Film Scanning and Re-Analysis Project

September 21, 2016

Greg Spriggs, Alan Carr (LANL), LTC Ben Kowash, Jim Moye, Peter Kuran

Lawrence Livermore National Laboratory

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Alan Carr, LANL's Historian and Film Custodian

Alan Carr
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Alan B. Carr currently serves as the Historian for Los Alamos National Laboratory. During his tenure as Laboratory Historian, Alan has produced several publications pertaining to the Manhattan Project, nuclear weapons testing, and the Laboratory's development during the Cold War years. He has lectured for numerous professional organizations and has been featured as a guest on many local, national, and international radio and television programs. Before coming to Los Alamos, Alan completed his graduate studies at Texas Tech University in Lubbock. His thesis, *The Long Road to Kursk: The Development, Abandonment, and Relearning of Soviet Military Strategy*, traces Soviet operational art from its roots in the early 1920s through its employment in the first half of World War II.

Film preservation and scanning team

Peter Kuran
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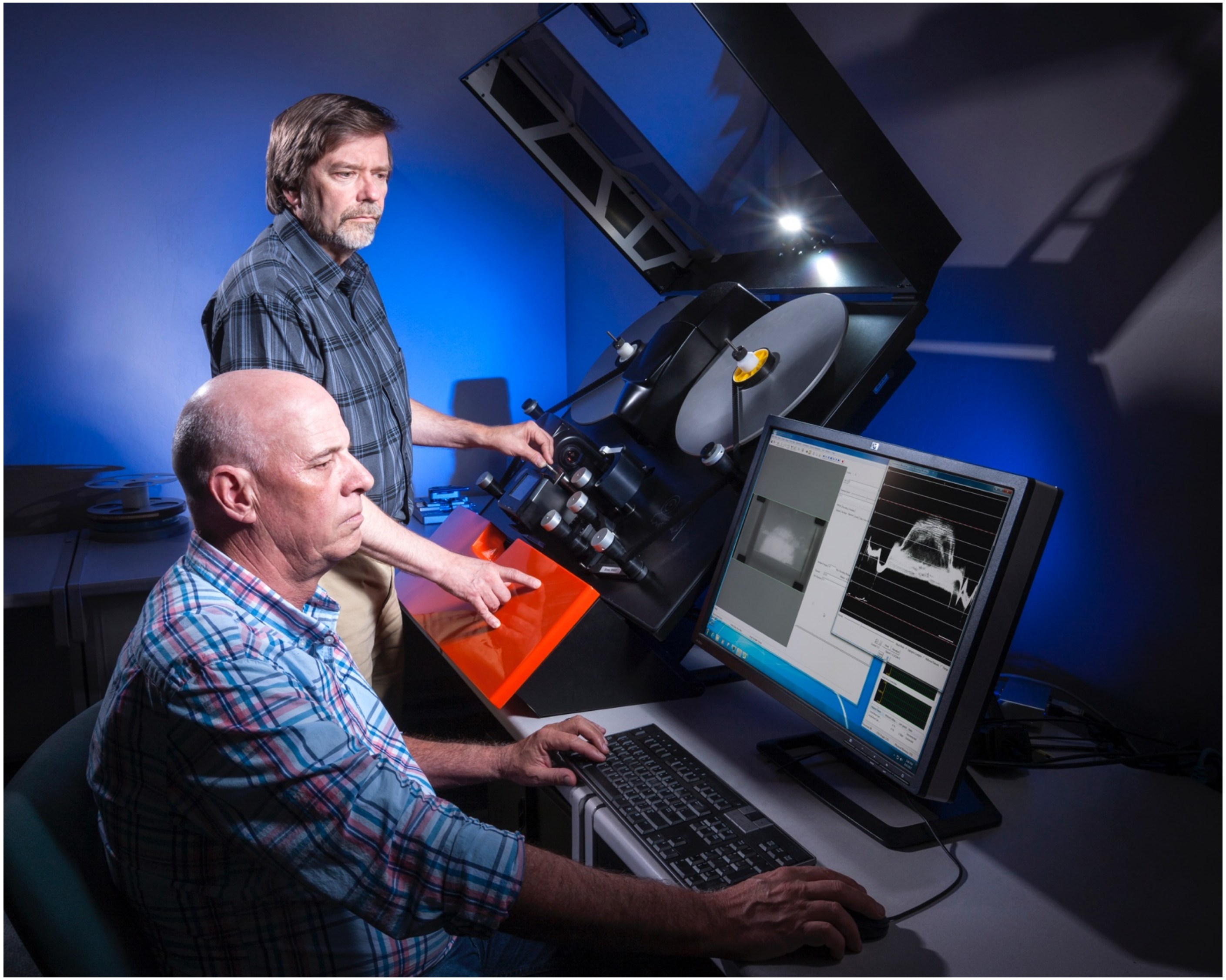


Jim Moye, film expert

Jim Moye has 40+ years experience in the motion picture post-production industry having worked on feature films for most of the major studios (Disney, Universal, Warner Bros, Paramount, Fox...) as well as some local studios such as Pixar, Lucas Film, and Tippett. For the last 25 years, Jim has worked for Monaco Film Labs in San Francisco, a world renowned film company, and has been involved in restoration/preservation of films produced by some well known directors and filmmakers such as Steven Spielberg and John Sayles.

As a recognized expert in film preservation, Jim was asked by the National Archives (NARA) to perform a full forensic preservation of the Zapruder film (the Kennedy assassination).

Peter Kuran, film expert

Peter Kuran has produced five documentaries on the subject of atomic history, weapons and testing. Beginning in 1995, Peter produced and directed the award winning film *Trinity and Beyond* and has since produced Atomic Filmmakers, Atomic Journeys, Nukes in Space, and Nuclear 911.

In 2002, Peter won a *Scientific and Engineering Academy Award* for inventing a photo-chemical color restoration process for faded color negative which he created during the making of *Trinity and Beyond*.

Code Developers for automated film analysis tools

Lt Col Ben Kowash is a Defense Threat Reduction Agency (DTRA) Stockpile Associate assigned to Lawrence Livermore National Laboratory (LLNL). As a Stockpile Associate, Ben serves as a technical military representative to the lab and facilitates open and productive communication between LLNL and USSTRACOM, DTRA, and the USAF on issues related to the development and sustainment of the US nuclear stockpile. As an expert on image processing, he is also the co-developer of many of the automated computer tools that are currently being used by LLNL to re-analyze the films.

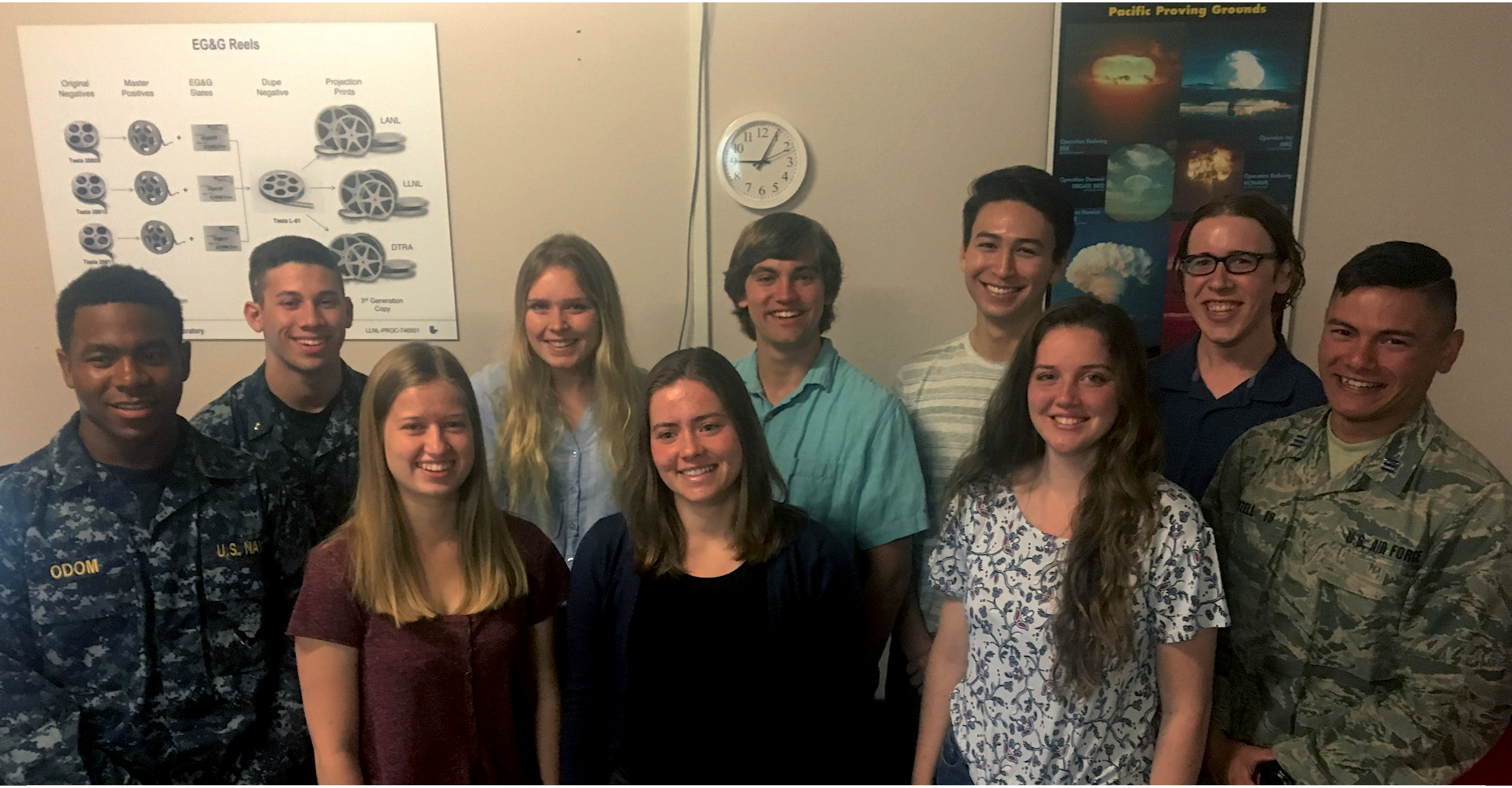
Jason Bender is a new employee in the Design Physics Division. Jason came to us from the NASA Jet Propulsion Lab where he worked on hypersonic aerodynamics. Jason has a PhD in Aerospace Engineering and Mechanics from the University of Minnesota and has exceptional skills in computer programming. During the past year, Jason has been able to take all of our previous codes (written in Visual Basic, Java, Matlab, Python, and Fortran) and convert them into one consistent Python tool that can do the vast majority of our film analysis. Analyses that used to take several hours can now be done in several minutes using Jason's tool.

Support from the military academies and universities

Every summer, cadets from the military academies, as well as other summer students from various universities, come to LLNL to perform a summer project. They help us analyze films and/or develop new automated computer tools that speed up the analysis process.

Many of the students have gone on to write technical papers about their projects for scientific journals and/or have presented their work at national conferences. Several of the students have turned their summer projects into a Master thesis or a PhD dissertation.

This year's HEDP and MARA students working on film project



Deon Odom USNA	Daniel Fisher USNA	Mindy Cook Univ of Utah	Kayla Schroeder UCLA	Adele Myers Pomona	Trevor Pollack UC Davis	Aaron Kawahara Cal Poly	Alea Delmastro Stanford	Lansing Horan Texas A&M	Tyler Buzzell USAFA

Acknowledgement

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  - Mindy Cook (Univ. of Utah)
  - Alea Delmastro (Stanford)
  - Lansing Horan (Texas A&M)
  - Justin Nyugen (Cal Poly)
  - Aaron Kawahara (Cal Poly)
  - Will Mullins (Whitman College)
  - Adele Myers (Pomona College)
  - Trevor Pollack (UC Davis)
- Military Academies (USNA, West Point, USAF)
  - Midshipman David Grunzweig
  - Midshipman Brian He
  - Midshipman Brendon Troutman
  - Midshipman Jonathon Johnson
  - Midshipman Treye Harrison
  - Midshipman Ben Etringer
  - MAJ Thomas McQuary (Faculty)
  - Cadet Hannah Stihel
  - Cadet Connor Dougherty
  - Cadet Alix Idrache
  - Midshipman Steve Callas
  - Midshipman Anthony Giancarli
  - Midshipman Sam Jung
  - Midshipman Frank Smeeks
  - Cadet John Testerman
  - Midshipman Rachael Wible
  - Midshipman Deon Odom
  - Midshipman Daniel Fisher
  - Cadet Tyler Buzzell
- Air Force Institute of Technology (AFIT)
  - MAJ Benjamin Kowash (Faculty)
  - Dr. John McClory (Faculty)
  - COL Matthew Sambora (Faculty)
  - LTC Steve McHale (Faculty)
  - CAPT David Lynes
  - LT Curt Pacleb
  - CAPT Tyler Peery
  - MAJ Matthew Gettings
  - MAJ Christopher Lenyk
  - LT Joseph McKinney
  - CAPT Robert Slaughter
  - CAPT Mike Dexter
  - LTC James Fee
  - LTC Steve McHale (Faculty)
  - 2LT Peter Jackson
  - 1LT Ashley Green
  - MAJ Christopher Charles
  - 2LT Christopher Reinecke
  - LTC Christopher Young
  - CPT Mike Fish
  - CPT Will Johnston
- Other Organizations
  - Lauren Wilson (AFNWC)
  - Vince Jodoin (ORNL)

