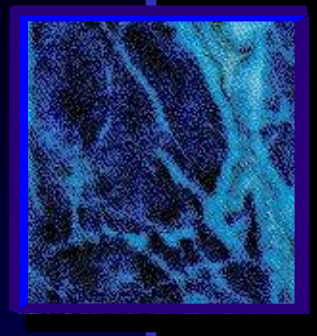
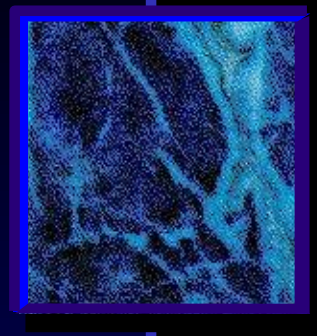


NASA Space Shuttle *Challenger* Flight Data Recorder Tape Recovery Effort

A team effort by the General Products Division,
Tape Development Group in Tucson, Arizona

April 17 – July 12, 1986

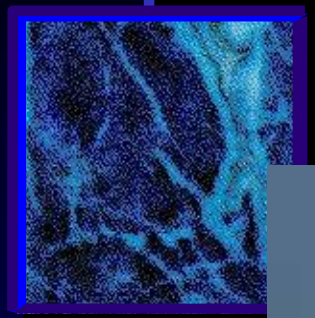
Dr. Richard Bradshaw
Tape Technology Consulting
Tucson, Arizona USA

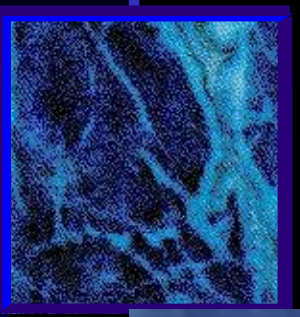


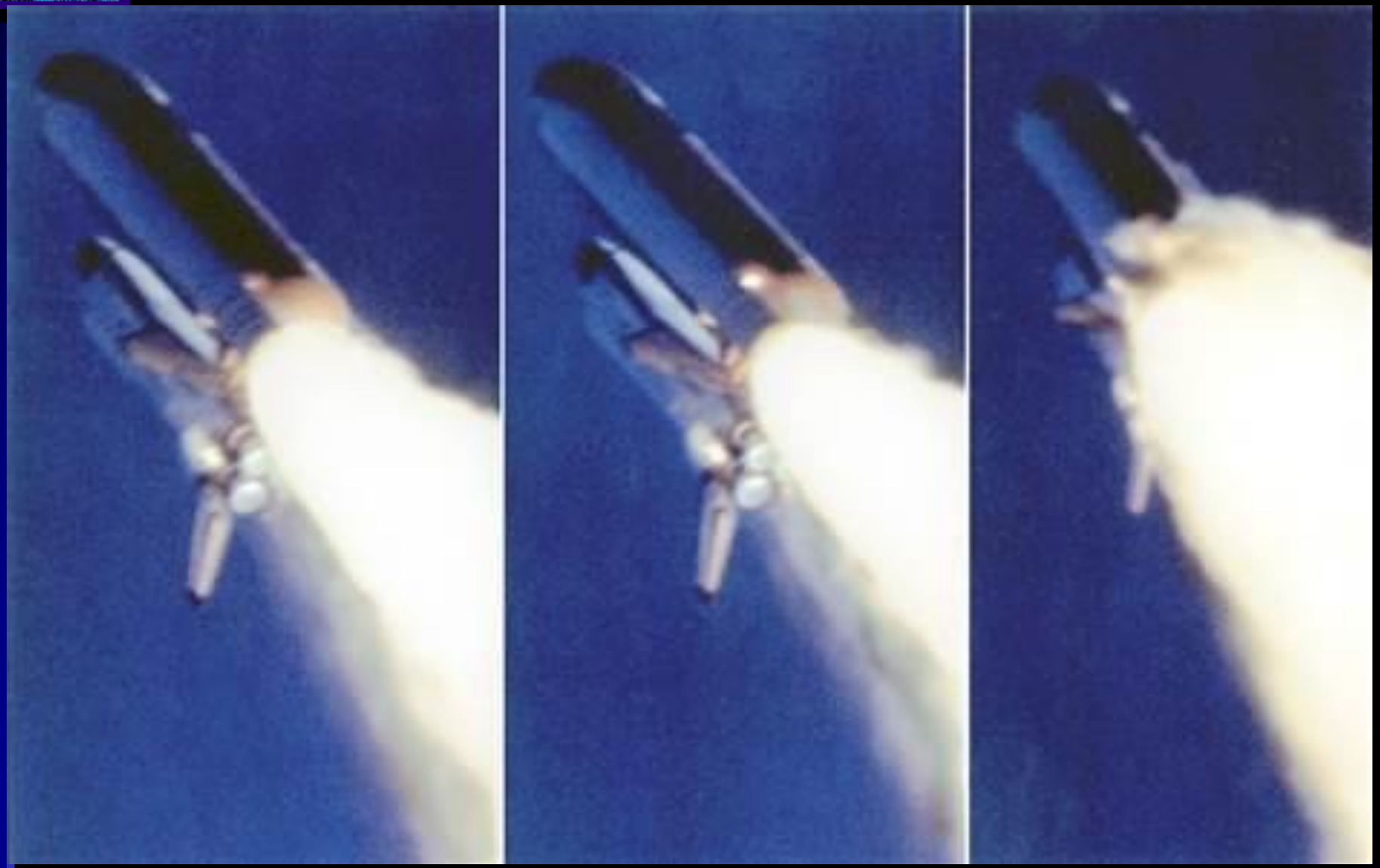
Recovery of Flight Recorder Tapes from *Challenger* Space Shuttle

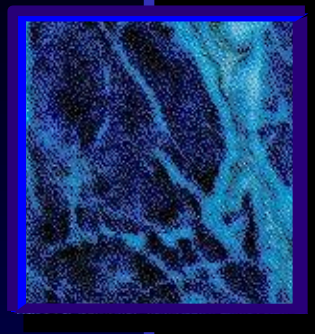
January 28, 1986

the Space Shuttle *Challenger* carrying what would have been the first civilians into Earth Orbit exploded shortly after lift off.



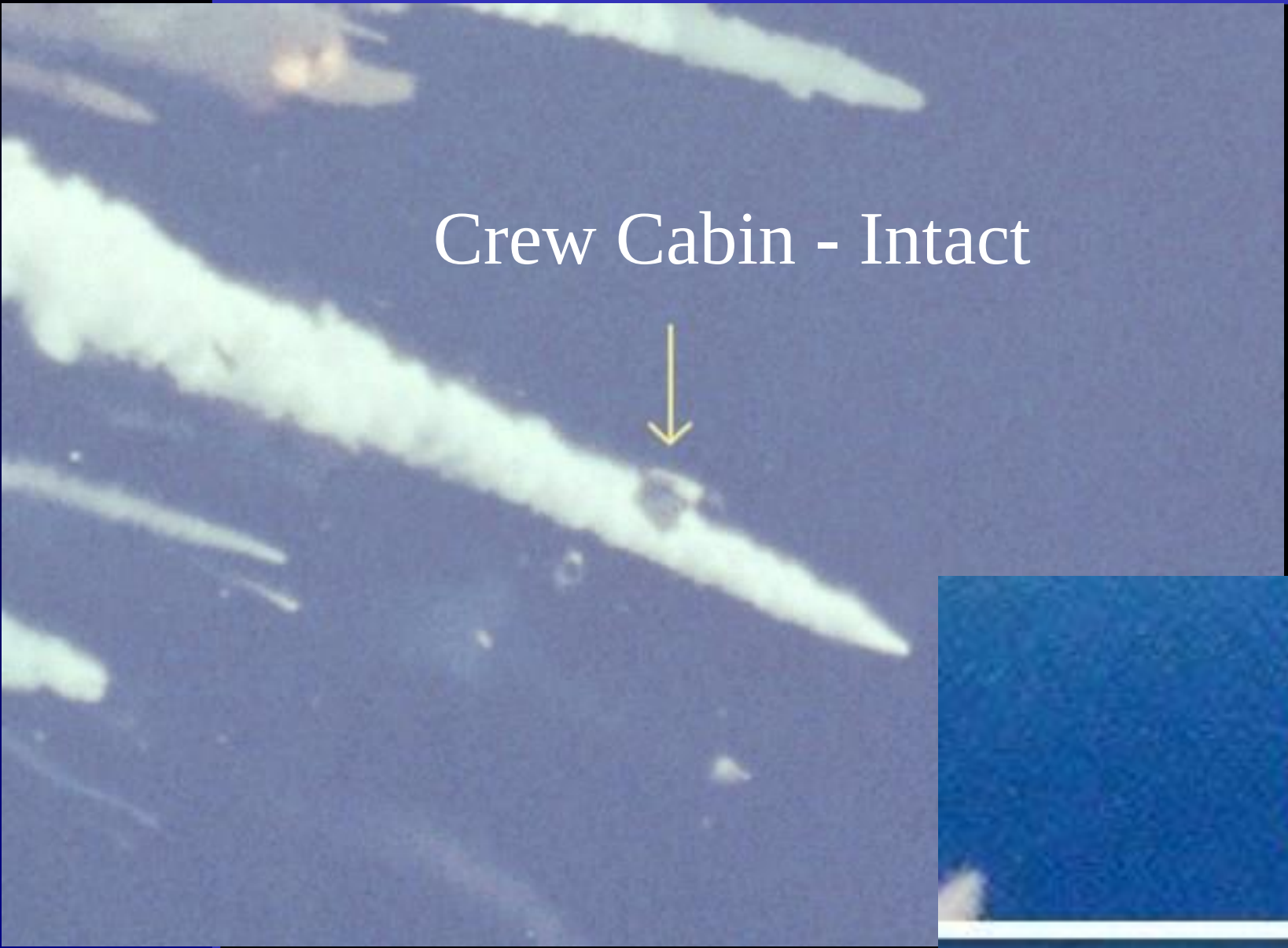


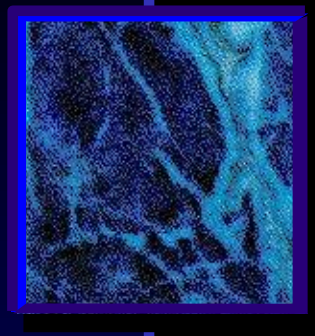




Failure of solid fuel rocket boosters seals just after launch due to excessive cold conditions at launch

Crew Cabin - Intact

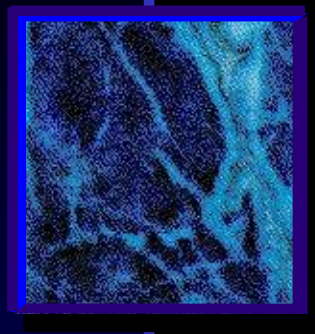




The Flight Recorders from the Shuttle were recovered after six weeks exposure to salt water at a depth of over 90 feet.

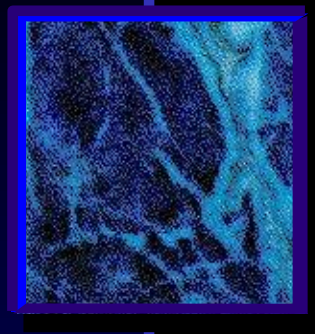
Tapes from all three of the shuttle recorders were recovered:

Payload (cargo), Ops-1(engines) and Ops-2 (voice and crew function)



The *Challenger* Data Recorders

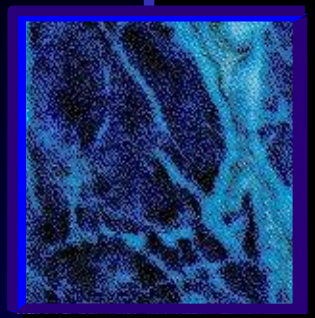
- Reel to Reel Recorders
- Magnesium alloy reels
- γ-iron oxide 3M Series 892 & Ampex 799 tape
- Reels mechanically damaged and corroded
- tape media encrusted in white crusty coating
- NASA recovery efforts unsuccessful



The *Challenger* Data Recorders

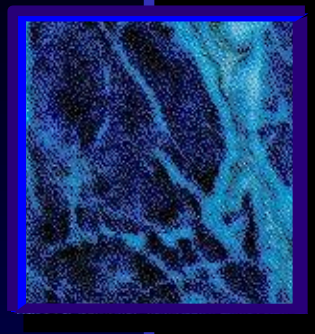
The recorders were build by Odetics using tape media produced by Ampex (Series 799) & 3M (Series 892). IBM Federal Systems Division (FSD) in Owego NY was involved in loading the media and certifying the drives to NASA prior to use. In 1985, FSD contacted IBM Tucson regarding a concern with the media degradation as IBM Tucson was the Corporate Center of Competency for Tape.

