

X-ray Imaging for On-The-Body
Contraband Detection

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Introduction

Here's an interesting equation: (One person + a desire to smuggle contraband past a security checkpoint + need for security + a desire for personal privacy) X large numbers of people = One massive headache for security. Variations on this theme are occurring in a wide variety of locations today. It will only get worse. The basic question is, "How can a security team best assure that the people gaining access to secure areas are not carrying contraband in the form of weapons, drugs, explosives, or other restricted materials?"

This paper will describe some alternative screening methods for on-the-body contraband detection, but focus on American Science and Engineering's (AS&E's) solution to the problem - BodySearch™ - an X-ray backscatter system capable of rapid personnel inspection.

Due to an increase in world-wide terrorism, there is an increased need to protect United States interests, both domestic and foreign. One of the primary needs is to be able to inspect people as they move through security check points. At these check points, inspectors are typically interested in determining if the person under inspection is carrying illegal drugs, weapons and/or explosives. The two most commonly used methods of inspection – metal detectors and pat searches – both suffer from significant inadequacies.

Metal detectors are inherently quick, since the person has only to walk through a portal at a normal gait. They are limited however, in that they only detect metallic objects, and are subject to variations in detection, depending on how they are set up by the operator, and where on the person the metallic object is located. Pat searches are extremely intrusive, potentially uncomfortable for both inspector and inspectee, and are limited by the skills of the inspector. Further, because a pat search is conducted by a human, there is the potential for extreme variation search to search. To exacerbate the situation even further, there have been a number of protests from the American Civil Liberties Union and other human rights organizations. Just the threat of such complaints makes inspectors wary of performing any type of physical search, even a cursory one.

To address this problem, American Science and Engineering (AS&E) has developed the BodySearch™ to quickly, unobtrusively, accurately and safely detect both metallic and non-metallic items being carried on the person being searched. Although BodySearch is not without its own set of interesting issues that need to be addressed, it offers a very viable alternative to other inspection methods.

The Technology

AS&E's BodySearch is a backscatter based X-ray inspection system that employs AS&E's patented "flying spot" pencil beam X-ray coupled to efficient backscatter detectors. The basic principle of AS&E's technology is shown in Figure 1.

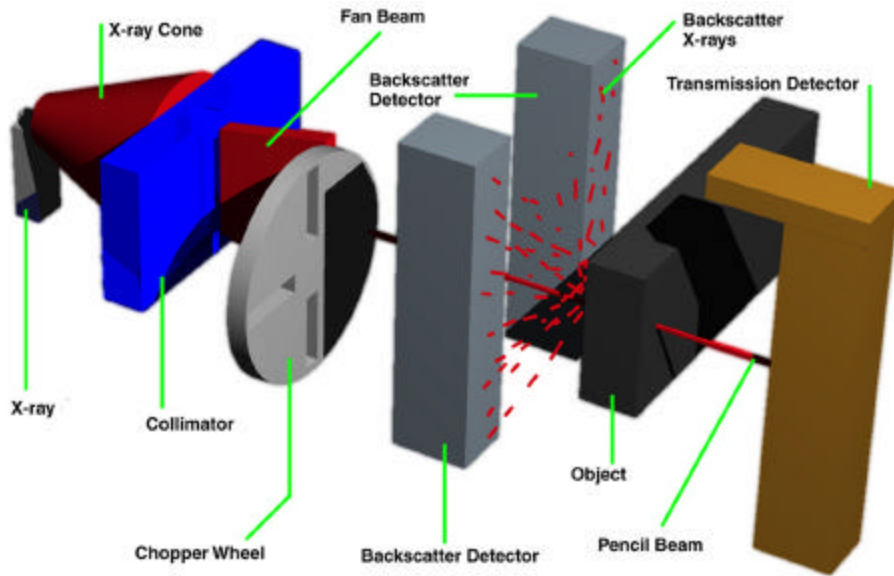


Figure 1. AS&E's Flying Spot Technique

For BodySearch, just the backscatter portion of the system is employed, and the flying spot is generated in a horizontal direction, as shown in Figure 2.

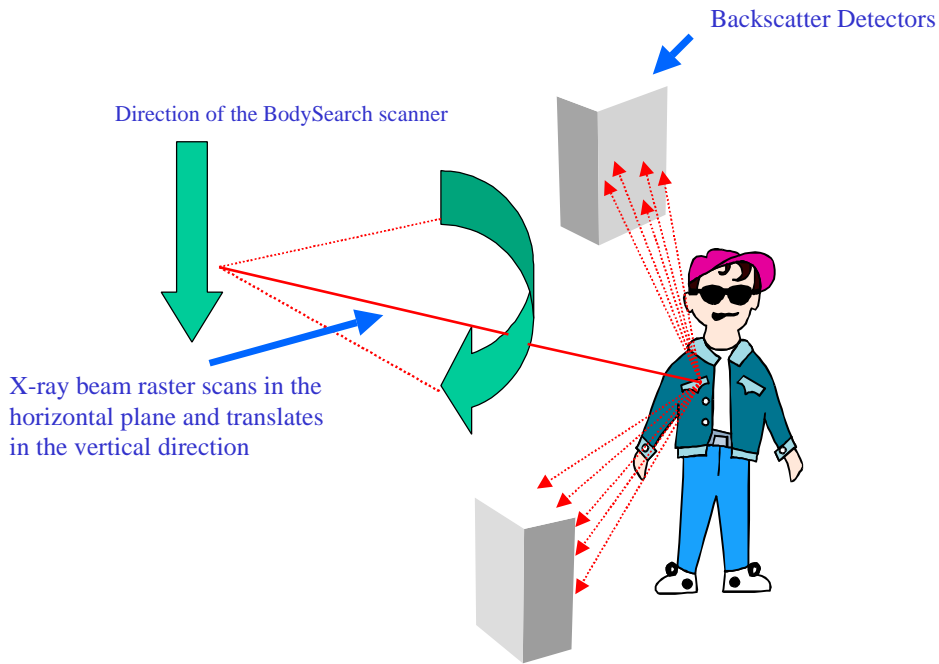


Figure 2 How AS&E's BodySearch creates its image

Figure 3 shows that the Compton backscatter effect dominates for low Z materials ($Z < \sim 15$) in the region utilized by AS&E's X-ray energy, nominally a mean value of 60 KeV. Backscatter technology is uniquely able to detect low Z (e.g. organic) materials in complex, backgrounds. Unlike transmission X-rays, backscatter X-rays do not need to penetrate all objects in the beam path of a

complex environment in order to detect the presence of organic or inorganic materials. Akin to reflection, backscatter signals are particularly strong whenever the incident X-rays interact with drugs, tobacco, explosives, and foodstuffs, which typically contain low atomic number (low Z) material. By contrast, metallic objects, including guns, knives, files and the like consist of high atomic number materials (high Z), absorb X-rays, and show up as dark, but recognizable objects in backscatter images. The images created by backscatter detectors are clear, uncluttered, and visually much easier to interpret than traditional X-ray transmission images.

