Nondestructive measurement of the elemental composition of advanced armor materials by ion beam analysis.

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Motivation

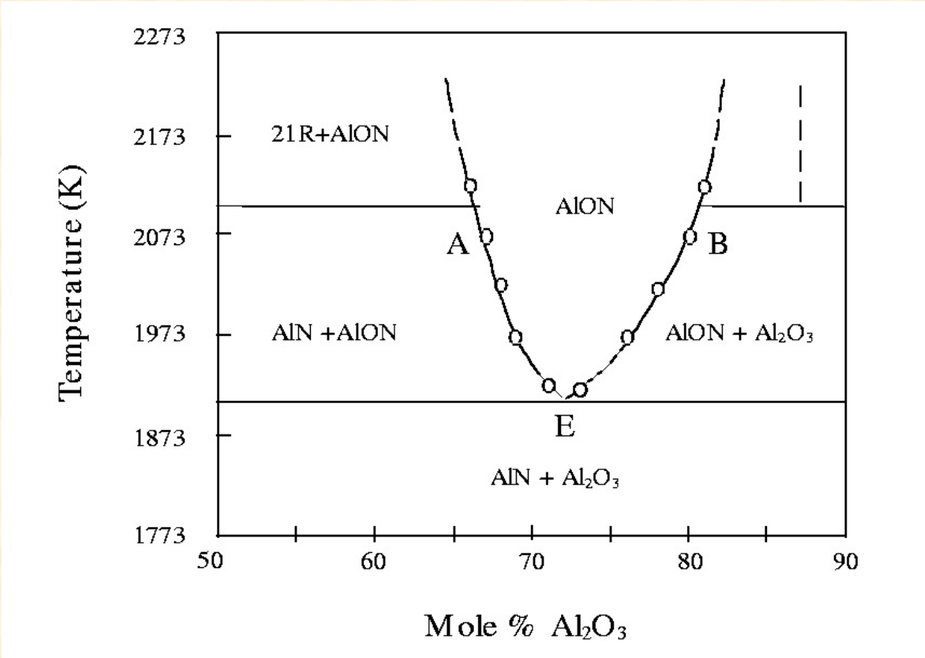
- Development of next-generation armors
  - Increase survivabilty of soldiers and combat vehicles
  - Decrease weight compared to current armors
  - Increase possible size for individual armor panels
  - Decrease development and production costs
  - Desire transparency over much of electromagnetic spectrum
- Ceramics , specifically γ-aluminum oxynitride (known as AlON) look promising.

Objective

- Correlate elemental composition of AlON to mechanical properties
  - Small variations of a few atomic percent in the elements of armor ceramics can dramatically affect their performance.
  - Changes in starting materials and processes can and do change the resultant relative abundances of the elements in armor ceramics.
  - AlON is formed over the range of 30-40 mol% aluminum nitride in alumina.

Task

- Systematic study of the composition of potential aluminum oxynitride armor samples by nondestructive techniques.