Participating Organizations

Organization	Function(s)
LLNL	**Project lead**: scan films, analyze films, long-term storage of data, distribute data, provide film-analysis training, re-evaluation of fireball yields, develop new and/or improved post-detonation physics models and weapon-effects models
LANL	Provide films to LLNL, provide data sheets, and photo plans, long-term storage of data, perform peer-review
DTRIAC	Provide films, data sheets, and photo plans, make Quicktime movies available to nuclear weapon complex via STARS system
SNL	Perform peer-review of re-analysis methodology
AWE	Perform peer-review of re-analysis methodology
AFTAC	Perform peer-review of re-analysis methodology
Air Force Institute of Technology (AFIT)	Graduate students from AFIT perform basic research and development of post-detonation physics, and have been major contributors to the development of our film-analysis tools
Various Universities & Colleges	As part of LLNL's High-Energy Design Physics program (HEDP), summer students from various Universities and Colleges work on the film re-analysis project and perform basic research on nuclear weapon effects
Naval, West Point, and Air Force Academies	As part of LLNL's Military Research Associates program (MARA), cadets from the various military academies have worked on the film re-analysis project and have performed basic research on nuclear weapon effects

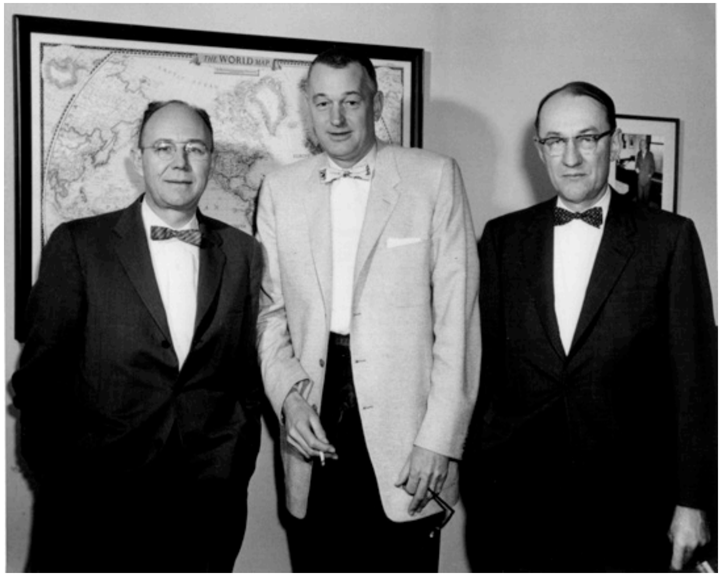
Brief History of Atomic Bomb Photography

- *Photographic and Optics Division,* Los Alamos Laboratories (Aug 1944 to 1947) and the U.S. Army Air Corps (also known as the U.S. Army Air Force).
  - Trinity (1945)
  - Hiroshima and Nagasaki (1945)
  - Operation Crossroads (1946)

During Operation Crossroads, most of the photography was taken from a Type F-13 aircraft, which was basically a B-29 that was retrofitted for 29 camera positions (1-29). Position 1 was in the nose of the plane, and position 29 was in the tail. Most of the scientific cameras started ~2 seconds too late.

Brief History of Atomic Bomb Photography

- *4881st Motion Picture Squadron (*later re-designated *as 1352nd Photographic Squadron)*, U.S. Air Force (Sep 1947 to ~1969). It's production facility was known as *Lookout Mountain Studios*.
  - Primarily responsible for filming scientific footage during Operation Sandstone (1948)
  - Several consultants from EG&G (Edgerton, Grier, and Germeshausen) were hired to help
  - EG&G scientists were responsible for designing the timing and firing electronics
- After Operation Sandstone (1948), *Lookout Mountain Studios* assumed primary responsibility for producing documentary films of the nuclear tests.
- After Operation Sandstone, the primary responsibility for obtaining the scientific films was shifted to *EG&G*
  - Operations Ranger, Greenhouse, and Buster-Jangle (1951)
  - Operations Tumbler-Snapper and Ivy (1952)
  - Operation Upshot-Knothole (1953)
  - Operation Castle (1954)
  - Operations Teapot, Wigwam, and Project 56 (1955)
  - Operation Redwing (1956)
  - Operations Project 57, Plumbbob, Project 58 (1957)
  - Operations Hardtack I, Argus, and Hardtack II (1958)
  - Operation Nougat (1961)
  - Operations Dominic and Storax (1962)



Edgerton, Grier, Germeshausen

Total number of atmospheric scientific films

Type	US	US-UK
Airburst	1	0
Airdrop	52	0
Balloon	25	0
Barge	36	0
Rocket	12	0
Surface	28	0
Tower	56	0
Total Atmospheric	**210**	**0**
Crater	9	0
Shaft	739	24
Tunnel	67	0
Total Underground	**815**	**24**
Total Underwater	**5**	**0**
TOTAL TESTS	**1,030**	**24**

Scientific Film Collection consists of:

210 atmospheric tests
(181 had a measurable yield)

~50 original "scientific" films per shot

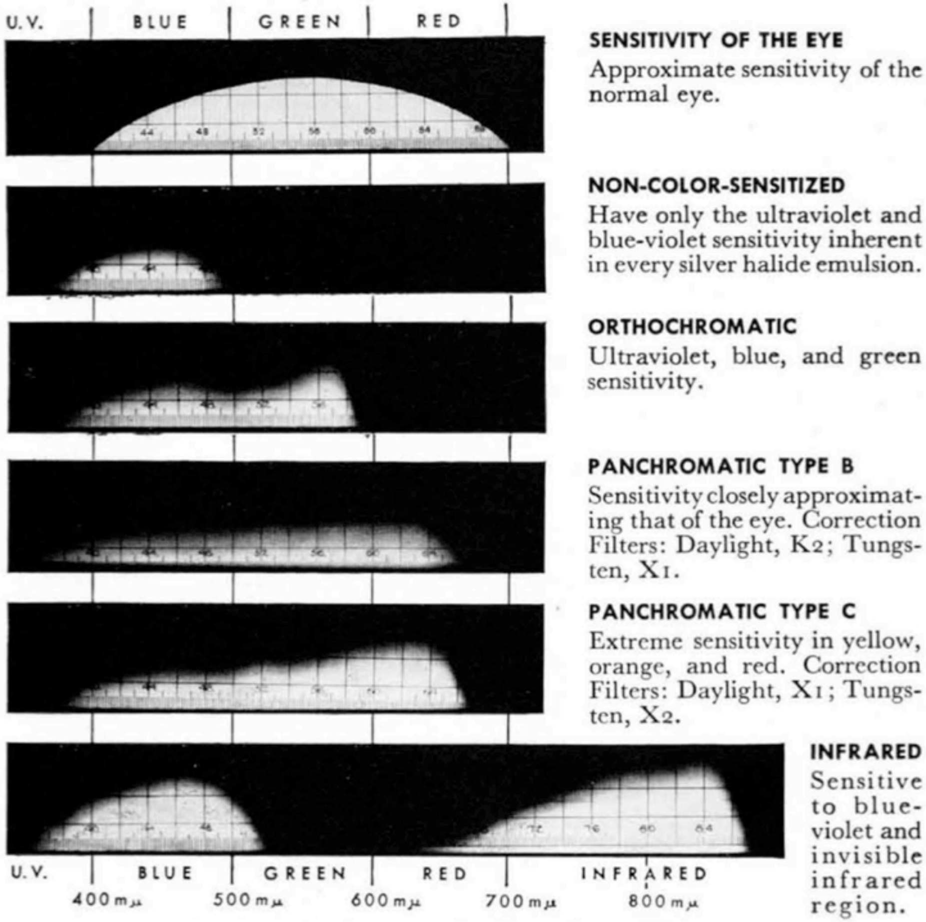
181 x 50 = ~9,000 original "scientific" films

Ave number of frames per film = ~2,000

Total frames = ~18,000,000

EG&G tested ~800 film types during the atmospheric testing era

- EG&G converged onto a small set of film types for different time regimes
- MicroFile (MF)
  - Used to capture fireball growth rate
  - Very fine-grained
  - EI = ~0.1
- Tri-X
  - Used to capture shockwave and early cloud behavior
  - Moderately fine-grained
  - EI = ~320
- BX, SXX, and FX
  - Used to capture late-cloud behavior
  - Coarse-grained
  - EI = ~500+
- IR and XR
  - Used to measure spectral effects
  - Relatively fined-grained
  - EI = ~100

