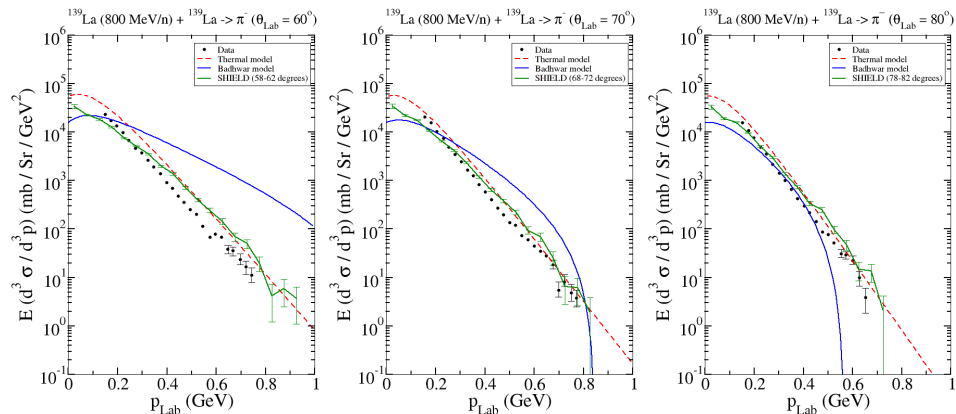
ACTION: CALCULATE PION CROSS SECTIONS



SHIELD & Thermal models reasonable agreement with data

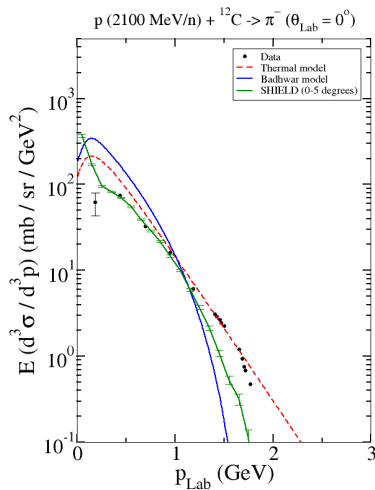
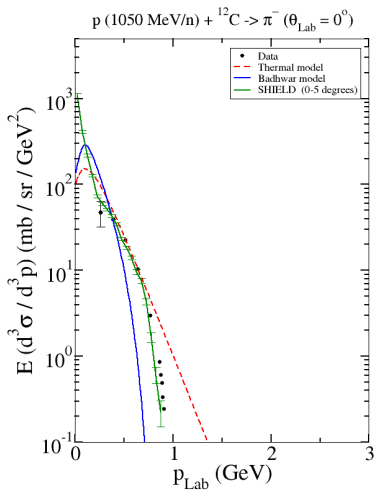
SHIELD added to Fig.9 of Werneth, Norbury, Blattinig, NIMB 298, 86, 2013

ACTION: CALCULATE PION CROSS SECTIONS



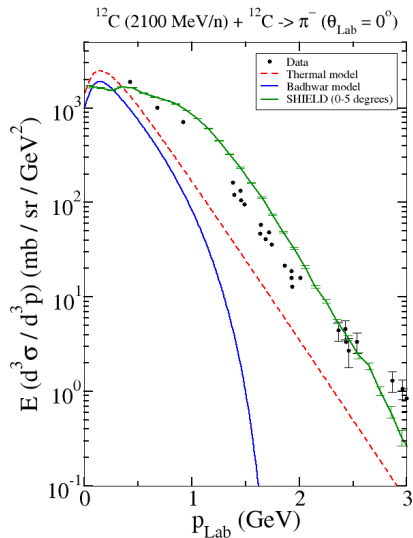
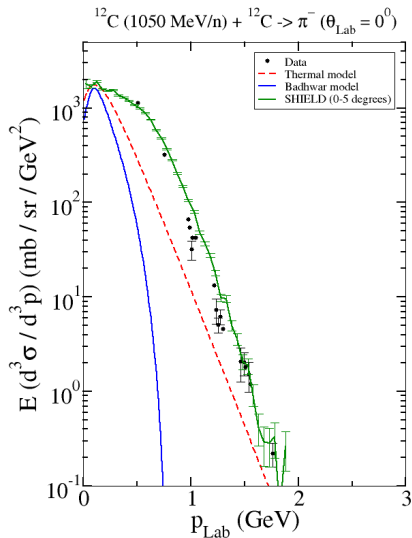
SHIELD & Thermal models reasonable agreement with data SHIELD added to Fig.10 of Werneth, Norbury, Blattinig, NIMB 298, 86, 2013

