IPRO 313: Detection of Ionizing Radiation

An Interprofessional Project at the Illinois Institute of Technology for Spring 2003

Key Contributors

- Faculty Advisor: Dr. Daniel Kaplan, BCPS
- Additional Advisors:
  - Dr. N. Solomey, BCPS
  - Mr. T. Torres, BCPS Machine Shop
- Team Members:
  - Jesse Sumner (Freshman, Physics)
  - Chris Meyers (Junior, CS)
  - Kiyoung Huh (Junior, Physics)
  - Soon Gang Choi (Junior, Biology)
  - Jon Caranto, website manager (Senior, Chemistry)
  - Justin Albanese, project manager (Senior, CheE)

Presentation Outline

- The Project Purpose (Justin)
- Ionizing Radiation and Its Detection (Justin)
- Detection Apparatus (Jesse)
- Electronics and Software Used (Chris)
- Website Content and Design (Jon)
- Ionizing Radiation Applications (Soon Gang)
- Problems, Solutions, Future Plans (Kiyoung)
- The IPRO Experience (Justin)

Purpose

- Detecting and Counting Muons
  - Scintillation
  - Spark Chamber
- Website Development
- Application of Ionizing Radiation

A Worthwhile Project

- Scientific
  - Accurate and Precise Muon Identification
  - Collection of Cosmic Shower Data
  - Potential Collaboration with Pre-Existing Array Detection Networks
- Educational
  - Demonstrating Ubiquity of Ionizing Radiation
  - Make Particle Physics More Accessible
  - "Spark" Curiosity
  - Relating the Sciences to Everyday Life
  - Potential Collaborations

Ionizing Radiation

- High Energy Sources That Displace Electrons From Molecules
  - X Rays, Gamma Rays
  - Particle Beams
- Used in Medicine, Science, and Engineering
  - PET and CAT scans
  - Cosmic Event Detection
  - Surface Uniformity Verification (ESCA)

Ionizing Radiation and Its Detection

- Muons, A Naturally Occurring Source
  - High Energy Cosmic Rays
  - Relativistic Speed
  - Fast Decay
  - Consistent, Variable Source That Can Be Isolated and Measured

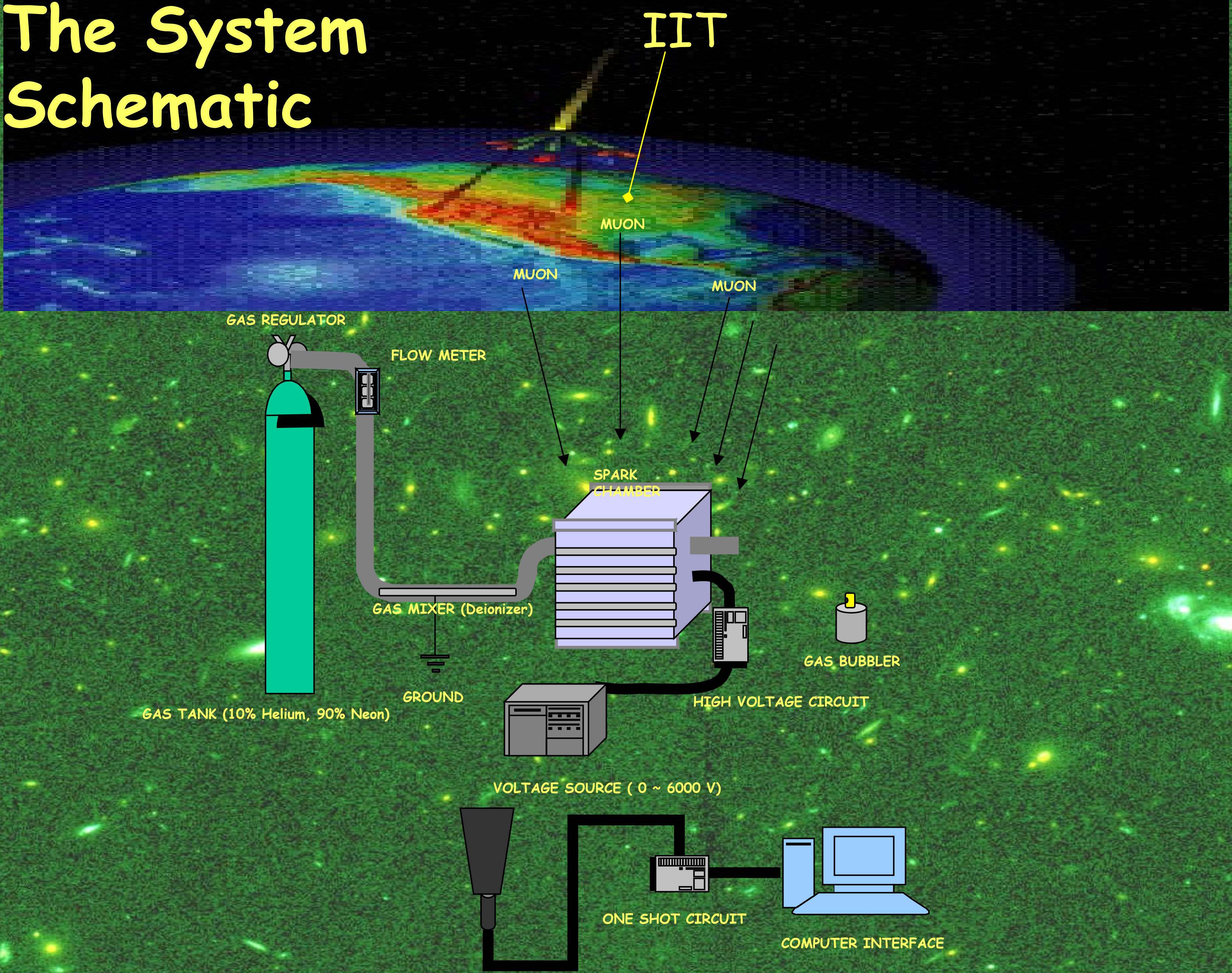
Detection of Muons

- Scintillation
  - Muon Passes Through Plate, Loses Energy
  - Lost Energy is Detected
  - Signal Is Amplified
  - Computer Records Signal and Time
  - Background Eliminated by Use of Two Plates