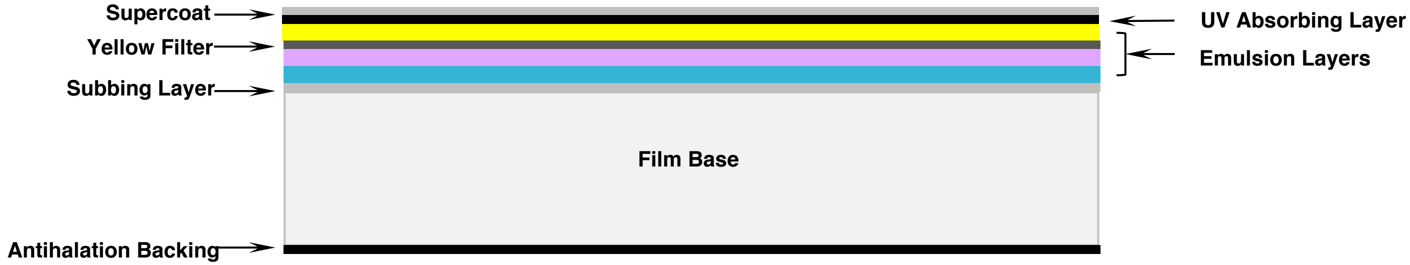


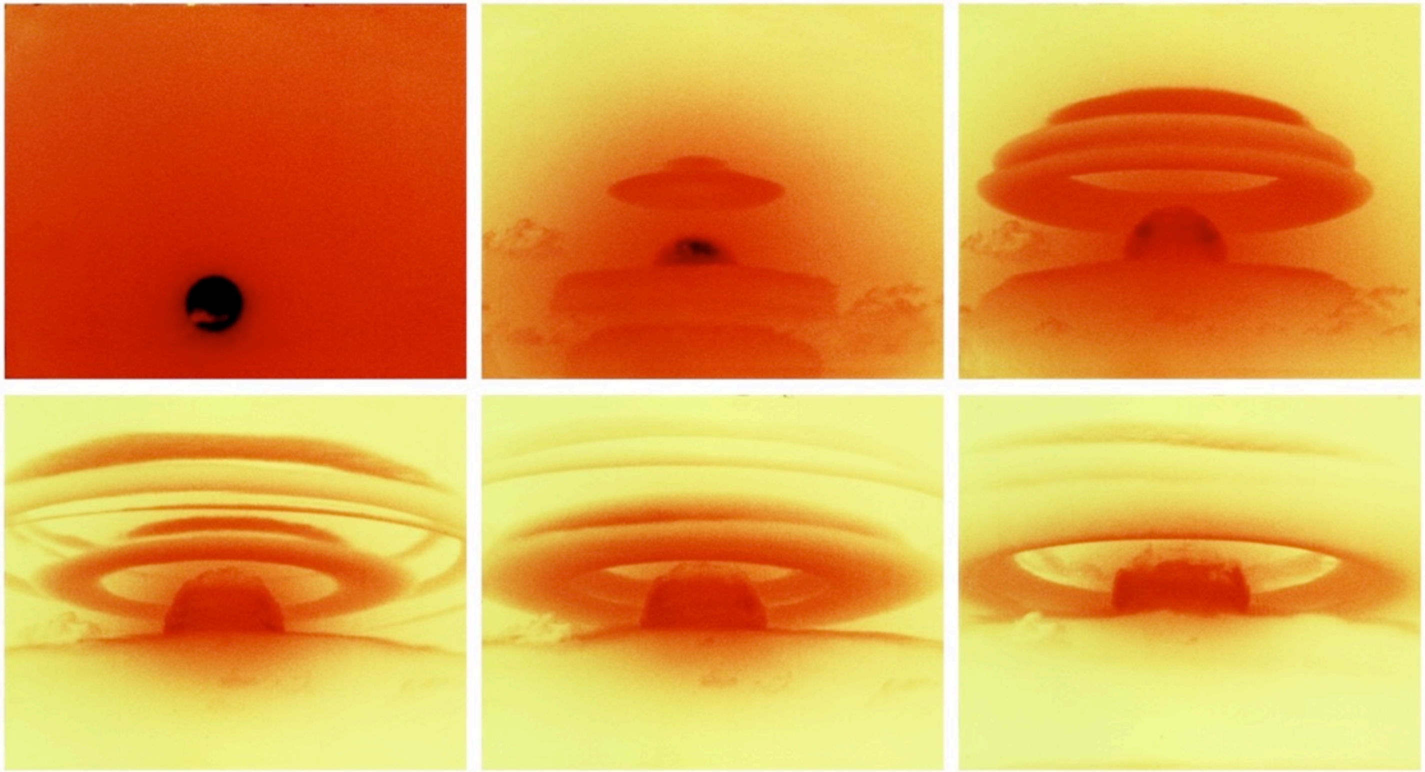
InfraRed (IR) film

Simon 17668 photographed with
Wratten K-2 filter on Super XX

Simon 17669 photographed with
Wratten 25 (Red) on InfraRed film

Extended Range (XR) film

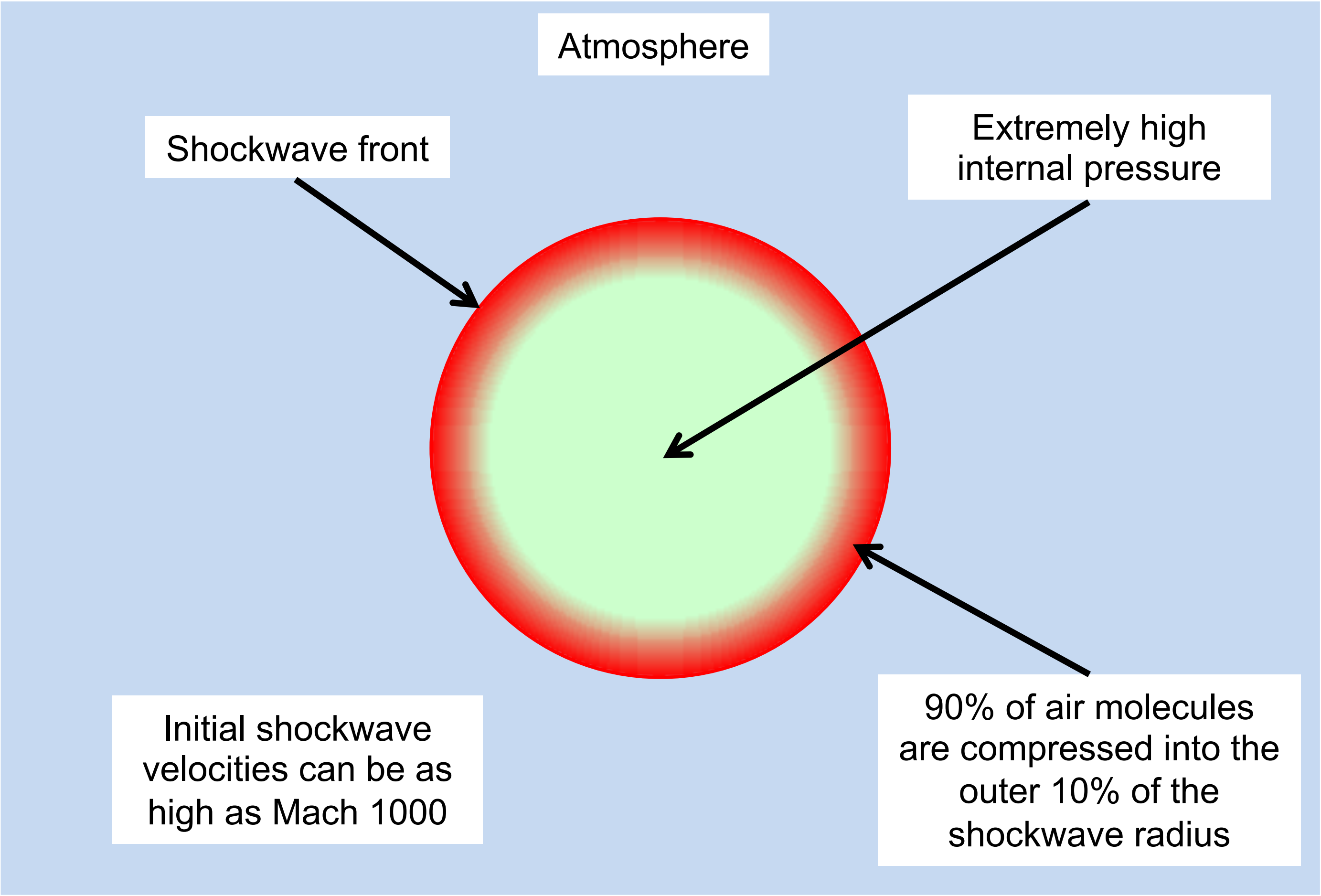




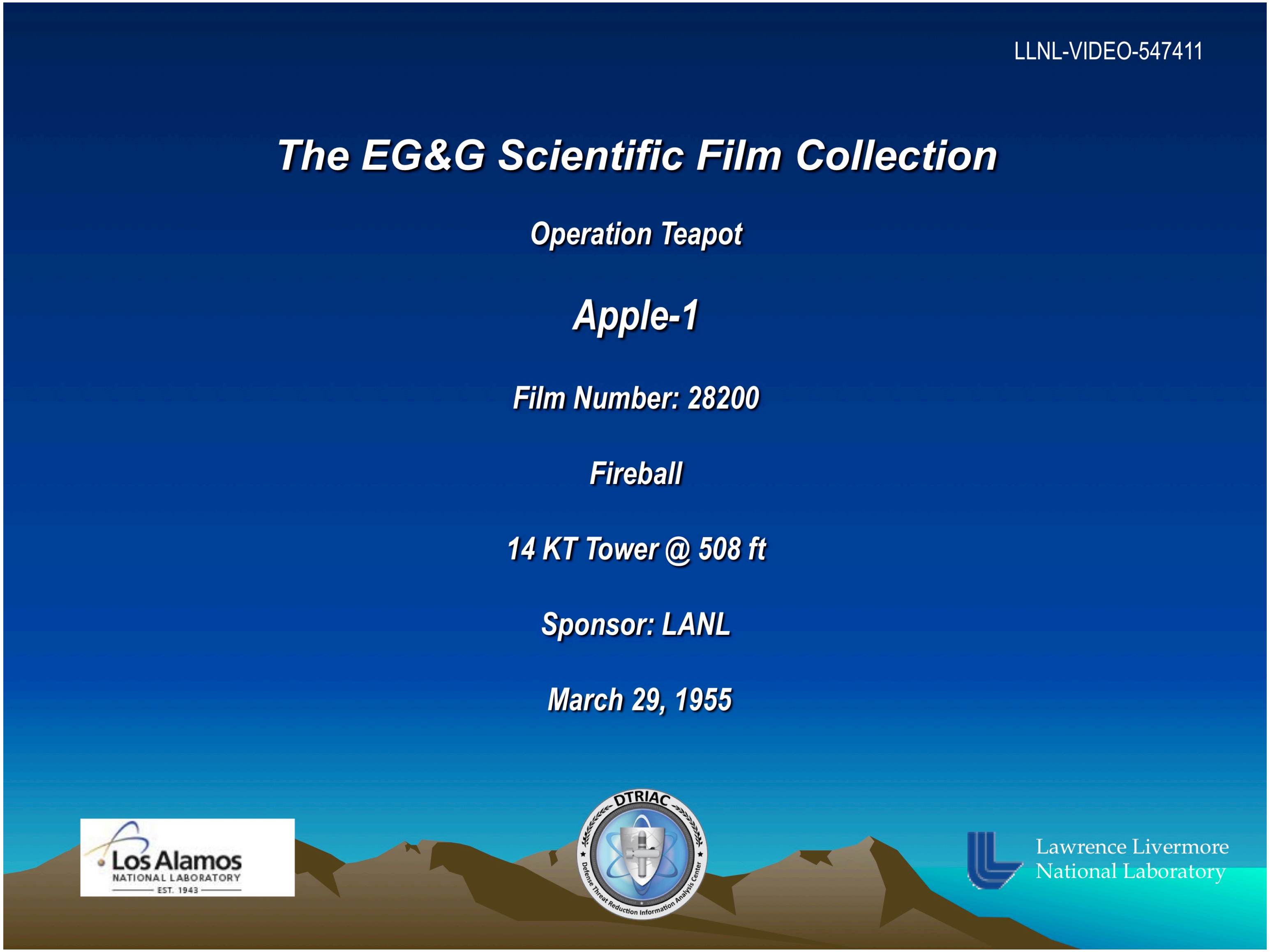
35mm Mitchell camera using XR film

The need for high-speed, high-resolution photography

- A high-speed, high-resolution camera was required to record the growth rate of the shockwave
- The yield can be determined from shockwave radius vs. time data

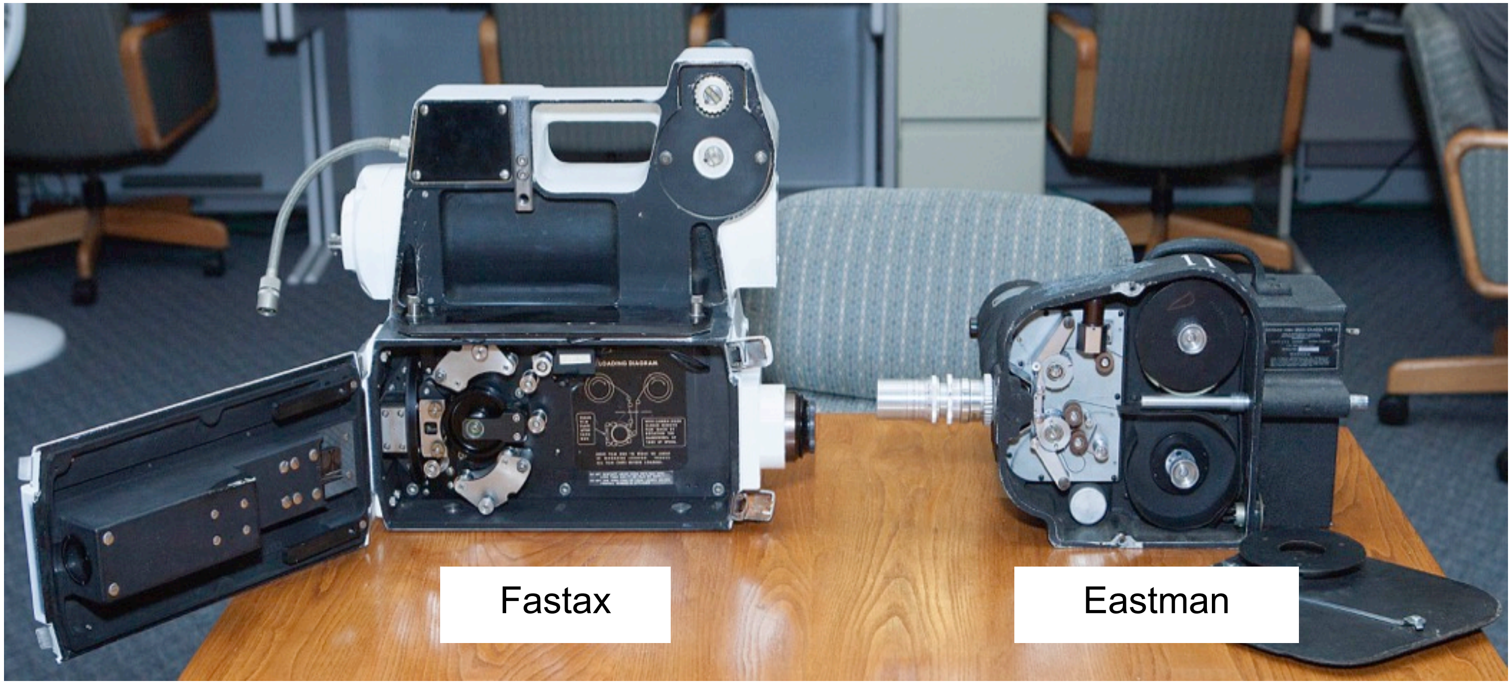


Example of a shockwave



High-speed, rotating-prism cameras

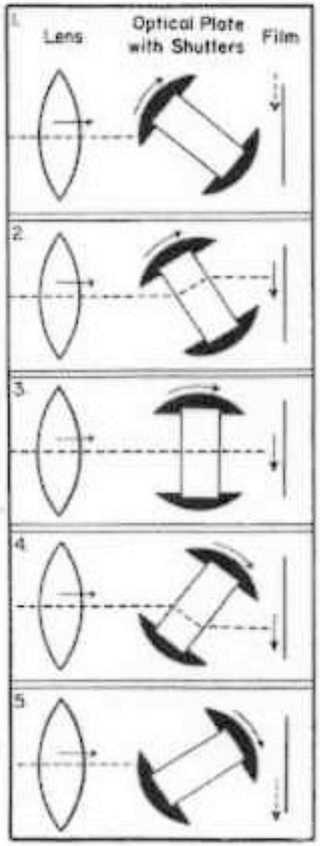
- Eastman High Speed Camera
  - 16mm
  - Speed 500 – 3,000 fps
- Fastax High Speed Camera
  - 8mm, 16mm, 35mm
  - Speed 500 – 12,000 fps



Principle of operation of high-speed prism camera

Principle of the high speed rotating prism camera.

The rotary prism camera allows higher frame rates without placing as much stress on the film or transport mechanism. Unlike a camera with an intermittent movement, the film moves smoothly past a rotating prism which is synchronized to the main film sprocket. Examples of this type of camera are the Eastman High Speed, the Fastax camera and the Photosonics 4B/4C (35mm) and 10B (70mm).



The image-forming light ray enters the lens from the left and is prevented from reaching the film the opaque end of the prism acting as a shutter. (Figure 1)

As the prism rotates, the light enters the glass plate. Due to the angle at which light enters, it is refracted upward. Upon leaving the glass prism, the light is bent again and so it reaches the film at the top. (Figure 2)

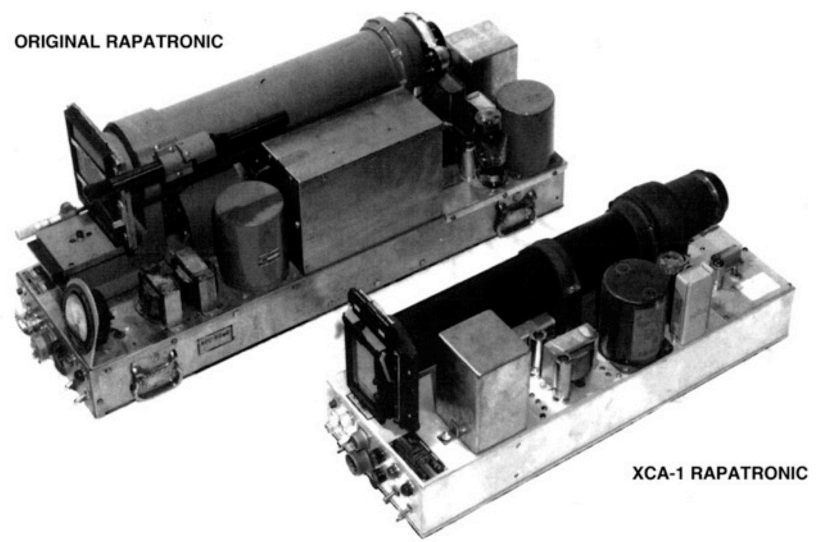
As the optical plate rotates, the angle of entry and exit of the light, and consequently the degree of displacement, become less until the glass prism reaches an exact vertical position, at which point the light ray passes without deflection. (Figure 3).