ACTION: CALCULATE PION CROSS SECTIONS



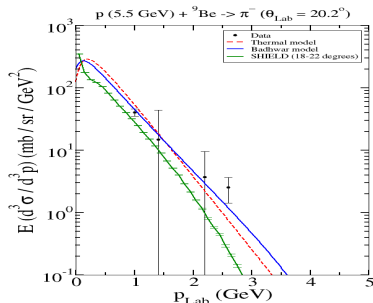
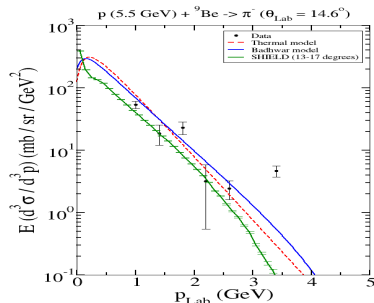
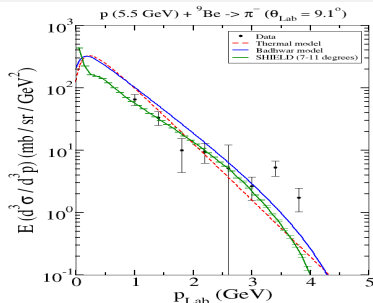
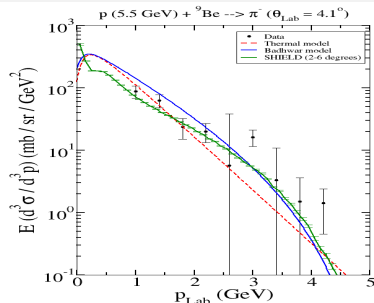
SHIELD best at low energy (left) SHIELD added to Fig.11 of Werneth, Norbury, Blattinig, NIMB 298, 86, 2013

ACTION: CALCULATE PION CROSS SECTIONS



SHIELD best SHIELD added to Fig.12 of Werneth, Norbury, Blattnig, NIMB 298, 86, 2013

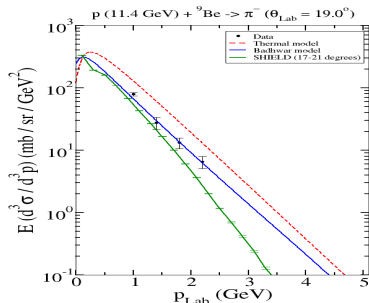
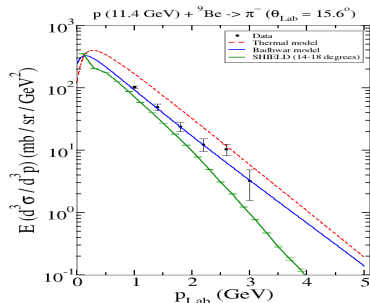
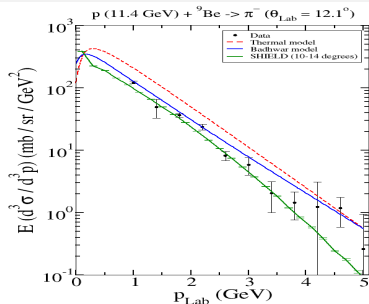
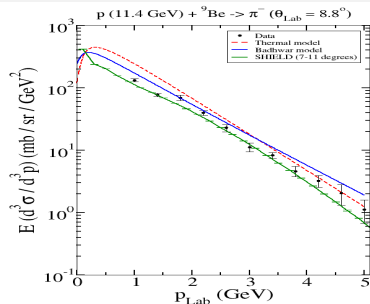
ACTION: CALCULATE PION CROSS SECTIONS