A detailed analysis of Ampex 799 tapes used to construct the flight recorders was carried out and a report to FSD sent Sept 1985. IBM thus had in its possession details as to what the undamaged tape looked like chemically and mechanically before NASA visited IBM Tucson on April 17, 1986. Analysis of the 3M 892 tape was carried out later with the final report completed in late April 1986.



The *Challenger* Data Recorders

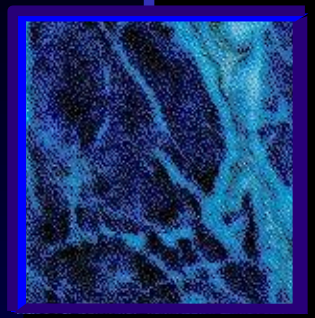
Modified Odetics Deck ~1988



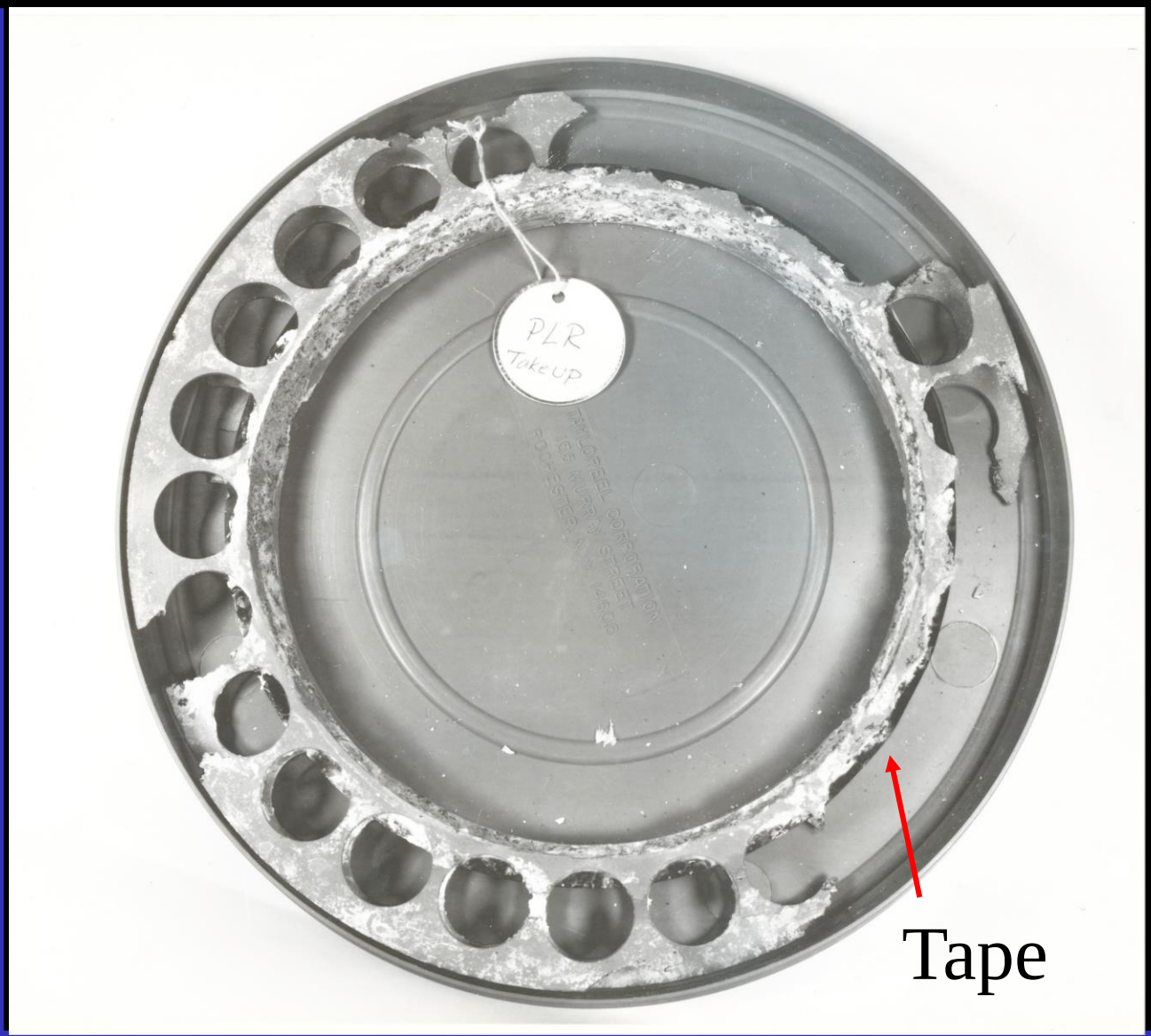
- An almost accidental visit to the IBM Tucson Tape Products Laboratory by the NASA Team after visiting the JPL Labs in California was held in CR 2333 Bldg. 061, 1PM 17 April 1986

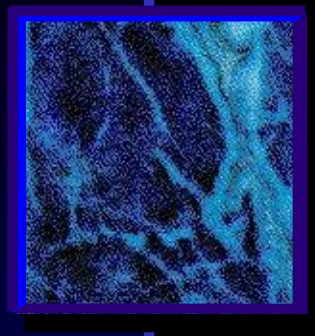
- a sample of the recorder tape from a supply reel recovered from the shuttle payload bay was shown to those present as an example of the condition of the recovered tapes

- Dr. Richard Bradshaw of the Media Development Department, Tape Development Group, General Products Division of the IBM asked and obtained a five inch long sample of the encrusted and damaged tape for analysis.



Challenger Payload Take Up Reel (no data)

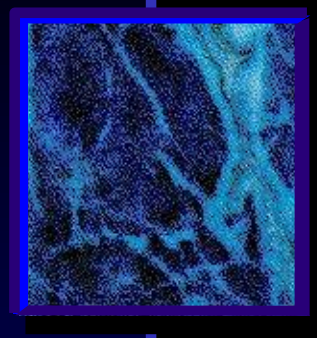




IBM Chemical Analysis

SEM/EDAX of small sample by Dr. Ed Bartkus

- magnesium hydroxide encrusted
- calcium and biological deposits
- organic crystalline deposits (binder & substrate degradation)

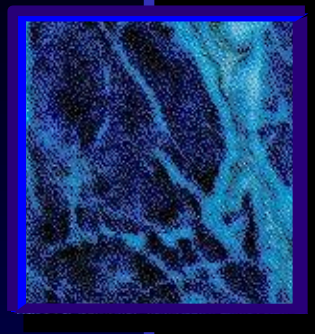


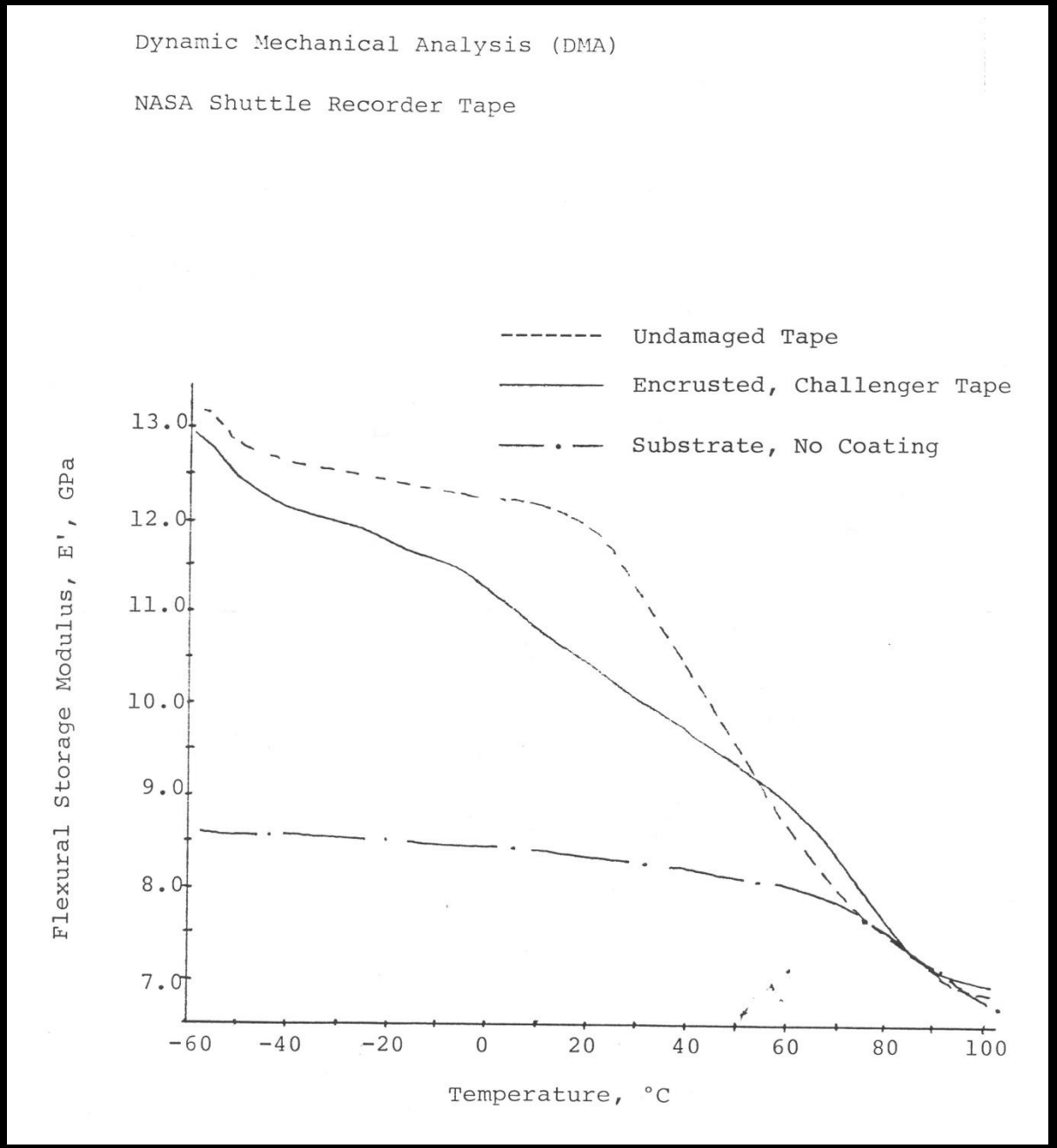
Mechanical Analysis

DMTA by Dr. Ric Bradshaw

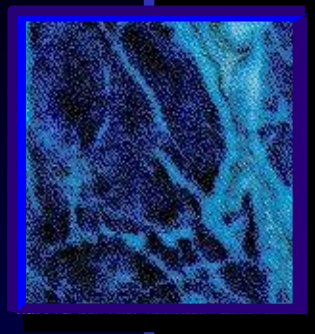
- very poor coating integrity
- poor coating adhesion

But: dynamic mechanical analysis (DMA) indicated sufficient binder integrity to make separation of the tapes possible





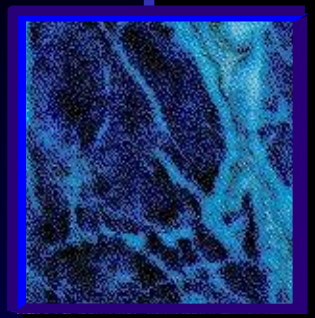
DMTA plot presented by Dr. Ric Bradshaw to IBM and NASA personnel present during the NASA Visit to IBM Tucson

