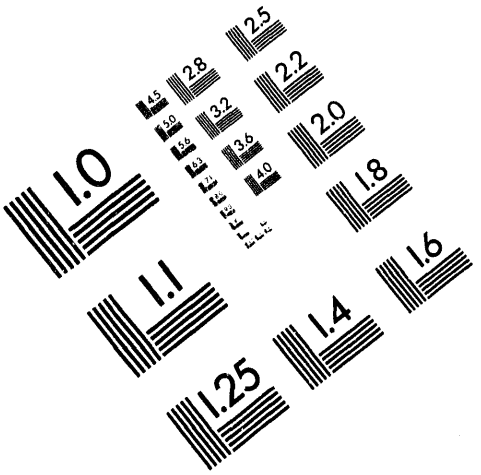


AIIM

Association for Information and Image Management

1100 Wayne Avenue, Suite 1100
Silver Spring, Maryland 20910

301/587-8202

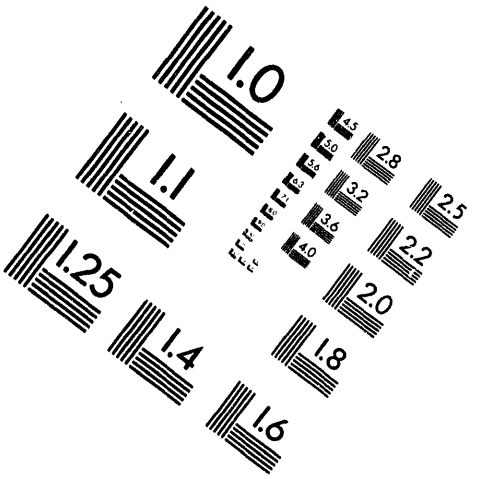
Centimeter

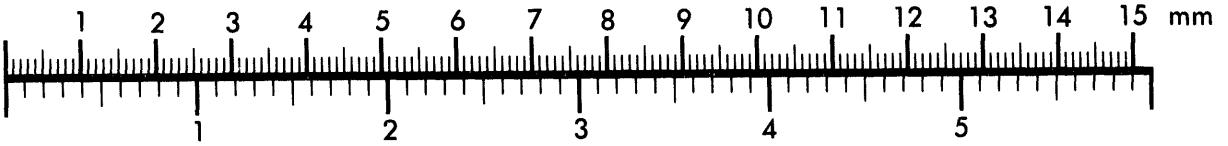
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 mm

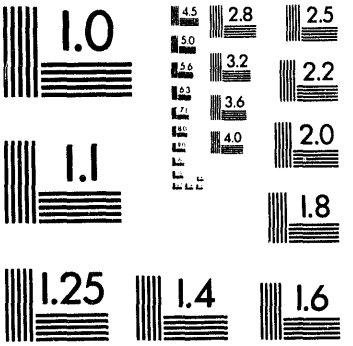
1 2 3 4 5

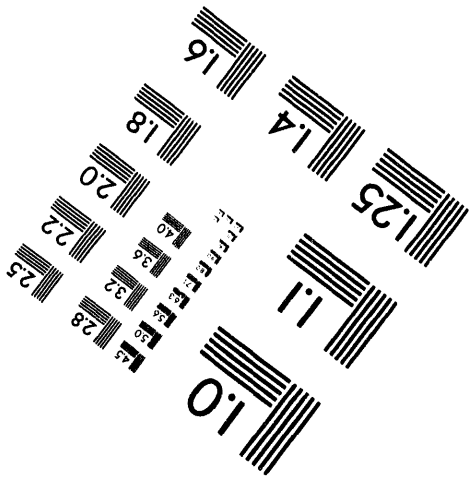
Inches

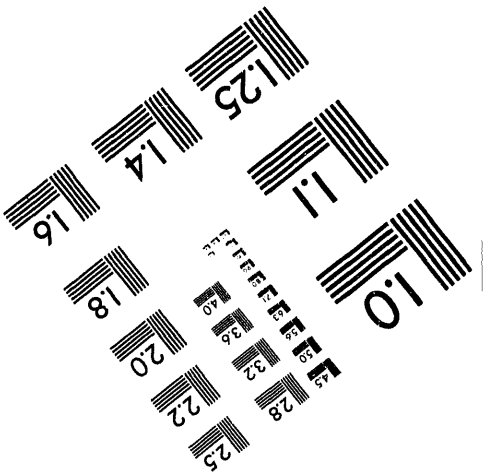
MANUFACTURED TO AIIM STANDARDS
BY APPLIED IMAGE, INC.