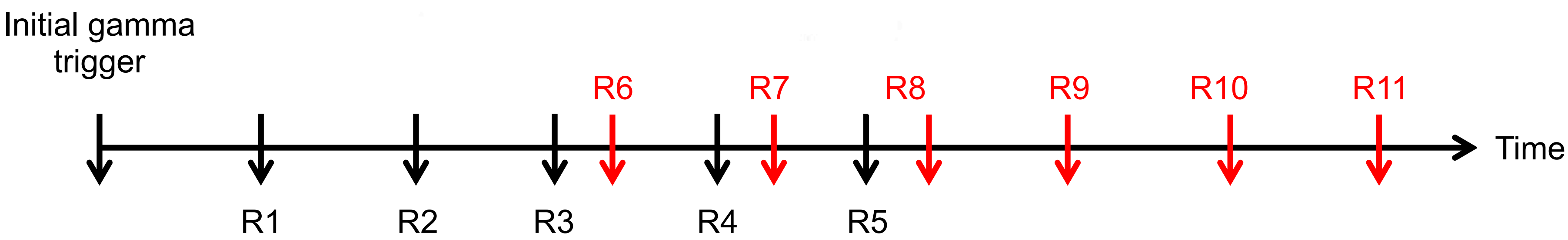
As the prism continues to rotate, the angle of entry and exit of the light become greater with the result that the image continues to be shifted downward (Figure 4) until the prism "shutter" cuts off the light ray. (Figure 5)

As the image shift is continuous and at the same rate of speed and directionas the film movement, a relatively stationary imaage is produced on each frame.

Rapatronic cameras

- These cameras were used to capture the fireball size at ~12 different precise points in time following the detonation. Their magneto-optical shutters could open and close in ~4 μs.
  - Using the initial gamma-ray pulse from the detonation as a trigger, each camera would take a *single* snapshot of the fireball after some pre-set time delay



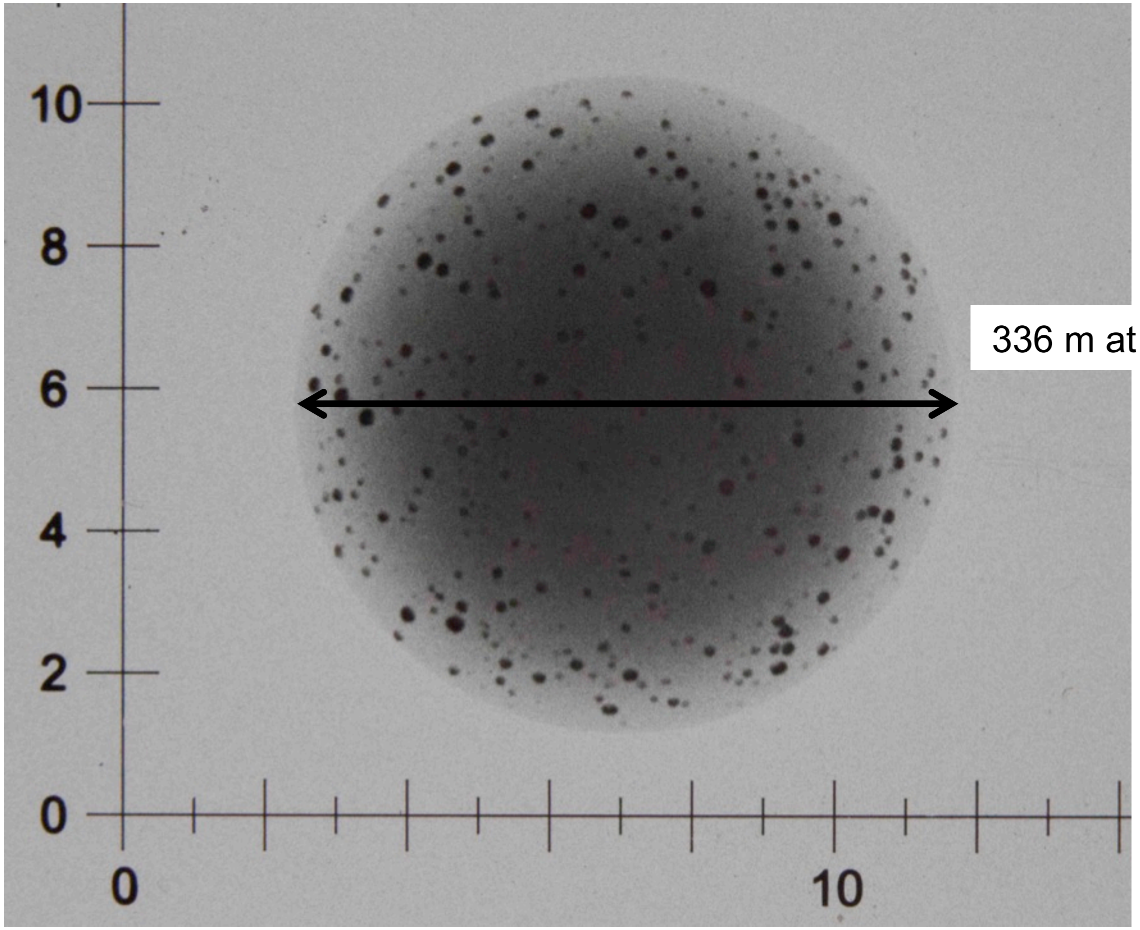


Example of Rapatronic plate at early times

Whitney, 19 kt
Tower shot at NTS

Shows X-ray diffusion process during early evolution of a fireball

Example of a Rapatronic plate at later times



336 m at 0.03 sec

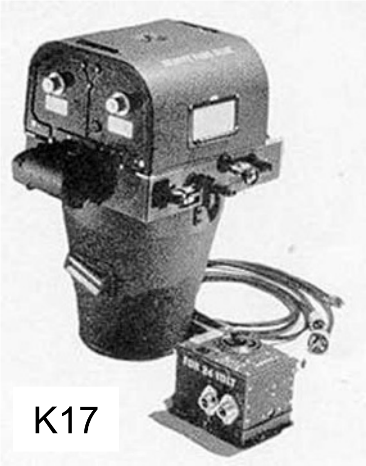
Allows a precise measurement of fireball size at a precise time following a detonation.

Climax, 61 kt Airdrop at NTS

Shockwave, early-cloud and late-cloud cameras

- EG&G used a variety of cameras that ran at speeds of 1 to 125 fps
  - 35mm Bell and Howell Standard
  - 35mm Mitchell High Speed
  - 35mm A-5 Camera
  - 35mm Robot Camera
  - 70mm Cloud Camera
  - 70mm EG&G Camera
  - 70mm Hulcher Camera
  - 70mm Mauer
  - K17 Aerial Camera

35mm Mitchell

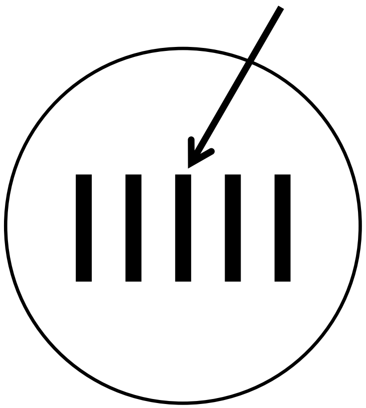


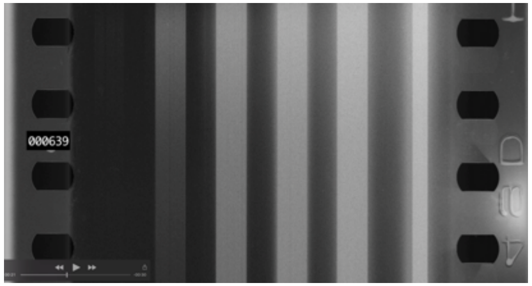
K17

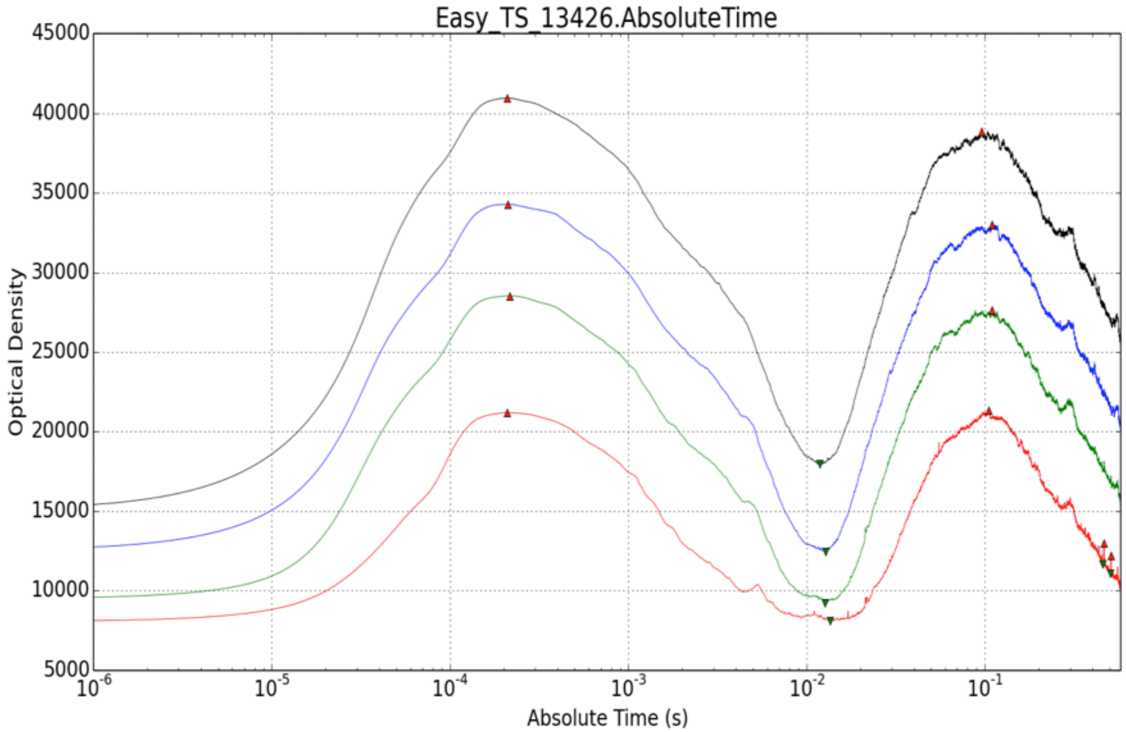
70mm Hulcher camera

Slit camera were used to record the time-dependent light output

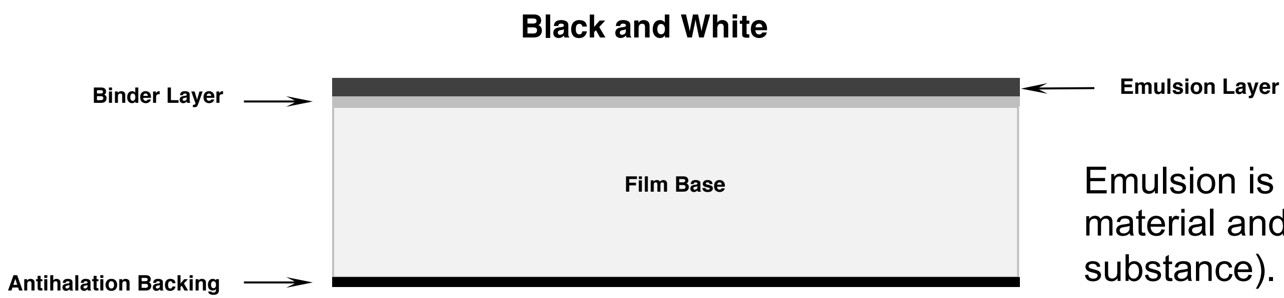
- General Radio
  - 35mm
  - ~400 fps







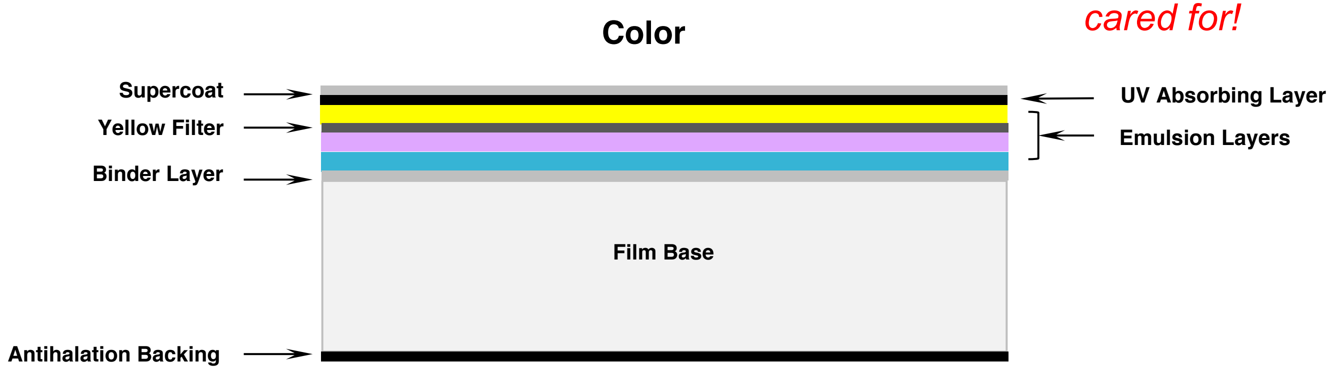
Films are "not forever"



Emulsion is comprised of light-sensitive material and gelatin (an organic substance).