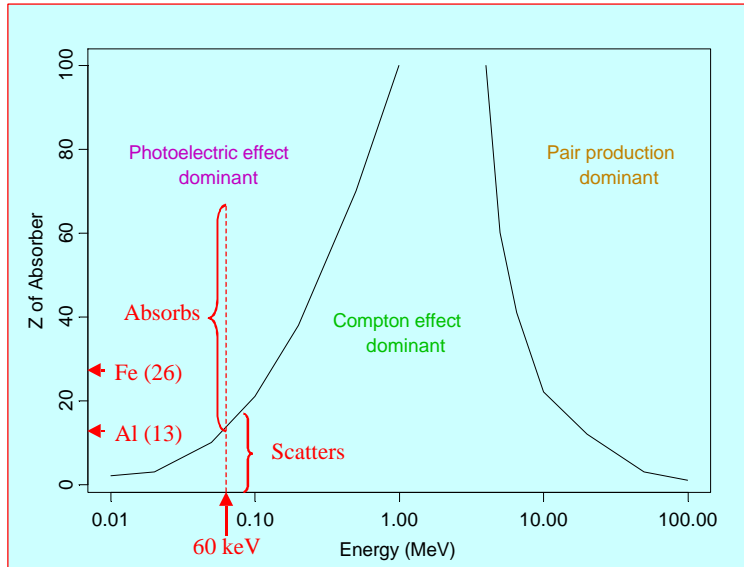


Figure 3. X-ray Interaction Cross Sections

BodySearch System Description and Operation

AS&E has developed BodySearch to adapt to a variety of inspection locations. It has already found a home in such diverse places as state prisons, immigration offices, and international airports. Figure 4 depicts AS&E's BodySearch in its current standard configuration.

In operation, BodySearch has a footprint of 127" long x 46" wide x 120" high. Projected modifications to the system will shrink this footprint, specifically in the height and length dimensions, allowing for easier set up in rooms with standard height ceilings. Today's system requires about 30 seconds to perform a complete, two-sided scan of the subject. Each scan takes approximately ten seconds, but there needs to be some time allowed to reposition both the scan head and the subject in between scans. Again, projected modifications, based on user needs, may shorten this scan time to under twenty seconds. The system operator sits at a console that can be connected to the system or placed in a remote area, up to fifty feet away, depending on room arrangements and logistics.

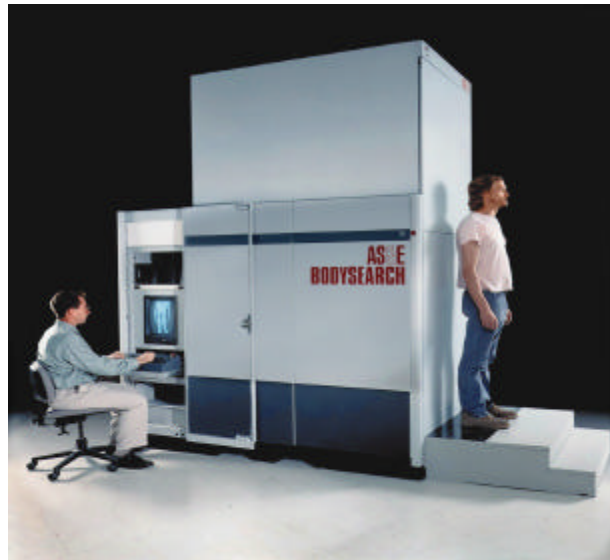


Figure 4 - AS&E's BodySearch System

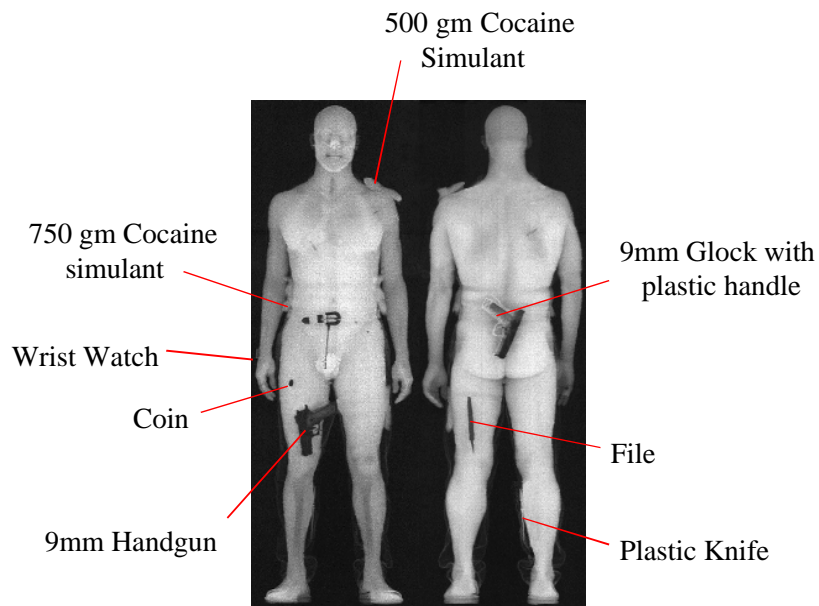


Figure 5 - Front and Back Images from BodySearch

To perform a scan, the operator positions the subject on the external stage, and enables the X-ray beam. Upon completion of the initial scan, the subject turns 180 degrees, and the scan process is repeated. The electronic image of the subject is formed

using the intensity of the X-rays backscattered from each location on the body via Compton scattering interactions. This X-ray scatter intensity is a function of both the atomic number and density of the materials probed by the primary X-ray beam, namely the body itself, or items on the body. Since hair and clothing have very low densities, very few X-rays interact with these materials, and they effectively vanish from the image. Denser objects, such as metals, explosives, plastics, and drug packets interact more strongly, and therefore appear in the image together with the body itself. Figure 5 shows a representative set of images from BodySearch. Annotations added to the images indicate metallic, organic, and plastic items. The tight collimation of the X-ray beam results in high spatial resolution in the acquired images, making identification of the objects on the body easier. It is important to note, nonetheless, that backscatter imaging will only show materials on the surface of the body. It is normally not effective for seeing completely through flesh and/or detecting contraband that may be concealed within body cavities. Taking a front and back scan provides additional data to the operator. If the operator so desires, he can perform more scans from different angles to assist in identifying suspect objects. Obviously, operator training and experience become exceptionally important in maximizing system effectiveness.