1 of 1

SAND94-0428C
Conf-940678--7

Fiber-optic Control of Current Filaments in High Gain Photoconductive Semiconductor Switches[x]

F. J Zutavern, G. M. Loubriel, W. D. Helgeson, M.W. O'Malley,
R. R. Gallegos, A. G. Baca, T. A. Plut, and H. P. Hjalmarson

Sandia National Laboratories, MS 1153, Albuquerque, NM 87185-1153 (505) 845-9128

Introduction

The discovery of current filaments in GaAs photoconductive semiconductor switches (PCSS)[1,2] raised concerns about the location and density of the current distribution during high gain switching. This paper describes experiments using fiber-optic coupled laser diode arrays (LDA) to control the location and number of current filaments in GaAs PCSS. Infrared (IR) images of the recombination radiation, that is emitted from the surface of the PCSS, show precisely where the current is concentrated. These were recorded as the fiber-optic configuration and switch test parameters were varied. Up to twenty individually-coupled laser diodes and fibers were used to initiate multiple, simultaneous filaments. Fibers were configured in a row both parallel and perpendicular to the direction of current.

Two types of experiments were performed: high current and high voltage. System impedances of 0.25 Ω and 50 Ω were used with switch currents up to 5.2 kA and initial charging voltages up to 100 kV, respectively. Switch sizes were 1×5 mm^2 and 15×38 mm^2 (parallel × perpendicular to the current). With the 0.25 Ω system charged to 4 kV (40 kV/cm across the PCSS), individual filaments were triggered with 150 nJ of optical trigger energy. In this case, filaments were triggered at both ends near the contacts with pairs of 250 μm fibers, each of which delivered 75 nJ in 140 ps. The use of multiple fiber pairs to distribute the current more uniformly across the switch improved switch performance. It allowed higher total currents to be switched with narrower switches. With the 50 Ω system charged to 100 kV (67 kV/cm across the PCSS), individual filaments were triggered with as little as 90 nJ of optical trigger energy. The trigger pulse was delivered in 2 ns through one fiber which was 400 μm in diameter.

High Current Tests

The application for this work was optically activated electrical firesets. Firesets are high current circuits used to detonate explosives. This is a low impedance application, where the current is limited by the inductance in the circuit. Figure 1 such a circuit using a PCSS, which is triggered with uniform illumination from a LDA. The low inductance capacitor (210 nF) and copper foil connections in this circuit amount to a total circuit inductance of 25 nH. The original PCSS dimensions were 2 mm long (parallel to the current path) by 30 mm wide and 0.625 mm thick. If current passed uniformly through this region, the switch inductance would be less than 0.1 nH. However, when current filaments form, switch inductance can be much higher. A 1 μm diameter filament that is a few mm from the ground plane has a few nH of inductance. Concentration of the current near the contacts also produces larger power losses if one assumes a fixed contact resistivity. Under almost any assumptions, concentrated current near the contacts deposits more energy per unit volume and increases contact degradation. Before current filamentation was demonstrated in high gain PCSS, it was assumed that uniform illumination would produce a relatively uniform current distribution. When filaments were shown to be present during high gain switching, controlling their number and location became a key issue.

The images in figure 2 show the concentration of current in a GaAs PCSS when triggered with uniform optical illumination. As the current is increased, many filaments are formed, but they are concentrated near the edges of the switch. These images were obtained with a 5 mm wide switch. The original results for the fireset application (4.2 kA at 4.6 kV) were obtained with a 30 mm wide switch using uniform illumination before current filaments had been discovered[3]. No IR images were being recorded during the original experiments, but damage near the contacts indicated that the current was actually concentrated in a few small regions of the switch.