All models reasonable agreement with data

SHIELD added to Fig.13 of Werneth, Norbury, Blattinig, NIMB 298, 86, 2013

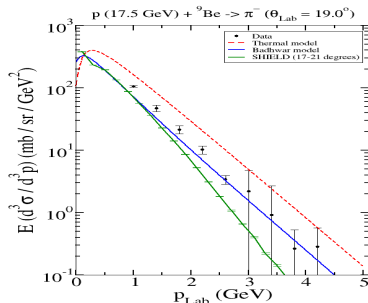
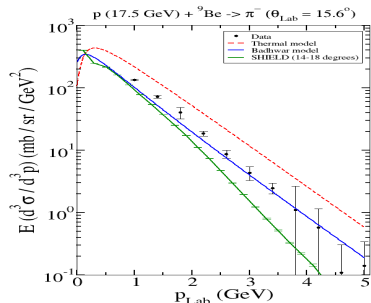
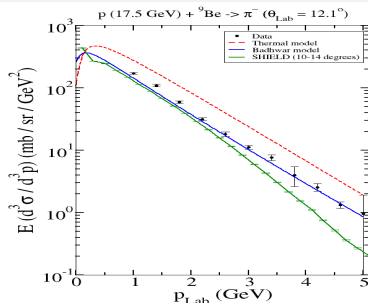
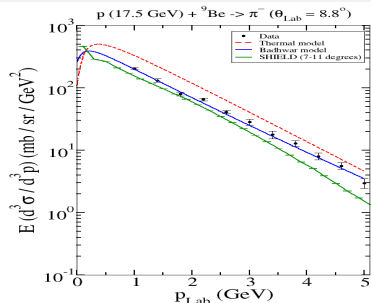
ACTION: CALCULATE PION CROSS SECTIONS



Badhwar model best

SHIELD added to Fig.14 of Werneth, Norbury, Blattinig, NIMB 298, 86, 2013

ACTION: CALCULATE PION CROSS SECTIONS



Badhwar model best

SHIELD added to Fig.15 of Werneth, Norbury, Blattinig, NIMB 298, 86, 2013

ACTION: CALCULATE PION CROSS SECTIONS

SUMMARY

- SHIELD and Thermal model show overall comparable agreement with data
- Overall, much better than Badhwar model
- Badhwar model best when $KE_{\text{projectile}} > 5 \text{ GeV/n}$

Note: NASA pion model in HZETRN =

- $KE_{\text{projectile}} < 1 \text{ GeV/n}$: Thermal model
- $KE_{\text{projectile}} > 5 \text{ GeV/n}$: Badhwar model
- $1 \text{ GeV/n} < KE_{\text{projectile}} < 5 \text{ GeV/n}$: blend both models
- Therefore, NASA model $\approx$ SHIELD model

FIRST PUBLISHED PAPER FROM THESE TECHNICAL INTERCHANGE MEETINGS!