The film base is also an organic substance (either cellulose nitrate, cellulose acetate, or polyester).

All organic substances will eventually decompose no matter how well they are cared for!

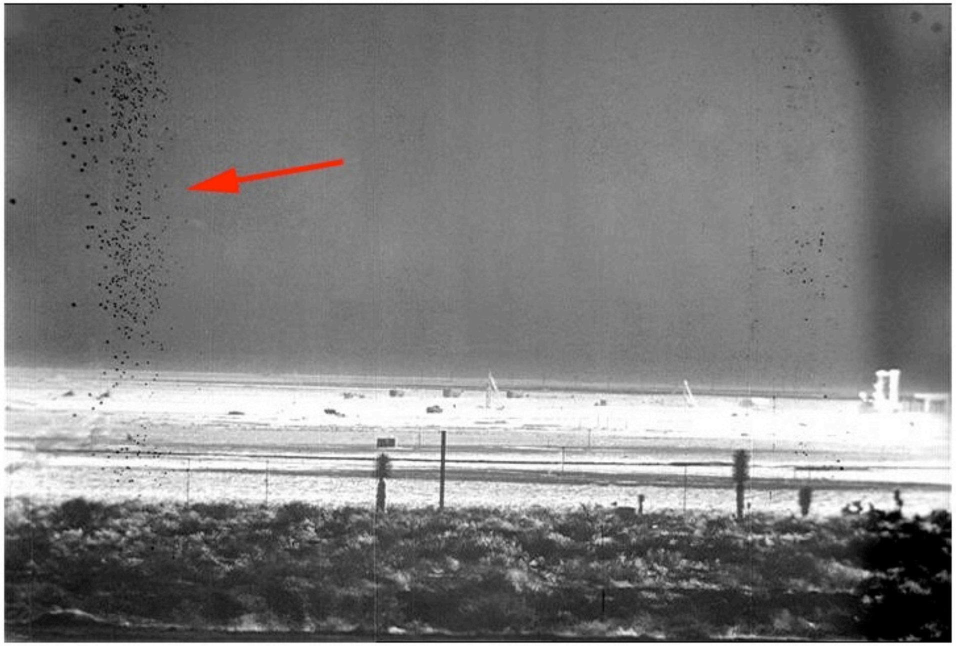


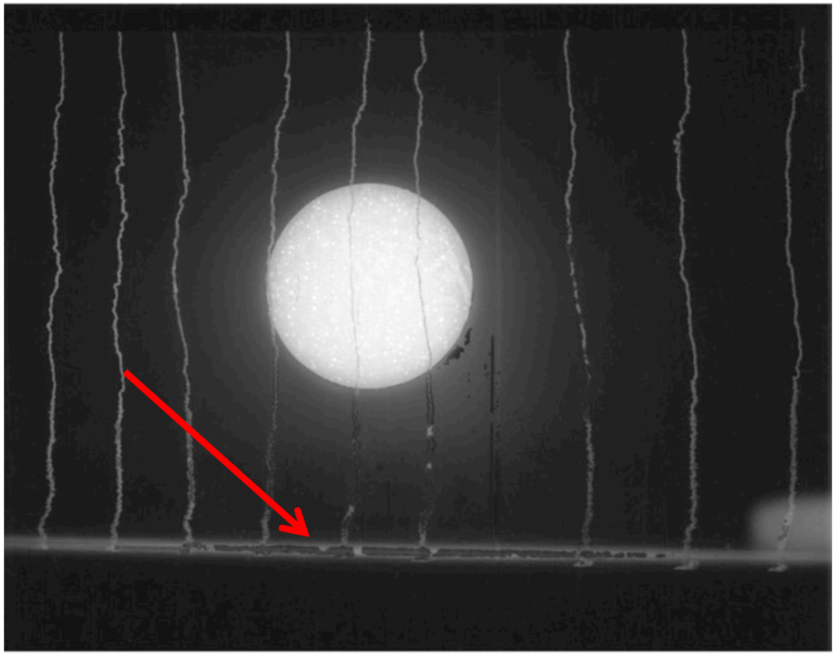
Life expectancy of a film

Recommended Conditions for Storage
per ANSI Standard IT9.11-1992

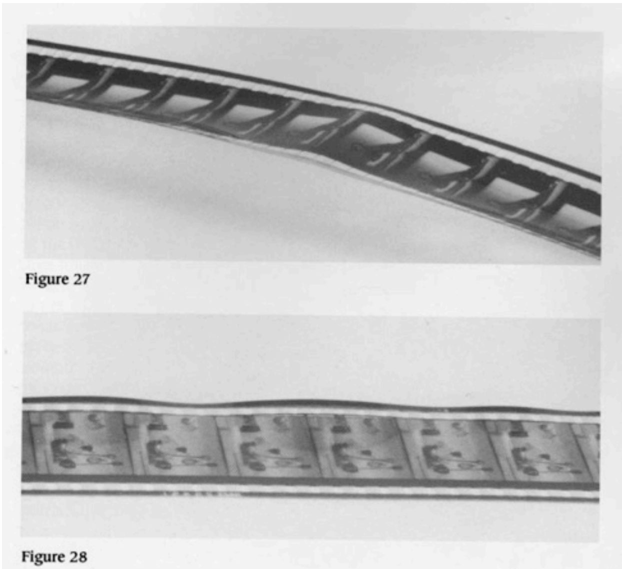
Film Type	Medium-Term Storage		Extended-Term Storage		Life Expectancy
	Relative Humidity Range (%)	Maximum Temperature	Relative Humidity Range (%)	Maximum Temperature	
B/W Acetate	20-50	77 F	20-30	70 F	100 years
B/W Polyester	20-50	77 F	20-30	70 F	500 years
Color	20-30	50 F	20-30	36 F	a few years

With age, the emulsion begins to flake off

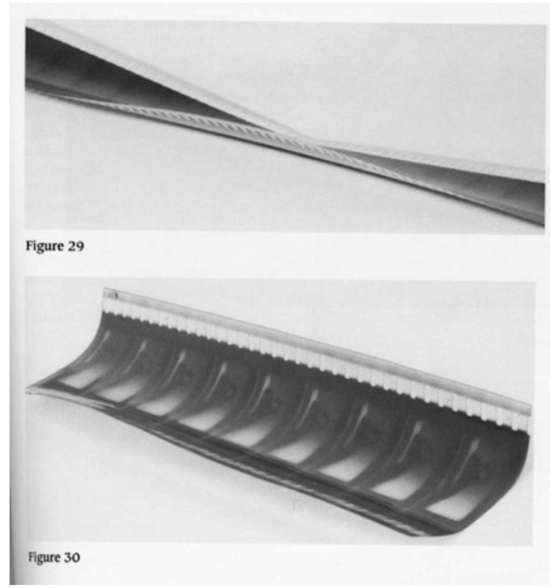




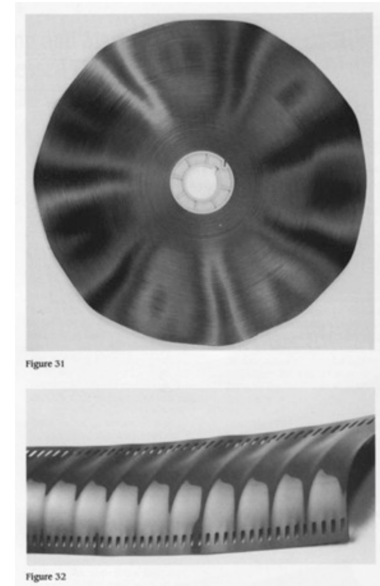
Film damage due to film shrinkage



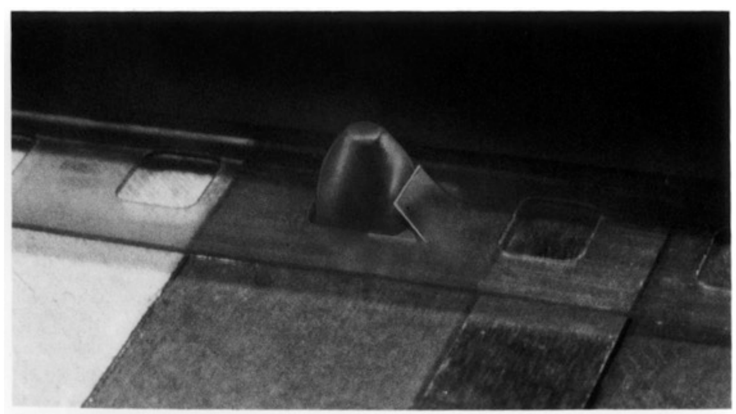
Bucking and Fluting



Twist and Curl



Spoking and Embossing



Many of the EG&G films have shrunk as much as 2.0 %.

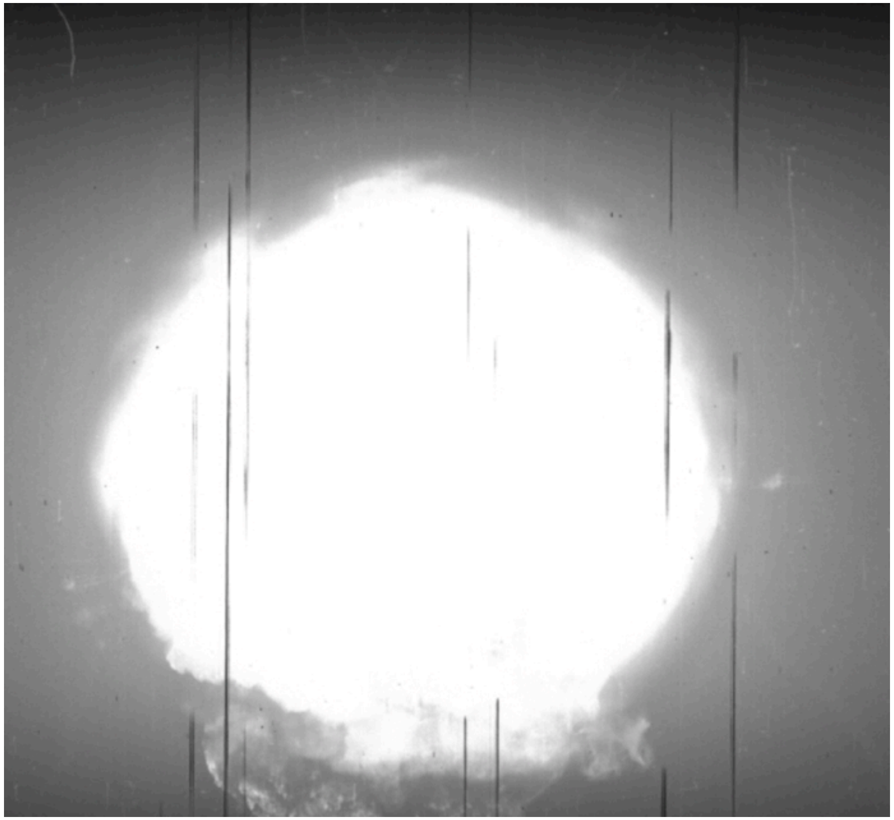
If projected, the perforations will break.

Color fading from a color negative

Scratches on the original films

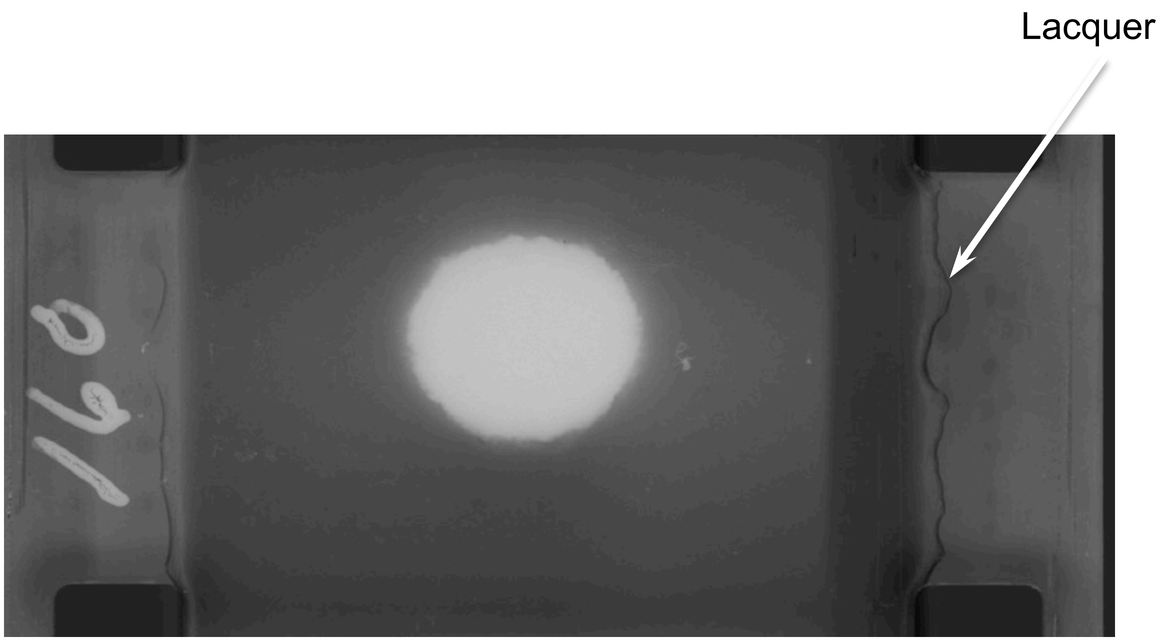
Fig. 5.2 Kodagraph Film Reader

Kodagraph



EG&G analyzed the negatives in order to obtain a true reading of the optical densities. Even though the negatives were lacquered, they still got scratched.