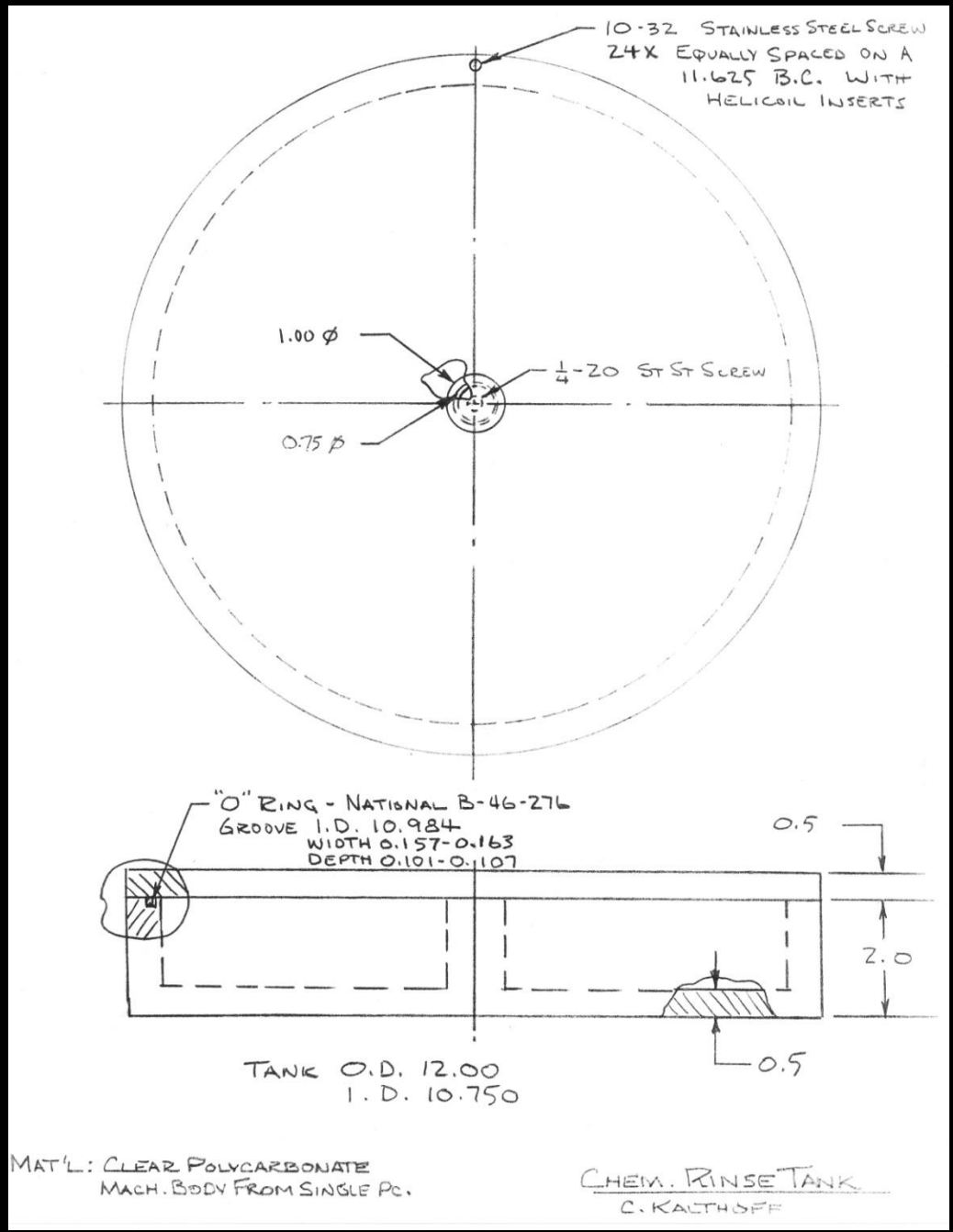


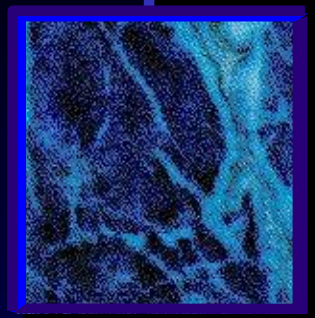
A planning meeting was held in Clem Kaltoff's office Bldg. 061-2 after NASA meeting to plan our effort to treat the damaged supply reel (no data on it) from the payload recorder left with us by the NASA team.

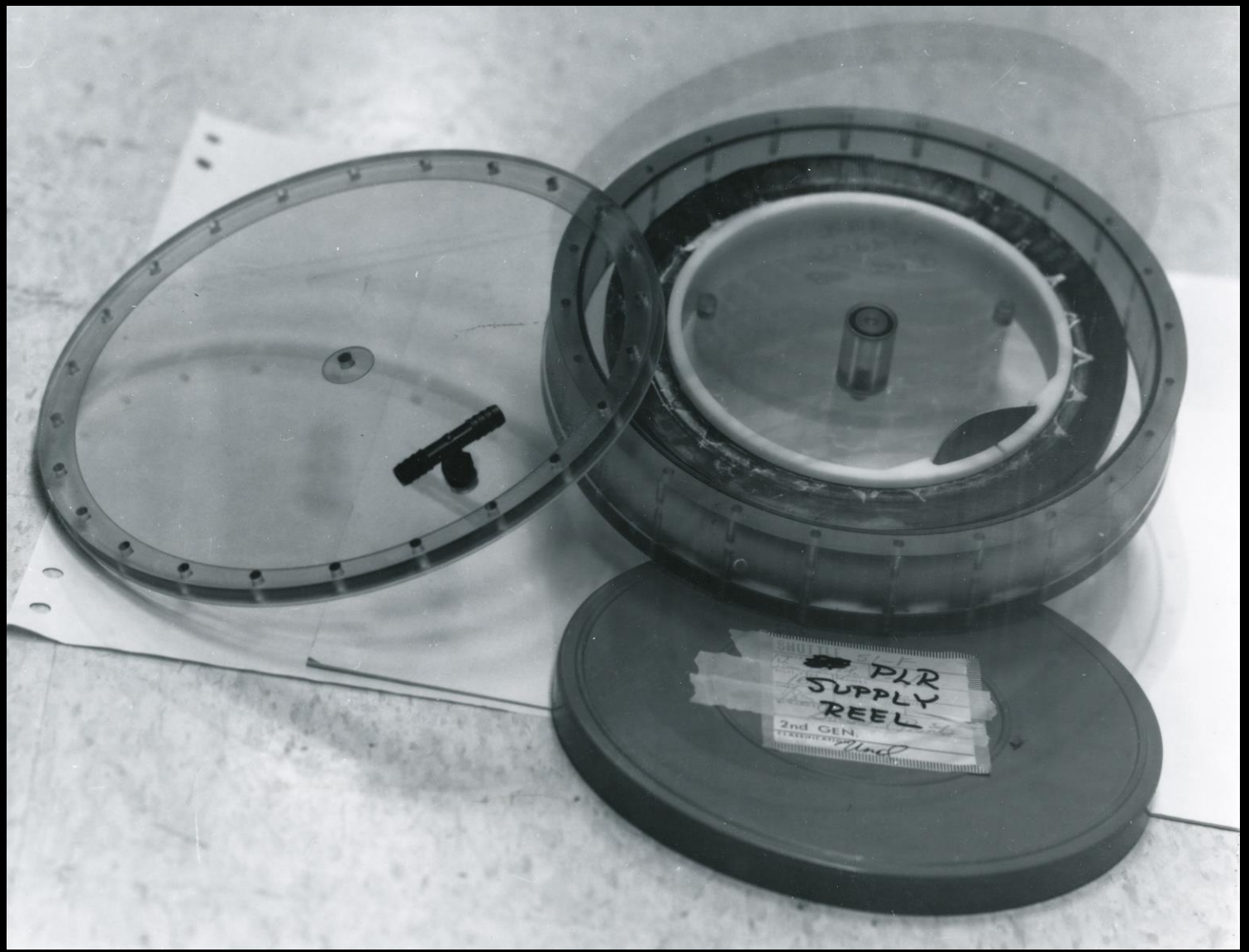
Ric Bradshaw was tasked with setting up the chemical treatment procedures and equipment to remove the magnesium crust once the tape had been mechanically removed from the supporting magnesium flange by the IBM model shop.

Clem Kalthoff designed on his desk a treatment vessel to be made from a clear but inert material (polycarbonate) as well an inert support hub to replace the magnesium hub once it was machined off. A Delrin hoop with a stainless steel flex spring to provide a small outward pressure on the split hub ring was designed and sent to the model shop that afternoon.

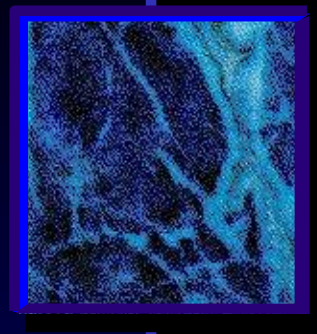



10-32 STAINLESS STEEL SCREW
24X EQUALLY SPACED ON A
11.625 B.C. WITH
HELICOIL INSERTS
1.00 Ø
1/4-20 ST ST SCREW
0.75 Ø
"O" RING - NATIONAL B-46-276
GROOVE I.D. 10.984
WIDTH 0.157-0.163
DEPTH 0.101-0.107
0.5
2.0
0.5
TANK O.D. 12.00
I.D. 10.750
MAT'L: CLEAR POLYCARBONATE
MACH. BODY FROM SINGLE PC.
CHEM. RINSE TANK
C. KALTHOFF





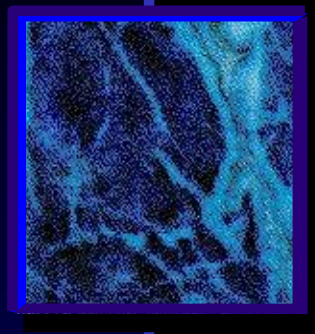
All of the equipment was machined and ready for initial trials before the end of the week, with the treatment vessel available for the rinse process assembly in just a few days!



Process Development/Verification

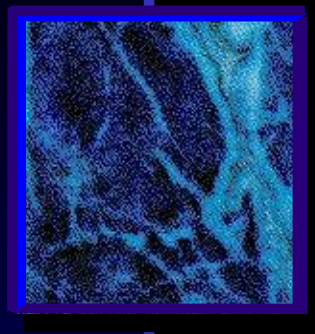
- unrecorded supply reel from payload recorder was used to develop a recovery procedure

- separated tape was written several times & returned to NASA

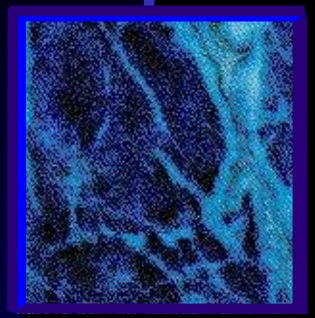


Treatment Process Development Effort

Initial rinse and re-lubrication treatments of damaged unwritten supply reel tape was undertaken slowly and methodically with continual chemical analysis of all rinses to determine when to end each step to prevent risk of further damaging the tape as a result of the acid and solvent rinses. The final step was a re-lubrication treatment prior to the removal of the tape from the pack onto another special metal hub from which rewind could be done on an inspection tool transport (designed by D. Byrne of IBM Tucson) .