Life Sciences in Space Research xxx (xxxx) xxx–xxx



ELSEVIER

Contents lists available at ScienceDirect

Life Sciences in Space Research

journal homepage: www.elsevier.com/locate/issr



Comparing HZETRN, SHIELD, FLUKA and GEANT transport codes

John W. Norbury^{a,*}, Tony C. Slaba^a, Nikolai Sobolevsky^b, Brandon Reddell^c

^a NASA Langley Research Center, Hampton, Virginia 23681, USA

^b Institute for Nuclear Research of the Russian Academy of Sciences, Moscow, Russia

^c NASA Johnson Space Center, Houston, Texas 77058, USA

ARTICLE INFO

Keywords:

Space radiation

Radiation transport

HZETRN

SHIELD

ABSTRACT

For the first time, the American (NASA) and Russian (ROSCOSMOS) space radiation transport codes, HZETRN and SHIELD respectively, are directly compared to each other. Calculations are presented for Galactic Cosmic Ray (GCR) minimum Hydrogen, Oxygen and Iron projectiles incident on a uniform Aluminum cylinder of varying thickness. Comparisons are made for the flux spectra of neutrons, light ions ($Z \leq 2$), heavy ions ($Z > 2$) and pions emitted from the back of the Aluminum cylinder. In order to provide more benchmark comparisons, some calculations with the GEANT and FLUKA transport codes are also shown.

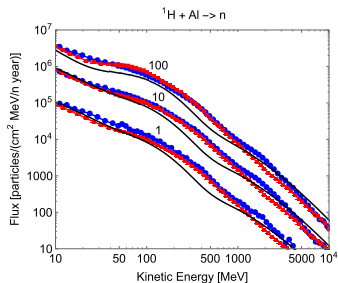
1. Introduction

International cooperation in the exploration of space is expected to continue with human missions to Mars. Protection of astronauts from the harmful effects of space radiation is a major factor that needs to be taken into consideration in mission planning. Accurate prediction of

is a direct comparison of the American and Russian codes HZETRN and SHIELD respectively, with each other. The present paper represents the first such direct comparison of these two important space radiation transport codes.

While the main focus of this paper is to compare the NASA deterministic HZETRN code and the ROSCOSMOS Monte Carlo

ACTION: DEVISE OTHER TESTS TO COMPARE SHIELD & HZETRAN

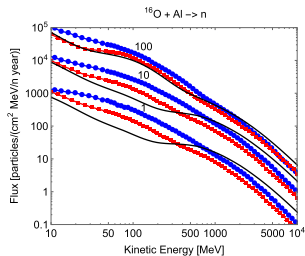


HZETRAN2015

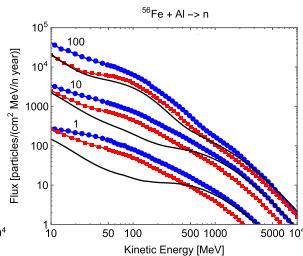
SHIELD

GEANT

(a)



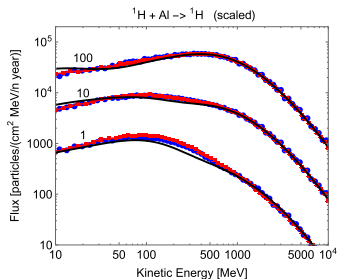
(b)



(c)

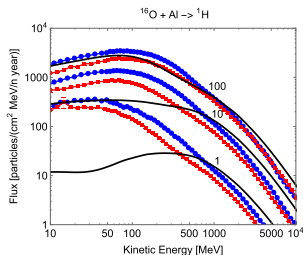
Neutrons (n) exiting Al cylinders exposed to GCR solar minimum for a) ^1H , b) ^{16}O , and c) ^{56}Fe projectiles.

ACTION: DEVISE OTHER TESTS TO COMPARE SHIELD & HZETRN

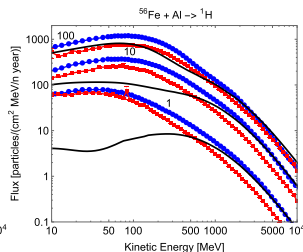


HZETRN2015
SHIELD
GEANT

(a)