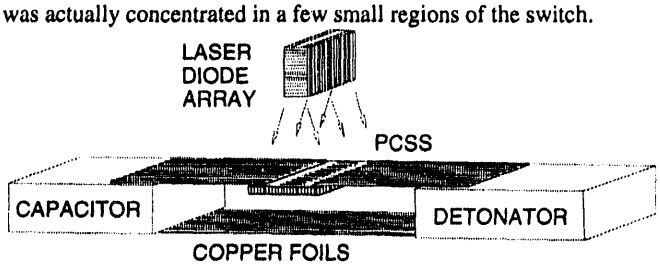


Figure 1. A diagram of an optically activated electrical fireset triggered with uniform illumination from a LDA. High gain PCSS are appropriate for this application because of their high optical trigger gain and low inductance.

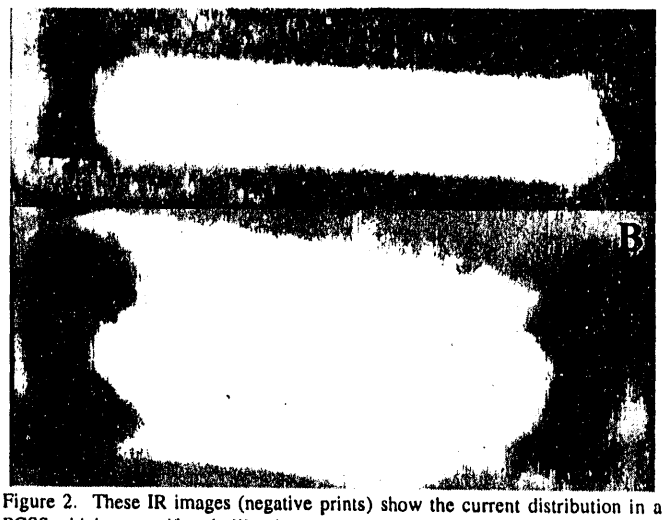


Figure 2. These IR images (negative prints) show the current distribution in a PCSS which was uniformly illuminated. The white regions are the active region of the semiconductor which is normally insulating. This region is bounded above and below by metallized contacts which look darker in these photographs. The dark regions are current filaments. Switch A (1×5 mm^2) is conducting 600 A, and switch B (2×5 mm^2) is conducting 1920 A.

Fiber-optic Triggering

Control of filament locations was demonstrated with low divergence laser beams which were focused either directly on the PCSS or through 1 mm diameter fibers[3,4]. This work also showed that filaments could be triggered most easily near the contacts.

[x] This work was supported by the United States Department of Energy under contract DE-AC04-94AL85000.

MASTER
DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

Optical triggering required roughly 100 times more light when it was uniform than when it was focused to a 1 mm spot on these 15×20 mm^2 PCSS. Figure 3 shows the new approach to optically activated electrical firesets. In this diagram, the LDA is coupled to the PCSS with a ribbon of fiber-optics. The fibers capture the power density produced near the lasers and deliver it to the PCSS surface near the contact boundaries. This results in more efficient use of the optical energy and a more uniform current distribution. The images in figure 4 show results of this technique when distributing current across 2×5 mm^2.

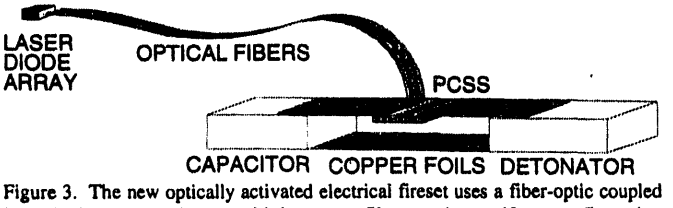


Figure 3. The new optically activated electrical fireset uses a fiber-optic coupled laser diode array to trigger multiple current filaments in a uniform configuration across the switch.