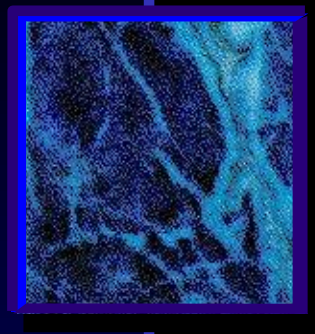
- rinse tank and collapsible, spring-loaded replacement hub designed and built
- method to remove damaged reel from tape perfected
- chemical rinse and re-lubrication method developed



NASA Shuttle Tape REcovery - Initial Attempt

	Supply Reel	Data Reel
	flanges, hub removed on Delrin Ring	hub cut, flanges intact
0.5M HNO_3	2 liters (pH 0.8-1.2)	2 liters (pH 0.6-1.8)
Distilled Water	10 liters (pH 1.3-2.2)	10 liters (pH 0.9-3.1)
	leaks fixed	hub, flanges removed
0.5M HNO_3	2 liters (pH 0.7-1.0)	2 liters (pH 0.6-0.8)
Distilled Water	78 liters (pH 1.2-5.9) two days	26 liters (pH 1.1-5.4) one day
Methanol, Anhydrous	8 liters one day	2.5 liters half day
Methanol + Lube (Butyl Stearate)	2 liters	2 liters
Methanol Rinse	None	2 liters
Methanol + Lube (Methyl Silicone)	1.5 liters	2 liters
Methanol Rinse	none	2 liters

Unwind, test

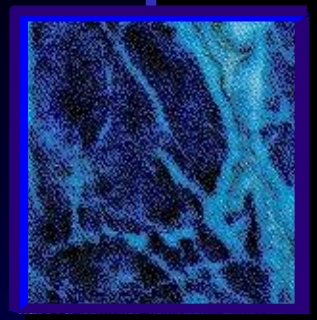


The final treatment process

Initial re-lubrication tried conventional lubricants but attempts to unwind a few wraps of the treated tape were unsuccessful with coating pull off or severe stick between layers observed during attempts to unspool the tapes.

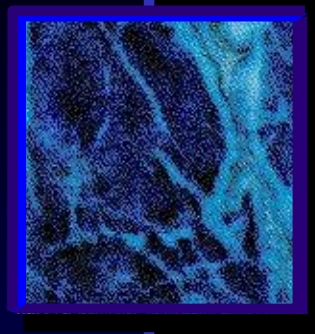
While the process of removal of the encrusting magnesium hydroxide layers was completely successful, the re-lubrication to permit good separation of the wraps of the tape on the treated spool was not acceptable. An experimental lubricant made by Dr. Bradshaw as a potential improved tape lubricant, a fluorine terminated long chain hydrocarbon with a carboxylic acid functionality on the other end was tried. It formed a monolayer on oxide surfaces and did not stick to itself or other surfaces….. contaminating the tape drive surfaces….so not useful as a practical product lubricant.

BUT it worked ! Allow unwinding of the treated tape spool!

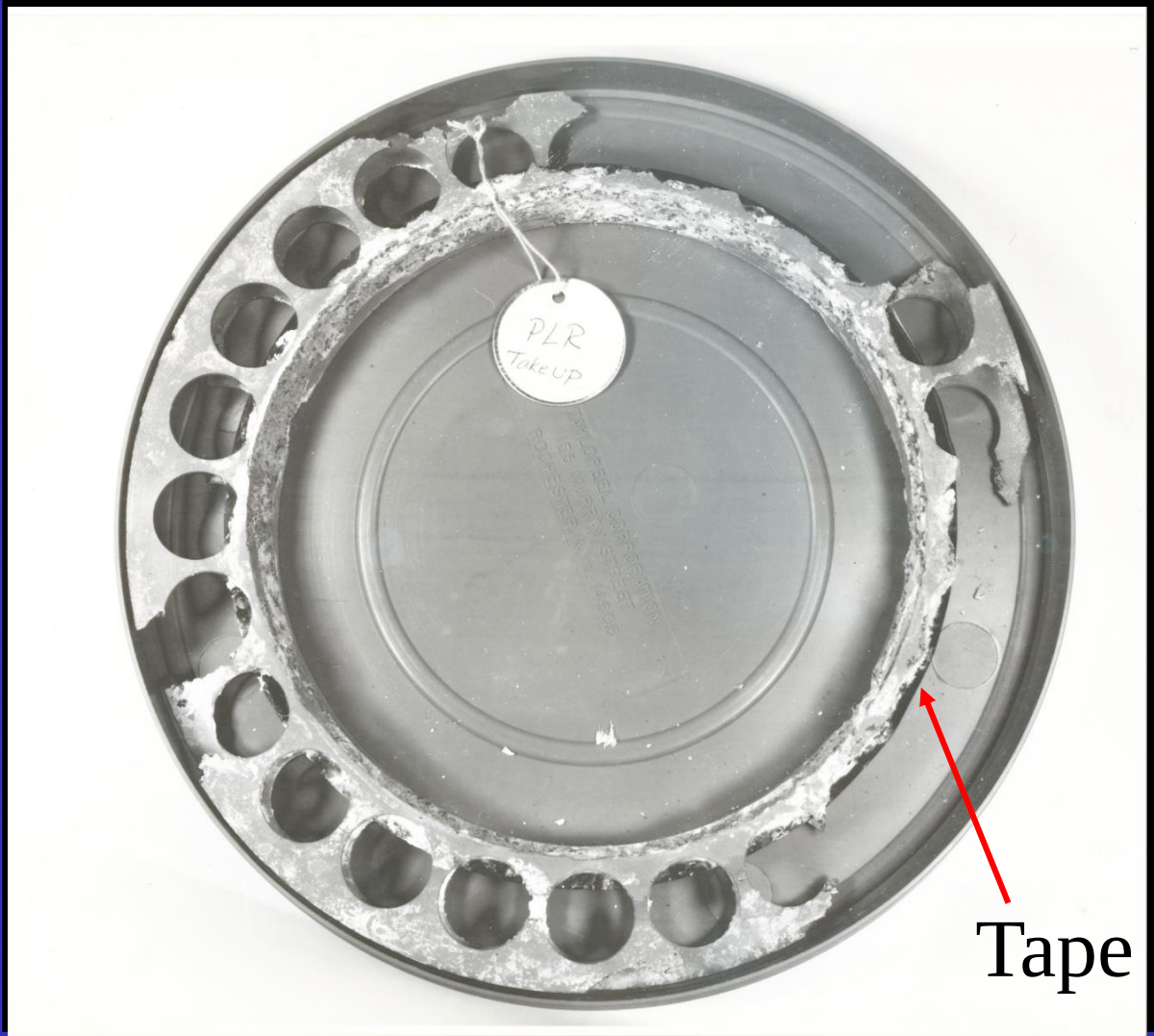


Data Tape Recovery – Ops-1

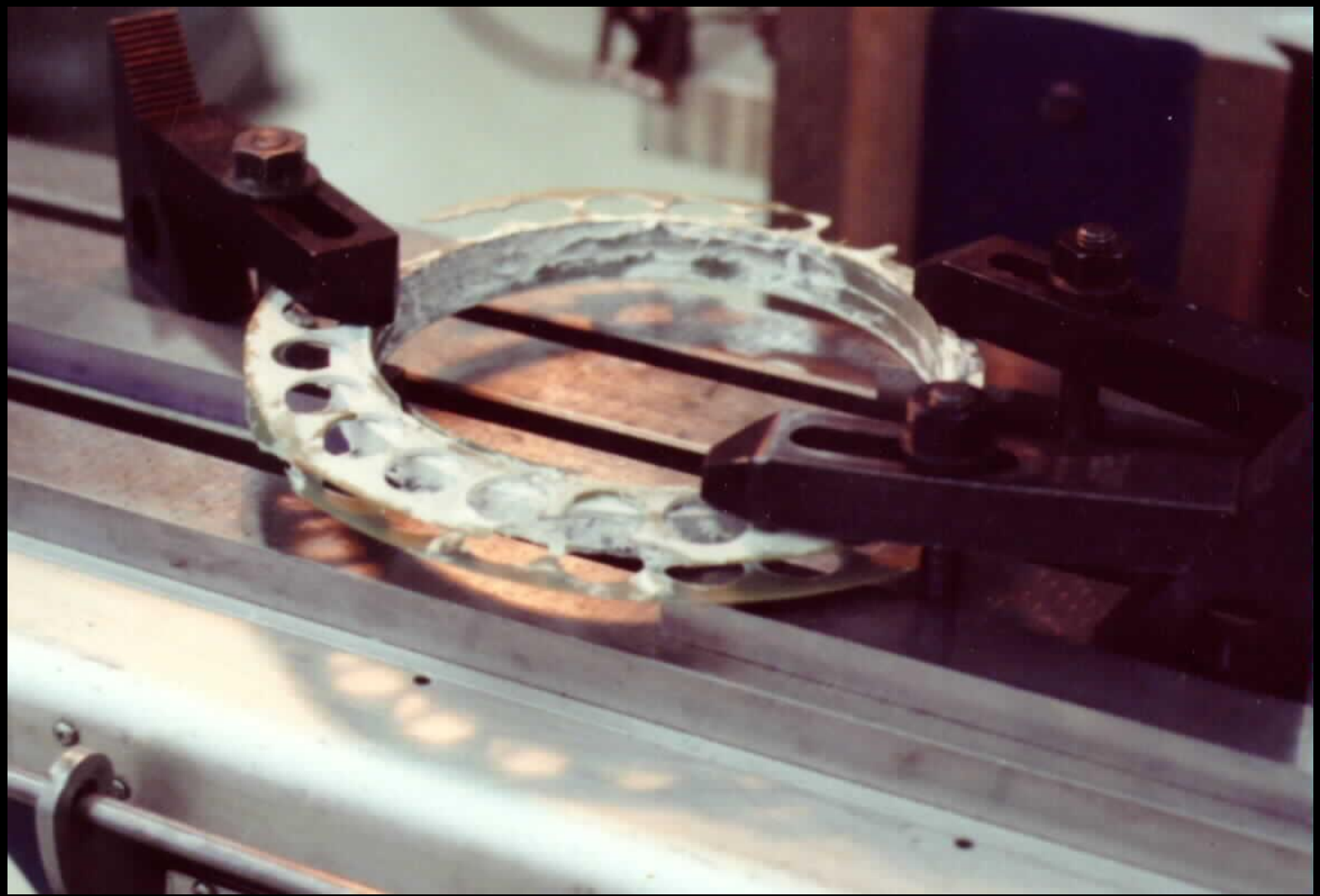
Data Tape Recovery – Ops-2



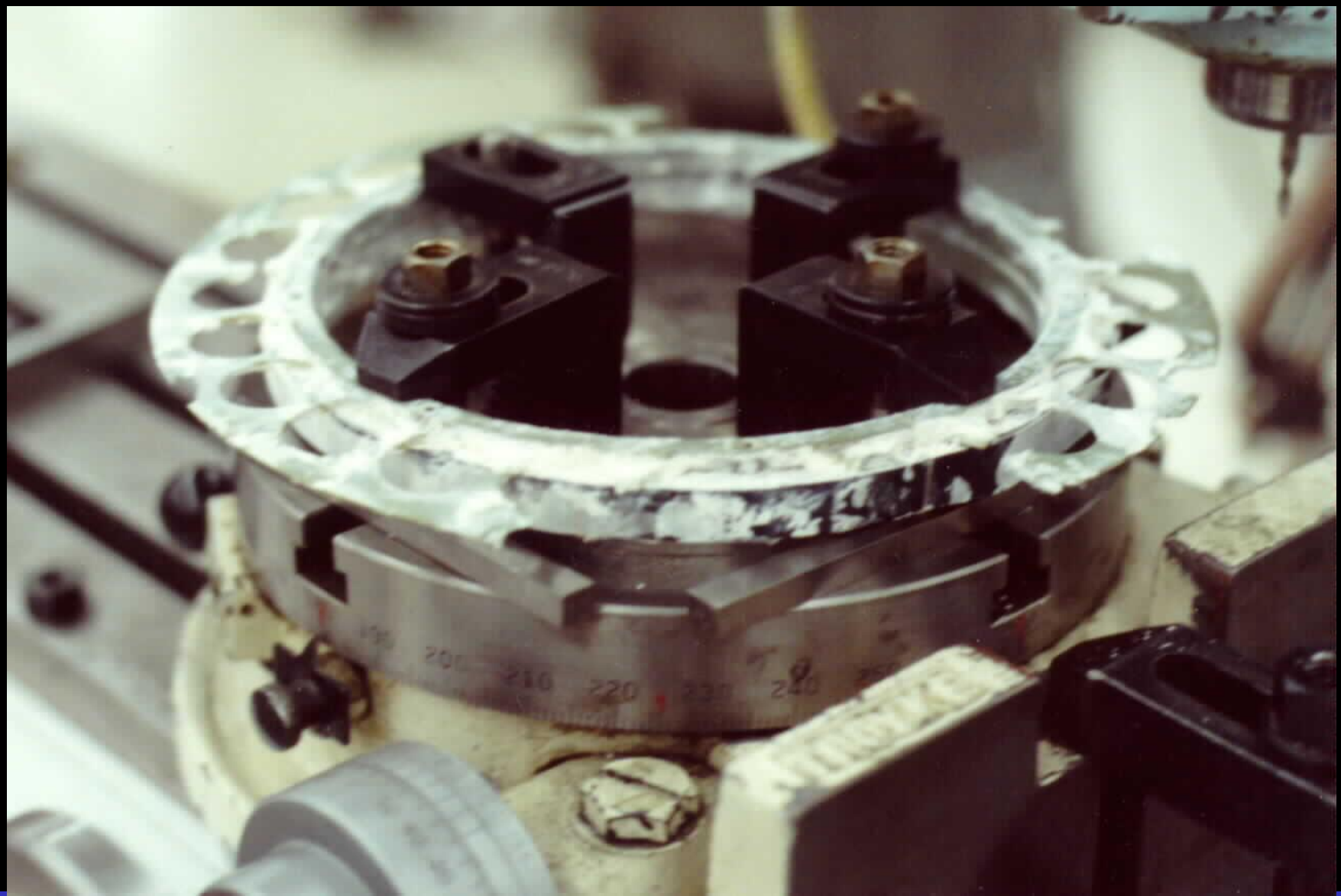
Challenger Payload Take Up Reel (no data) prior to IBM model shop flange and hub removal