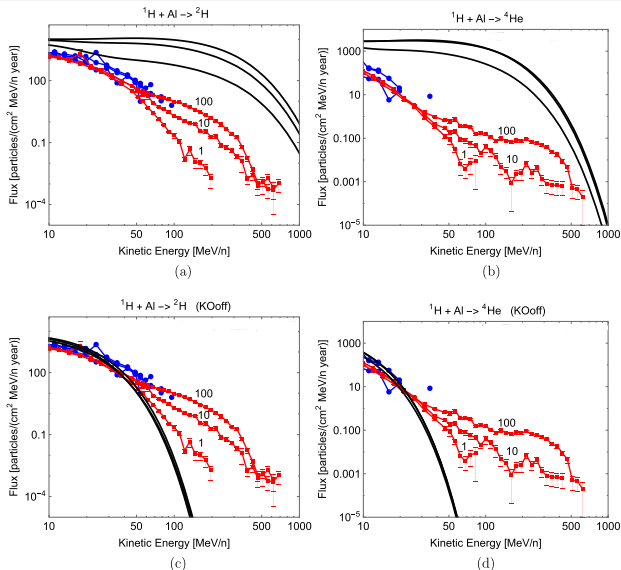
(b)



(c)

^1H exiting Al cylinders exposed to GCR solar minimum for a) ^1H , b) ^{16}O , and c) ^{56}Fe projectiles.

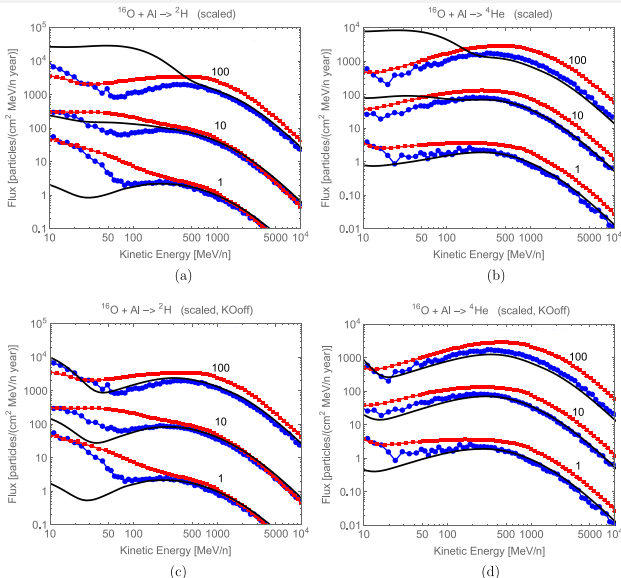
ACTION: DEVISE OTHER TESTS TO COMPARE SHIELD & HZETRN



HZETRN2015
SHIELD
GEANT

^2H and ^4He exiting Al cylinders exposed to GCR solar minimum ^1H projectiles.
A direct knockout model is used for a) and b) and is turned off for c) and d) (KOoff).

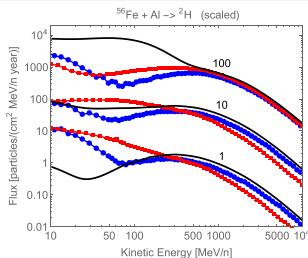
ACTION: DEVISE OTHER TESTS TO COMPARE SHIELD & HZETRN



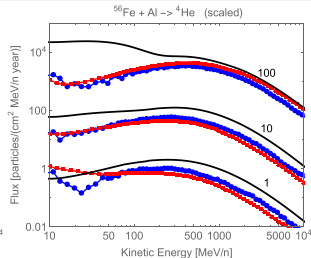
HZETRN2015
SHIELD
GEANT

^2H and ^4He exiting Al cylinders exposed to GCR solar minimum ^{16}O projectiles.
A direct knockout model is used for a) and b) and is turned off for c) and d) (KOff).