To assist the operator in image analysis and threat detection, BodySearch incorporates a number of X-ray image manipulation tools:

- Image Zoom: A 2x- 4x magnification connected to a joystick control to roam continuously through the full field of view
- Reverse Video: The ability to reverse the polarity of white and black contrast. This can be particularly helpful in detecting low density/low atomic number objects.
- Density Expand: Three pre-set levels for enhanced contrast of specific regions of interest. The operator would use these presets to ensure that very dark or very light appearing areas were examined thoroughly.
- Background Enhance: A control enabling the operator to increase contrast in the area surrounding the subject by performing a histogram equalization of brightness values in the image. This control can be useful in enhancing the outline of the subject's clothing.
- Side by Side: This control juxtaposes the front and back views taken of the subject for a side by side comparison.
- Previous Image View: Using this function, the operator has one-touch recall of any of the last five images.

Under normal conditions, images taken are not stored beyond the previous five mentioned above, but if so desired, the operator can print out a hardcopy of the image being viewed, or store a larger number of images for file reference (as may be needed in prisons, for example) using a video tape recorder.

As operators become more familiar with and better trained on any piece of inspection equipment, BodySearch included, they will be better able to interpret the images created by that system. For example, BodySearch's pencil beam has a very small spatial extent, and X-rays which scatter from the body immediately next to a foreign object are somewhat shielded by that object. The resulting image contains darker pixels surrounding the object, creating a "shadow" that actually helps define the object. Figure 6 shows a good example of the phenomenon, using a plastic explosive simulant taped to a subject's back.

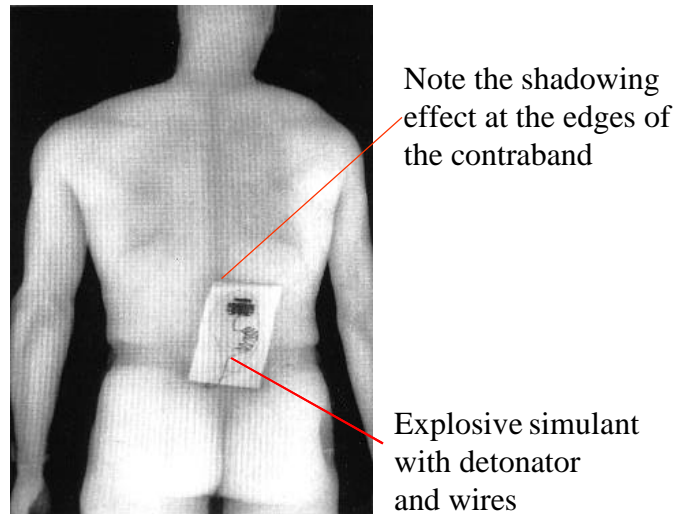


Figure 6 – BodySearch image of contraband, with “shadow”.

Radiation Safety

One of the most important issues to be addressed with an X-ray based inspection system is that of radiation exposure both to the system operator and to the subject under inspection. AS&E's BodySearch system complies fully with all applicable federal health and safety regulations, and is certified under the U.S. Bureau of Radiological Health Standards for Cabinet X-ray Systems (21 CFR 1020.40). The operator receives less than 5 $\mu\text{Sv/hr}$. at the cabinet surface, and since he is likely to be some distance away from the cabinet, the actual dosage received is less. The subject being inspected receives less than 0.05 μSv per exposure. For some points of comparison, average naturally occurring background radiation is approximately 8 $\mu\text{Sv/day}$; the average radiation dose seen in a chest X-ray is 30 – 100 μSv ; and the dose obtained in a round trip cross country flight is 50 μSv . A person would have to be subjected to 1000 BodySearch scans to obtain the same doses as occur in a long airplane flight. The FDA currently considers BodySearch to have such low levels of radiation as to not require any restriction in its use, and has issued a letter stating that the system may be entered into commerce.

The Next Step

As with any inspection system, there are potential enhancements to BodySearch that may improve its performance and make it more effective and efficient in providing check point security.

From a physical configuration view, a smaller, lighter device would allow more freedom in system placement, and ease re-location of the system within a facility. A faster scan cycle would permit better throughput and reduce potential inconveniences to the personnel being inspected. Suppression of the actual body image, and highlighting of just anomalous conditions on or around the body would help mitigate arguments from civil rights groups that the system is too invasive of personal privacy. All of these areas have merit and are currently under consideration.

Conclusion and Summary

AS&E's BodySearch can provide a viable method for personnel inspection at security checkpoints. It is easy to use, effective, and safe. The system has been successfully installed and operated in several domestic and international locations. Enhancements and upgrades to BodySearch will continue to add to its value as a useful inspection tool for a wide variety of applications.

Acknowledgements

The author would like to thank Dr. Gerry Smith, Dr. Peter Rothschild and Dr. Joseph Callerame of AS&E for their technical assistance, advice, and editorial comments in preparing this paper.



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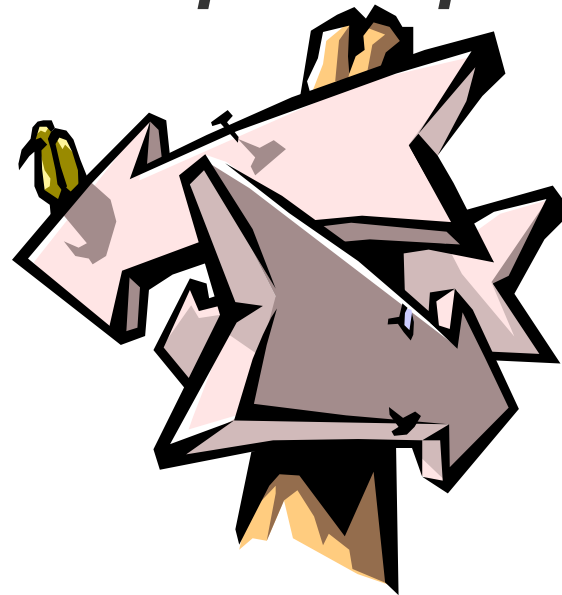
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Roadmap for the Presentation



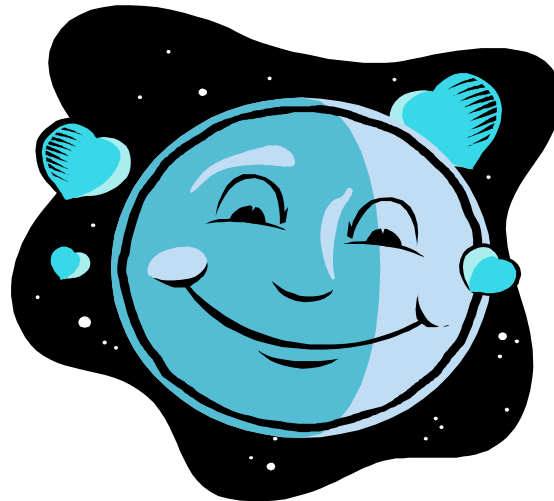
- *The Problem to be Solved*
- *An X-ray Based Solution*
- *System Description and Concept of Operation*
- *Radiation Safety*
- *The Next Step*
- *Conclusion & Summary*