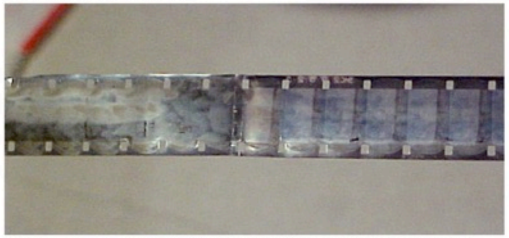
Lacquer was used to protect the films



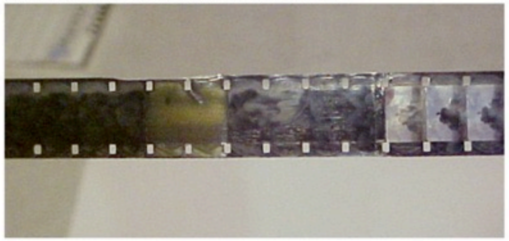
Baker_BJ 10502

EG&G used to lacquer the negatives in order to prevent them from getting scratched, dirty, etc. After the negatives were analyzed, the lacquer was usually removed.

D-20-002 Operation Greenhouse OR -perf damage in leader area within body of roll. Also shows residue from film lacquer.



Film lacquer which had been appliedto the film interacted with cleaning solvents leaving this mess. The resulting chemical soupmay be accelerating the decomposition of the film.



Cleaning a lacquered film can be harmful to the film.

Chemical decomposition of acetate-based films

As acetate film decays, it shrinks, loses flexibility, curls, and wraps.

Safety motion picture film (so called because it is not flammable like nitrate base film) was almost always made of cellulose acetate plastic. A key issue in preserving this type of film is controlling the form of decay known as "vinegar syndrome." More properly referred to as acetate film base degradation, vinegar syndrome is a very similar problem to nitrate base deterioration. Its causes are inherent in the chemical nature of the plastic and its progress very much depends on storage conditions.

The symptoms of vinegar syndrome are a pungent vinegar smell (hence the name), followed eventually by shrinkage, embrittlement, and buckling of the gelatin emulsion. Storage in warm and humid conditions greatly accelerates the onset of decay. Once it begins in earnest, the remaining life of the film is short because the process speeds up as it goes along. Early diagnosis and cold, moderately dry storage are the most effective defenses.

Chemical decomposition of nitrate-based films

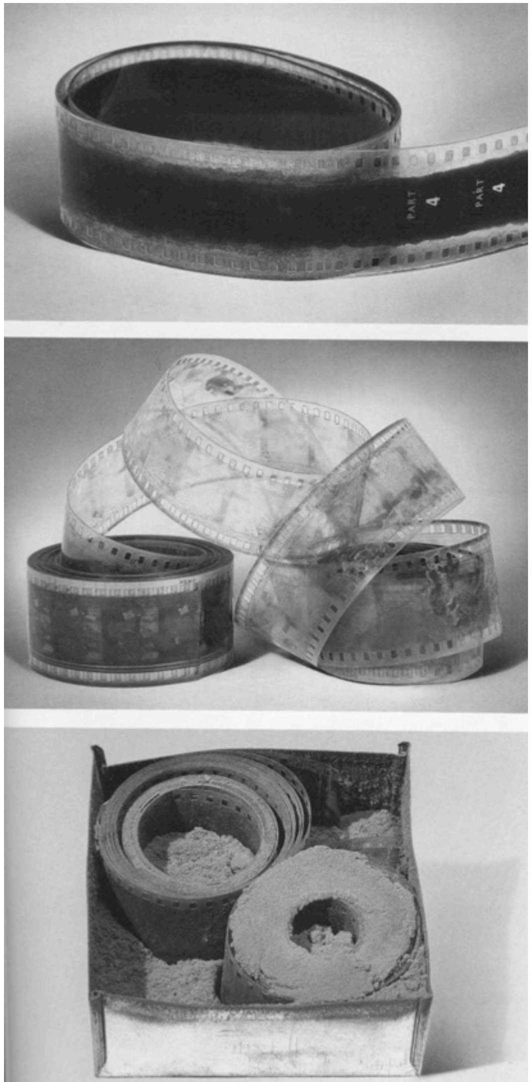


Figure 19

While it deteriorates, nitrate-base film makes a kind of pressure cooker of the film can in which it rests, especially when it's taped closed. If the gases can't escape, heat builds and spontaneous combustion may not be far behind. Therefore, nitrate film **must never** be closed in.

Escaping toxic gases (powerful oxidizing agents) can attack nearby acetate- and polyester-base films, so store nitrate films in their own special place and not in a place too heavily concentrated.

If the conditions are right, their image layers may last for decades or generations. Because of their great value, many nitrate-base films have been reprinted on current longer-lasting safety base. Somewhere, nitrate film is still with us, so we offer a few more comments.

Probability of Rapid Decomposition

If you store old nitrate-base films, the first thing you need to check is the temperature of the storage area. High readings of the temperature and/or the relative humidity are unfavorable to nitrate and to other films. Are the by-products of decomposition being discharged from the storage area? Is there too much nitrate in a confined area? The more rolls collected in one place, the greater the chance of trouble. With nitrate film, it's important to design separate and specialized storage compartments.

Nitrate-based films should be separated from acetate- and polyester-based films

Cellulose nitrate was the first material used for film base.

Discontinued by 1949 because it was highly flammable. Nitrate film continued to be used as late as 1952.

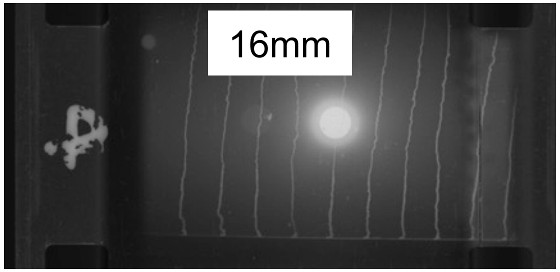
Chemically unstable if stored in damp environment.

Self-igniting if stored in hot environment.

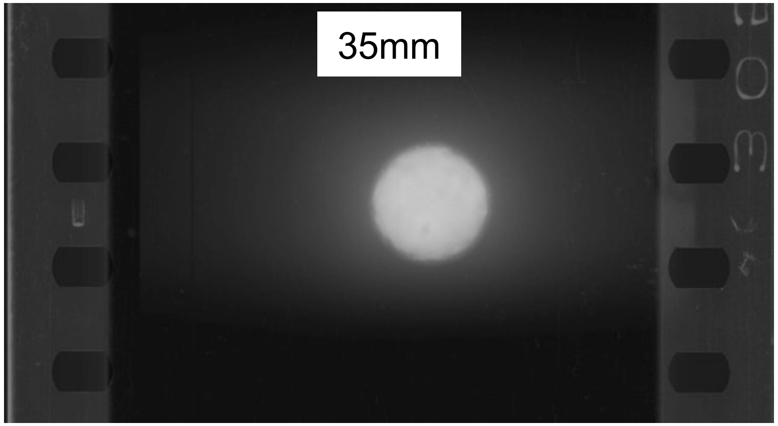
Decomposition of Trinity nitrate films

Golden Eye high-resolution digital film scanner

- True frame-by-frame scanner
  - 12-bit BW line camera
    - Used for 16mm, 35mm, and 70mm
    - Optical Density Range: 0 to ~3.6
  - 8-bit RGB line camera
    - Used for 16mm and 35mm
    - Optical Density Range: 0 to ~1.8
- Spatial Resolution
  - 2K for 16mm film
  - 4K for 35mm films
  - 8K for 70mm films
- Sprocket-less system
- Non-contact gates



1831 by 883 pixels: 3.2 Mb



4015 by 2186 pixels: 17.6 Mb

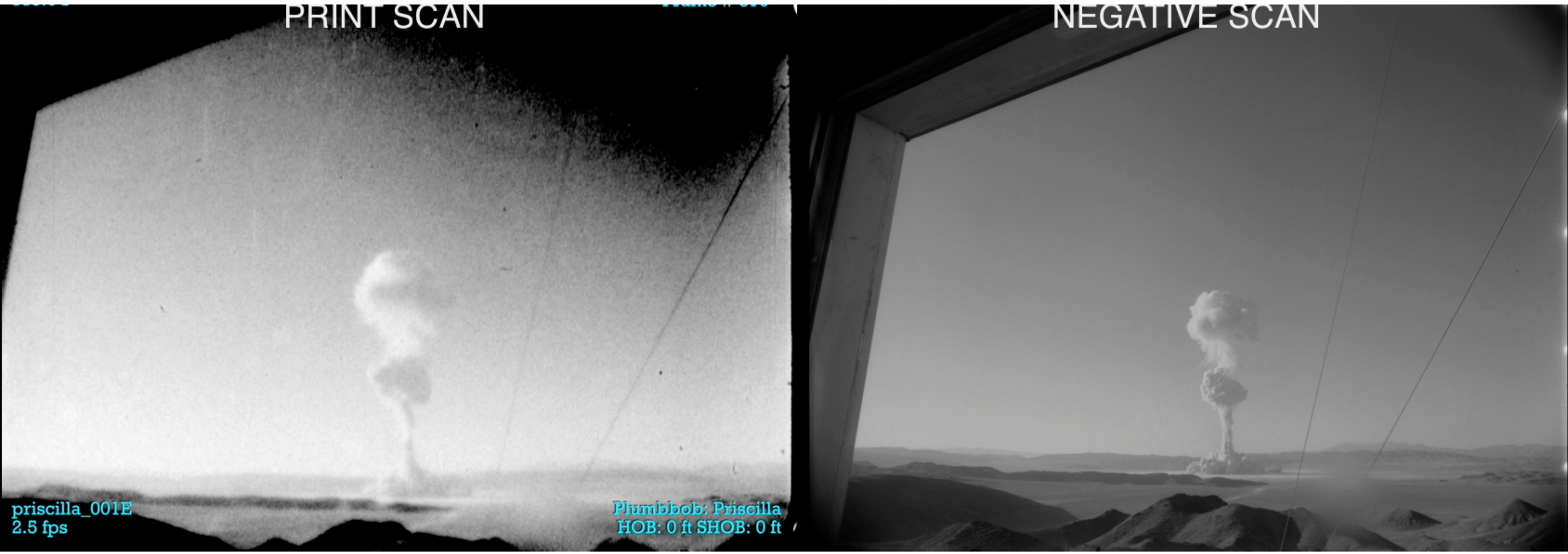
Archival and scientific objective

- High-resolution digital scanners have the ability to make a *near-exact copy* of the original negative by recording the optical density at a large number of pixel locations on each frame.
- Exact copies, in an optical density sense, cannot be accomplished by doing *film-to-film transfers* since print stocks and negatives stocks have different optical characteristics

Original Negative

Frame File

Negative vs. print



Overall Objectives

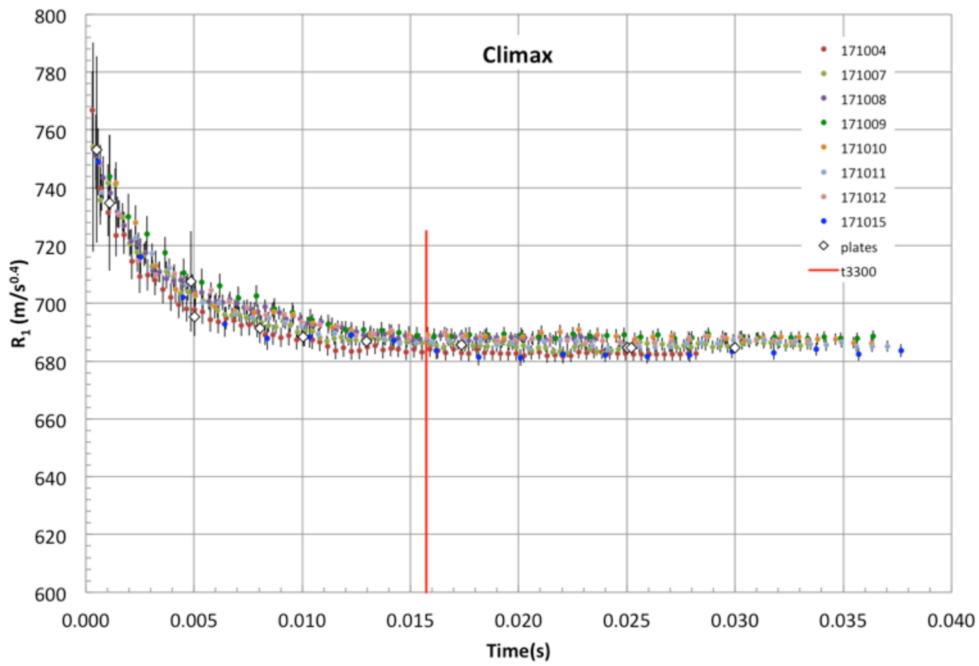
- Scan the atmospheric nuclear tests films and archive data
- Re-analyze the films and extract benchmark data for:
  - Yield determination
  - Post-detonation physics
    - — Shock phenomenon
    - — Light output
    - — Thermal blast
    - — Mushroom cloud formation
    - — Nuclear fallout
- Share data with the nuclear weapon complex
- Use data to benchmark:
  - Weapon design codes
  - V&V post-detonation physics models

Primary Objective: More accurate yield estimates

- By using computer-aided analysis, we have been able to obtain more accurate and more precise yield estimates. In most cases, the yield uncertainty has been reduced from ~7% to less than 1%.