Detection Of Muons

- Spark Chamber
  - Scintillator Detects Muon Signal
  - Voltage in Chamber Increased
  - Muon Passes Through A Charged Plate
  - Spark is Formed Due to Electric Field
  - Visual Demonstration for Casual Observer

The System Schematic



Spark Chamber

- Poor for Analytical Use
  - Impurities due to leaking
  - Random effects by other particles
  - Not very sensitive
  - Gas and electric costs higher than for scintillator
- Excellent for Visual Demonstrations
- How We Use It
  - Charged, high voltage plates are at sparking threshold (several 1000s volts)
  - Muon passes through the plate
  - Voltage is increased over threshold
  - Spark occurs

Scintillator Detector Design

- Change in surrounding media causes muon energy loss in the form of a released photon
- Photomultiplier amplify signal
- Two detectors
  - Reduces random error and light leak effects
  - Provides system redundancy
  - More sensitive and precise than a spark chamber

Gas Delivery System

- Gas Mixture (90% Ne, 10% He)
  - Colorful but inert
  - Costing, delivery, supply, and comparison to argon mix
- Connection Types and Tubing Types
  - NPT, the standard in gas leak prevention
  - Nylon and copper used for flexibility and ion reduction
- Regulator, Flow Meter, and Needle Valve
  - Flow control
  - Effective leaking rate measurement and comparison
- Laminar Flow Tube (Reduce Inlet Ionization)
- Bubbler
  - Pressure Limitations (<1 psi)
  - Prevention of Backflow
- Sealant (RTV Instead of Rubber O Rings)