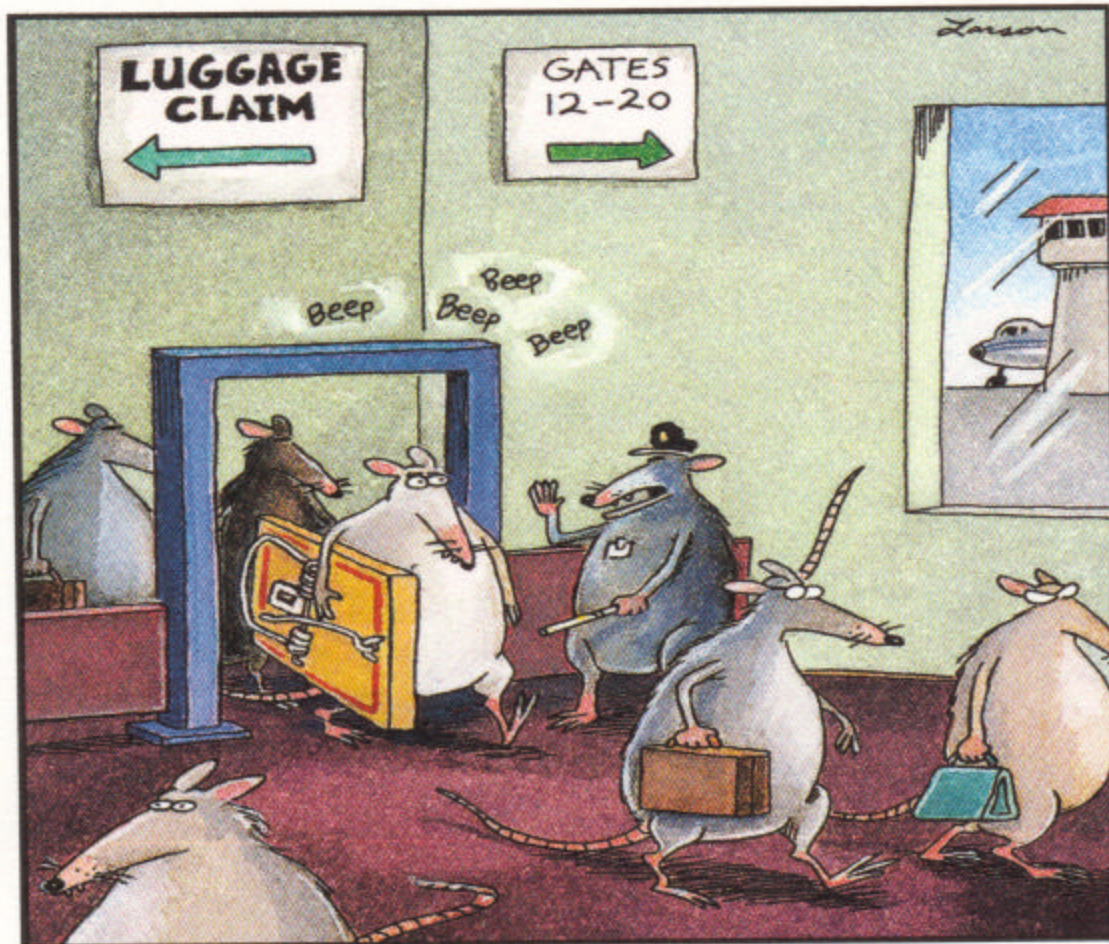
Acknowledgements



- ***Thanks to Dr. Gerry Smith, Dr. Peter Rothschild, and Dr. Joe Callerame of AS&E for their technical and editorial assistance in the preparation of this paper and presentation.***



Not All Inspection Issues Are This Easy



“Whoa whoa whoa! ...You’ll have to go back and walk through again.”

The Problem is an Ongoing One



-
- *(1 person + 1 desire to smuggle contraband past a security checkpoint + 1 need for security + 1 desire for personal privacy) X Heavy traffic through a checkpoint = 1 Massive Headache for security personnel*
 - *How can a security team best assure that people gaining access to secure areas are not carrying contraband*
 - ✓ *Weapons*
 - ✓ *Drugs*
 - ✓ *Explosives*
 - ✓ *Other Restricted Material*

Some Potential Solutions



- ***Metal Detectors***
 - ✓ *Quick*
 - ✓ *Only detect metal*
- ***Vapor Detectors***
 - ✓ *Time consuming*
 - ✓ *Limited in what they can find*
- ***Physical Pat or Strip Search***
 - ✓ *Time consuming*
 - ✓ *Subject to human variation*
 - ✓ *Very intrusive*