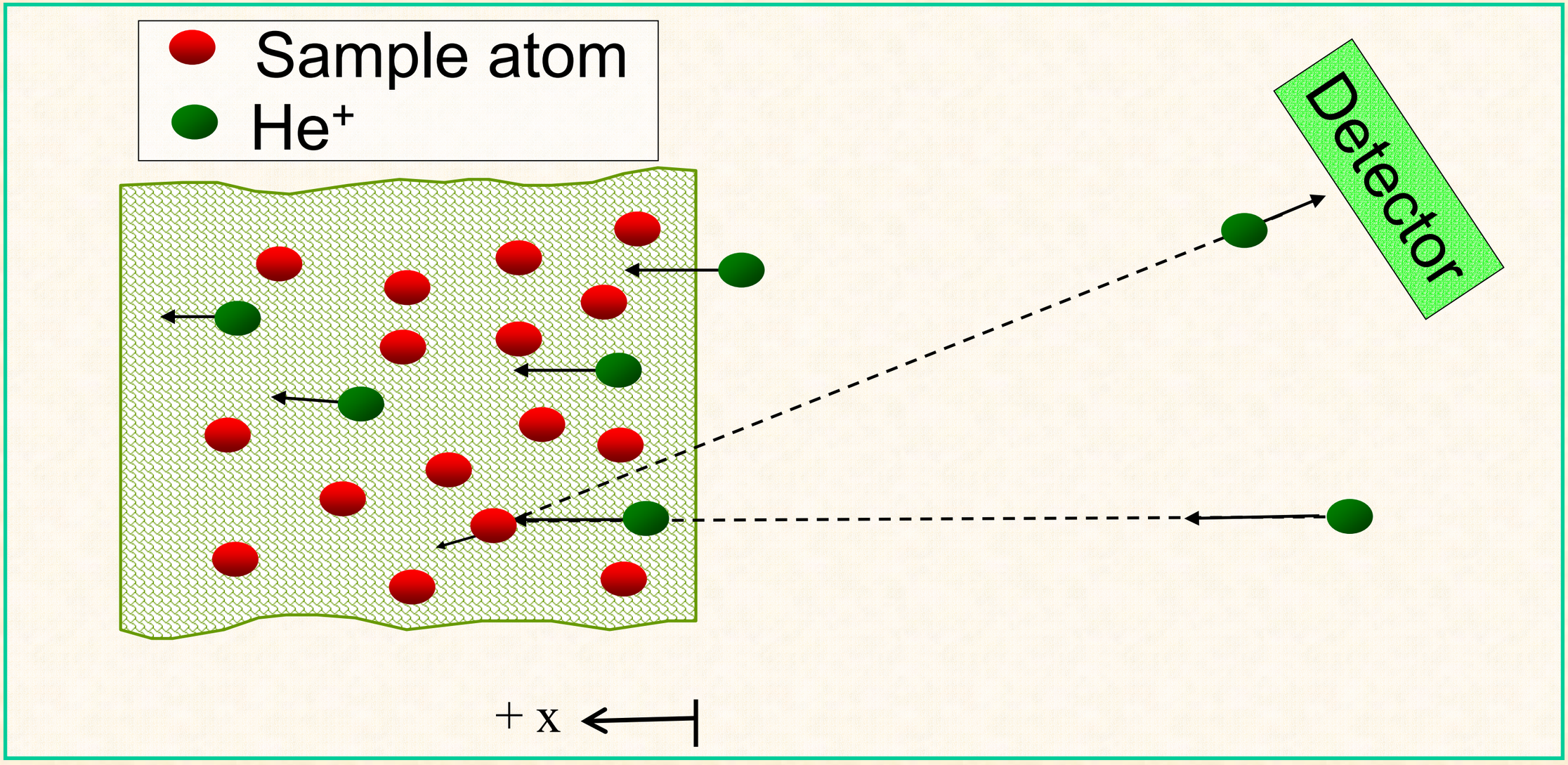


Raytheon Corp.

Procedure

- Samples are prepared under controlled but varied conditions by the hot isostatic press method.
- Samples are characterized with
  - Rutherford backscattering spectrometry (RBS) and
  - Resonant nuclear reaction analysis (RNRA).

Rutherford Backscattering Spectrometry



Schematic of Rutherford backscattering spectrometry.

Rutherford Backscattering Spectrometry

Projectile (ion) in → Same projectile out at different energy.

<u>BENEFITS</u>

- Simultaneous analysis of multiple elements.
- Simultaneous measurement of concentrations at all depths.
- Simple experimental set-up.
- 100% efficient detectors.