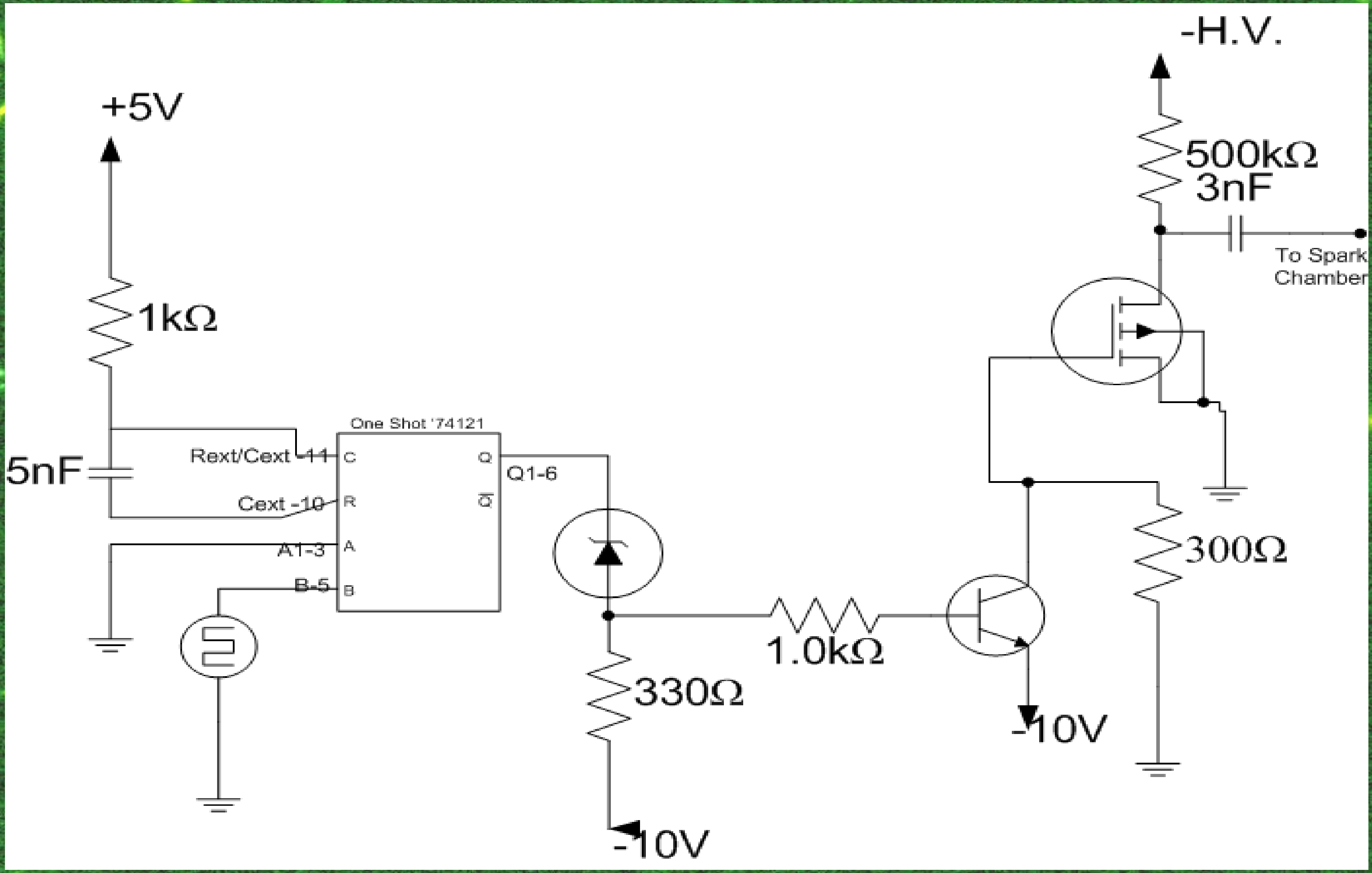
High Voltage Pulsing Circuit

- The input from the coincidence circuit is sent to a one-shot chip.
- This chip takes a short pulse from the coincidence circuit and makes the long pulse needed to properly charge the spark chamber

High Voltage Pulsing Circuit

- The voltage output of the one shot is shifted downward by a Zener diode to trigger a transistor
- This is one of several solutions which we pursued to shift the voltage
- It proved to be the quickest (~65ns)
- This transistor switches on a High Voltage MOSFET transistor
- The High Voltage transistor is then fed to a transformer, which changes the small AC pulse into a large (several thousand volts) AC pulse

Pulsing Circuit Diagram



Computer Interface

- The output pulse from the scintillation counters is converted by the coincidence circuit into a single TTL pulse
- The short pulses from the Photomultiplier tubes, each of a few hundred negative millivolts, are converted into a single TTL digital pulse
- The TTL pulse is only sent if pulses are received from both PMTs at the same time, signifying a particle

Signal Processing

- The TTL pulse is sent to the computer, and the hardware port interrupts the microprocessor, calling the interrupt handler.
- One of the computer parallel port pins, (#10, the Ack pin) is used to receive the message.
- The interrupt handler (installed/created by the IPRO) records the particle detection in a database.
- The data is stored in the database efficiently, both in terms of memory and speed

Data Storage

- The database can be queried to create a graph
- By using a standard industry tool, it is easy to retrieve the data and use it in any form
- Large hard drive reduces the number of times data must be downloaded

Web Design
Restructuring of Fall 2002 Site

- General Appearance
- Content
- Following the progression of the project
- Team interaction

Appearance and Content

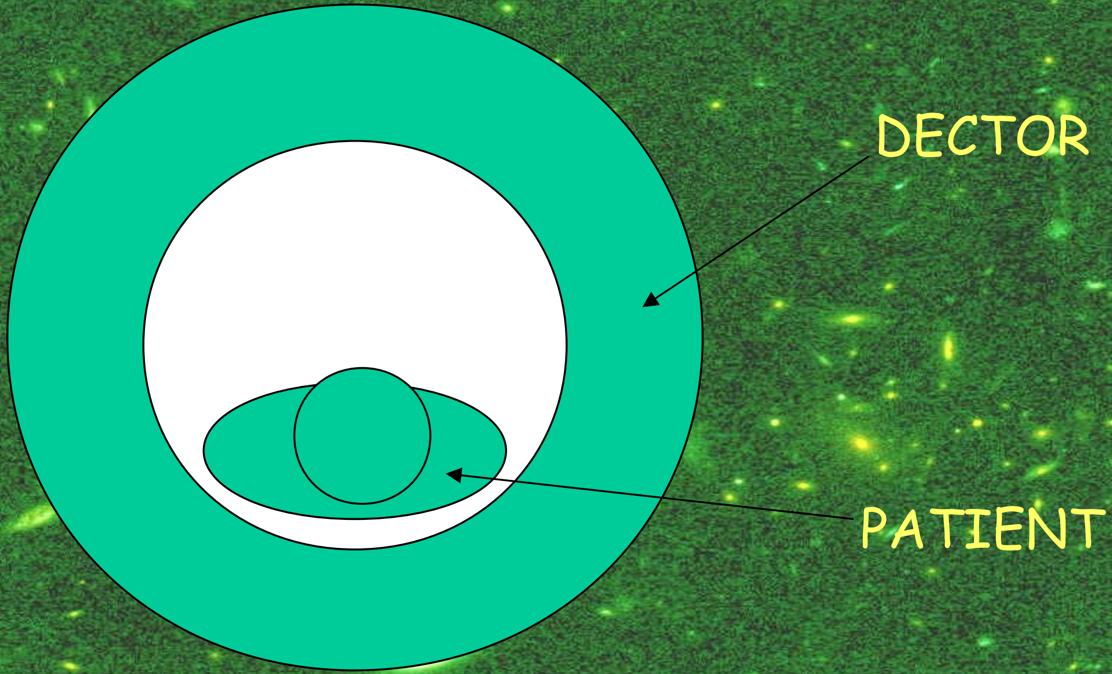
- Similar easily navigated sites
- More graphics for a more aesthetically pleasing site

- Background information
- Future Plans
- Societal Applications
- NALTA
- Team Picture

Current and Future Progress

- Theory
- Progress
- Bulletin Board
- Picture Gallery
- Further updating
- Visualization of Data

CAT



An x-ray procedure which combines many x-ray images with the aid of a computer to generate cross-sectional views or three-dimensional images of the internal organs and structures