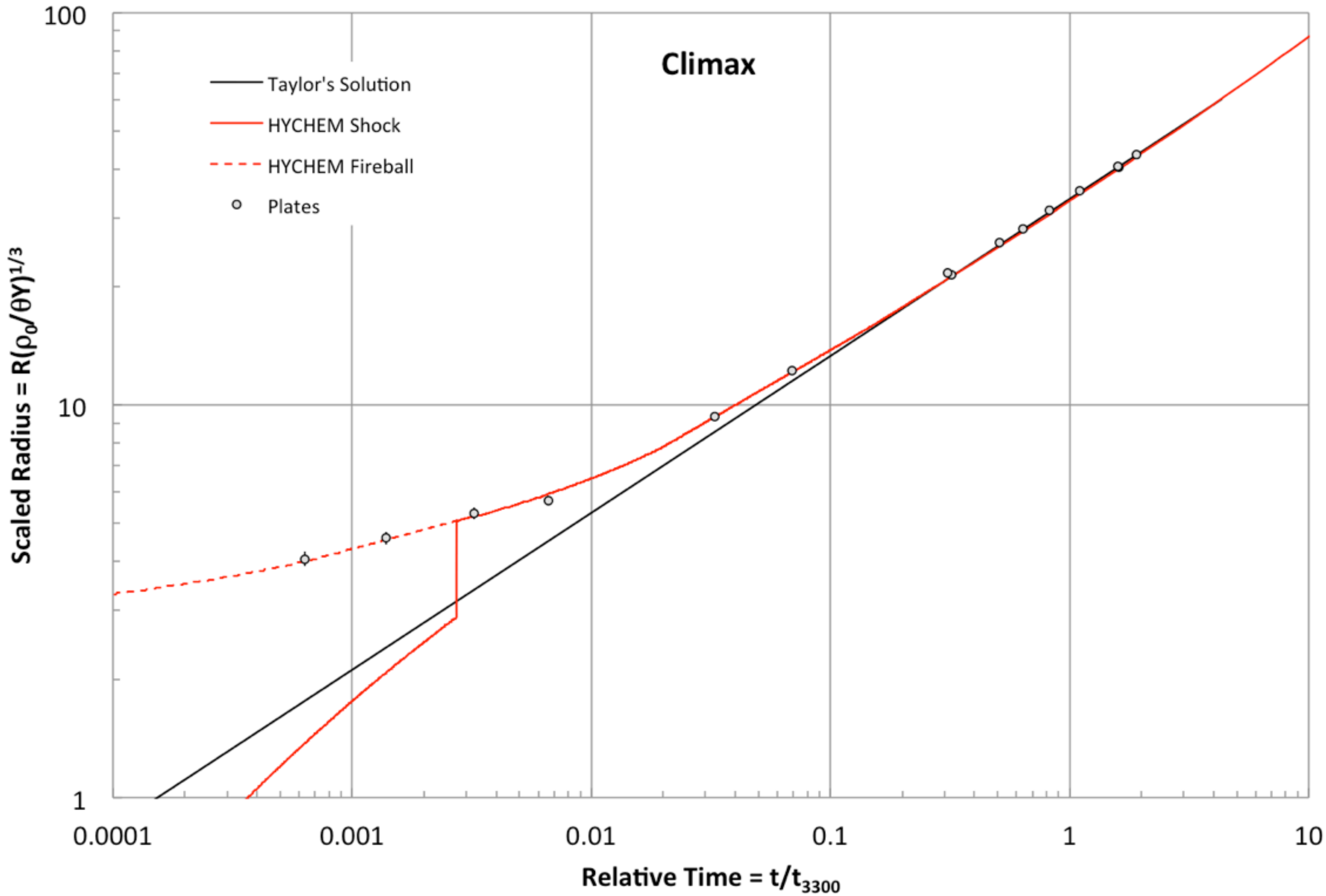
	Scaled_Yield	1-sig
171003	61.09	1.0
171004	57.48	0.26
171007	58.44	0.43
171008	59.52	0.20
171009	59.94	0.24
171010	59.87	0.46
171011	58.77	0.39
171012	59.41	0.40
171015	57.25	0.37
171053	58.39	0.80
171055	58.76	0.73
171056	61.47	0.81
171057	60.73	0.91

SCALED YIELD	=	59.02	0.10
Air Density (kg/m3)	=	1.0055	0.50E-02
Theta	=	1.0000	
YIELD (kt)	=	59.35	0.31

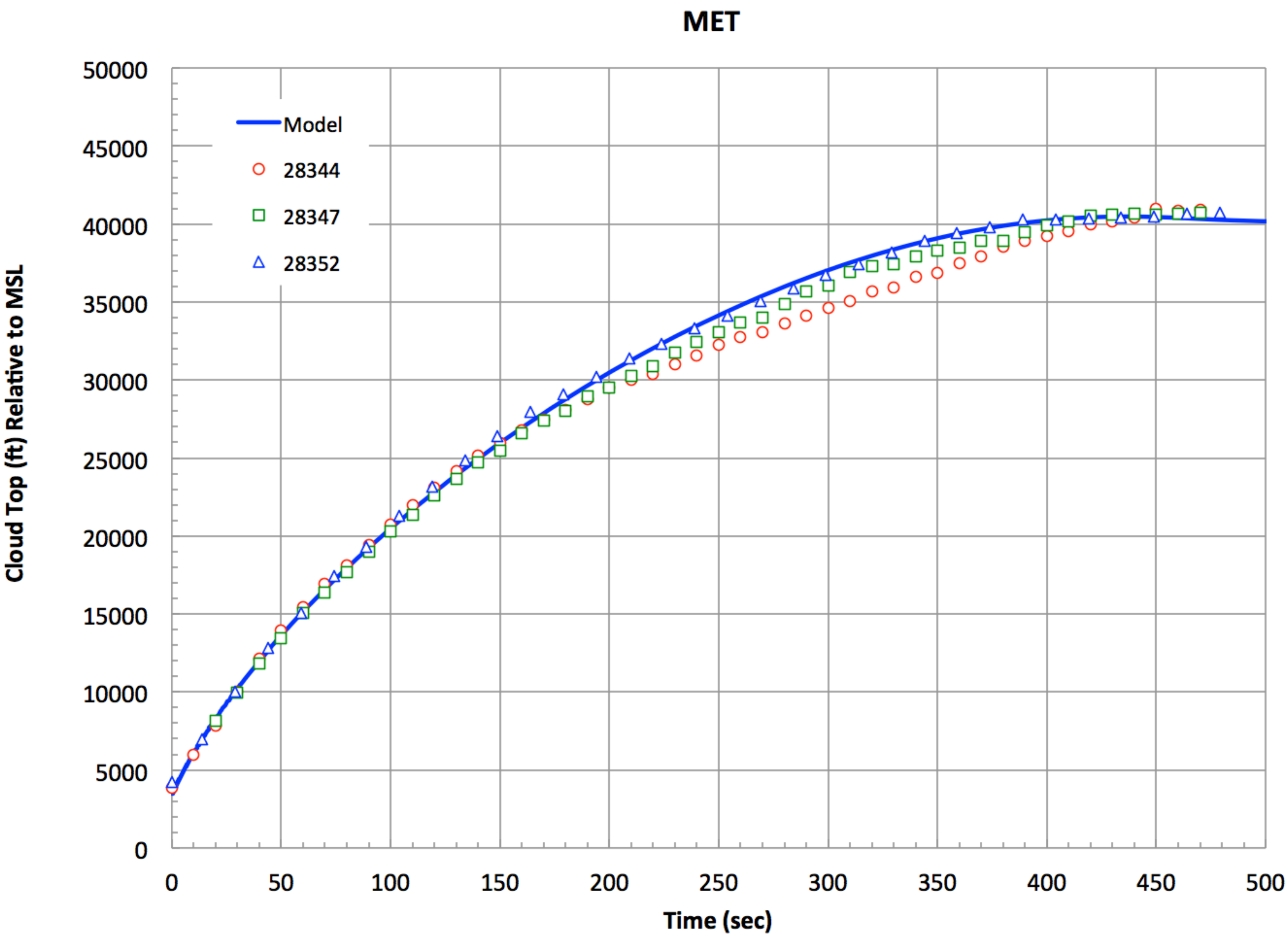


Shockwave phenomenon and code validation

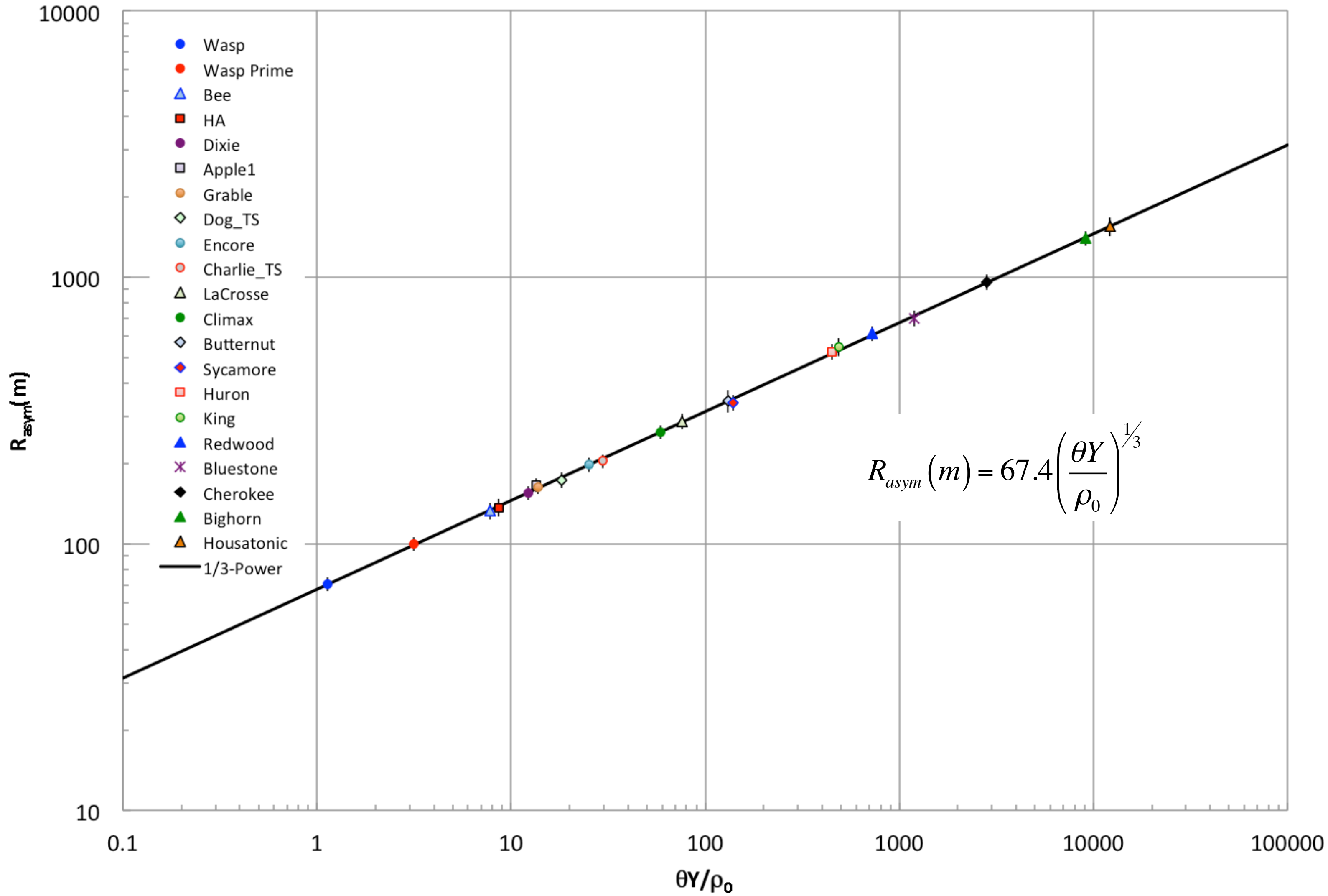
- Using the new film data, we have been able to demonstrate that our computer codes are fairly accurate.