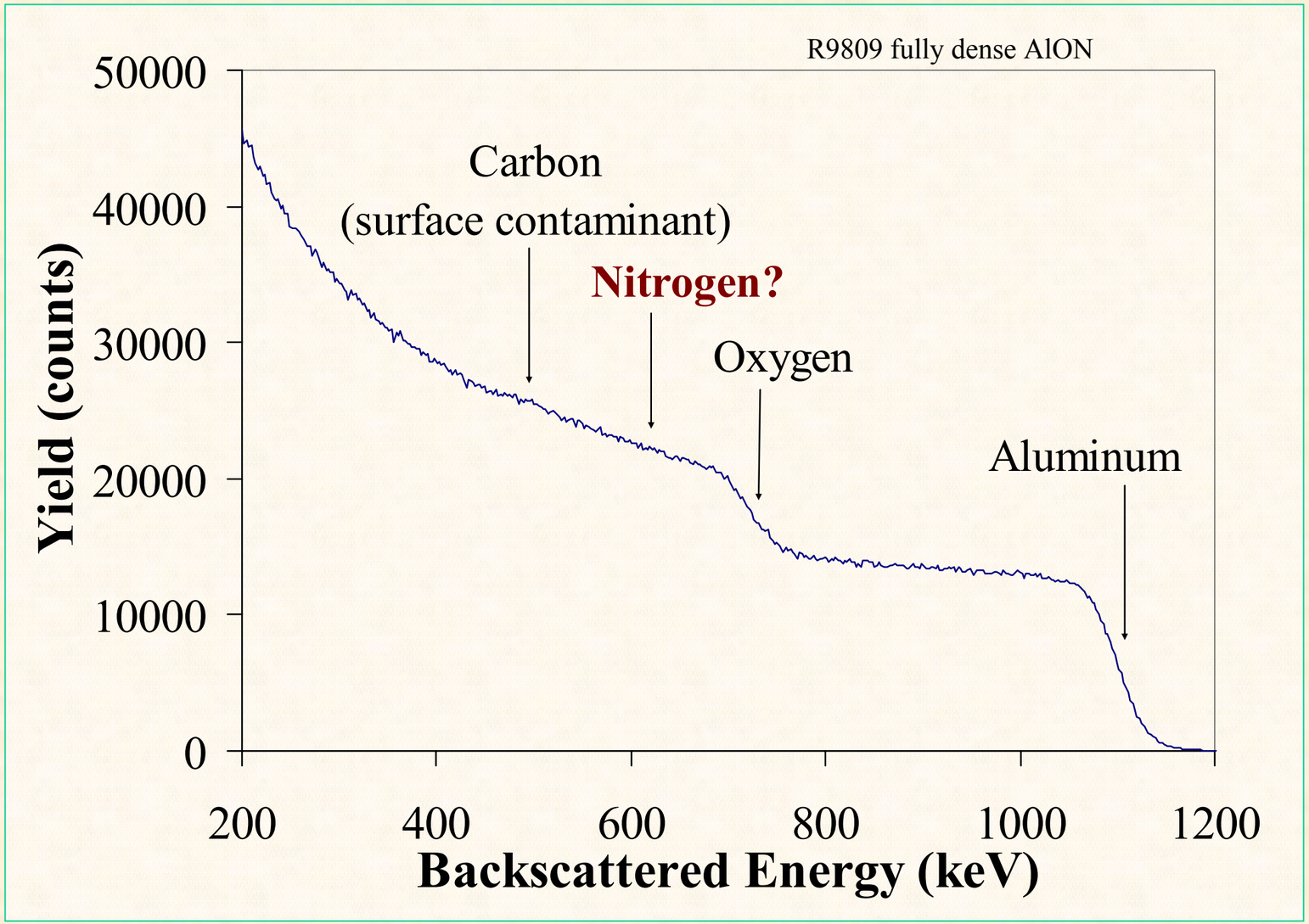
Rutherford Backscattering Spectrometry

Projectile (ion) in → Same projectile out at different energy.