**Combinations of approaches work well,
but can be expensive and time consuming**

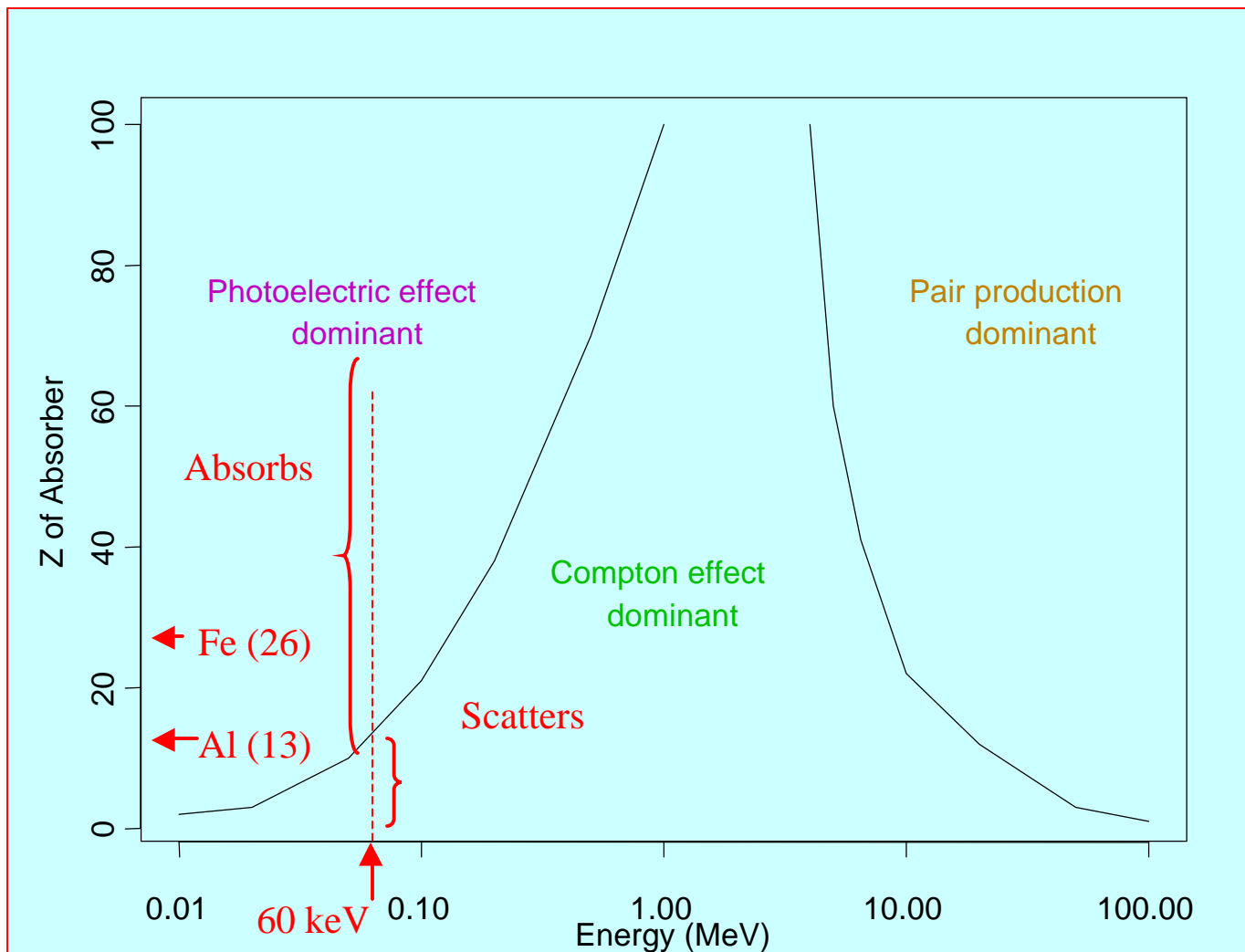
The X-ray Backscatter Solution



- **Effective**
 - ✓ *Finds metallic, non-metallic, organic and non-organic materials repeatably*
- **Quick**
 - ✓ *Detailed two-sided inspections in under 40 seconds*
- **Safe**
 - ✓ *Very low dose backscatter X-ray*
- **But --- There are some issues, too**
 - ✓ *Personal privacy*
 - ✓ *Objects hidden within body cavities*
 - ✓ *Misconceptions regarding use of X-rays*