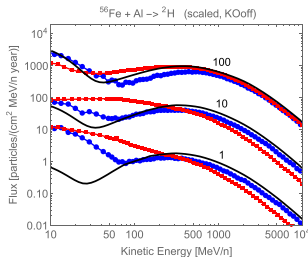
ACTION: DEVISE OTHER TESTS TO COMPARE SHIELD & HZETRN



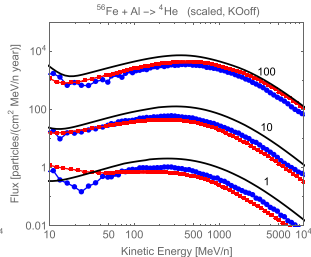
(a)



(b)



(c)



(d)

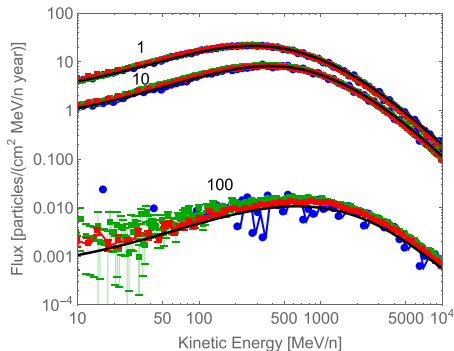
^2H and ^4He exiting Al cylinders exposed to GCR solar minimum ^{56}Fe projectiles.
A direct knockout model is used for a) and b) and is turned off for c) and d) (KOoff).

HZETRN2015
SHIELD
GEANT

ACTION: DEVISE OTHER TESTS TO COMPARE SHIELD & HZETRAN

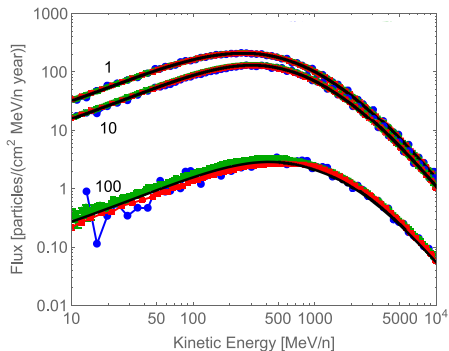
HZETRAN2015 SHIELD GEANT FLUKA

$^{56}\text{Fe} + \text{Al} \rightarrow ^{56}\text{Fe}$



(a)

$^{16}\text{O} + \text{Al} \rightarrow ^{16}\text{O}$

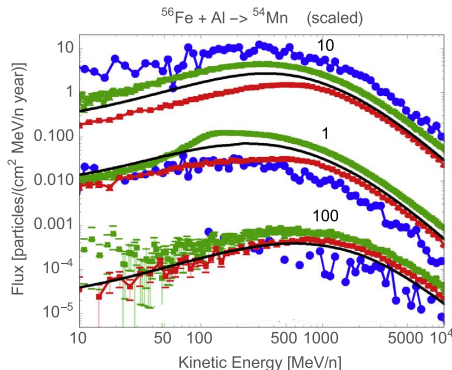


(b)

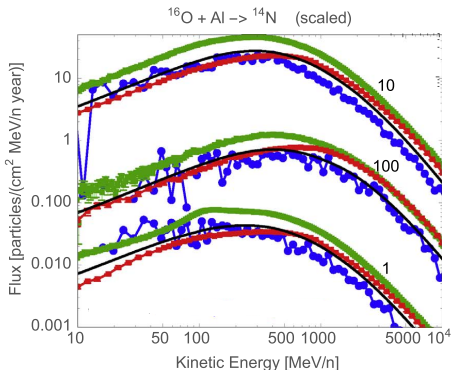
Calculations of a) ^{56}Fe and b) ^{16}O exiting Al cylinders exposed to GCR solar minimum a) ^{56}Fe and b) ^{16}O projectiles.

ACTION: DEVISE OTHER TESTS TO COMPARE SHIELD & HZETRN

HZETRN2015 SHIELD GEANT FLUKA



(a)



(b)

Calculations of a) ^{54}Mn and b) ^{14}N exiting Al cylinders exposed to GCR solar minimum a) ^{56}Fe and b) ^{16}O projectiles.