<u>CONCERNS</u>

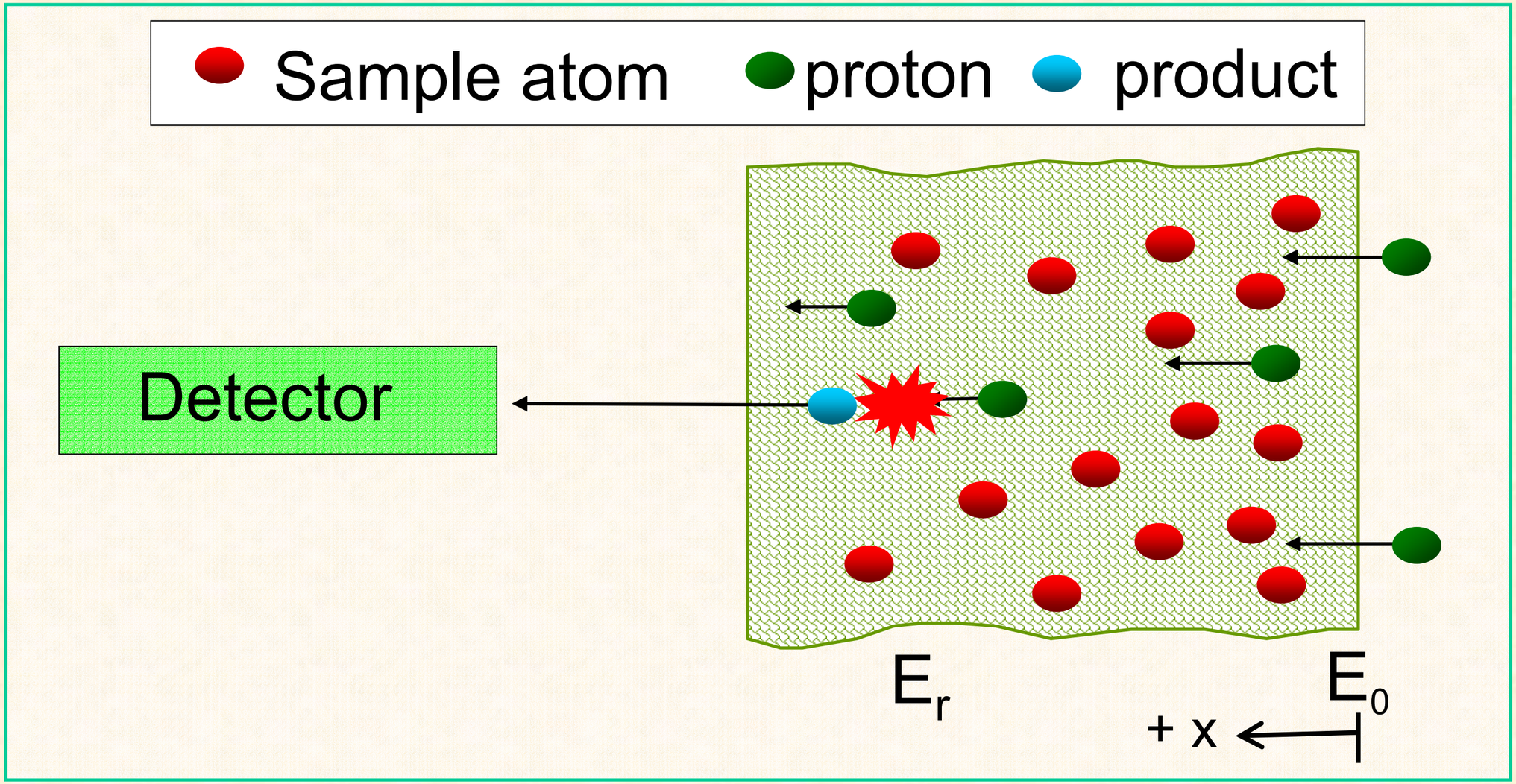
- Separation of adjacent elements in periodic table.
- Detection of light elements in a heavy-element matrix.
- Non-Rutherford scattering.
- Deconvolution of experimental data may result in multiple possible solutions.

Rutherford Backscattering Spectrometry



Typical RBS spectrum for an AlON sample obtained with 2-MeV He+ beam and a 100%-efficient silicon-surface-barrier detector subtending a solid angle of 5.2 msr at 170° in IBM geometry.

Resonant Nuclear Reaction Analysis



Schematic of resonant nuclear reaction analysis.

Resonant Nuclear Reaction Analysis

Ion in →Different (product) ion or neutron or γ-photon out.

<u>BENEFITS</u>

- Element identification by isotope-specific reactions.
  - Separation of adjacent elements in periodic table.
  - Detection of light elements in a heavy matrix.
  - Effective for many elements.

Resonant Nuclear Reaction Analysis

Ion in →Different (product) ion or neutron or γ-photon out.

<u>BENEFITS</u>

- Element identification by isotope-specific reactions.
- Excellent depth resolution.
- Results independent of surface contaminants (by measuring γ's).