A Viable Alternative to Other Inspection Methods

Body Search™ Works in the Compton Scattering Region



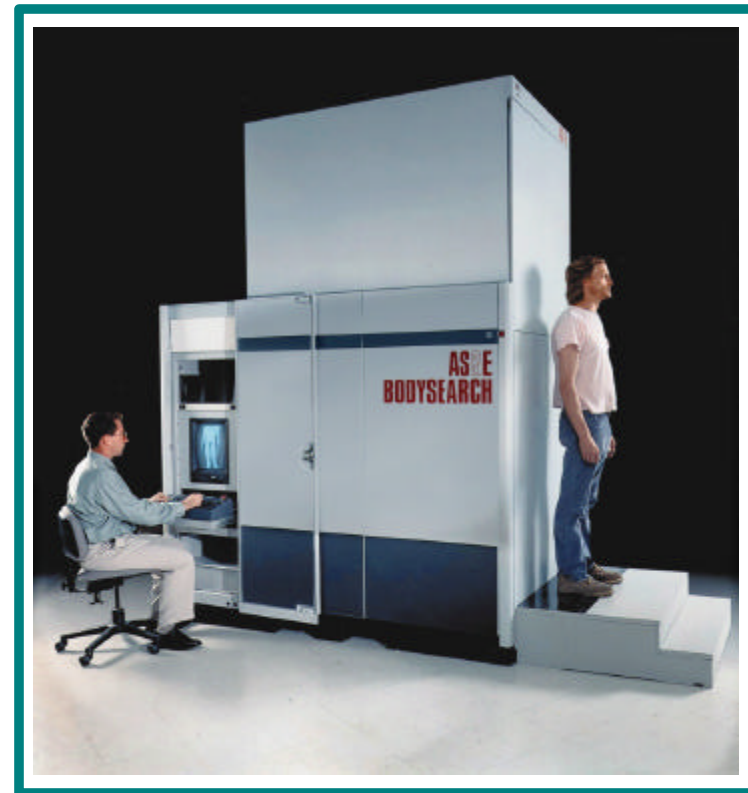
BodySearch™ Physical Configuration



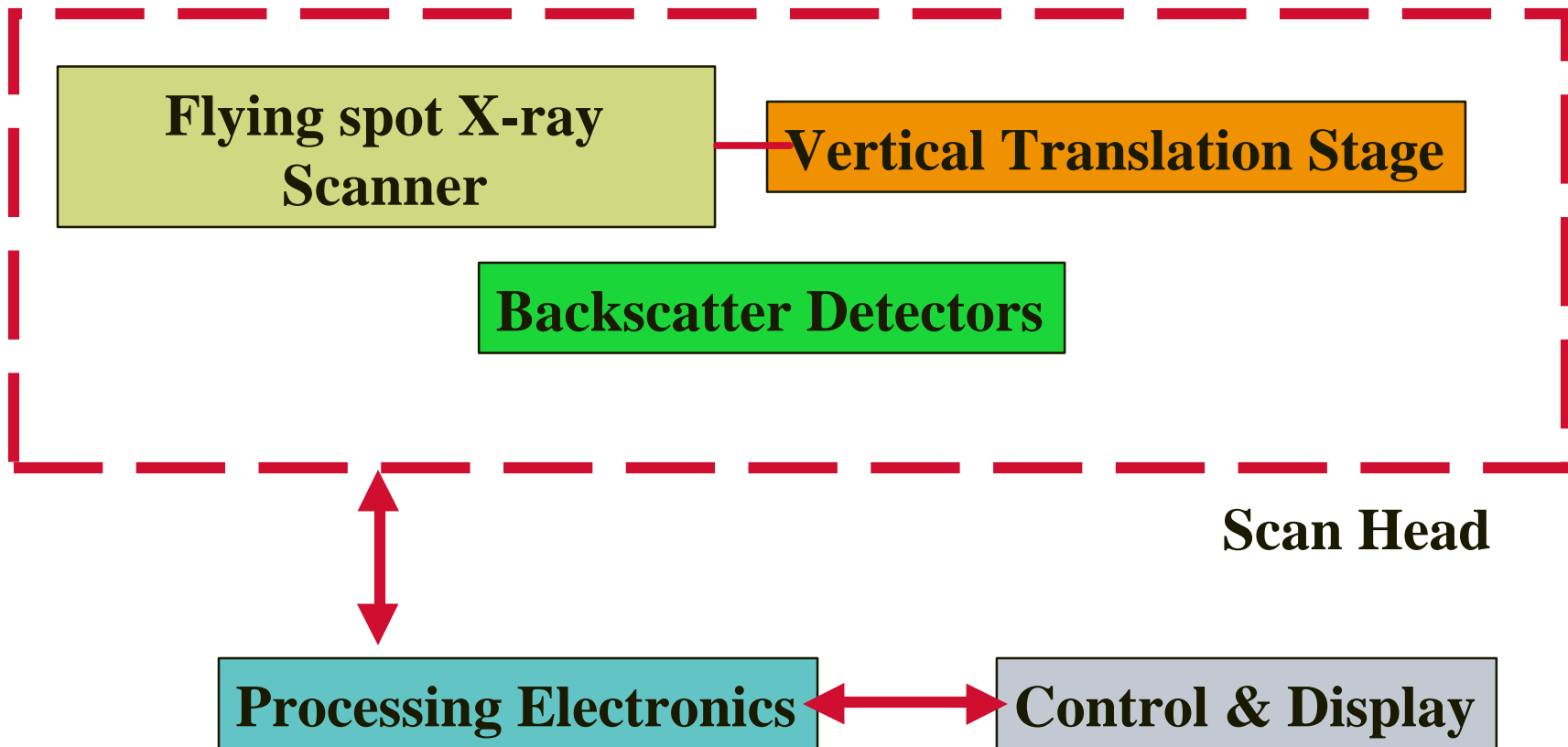
Check out on the factory floor



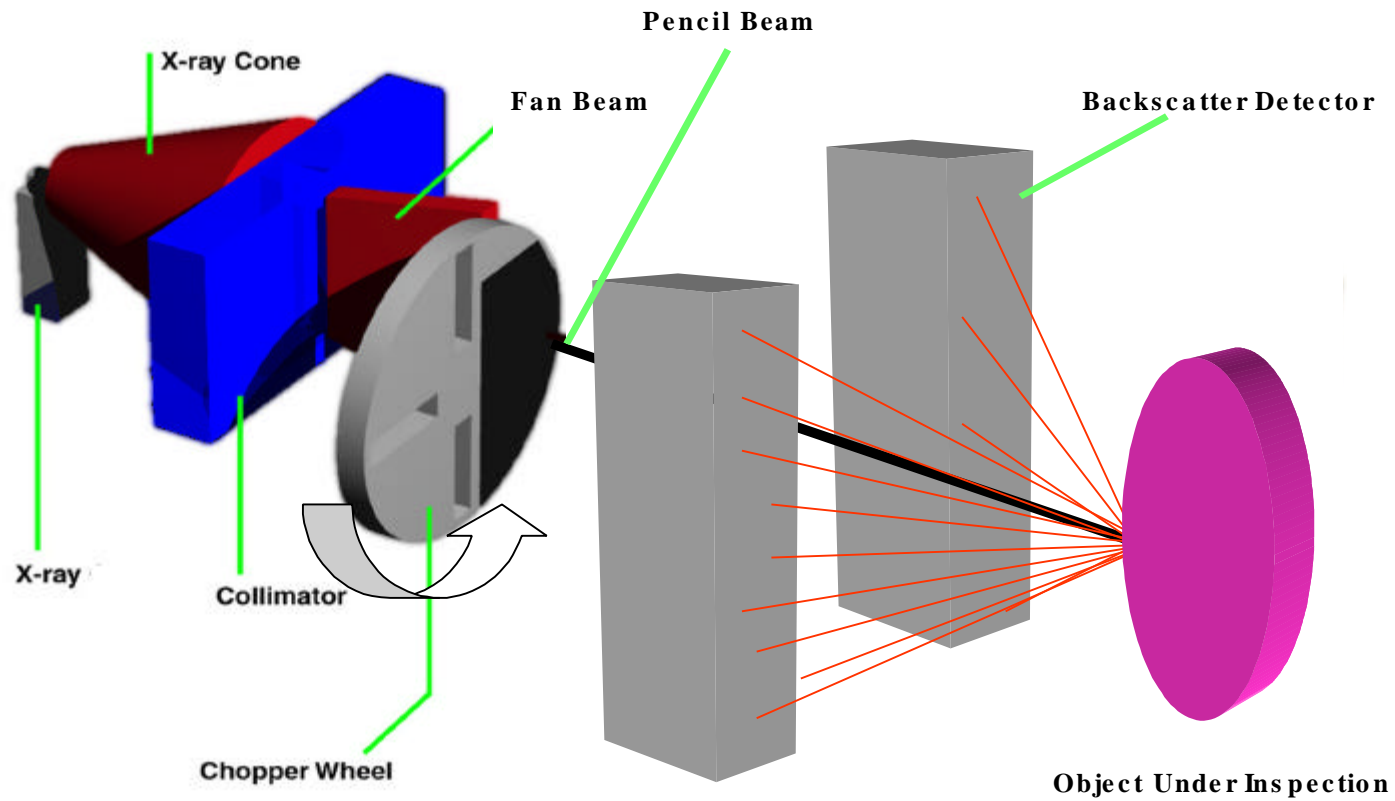
BodySearch in operation



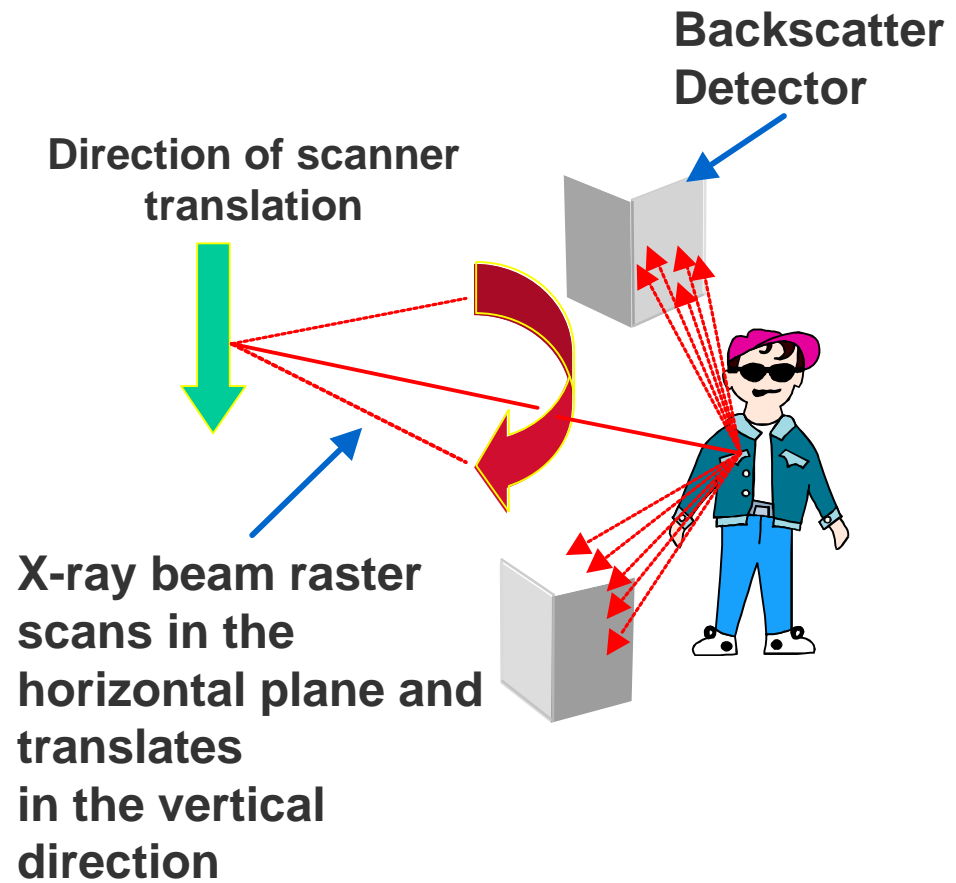
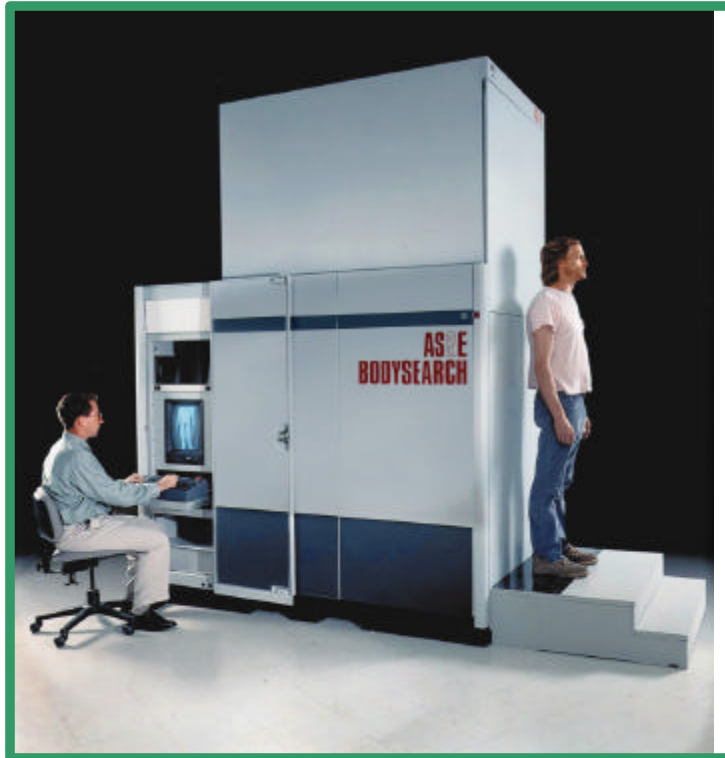
BodySearch's Basic Makeup



AS&E's Flying Spot Backscatter Technology



How BodySearch Performs its Scan