Cranial CAT Scan

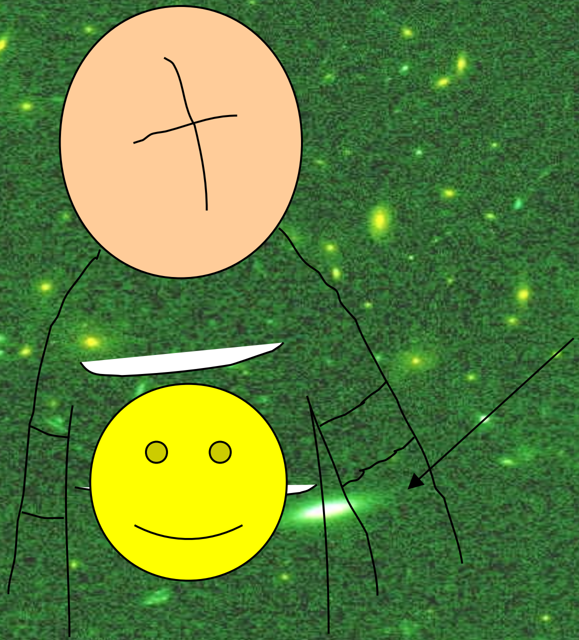
A Patient and His "CAT"

Adrenal metastases from lung cancer

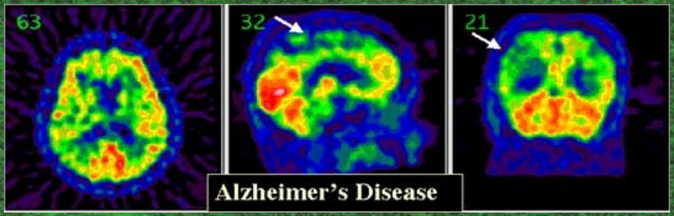
PET

Positron Emission Tomography or P.E.T. is the study and visualization of human physiology by electronic detection of short-lived positron emitting radiopharmaceuticals.

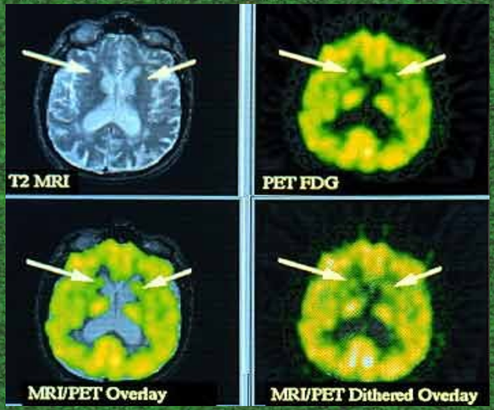
Radiopharmaceuticals such as 2-[F-18] Fluoro-D-Glucose (FDG) are administered intravenously