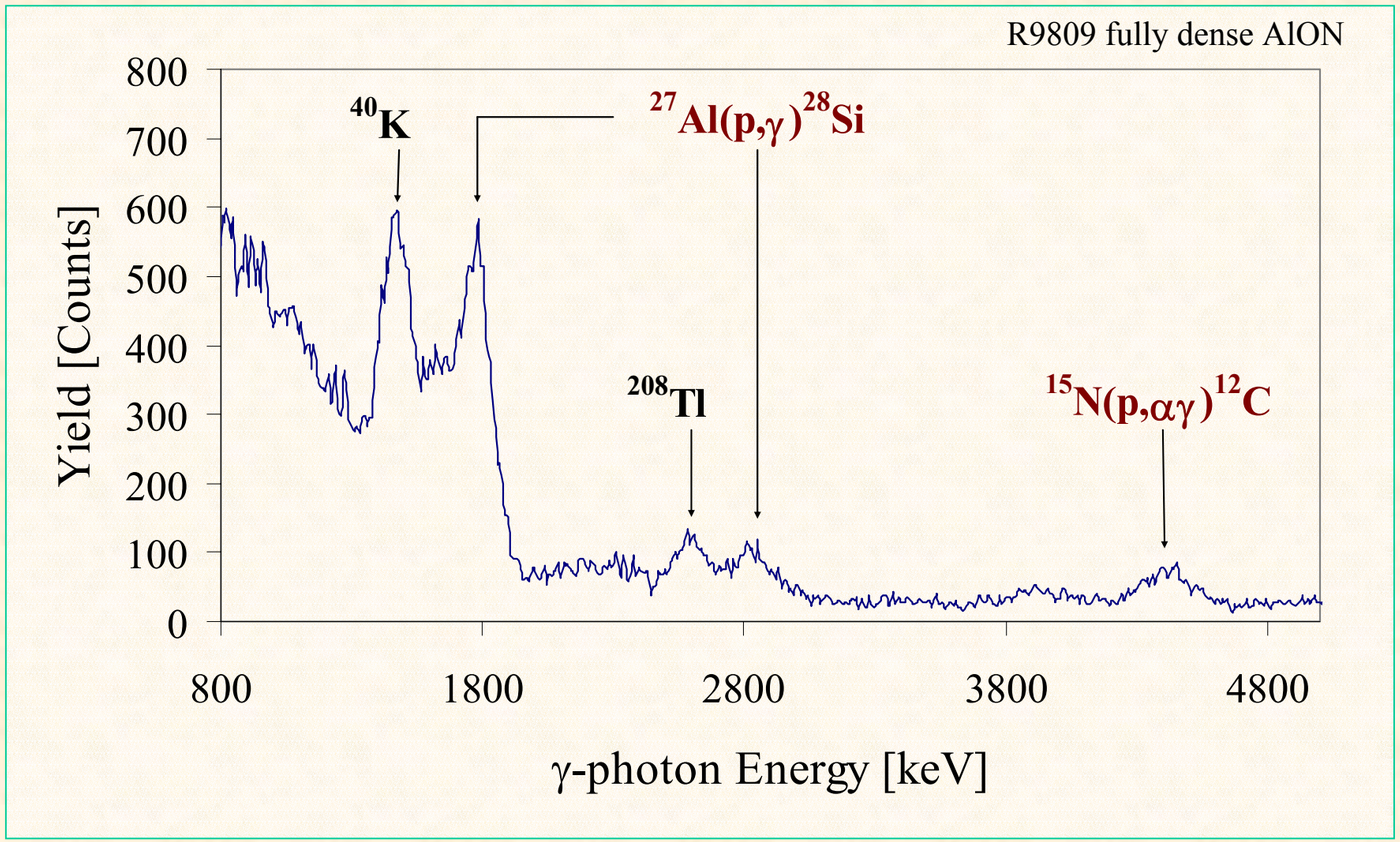
Resonant Nuclear Reaction Analysis

Ion in → Different (product) ion or neutron or γ-photon out.

<u>CONCERNS</u>

- Acquires information sequentially.
- Product ions out can be lost in scattered projectile ion signal.
- Neutrons may present unwanted radiation dangers.
- γ's can be lost in background present.