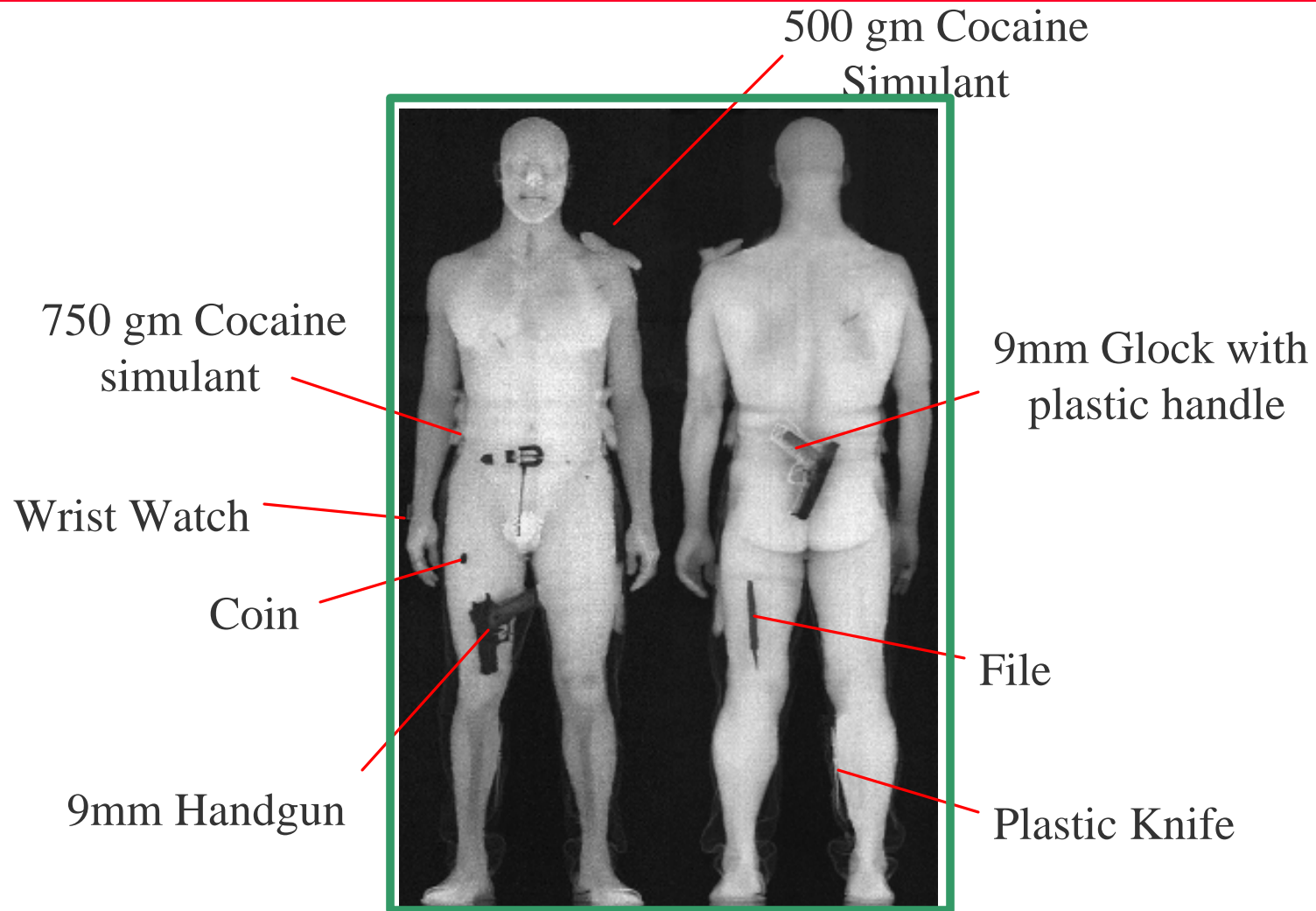


BodySearch Vital Statistics



-
- **Operational Footprint**
 - ✓ *127" long x 46" wide x 120" high deployed*
 - **Power**
 - ✓ *208-240 VAC, 20 Amps, 50/60Hz*
 - **High Resolution non-interlace color monitor**
 - **Controls and Displays**
 - ✓ *Zoom, Reverse Video, Density Expand, Background Enhance, Side by Side, Previous Image View*
 - ✓ *Can be remoted from unit*
 - **Time for one scan - Approx. 10 seconds**
 - **Extremely low dose - person under inspection receives 0.05 μ Sv./scan**