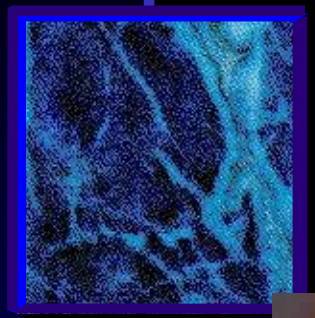


IBM Model Shop - corroded upper flange removal using precision lathe

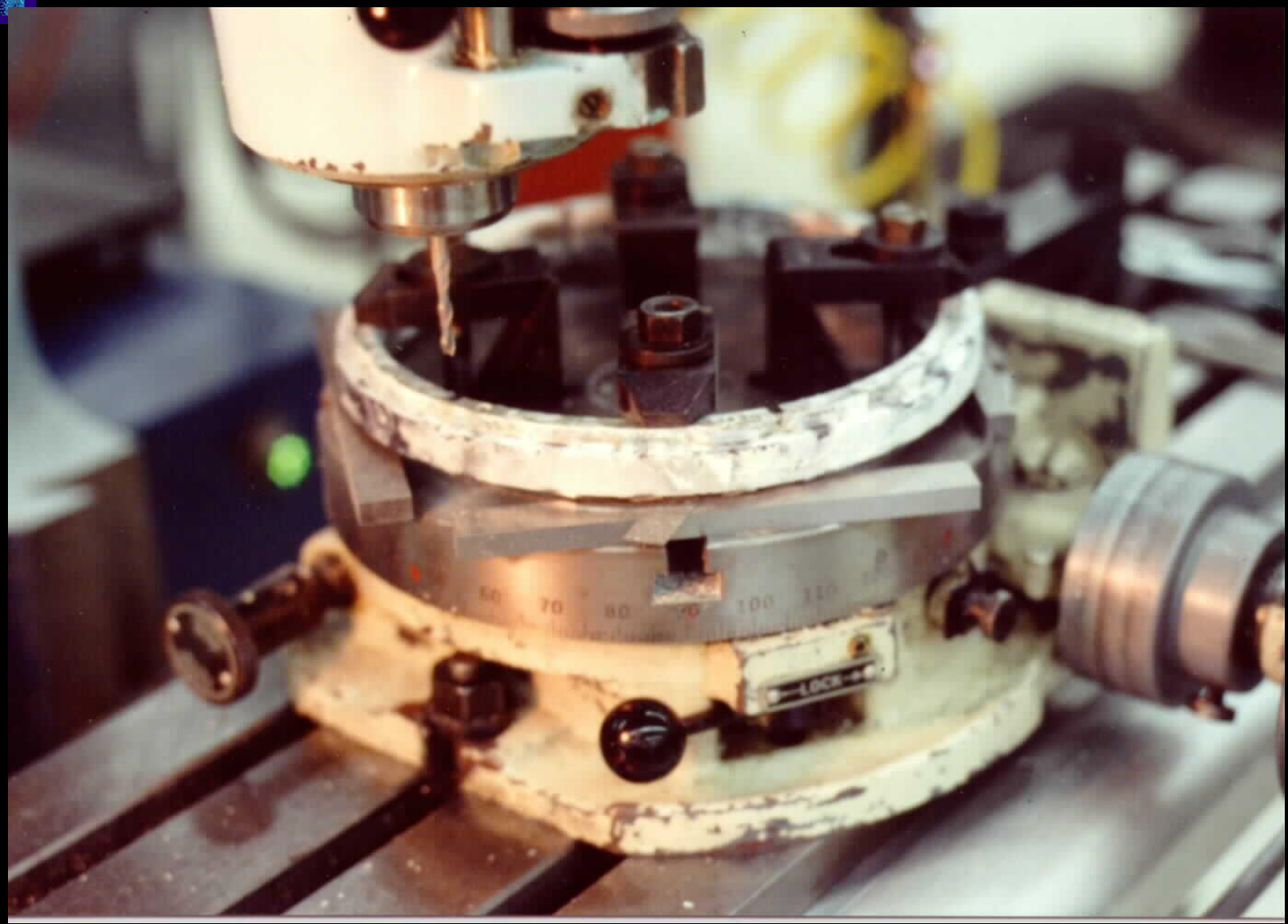


IBM Model Shop - corroded lower flange removal using precision lathe

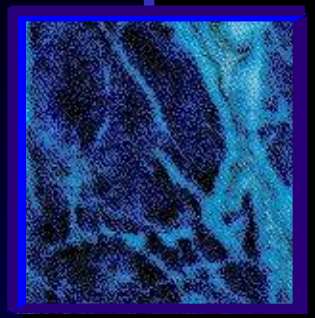




IBM Model Shop - corroded hub removal using precision lathe

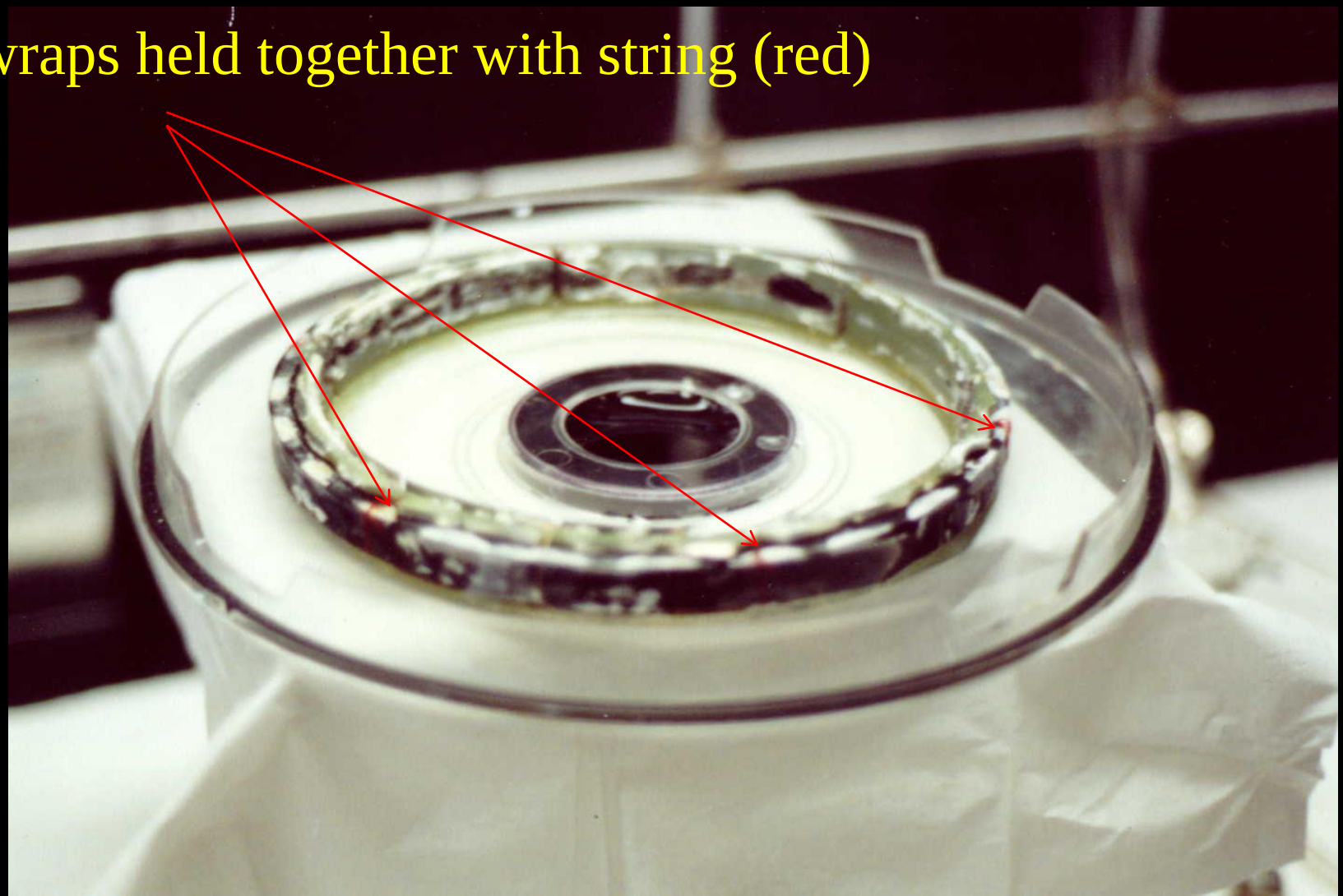


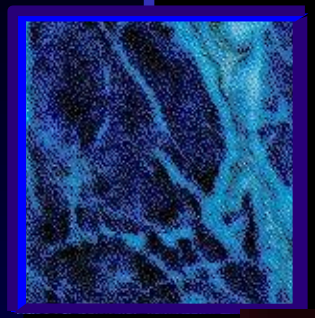
IBM Model Shop, R. Hendricks & D. Victory milled off the flanges and drilled through the hub to allow all remaining Mg metal to be removed from the encrusted tape prior to chemical treatment