Early-cloud and late-cloud behavior and code validation

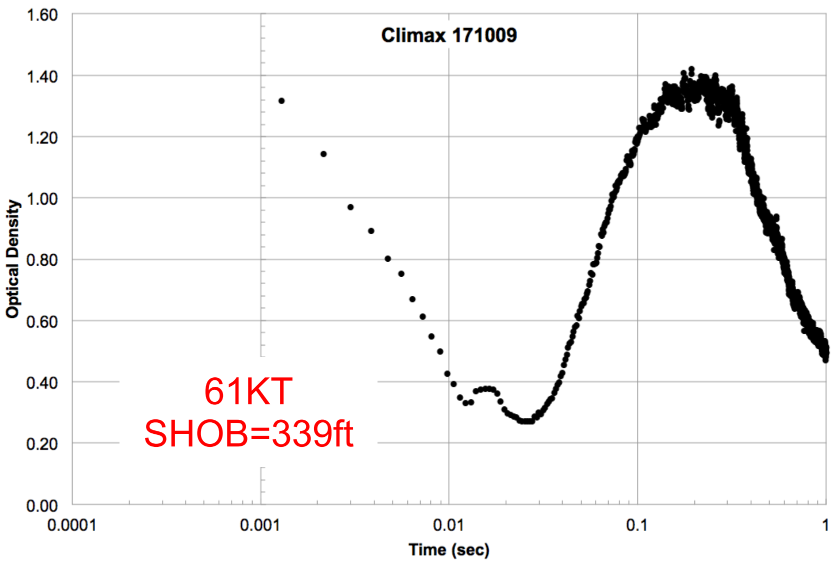


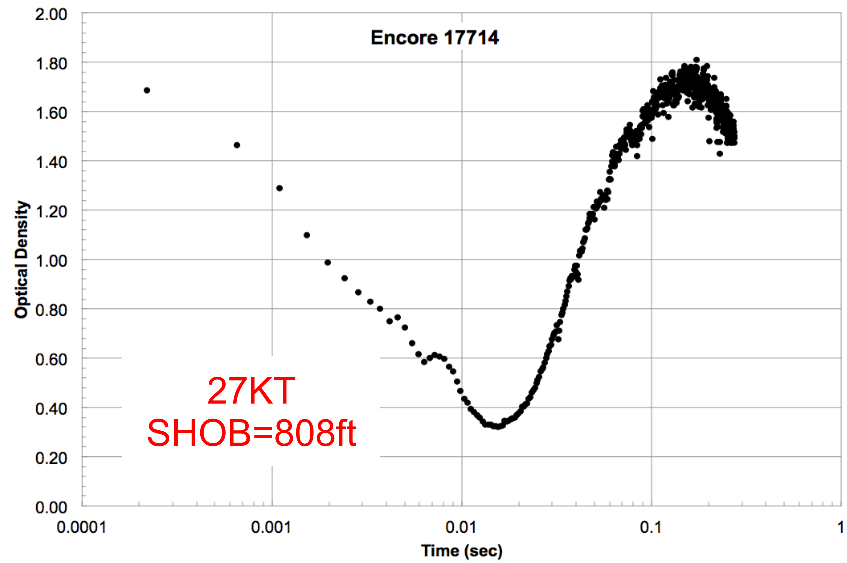
New film data has resulted in greatly improved correlations

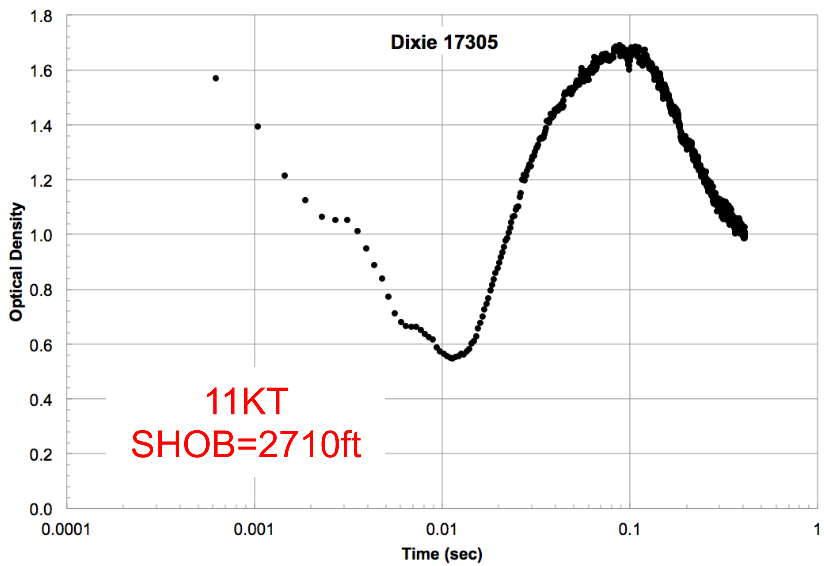


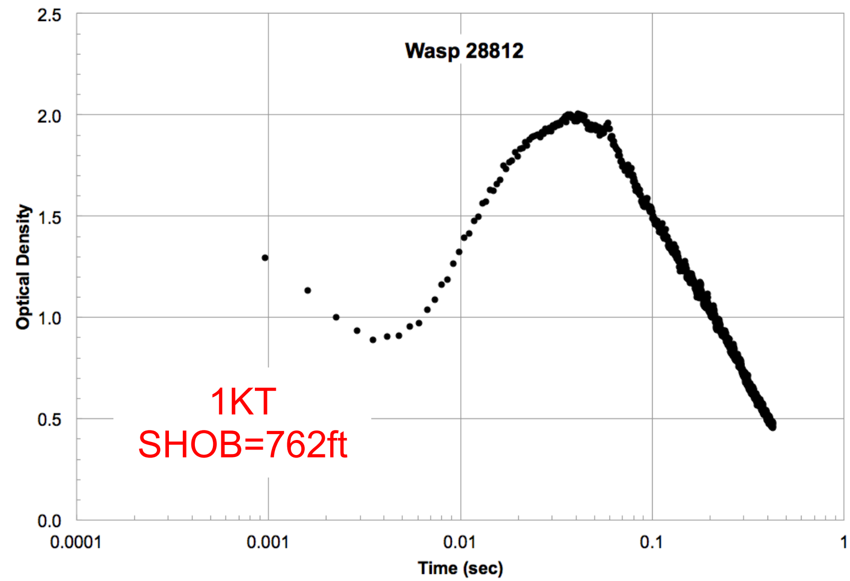
Light output for airdrops

Preliminary Results



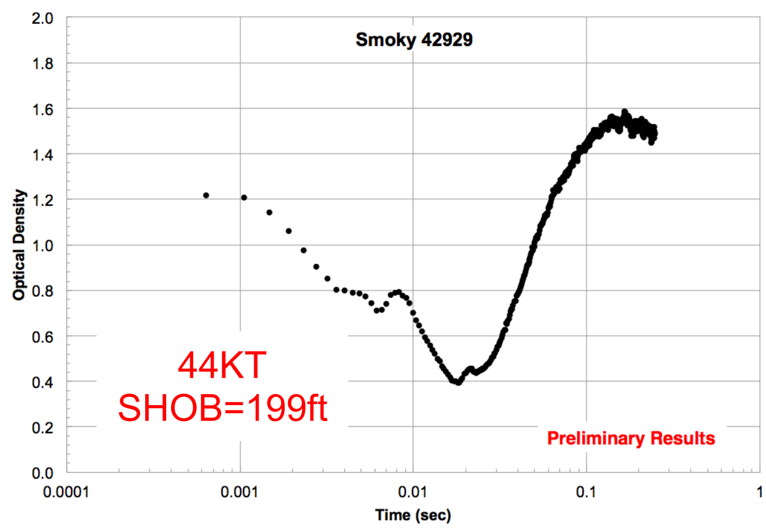


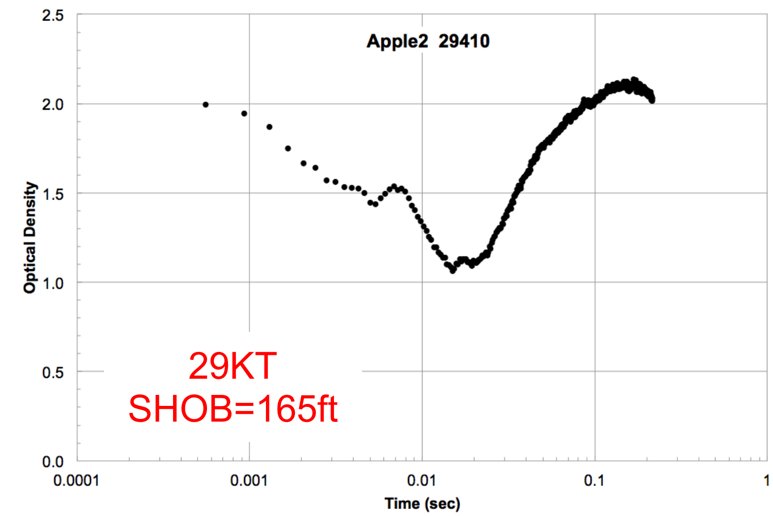


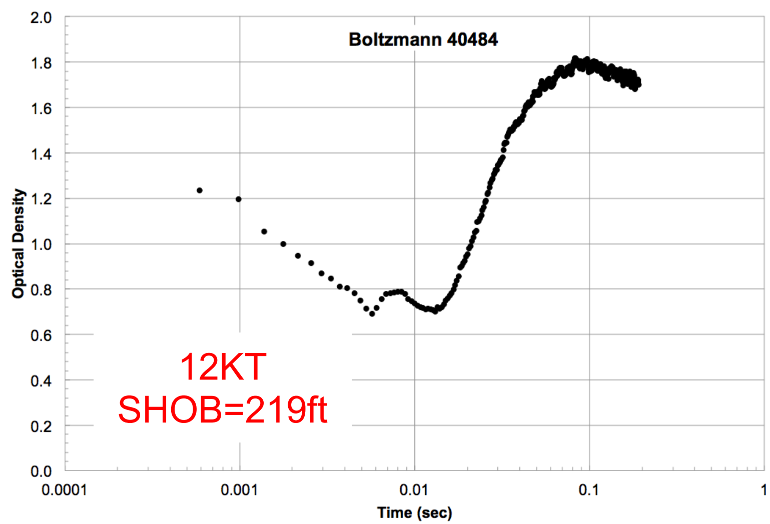


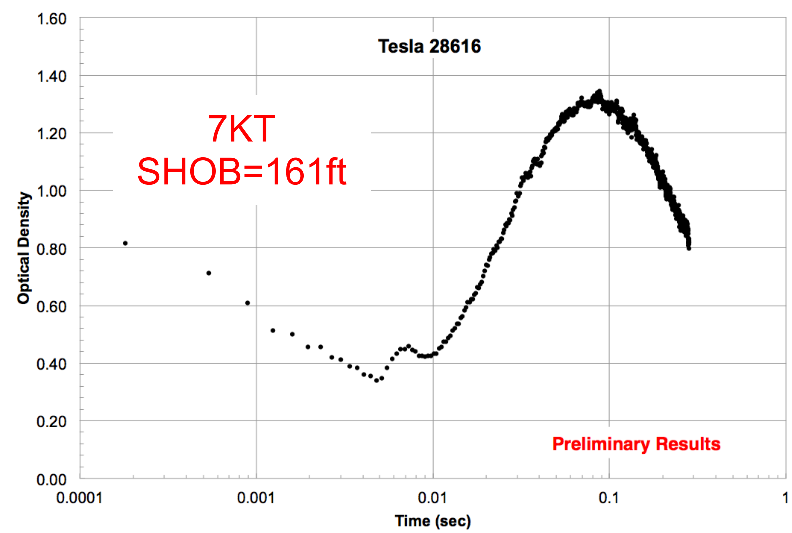
Light output for tower shots

Preliminary Results



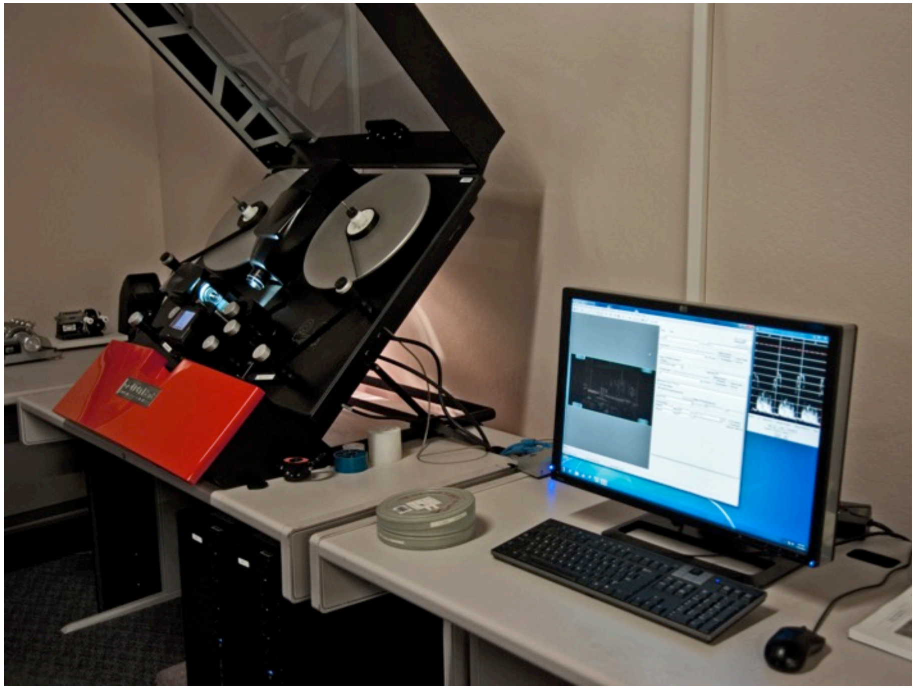






Project Status

Source	Films	Frames
Above-Ground Tests	3865	6,600,000
Historic Films	122	650,000
Total	3987	7,250,000



Links to some sites that contain more info about the project

- An article and a video about the film project was written by Wire.com:
  - http://www.wired.com/2015/12/nuclear-films/
- Los Alamos National Lab dedicated an entire volume of their monthly publication to the film project:
  - http://www.lanl.gov/discover/publications/national-security-science/2015-july/index.php
- Some of the films have been posted on the LLNL YouTube site:
  - https://www.youtube.com/playlist?list=PLvGO_dWo8VfcmG166wKRy5z-GIJ_OQND5
- The CBS Sunday Morning Show recently broadcast a story about the film project:
  - https://www.cbsnews.com/news/nuclear-explosions-lawrence-livermore-national-laboratory-film-preservation/