Pet Scan of Alzheimer's Disease



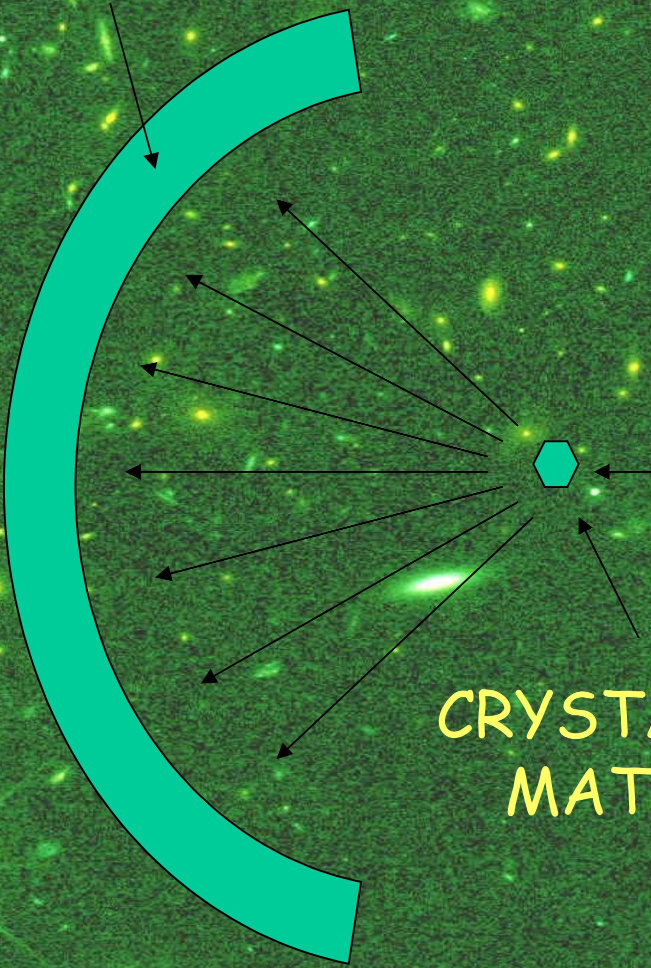
Pet Scan of Huntington's disease



PET scanner

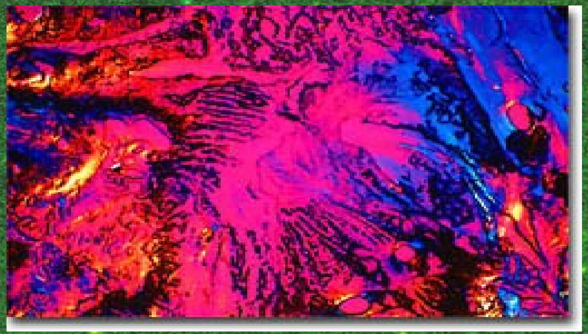
X-ray crystallography

DETECTOR

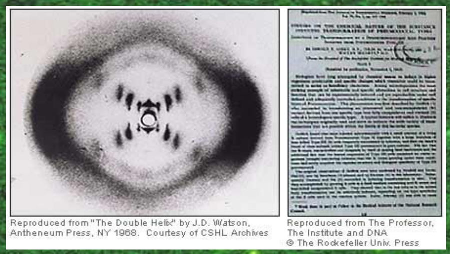


CRYSTALLIZED MATERIAL

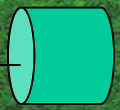
A photo of crystallized DNA



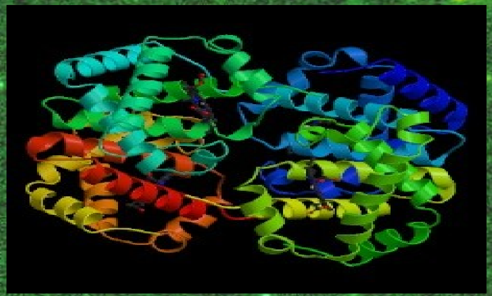
Diffraction pattern of DNA



X-ray source



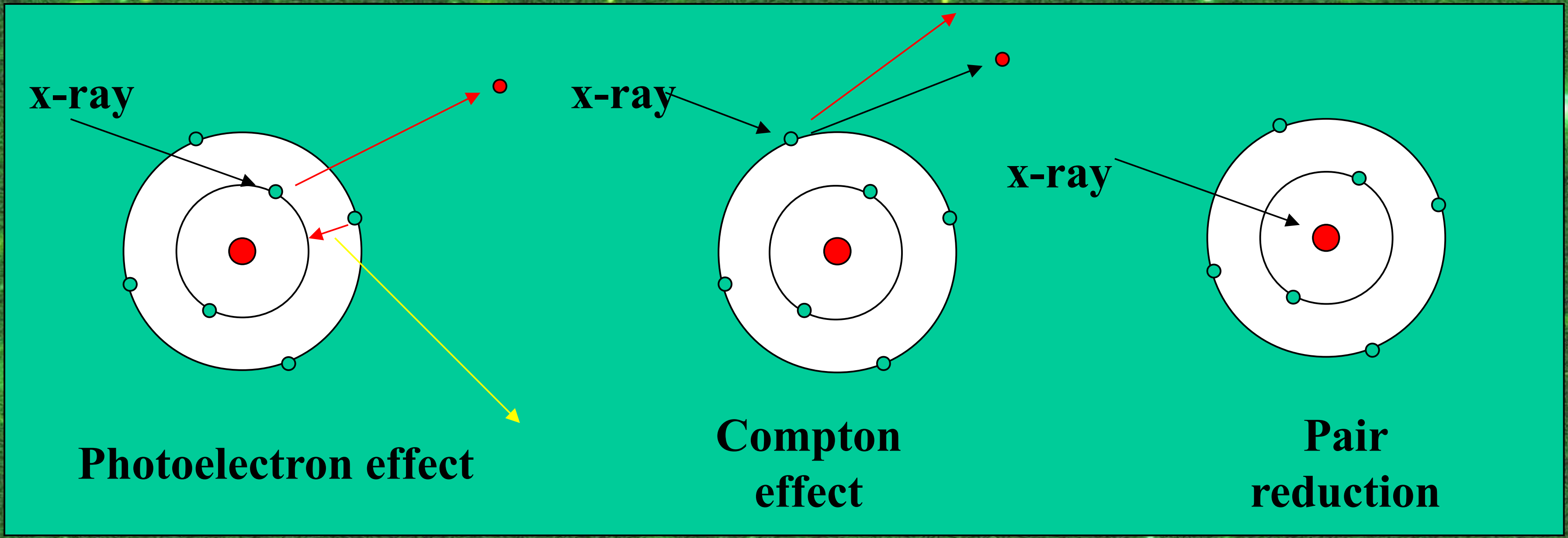
Determined structure of a protein



Mechanism of Ionizing Radiation interact with matter

Three modes of interaction (depending on the photon energy)

Photoelectric effect, Compton effect, and pair reduction



Indirect Effect

Ionizing radiation interact with several types of molecules in the cell causing ionization.