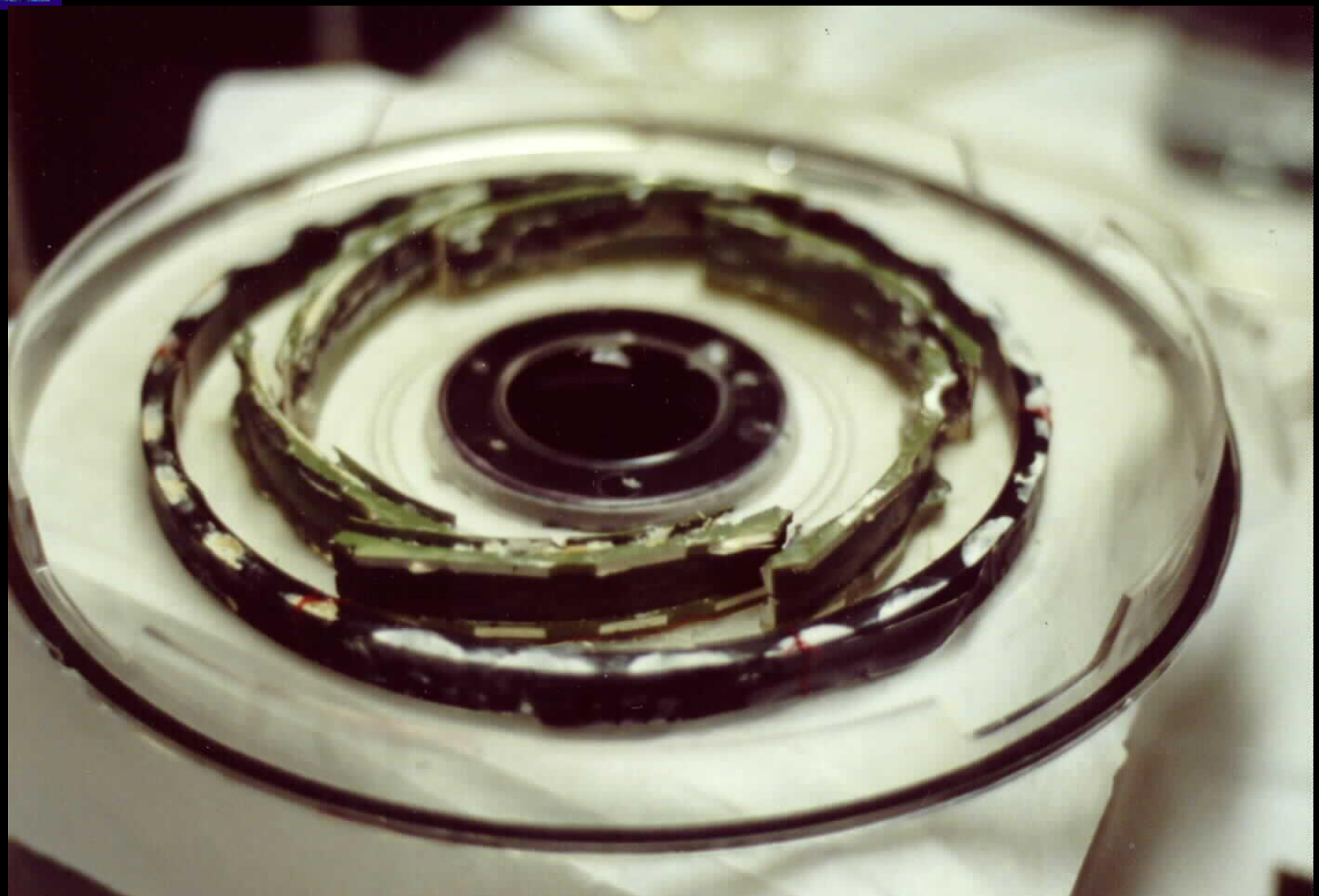
Ops-2 tape after model shop removal of flanges and drilling of hub

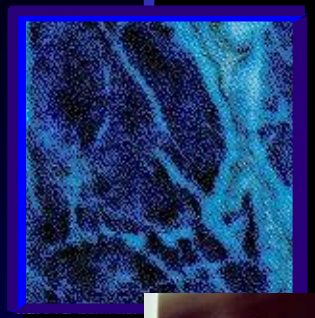
Tape wraps held together with string (red)