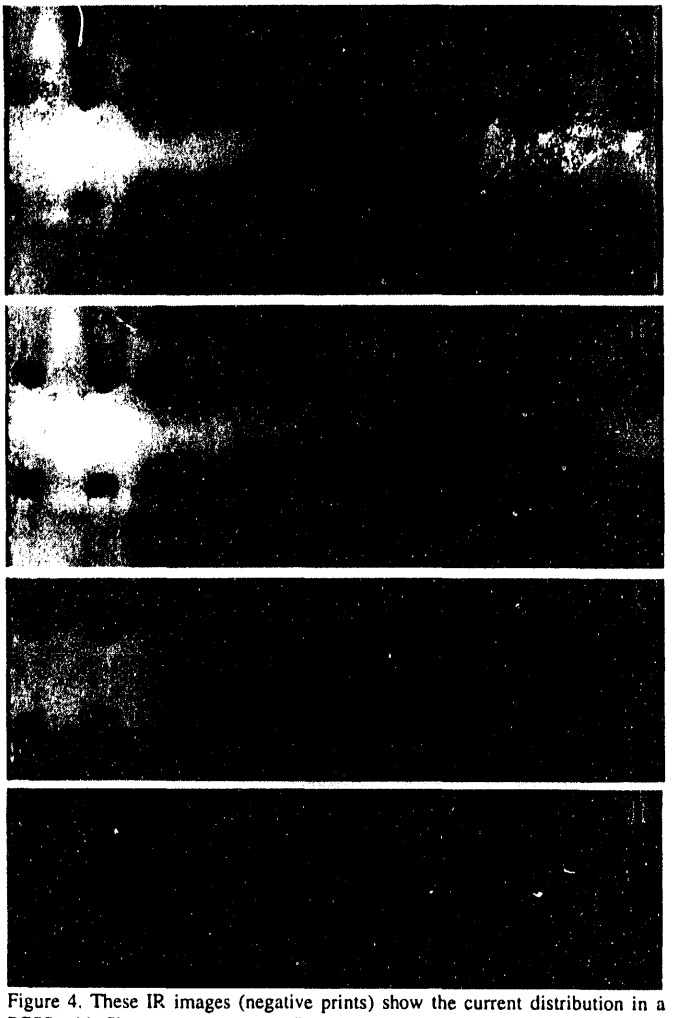


Figure 4. These IR images (negative prints) show the current distribution in a PCSS with fiber-optic triggering. The dark spots are produced by IR radiation from the ends of optical fibers which are lined up along the edges of both contacts. In between the fiber rows is the active region of the switch where current can flow. Only a few current filaments form at low currents, but as the current is increased filaments began to fill large regioins of the switch. The currents switched are: 220 A (A), 660 A (B), 1.1 kA (C), 2 kA (D). The dark regions comming from the contacts above and below the fibers are reflections of the intense light being emitted from the center of the switch.

Initially, two fibers were used to trigger each filament. The fibers were located at the ends of the filaments near contacts to control their location with the minimum amount of optical trigger energy. At low currents, filaments were not always triggered at every fiber. Triggering was also very sensitive to the precise location of the fibers near the edges of the contacts. However, as the current was increased, many filaments formed at each fiber. By the time 5 kA was reached (Figure 5), the current filled the entire switch. The increased current produces such a bright image that the detail of multiple filaments is washed out.