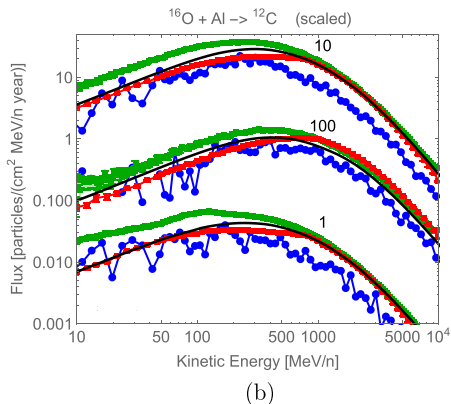
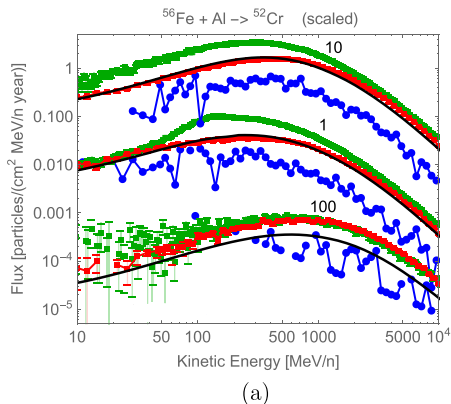
ACTION: DEVISE OTHER TESTS TO COMPARE SHIELD & HZETRN

HZETRN2015

SHIELD

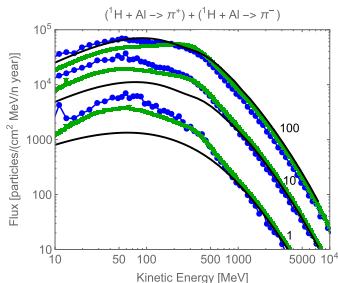
GEANT

FLUKA



Calculations of a) ^{52}Cr and b) ^{12}C exiting Al cylinders exposed to GCR solar minimum a) ^{56}Fe and b) ^{16}O projectiles.

ACTION: DEVISE OTHER TESTS TO COMPARE SHIELD & HZETRAN

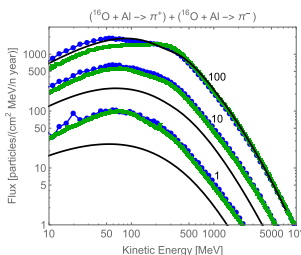


HZETRAN2015

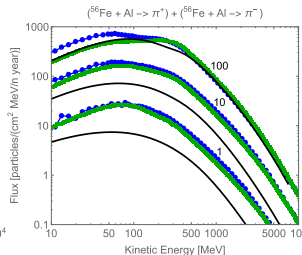
SHIELD

FLUKA

(a)



(b)



(c)

Charged pions exiting Al cylinders exposed to GCR solar minimum a) ^1H , b) ^{16}O , and c) ^{56}Fe projectiles.

SUMMARY

- HZETRN needs improved light ion (H, He isotopes) nuclear physics production models that lead to agreement of HZETRN with Monte Carlo codes and experimental data
- HZETRN needs improved pion production models
- Significant differences between Monte-Carlo codes remain

SUMMARY

- Obtain permission to transfer OLTARIS to ROSCOSMOS
Done - Russian colleagues can now access HZETRN & OLTARIS
- Verify HZETRN2010 TIM2 calculations with HZETRN2015
Done - Neutrons changed the most
Better agreement with Monte Carlo codes
- Calculate pion cross sections
Done - NASA model $\approx$ SHIELD
- Devise other tests to compare SHIELD & HZETRN
Done - Light ion tests
Norbury, Slaba, Sobolevsky, Reddell, Life Sci. Space Res. xx, xx, 2017
First published paper from Technical Interchange Meetings!
MSLRAD workshop

THE END

john.w.norbury@nasa.gov