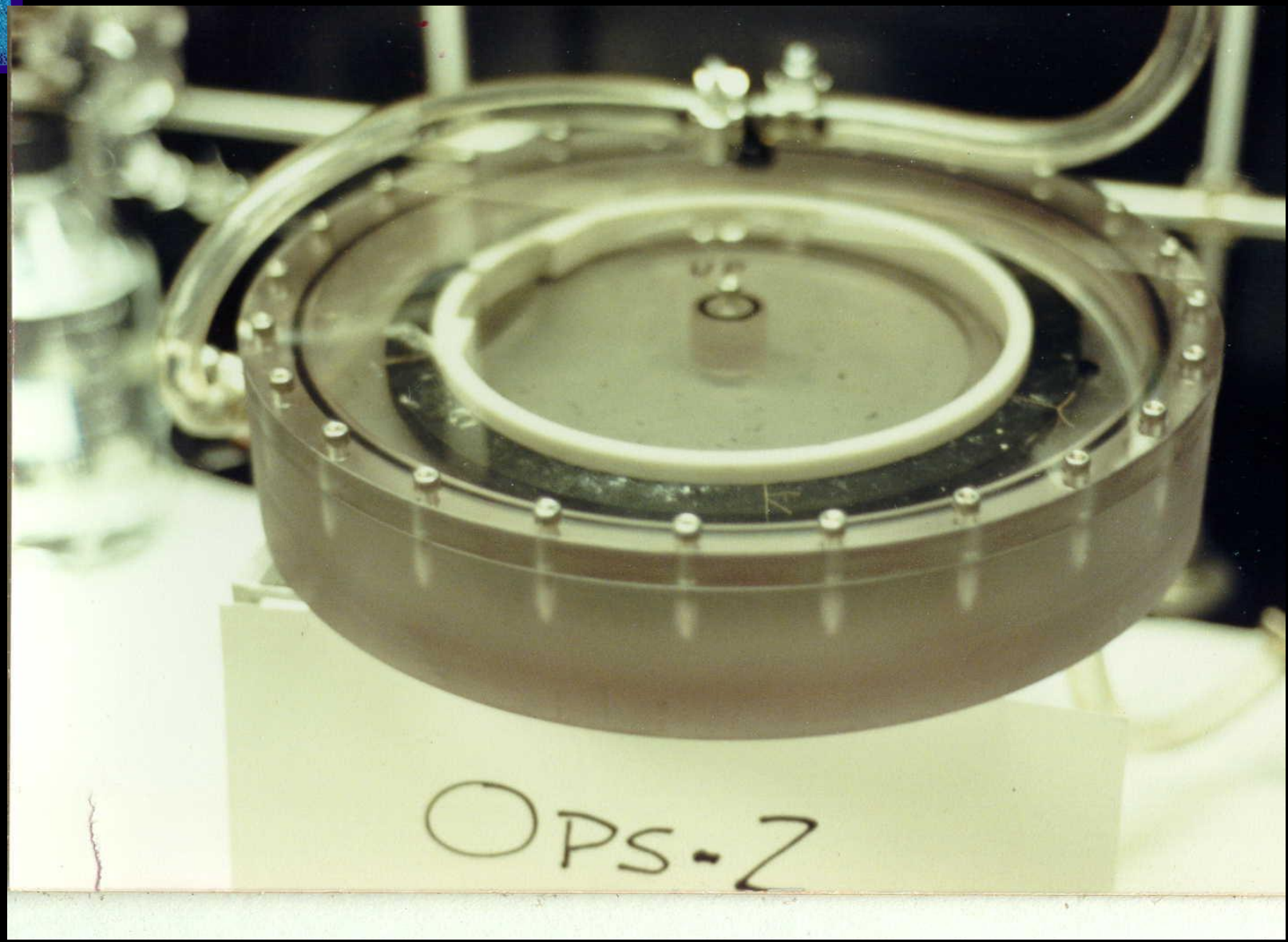
Ops-2 Tape, Flange & Hub Removed



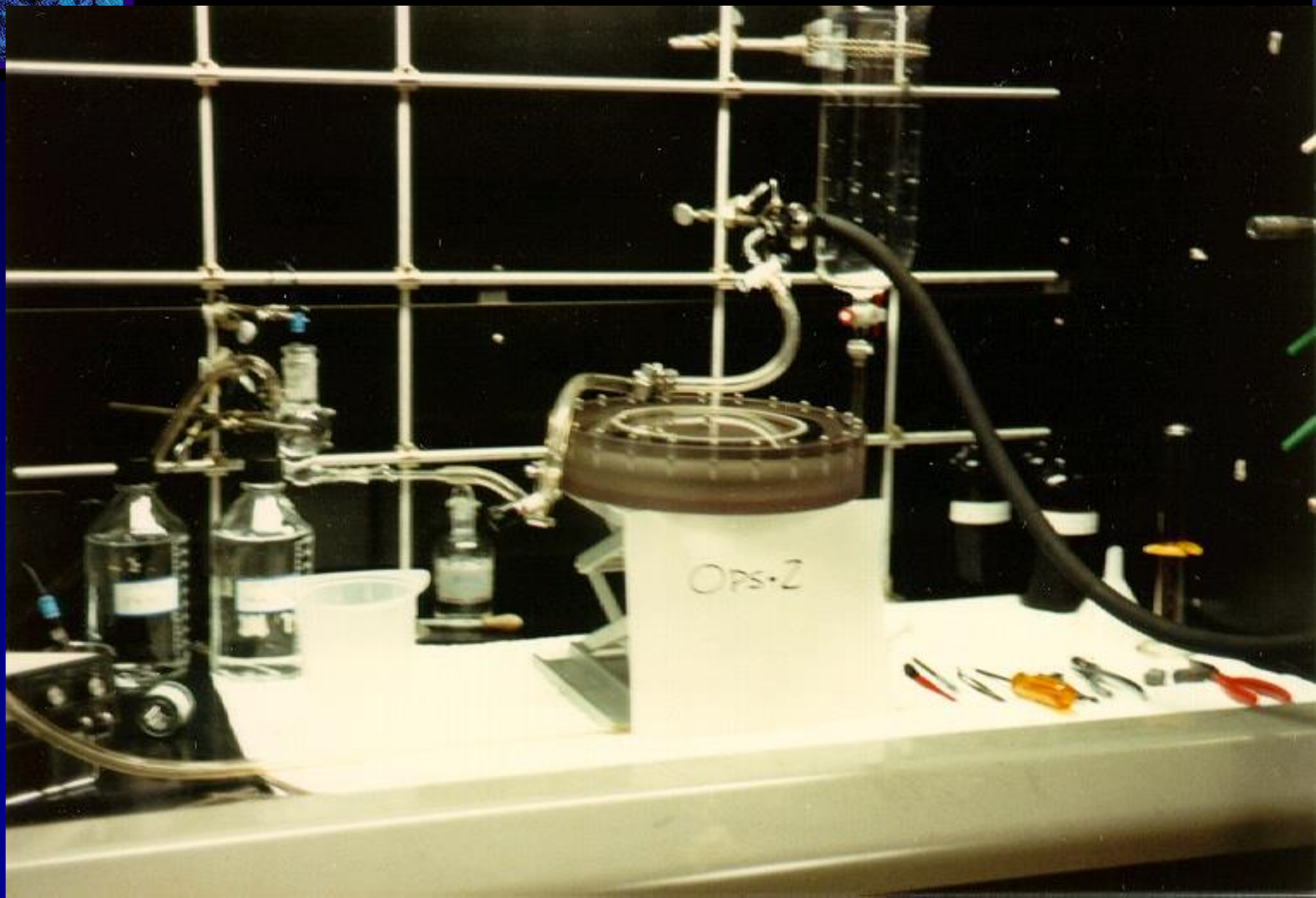


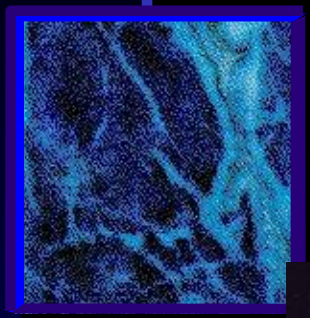
Ops-2 On Delrin Spring-load hub

Transferred to sealed rinse tank

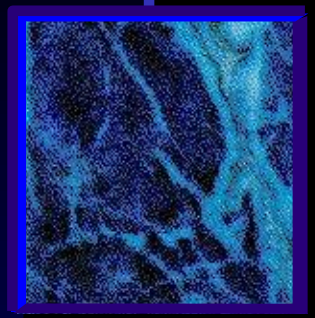


Chemical rinse process set up

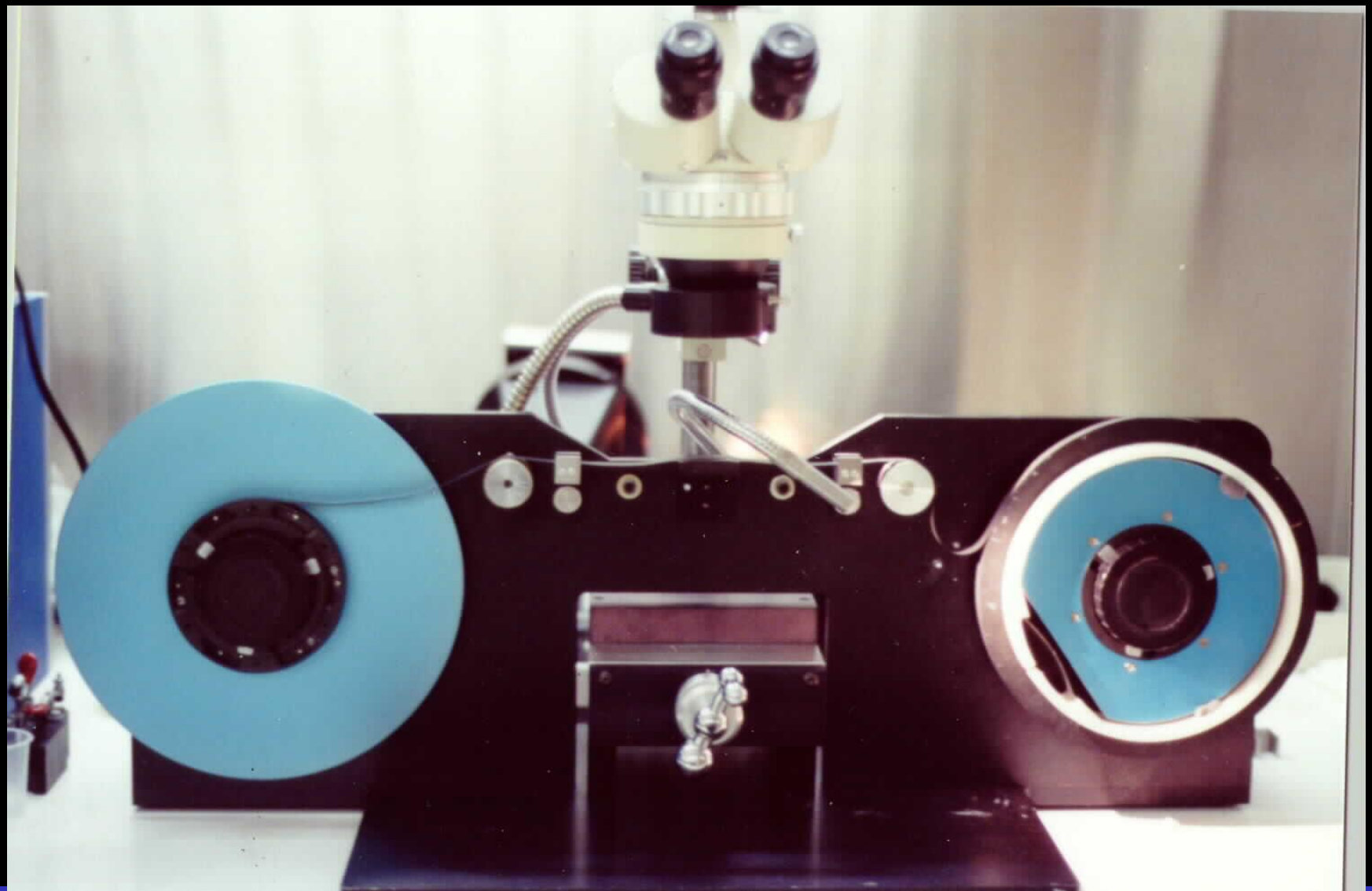


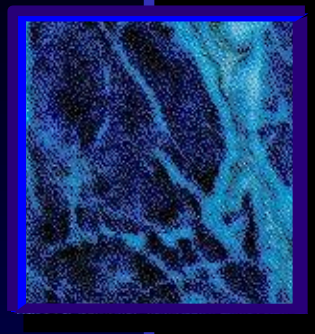


Chemically rinsed and lubricated tape on Delrin flange



Winding fixture to transfer tape to standard reel for play back

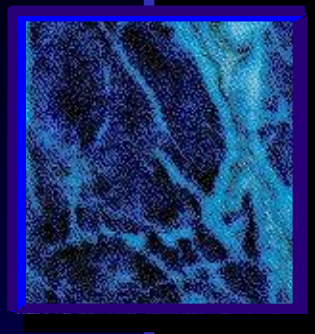




Treated tape slowly spooled off Delrin hub onto standard reel

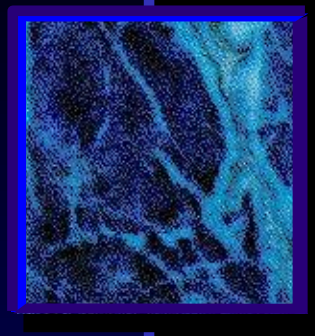
Residual salts at edges of tape and between wraps

Foam wedges fit hub adapter to Delrin hub



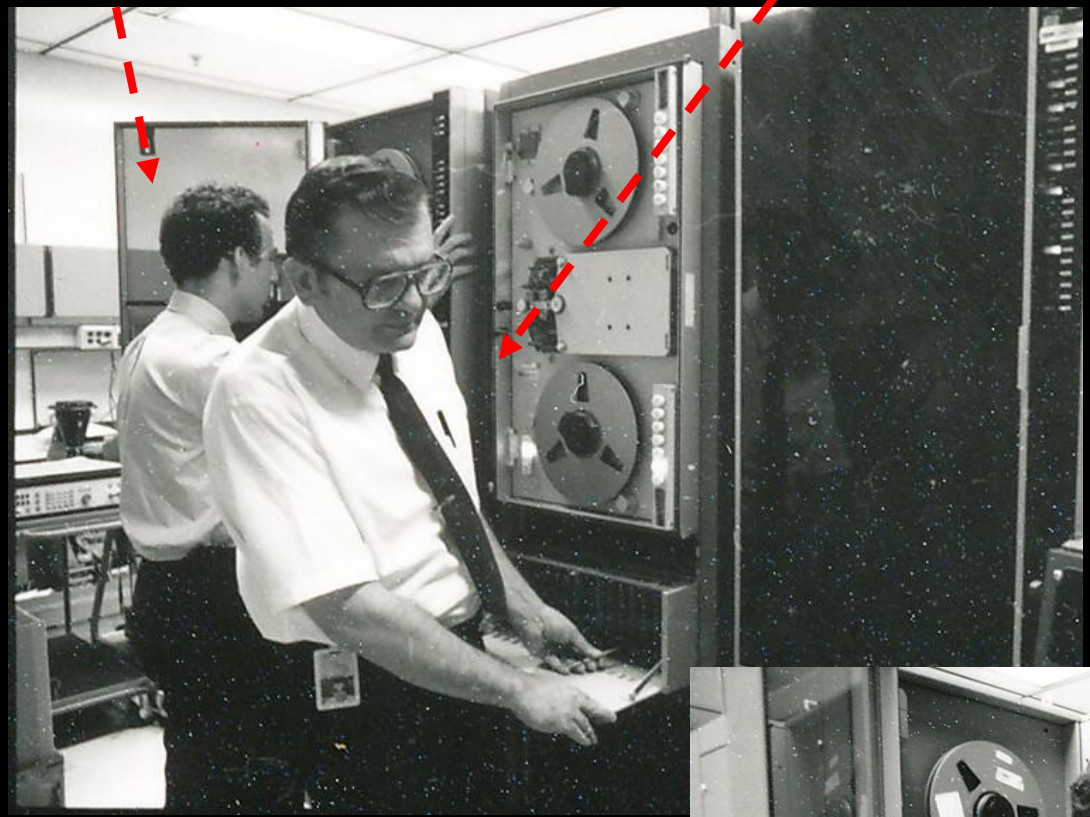
Dr. Ed Bartkus, IBM Tape Development unwinding the treated Ops 2 Tape

Recording surface with some residual salt contamination at edge

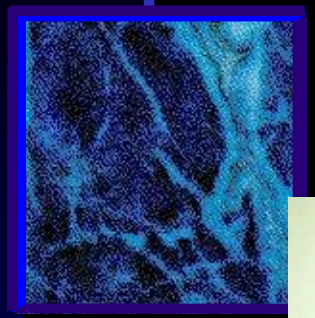


Data read and transfer to a new tape

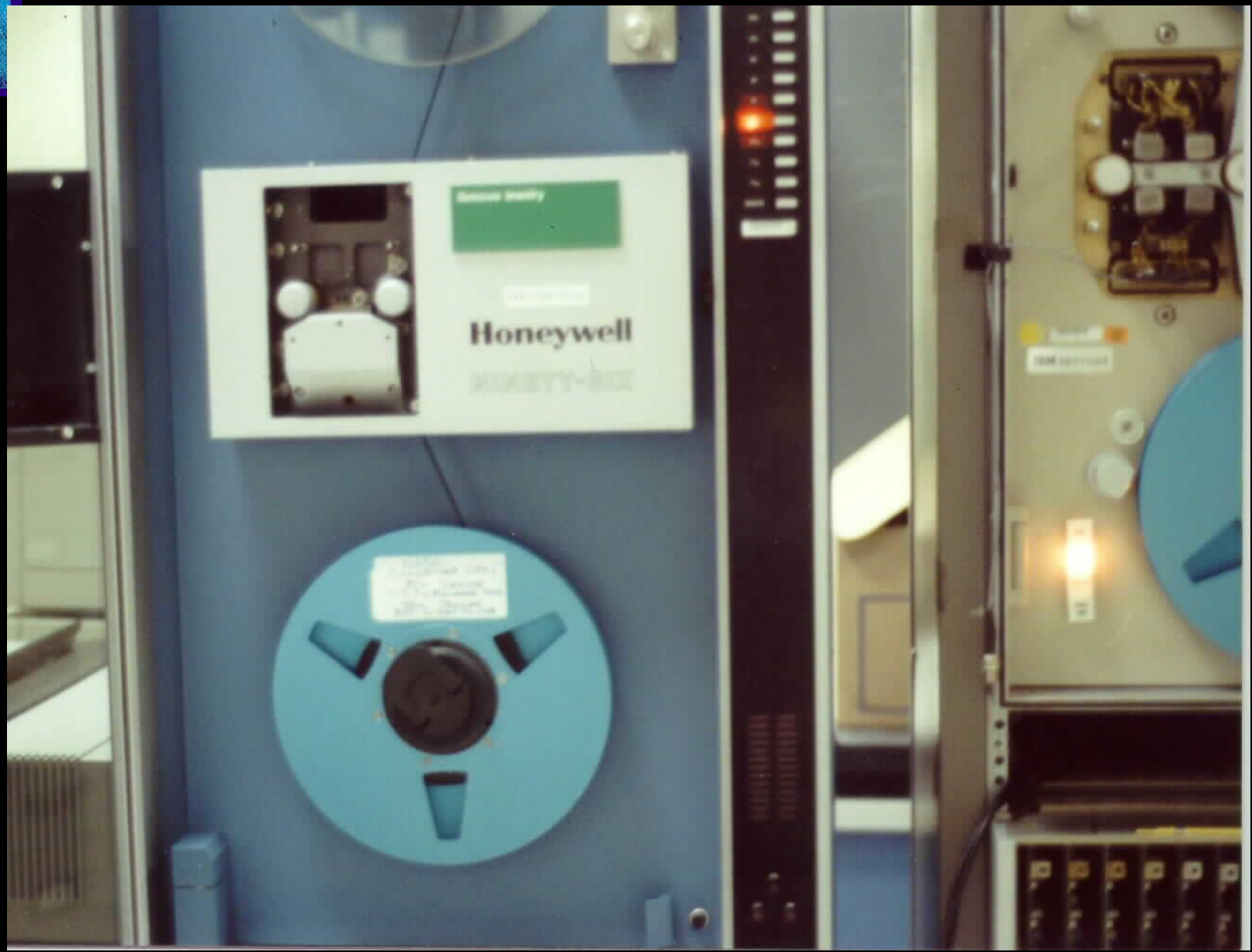
Blair Finkelstein and Ray Kamens of IBM Tucson