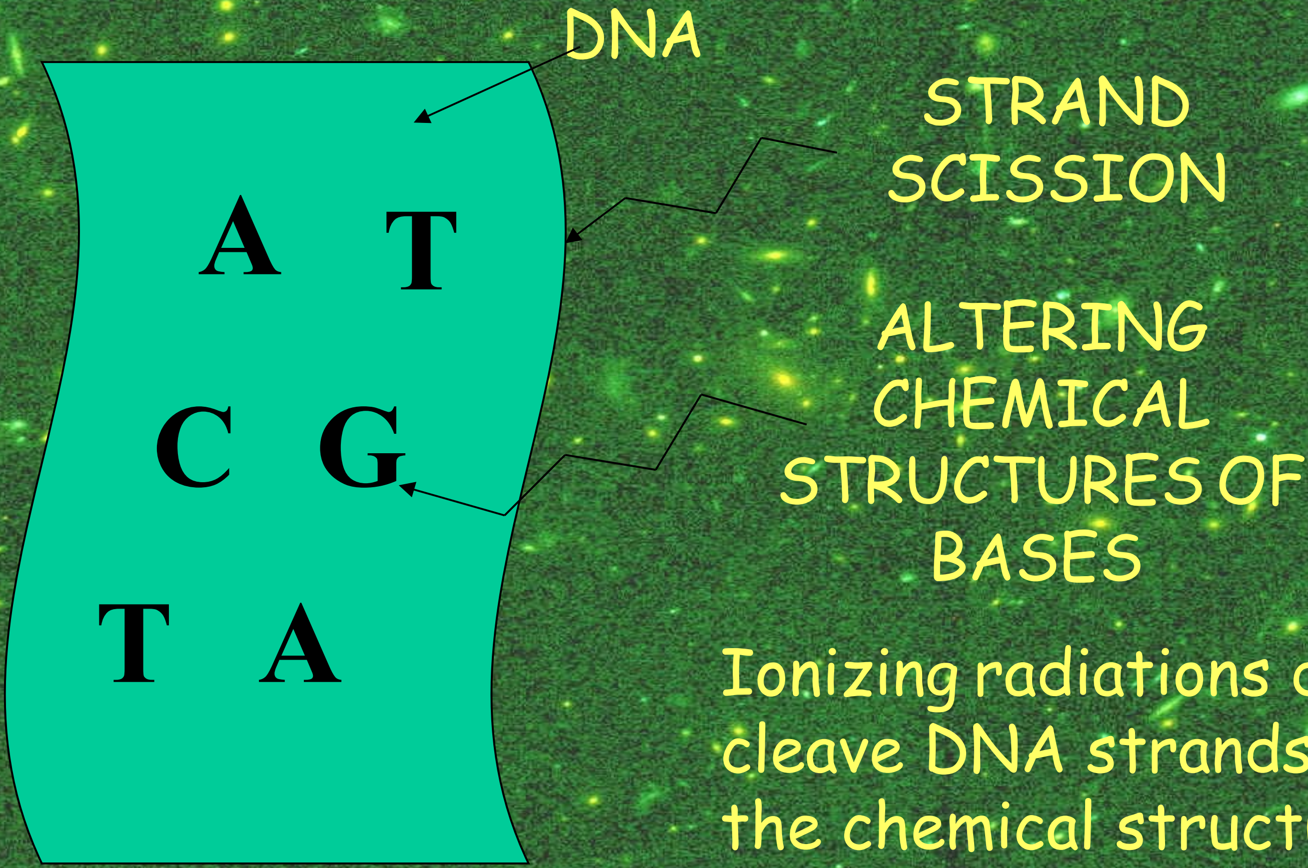
H-O-H ® H+ + OH- (ionization)

H-O-H ® H0+OH0 (free radicals)

OH0 + R-H ® R-OH + H0 (other reactions)

Ionized molecules can cause several chain reactions leading to degradation of key cellular components.

Direct Effect

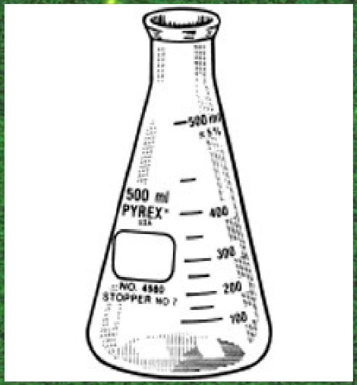


Ionizing radiations directly cleave DNA strands and alter the chemical structures of bases

Therapeutic Applications

Target specific radio therapy

Acquired cancer cells from a patient

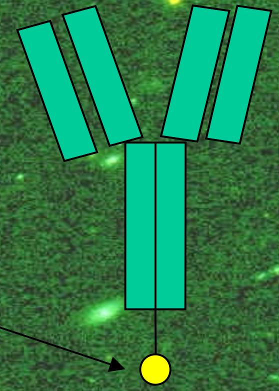


Processing

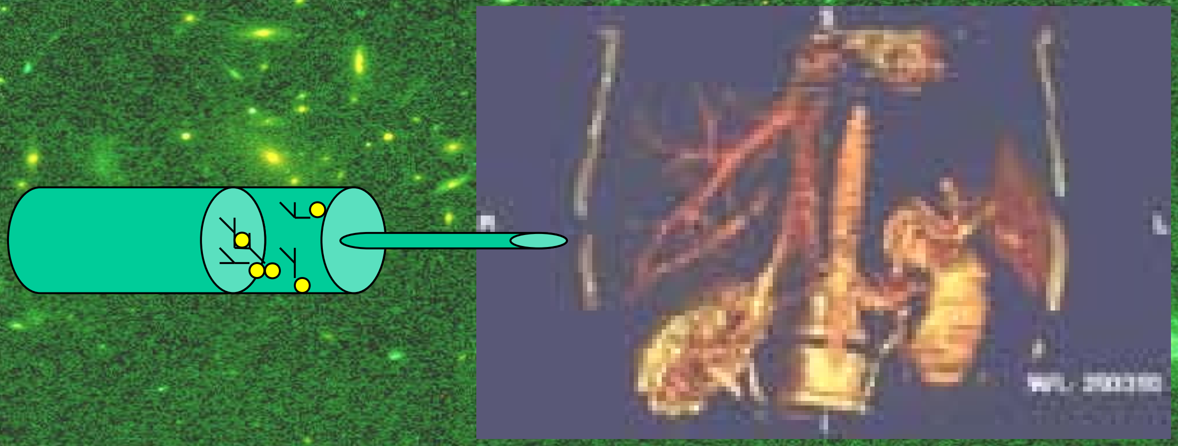
Inject processed fluid into an animal followed by Ab harvesting