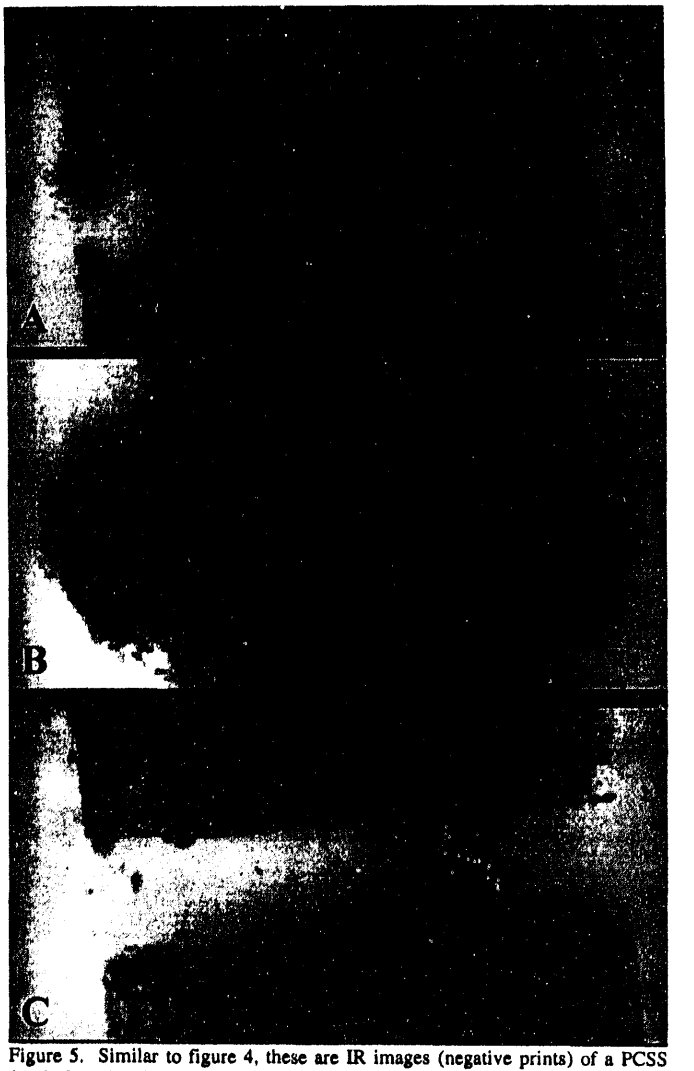


Figure 5. Similar to figure 4, these are IR images (negative prints) of a PCSS (A) before, (B) during, and (C) after a 5.2 kA current pulse. In A, these fibers are emitting (dark spots), but no voltage was applied. In B, current filaments fill the entire switch. Comparison of frames A and C show a change in the color and texture of the contacts.

Our previous results with uniform illumination, 4.2 kA in a 30 mm wide switch at 4.6 kV, were produced with 200 μJ of optical trigger energy delivered in 200 ns[3]. The total current produced with the new fireset and fiber-optic coupled LDA is shown in Figure 6. This 5 mm wide switch produced 5.2 kA at 4.0 kV with 1.5 μJ of optical trigger energy delivered in 140 ps. A lower limit for the average current density is 170 kA/cm^2, assuming the current is distributed over the entire cross-section of the PCSS, which is 625 μm thick. However, it is likely that the current is concentrated near the illuminated surface of the switch, especially near the contact boundaries.

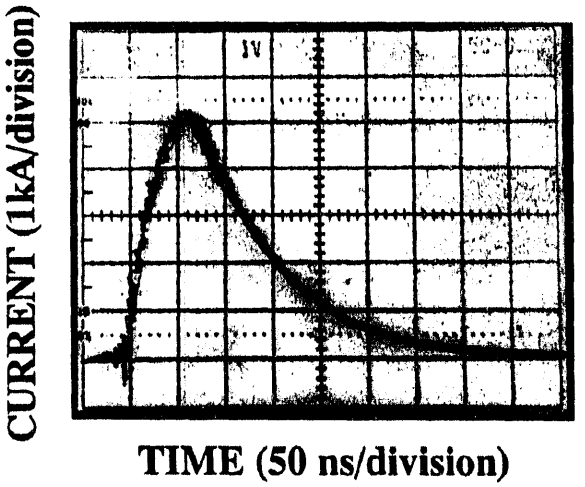


Figure 6. This current waveform shows the total current (5.2 kA) produced with the 2×5 mm^2 PCSS shown in figure 5. This PCSS was triggered with a fiber-optic coupled laser diode array which produced 75 nJ from each of twenty optical fibers.

High Voltage Tests

Much larger switches (15×38 mm^2) were tested in a high speed application with a 50 Ω load[5]. These switches were charged to 100 kV and delivered 1 ns long current pulses when triggered with fiber-optic coupled laser diode arrays. Multiple filaments were initiated by locating the fibers near the contacts. These switches were much longer than the diameter of the optical trigger spot, and the filament path was not straight across the switch. There was branching and they appeared to spread several millimeters as they crossed the switch. Figure 7 shows one of the high voltage filaments which was triggered with a fiber-optic near one contact. Somewhat straighter filaments were obtained by placing fibers in a line parallel to the field across the PCSS as shown in Figure 8. These filaments are not nearly as straight as those which we have obtained with a stripe of illumination from an Nd:YAG laser. Presumably, the LDA trigger source lacked sufficient energy to control the filament growth in the center of the switch. The total energy from the LDA was 1.5 μJ, while the energy from the Nd:YAG was 200-500 μJ. This type of triggering requires much more optical trigger energy per filament. When concentrated in spot near the cathode, the minimum trigger energy, which produced a single filament across the switch, was 90 nJ delivered in 2 ns through a single, 400 μm diameter fiber-optic.