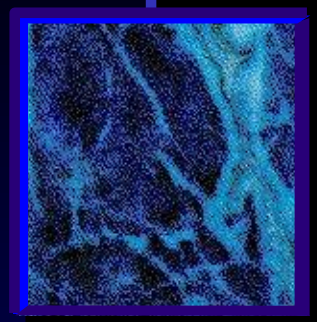


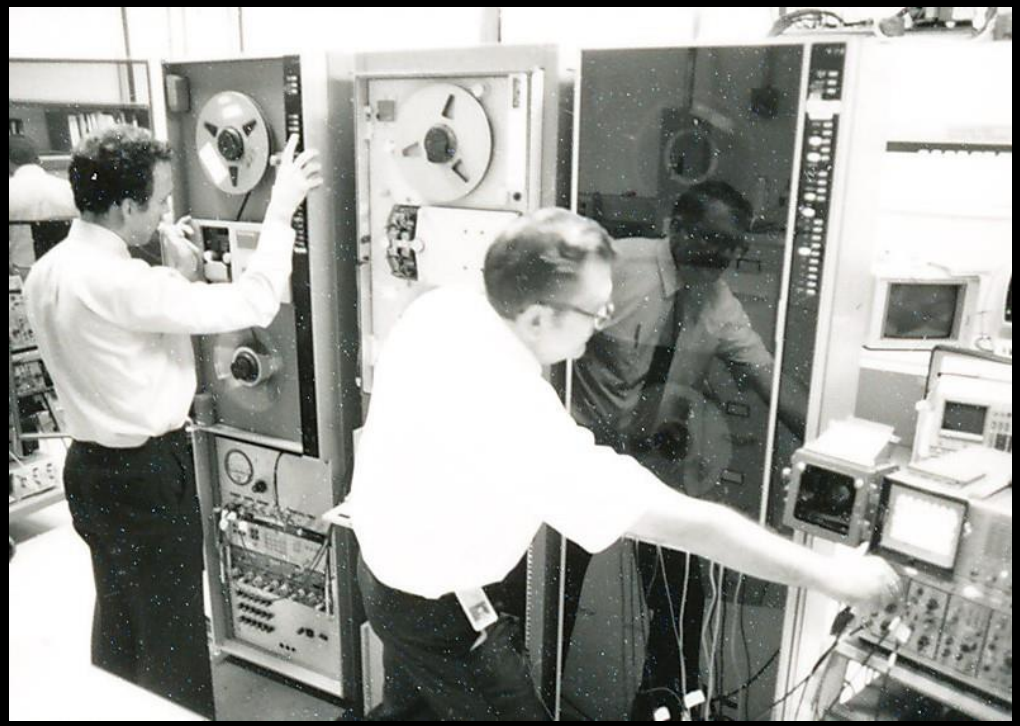
Payload tape: single 0.53mm wide track down middle of tape, biphase L coded data at 62 Kb/s 0.19 m/s tape speed



Read back and copy transports





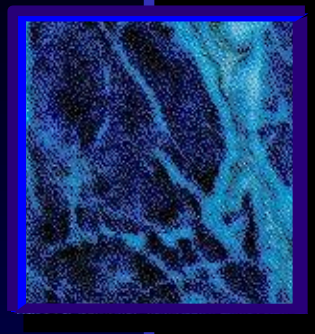


Operations 1 (Ops1) tape: three adjacent tracks 0.53 mm wide down center of tape at 0.19m/s tape speed

Operations 2 (Ops2) tape: (crew voice & data) single 0.53 mm wide track with a 0.61 m/s tape speed down center of tape

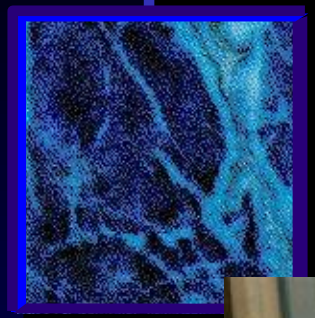
An analog copy of the recovered tape was made using a Honeywell Model 96C instrumentation tape drive with an inductive head. A custom built low noise preamplifier with flat response to 2MHz mounted as close as possible to the read head to minimize noise was used to capture the recorded signal. The write head was removed from the drive to eliminate any possible damage by the tape running across this unnecessary component for this exercise.

The adjustable gain allowed by this system was used to adjust the output signal amplitude to maintain an optimum range and signal bandwidth to send to the write head electronics on the other reel to reel Honeywell Model 5610 instrumentation drive.

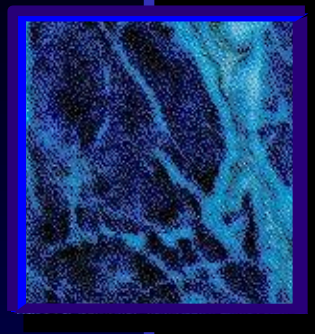


Recording of the recovered signal was made on a new high energy instrumentation tape running at 0.75 m/s. AC bias recording allowed linearizing the recording process and the best possible undistorted reproduction of the original signal from the damaged tapes. Two tracks were recorded for each track written on the original tapes to reduce the possible risk of data loss from a dropout on the new tape.

The low priority Payload tape was used to optimize the data rerecording process. As tape speed increased, SNR improved but the tape integrity suffered. A total of eight re-recordings were made. After the third pass the recovered tape began to degrade forcing the read head and drive capstan to be cleaned repeatedly.

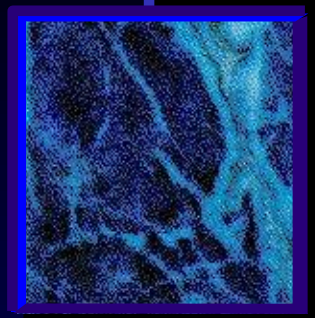


Signal capture and processing



Several copies of each reel were made at different speeds for the original and copied tapes; reading in both forward and backward directions.

The Ops 2 tape was read two times forward and backward at 0.19 m/s and then two more times, forward and backward at 0.38 m/s before the recovered tape began to shed coating and fall apart



The recorded copies and the original flight recorder tapes were returned to NASA's Johnson Space Flight Center in Houston. NASA informed IBM that they were able to read more than 90% of the recorded blocks on the Payload and Ops 1 tape and 100% of the Ops 2 tape.

"... the restoration by IBM engineers was a 'minor miracle.'"

(A NASA official quoted in *The Washington Post* concerning IBM Tucson's restoration of the *Challenger* intercom tapes.)

CHEMICAL AND ENGINEERING NEWS
August 25, 1986

Technology

Acid baths help recover *Challenger* tapes

Local IBM experts restored shuttle tapes

By Jim Erickson
The Arizona Daily Star

After three months of work by 16 IBM Tucson engineers, it all came down to a two-syllable exclamation by space shuttle Challenger pilot Michael J. Smith: "Uh-oh!"

Smith's remark, heard on a tape was restored by IBM engineers at the company's General Products Division laboratory on Rita Road. A transcript of the intercom tape was released by NASA earlier this week.

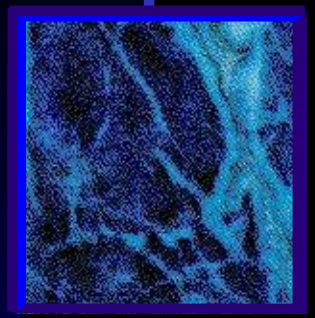
"It's clear that without the IBM (restoration) process, those tapes and that information would have

wreckage in the Atlantic Ocean o Cape Canaveral, Fla.

Initially, officials of the Nationa Aeronautics and Space Administra tion feared that the tape data woul be lost because salt water ha reacted with the magnesium tap reels to create a strong adhesiv

'A minor miracle'

IBM engineers defy odds — help save Challenger tapes



Finals words… Uh ..oh ...

The Arizona Daily Star

Vol. 145 No. 228 * Final Edition, Tucson, Tuesday, July 29, 1986 35¢ 40 Pages

Challenger crew alive after blast, NASA says

By Paul Recer
The Associated Press

SPACE CENTER, Houston — Space shuttle Challenger pilot Michael J. Smith exclaimed "Uh-oh!" at the moment the spacecraft exploded, and some of the crew apparently lived long enough to turn on emergency air packs, NASA said yesterday.

Smith's remark, heard on a tape of the shuttle's intercom system, was the first indication that any of the seven astronauts killed may have been aware of the Jan. 28 disaster, the worst in the history of space exploration.

The astronauts probably survived the explosion and breakup of the shuttle orbiter and could have had 6 to 15 seconds of "useful consciousness" inside the crew compartment after the blast, said Dr. Joseph Kerwin, an astronaut-physician who investigated the cause of death for the crew.

The force of the crew compartment's hitting the ocean was so destructive, however, that the precise cause of death for the crew could not be determined, he said.

The intercom tapes, which include enthusiastic chatter among the crew about the moments after liftoff, were recovered from the wreckage of the Challenger and analyzed by National Aeronautics and Space Administration and IBM engineers. (Some of the IBM work was done at the company's Tucson plant.)

The tape, a transcript of which was released by NASA yesterday, offered no evidence that any crew members other than Smith knew anything was abnormal prior to his single exclamation 73 seconds after launch — the very second that ground controllers lost communication with the craft.

Previously, the last known words from the Challenger were those heard from Commander Francis R. "Dick" Scobee to ground controllers, when he responded "Roger, go at throttle up," confirming that the shuttle's main engines had been raised to full power.

School teacher Christa McAuliffe and mission specialists Ronald McNair and Gregory B. Jarvis are not heard on the recording.

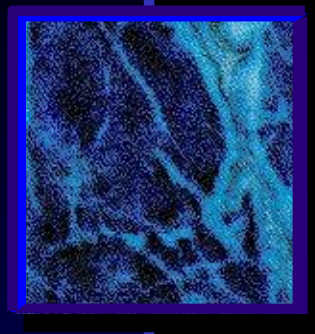
NASA said the three "could monitor all voice activity but did not make any . . . comments."

Admiral Richard H. Truly, associate administrator for space flight, said it was not unusual for there to be no comment from crew mem-

See CHALLENGER, Page 2A

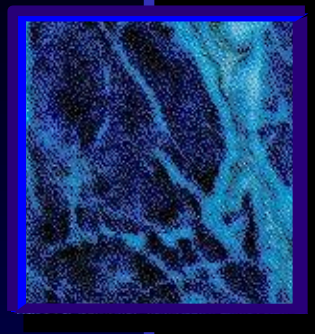
1983 AP photo

Michael J. Smith
At explosion: "Uh-oh!"



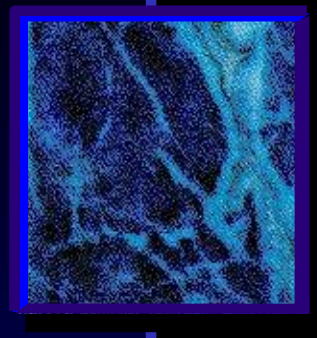
NASA Space Shuttle *Challenger* Flight Recorder Tape Recovery

- 28 January 1986 - launch and destruction of *Challenger*
- March - Recorders recovered from ocean (over 90ft depth)
- April 17 - NASA visits IBM Tucson (CR 2333, Bldg 061-2, 1:00-2:00 PM sample of unrecorded supply reel tape from payload recorder compared to undamaged 3M 892 tape from FSD study indicates possibility of successful tape recovery
- Noon April 18 - Analysis completed of sample and supply reel tape left for Tucson to develop a recovery process
- 2 May - report sent to NASA Johnson Space Flight Center



NASA Space Shuttle *Challenger* Flight Recorder Tape Recovery

- 8 May,1986 - Payload recorded tape received from NASA
- 16 May - completed treatment, copied data to new tapes and sent multiple copies and original tape to NASA
- 7 July – received Ops1 & Ops2 tapes from NASA
- 12 July – completed treatment, copied data to new tapes and send multiple copies and original tape to NASA
- 17 July – NASA releases Data Recovery Press Release



IBM Tape Recovery Team

Ed Bartkus, SEM, tape handling
Ric Bradshaw, chemical process
Blair Finkelstein, signal capture and copying
Clem Kalthoff, vessel & support hub design
Dennis Byrne, universal tape reel winder & inspection station design & build

Resources & technical support of entire