4. Attach radioactive material on the antibodies

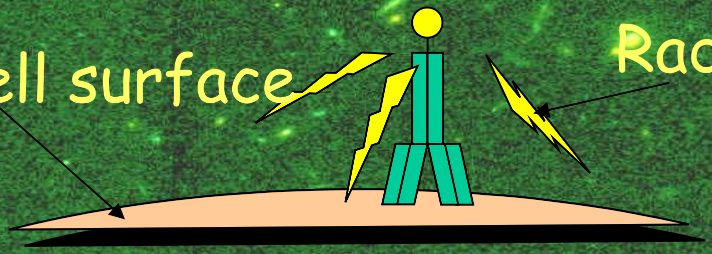
The common structure of an IgG antibody



5. Inject the antibodies into the blood stream of the patient.

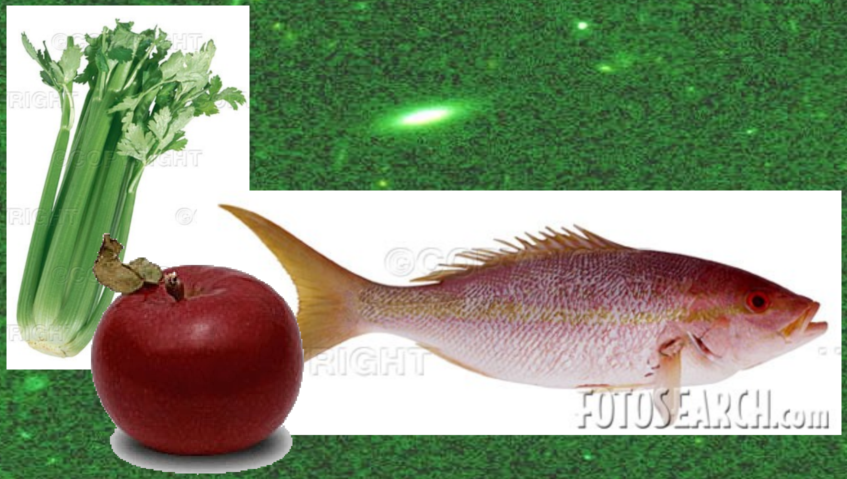


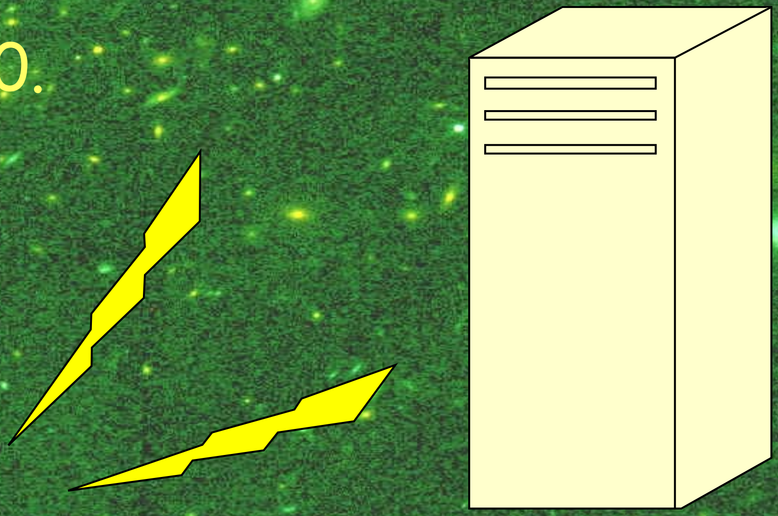
6. The radioactive antibodies attached to the surface of cancer cells and destruct them.



Food Processing

Exposes food to gamma rays from radioactive cobalt-60.





An exposer containing cobalt-60

Pollution Control

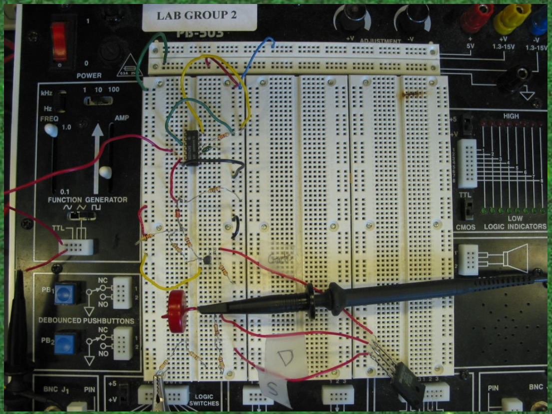
Water Treatment Technology

UV radiation can replace chlorine in water disinfection, which is particularly effective with Titanium Oxide catalyst, leading to the destruction of pathogenic bacteria and undesired volatile organic compounds via free radical oxidation

Air and Soil Treatment

Ionizing radiation can be used to form highly reactive compounds such as ozone. Ozone can break down hazardous compounds such as TCE in both soil and carbon sorption units used to clean flue gas emissions

Problem High Voltage Pulsing Circuit

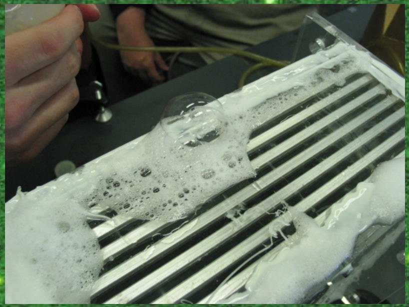


The schematic from the fall team design was studied.

The response time was too slow.