Figure 7. The filament shown in this IR image (negative print) was triggered with a fiber-optic near the bottom contact of a 15×38 mm^2 PCSS. The peak current switched was approximately 1 kA in a 1.4 ns wide pulse. Before it was triggered, this switch was charged tto 100 kV. Note that the location of the filament is only constrained in at the bottto near the optical trigger.

Contacts and Switch Lifetime

In the high current tests, significant damage was apparent near the contacts after each pulse. A change in the contact coloration and texture is evident between the frames shown in figure 5. The current pulse evidently produces sufficient heat to melt or anneal these contacts. The contacts shown were made with Ni-Ge-Au-Ni-Au deposited in thicknesses of 5, 75, 75, 75, 200 nm. The contacts were annealed at 450 °C for 30 s. A thicker top layer of gold (8 μm or copper 30 μm) eliminated this color and texture change, but did not improve switch lifetime substantially. Some damage was still noticeable at the edge of the contacts after eac shot. These switches lasted for approximately: 50 pulses at 200 A, 10 pulses at 600 A, 4 pulses at 1 kA, 2 pulses at 2 kA, and 1-2 pulses at 5 kA.

In the high voltage tests, contact damage was only apparent after many pulses. These larger switches lasted for several thousand pulses with one or two filaments conducting approximately 1 kA. The larger switches and much shorter current pulses (1 ns instead of 120 ns) are the most significant differences between these tests and may explain the differences in switch lifetime.

7 1/8 x 9 15/16 PRINT SURFACE FOR 8 1/2 x 11 PAGE TO 75% COPY

Figure 8. This IR image (negative print) shows a 15x38 mm^2 PCSS which was being triggered with a row of fiber-optics across the switch to constrain the filament to a straighter path. Dark regions are intense current and the vertical ribbon of fibers (gray) obscures the middle of this image. The current was not confined to the illuminated area near the center of the switch where more optical energy is required for triggering.

Conclusion

This paper has described experiments with GaAs PCSS, that were triggered with fiber-optic coupled laser diode arrays. The fiber-optics allow control of the location and number of current filaments produced during high gain switching. They also allow efficient transport of the optical trigger energy from the lasers to the surface of the PCSS. These experiments demonstrated efficient use of the optical trigger energy, control of the current distribution, and improved switch performance. Fiber-optic triggering is also convenient for applications which require multiple switches.

References

1. F. J. Zutavern, G. M. Loubriel, M. W. O'Malley, W. D. Helgeson, and D. L. McLaughlin, "High Gain Photo-conductive Semiconductor Switching," in Proc. 8th IEEE Pulsed Power Conf., San Diego, CA, 1991, pp. 23-28.

2. R. A. Falk, J. C. Adams, and G. L. Bohnhoff-Hlavlacek, "Optical Probe Techniques for Avalanching Photoconductors" in Proc. 8th IEEE Pulsed Power Conference, San Diego, CA, 1991, pp. 29-36.

3. F. J. Zutavern and G. M. Loubriel, "High Voltage Lateral Switches from Silicon or Gallium Arsenide", in *High-Power Optically Activated Solid- State Switches*, A. Rosen and F. J. Zutavern, Eds., Artech House, Boston, 1993, pp. 245-296.

4. G. M. Loubriel, F. J. Zutavern, H. P. Hjalmarson, R. R. Gallegos, W. D. Helgeson, and M. W. O'Malley, "Measurement of the Velocity of Current Filaments in Optically Triggered High Gain GaAs Switches," Appl. Phys. Lett., vol. **64** (24), 13 June 1994, pp. 3323-5.

5. G. M. Loubriel, F. J. Zutavern, M. W. O'Malley, R. R. Gallegos, W. D. Helgeson, H. P. Hjalmarson, A. G. Baca, and T. A. Plut, "High Gain GaAs Switches for Impuplse Sources: Measurement of the Speed of Current Filaments," to be published in Proc. 21st Power Modulator Symp., Costa Mesa, CA, 1994.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DATE
FILMED
10/3/94

END