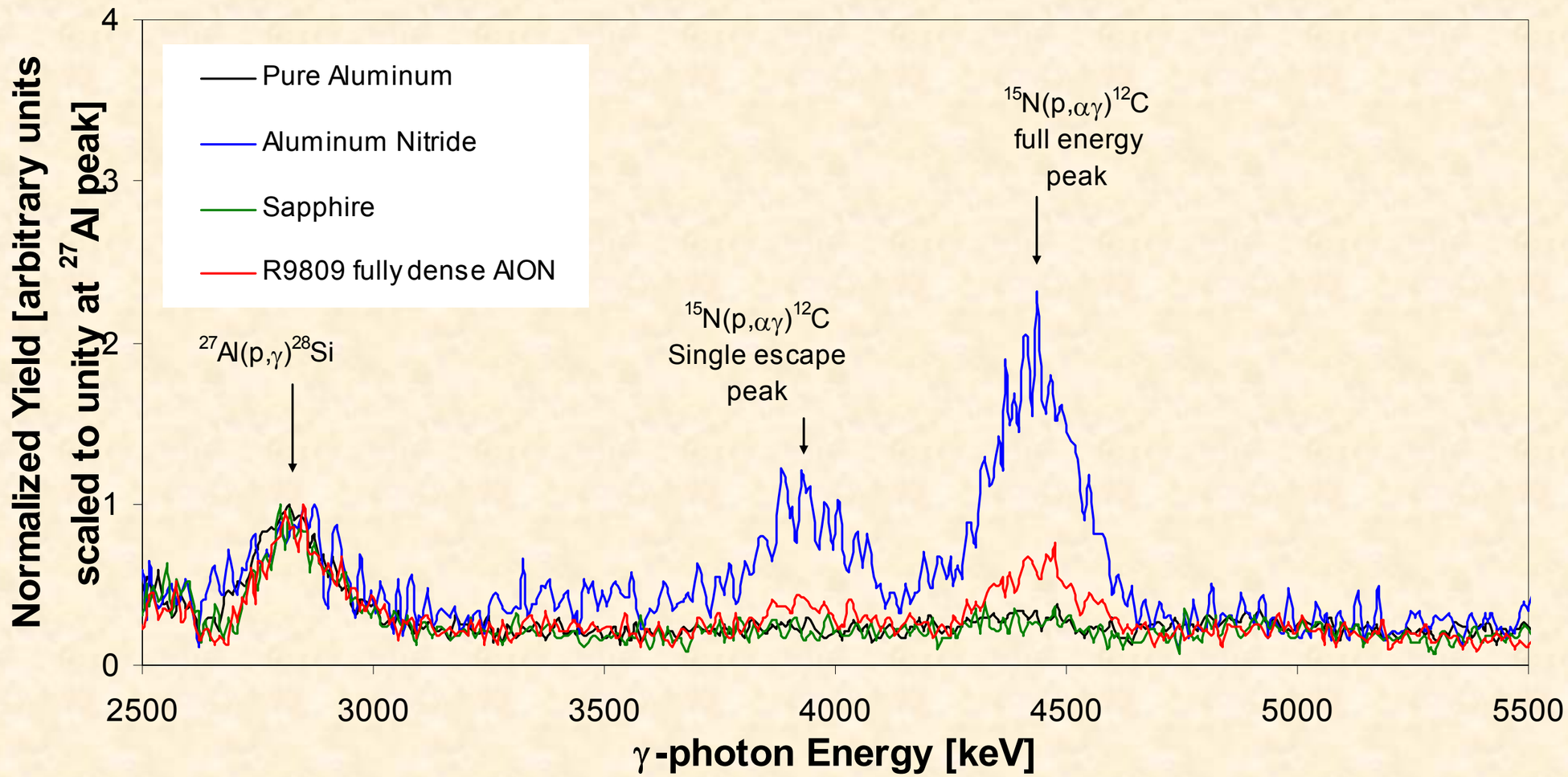
Resonant Nuclear Reaction Analysis



Typical unprocessed RNRA spectrum for an AlON sample resulting from the $^{27}Al(p,\gamma)^{28}Si$ and the $^{15}N(p,\alpha\gamma)^{12}C$ reactions. Reactions involving oxygen isotopes are not discernable due to small reaction cross sections (^{16}O) or low isotopic abundances (^{18}O).

Data Reduction

- Determine ratio of Al to N in AlON with RNRA



Background-subtracted RNRA spectra normalized to the aluminum peak

Data Reduction

- Determine ratio of Al to N in AlON with RNRA

$$\frac{n_N}{n_{Al}} = \left(\frac{x_N / x_{Al}}{y_N / y_{Al}} \right)$$

where n_N = number of N atoms,

n_{Al} = number of Al atoms,

x_N = net counts in the N peak for AlON sample,

x_{Al} = net counts in the Al peak for AlON sample,

y_N = net counts in the N peak of AlN standard,

and y_{Al} = net counts in the Al peak of AlN standard.

Data Reduction

- Combine the RNRA and RBS information.

With the RNRA-determined values for the Al-to-N ratio in AlON samples, the atomic percents of Al, N, and O in the samples can be determined from the RBS data. For each sample, the atomic percents of the Al, N, and O are varied in the simulation RUMP while maintaining the Al-toN ratio determined by RNRA until a best fit to the RBS data is achieved.

Results

Atomic percentages of the elements in the AlON samples investigated

	R9809	AlON38	AlON36	AlON30	AlON28
Al [at%]	35.7	39	35.6	37	40
O [at%]	55.3	60	56.8	62	60
N [at%]	9	<1	7.6	<1	<1

Summary

Individually, RBS and RNRA did not yield the complete compositional information for samples of AlON, a possible next-generation armor material. We have successfully combined RBS and RNRA data to extract that composition for the samples.

Predictions

The further systematic investigation of the relation between composition and performance of AlON and related materials will contribute to the development of improved armor systems needed by the Army and to the reduction in both the cost and time required for their development. Ion beam techniques, such as RBS and RNRA, will continue to play a role in those investigations.

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QUESTIONS?