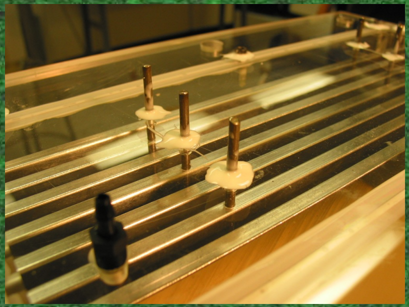
Modifications improved response to 70 ns

Problem Spark Chamber



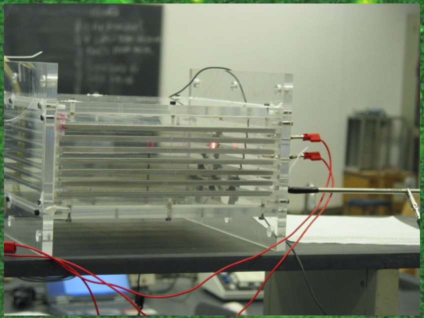
Leak Test(bubble test)
The spark chamber leaked too much,
causing contamination.

The solution included repeated sealing with a 2 component sealant, RTV.
A groove holding for RTV was required.
Leaks have been reduced substantially.

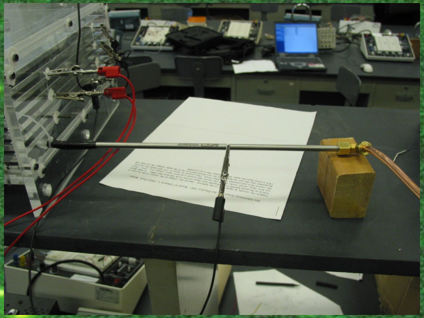


Problem Sparking

The first spark that appeared.
It is an artifact caused by ions near the gas inlet.



First part of the solution:
reduced gas flow rate and multiple inlets.



Second part of the solution:
Use of a laminar flow tube, copper tubing, and testing with an argon gas mix.

Additional Problems

- Development of an effective gas delivery system
  - Finding reasonably priced suppliers
  - Need to determine appropriate size, thread type
  - Poor supplier turnaround time
  - Poor quality products requiring replacement
  - Poor specification information

Additional Problems

- New Ideas for the System
  - Switch from a DC pulse to an AC pulse
    - Requires a specially modified transformer with low inductance
    - Required for proper pulsing and sparking
  - Low pressure sensor
    - Allows timely ordering of new gas cylinder
  - Coincidence timing using GPS
    - Universal time code for muon detection
- Need for Improved Communication
  - Addition of the bulletin board
  - Pictures documenting progress
  - Increased number of hours outside of class

The Future

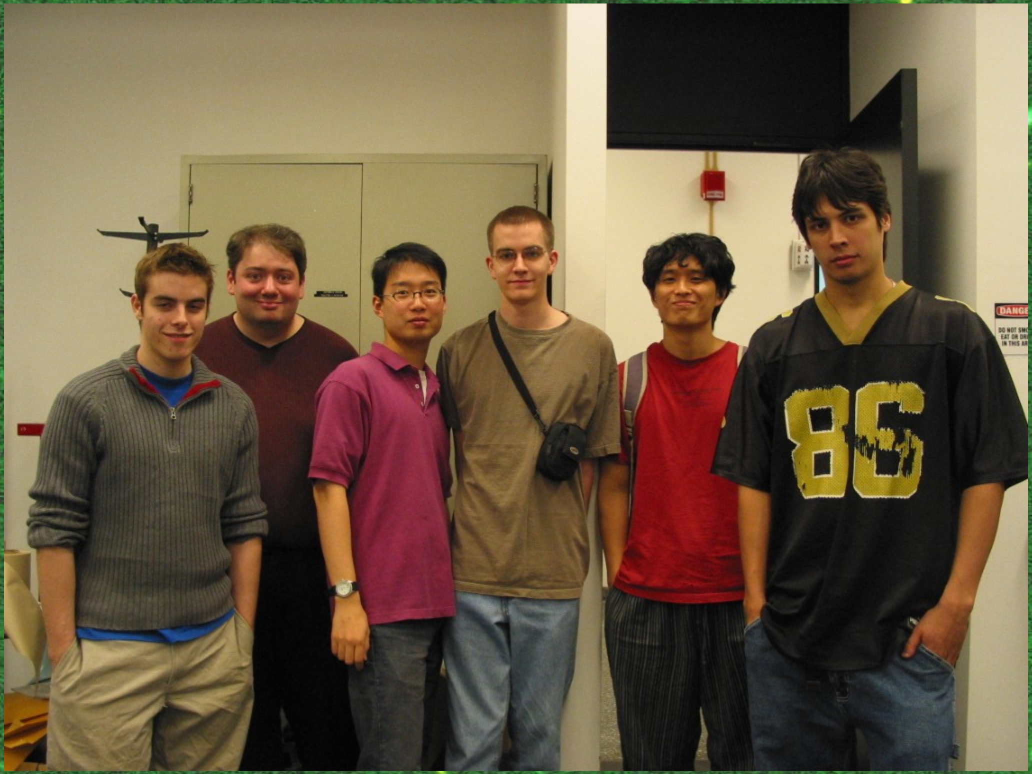
Arrangements in progress for the following:

- Exhibition of the spark chamber at the Museum of Science and Industry
- Permanent display in the LS building lobby
- Joining or forming an array with other educational institutions

The IPRO Experience

- Communication is the key
  - Awareness of team member skills
  - Communicating progress
  - Coordination of activities
  - Problem solving through peer support
  - How to deal with real world problems
  - Learning how to work together over time
  - Surprises never end

Questions and Answers



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