BodySearch Reveals Both Metallic and Non-Metallic Objects Concealed on a Body

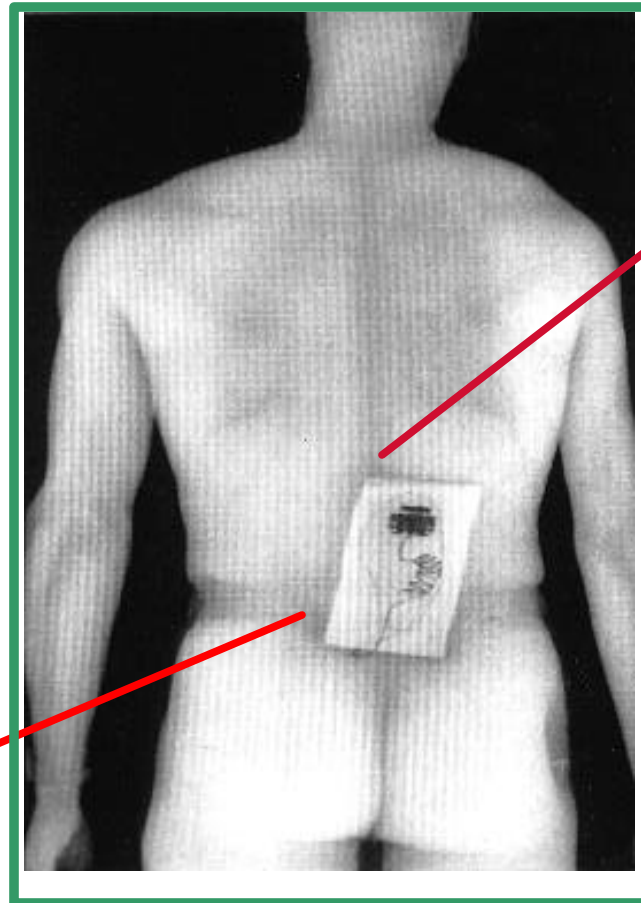


The Operational Scenario



- *Operator positions subject on external stage and enables scan*
- *Operator turns subject 180° and repeats scan*
- *Using control panel, operator manipulates and reviews images*
- *Subject is dismissed or required to undergo further search*
- *Total elapsed time -- 30 seconds*

The “Shadow” Created by a BodySearch Scan Aids the Operator



**Note the “shadow”
created by the
suspect object**

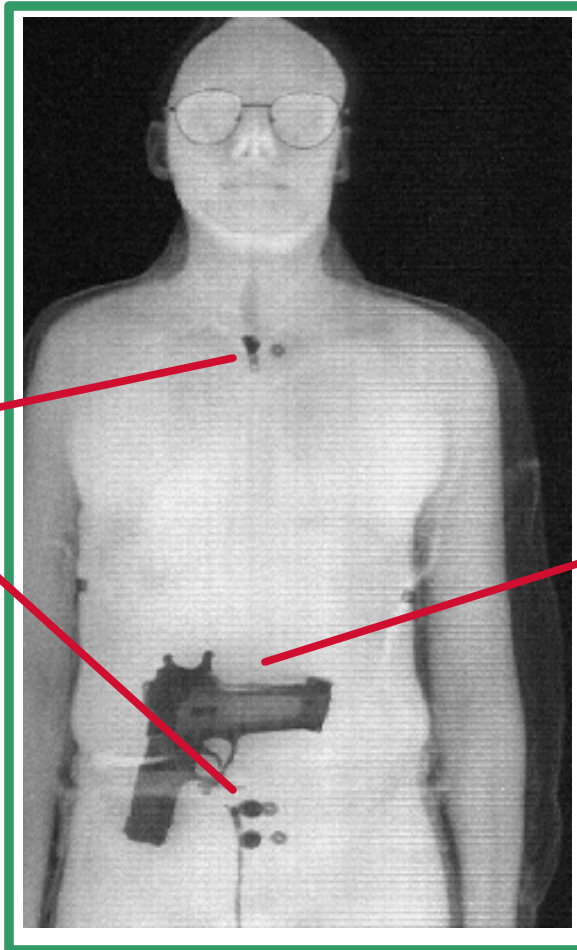
**100 gm explosive
simulant with detonator
and wires**

BodySearch Shows High “Z” Metallic Objects Well



Metal buttons

9 mm metal handgun



BodySearch is a Safe System

- ***Only 5 $\mu\text{Sv/hr.}$ at the cabinet surface***
 - ✓ *Remote control operation provides even less dose to operator*
- ***Subject receives 0.05 $\mu\text{Sv/scan}$***
- ***For Comparison ---***
 - ✓ *Natural background radiation is 8 $\mu\text{Sv/day}$*
 - ✓ *A typical chest X-ray is 30 - 100 μSv*
 - ✓ *A round-trip cross country flight provides 50 μSv*
 - *1000 BodySearch scans needed to provide this dose*
- ***BodySearch has received FDA approval for entry into commerce with no restrictions***

$$1 \mu\text{Sv} = 100 \mu\text{R}$$

An Example of How BodySearch Can Help



Montana State Prison Work Release Program

- **400 work release inmates leave the prison in Deer Lodge daily to work outside the walls.**
- **Past practice has been 100% pat searches with random strip searches.**
- **Searches are an irritant, but necessary due to the quantity of contraband smuggled into the prison.**
- **The problem was so bad that wardens considered issuing inmates two sets of clothing (estimated to cost \$200,000 plus additional operational costs).**
- **BodySearch system now used on all prisoners in the program**

BodySearch eases the inspection process

Potential for Improvements and Upgrades



- ***Smaller footprint***
 - ✓ *Facilitates placement*
- ***Lighter in weight***
 - ✓ *Eases movement*
- ***Faster scan***
 - ✓ *Increases throughput*
- ***Suppression of body image***
 - ✓ *Only anomolous objects highlighted*
 - ✓ *May reduce concerns of human rights organizations*



The Bottom Line



- *X-ray Backscatter imaging can be an effective aid in security screening of personnel*
- *BodySearch is safe, effective and efficient*
- *Improvements and upgrades will enhance performance further*
- *BodySearch is available now*

