

# *INSPECTING A RESEARCH REACTOR'S CONTROL ROD SURFACE FOR PITTING USING A MACHINE VISION APPROACH*

***Akira Tokuhiro\****

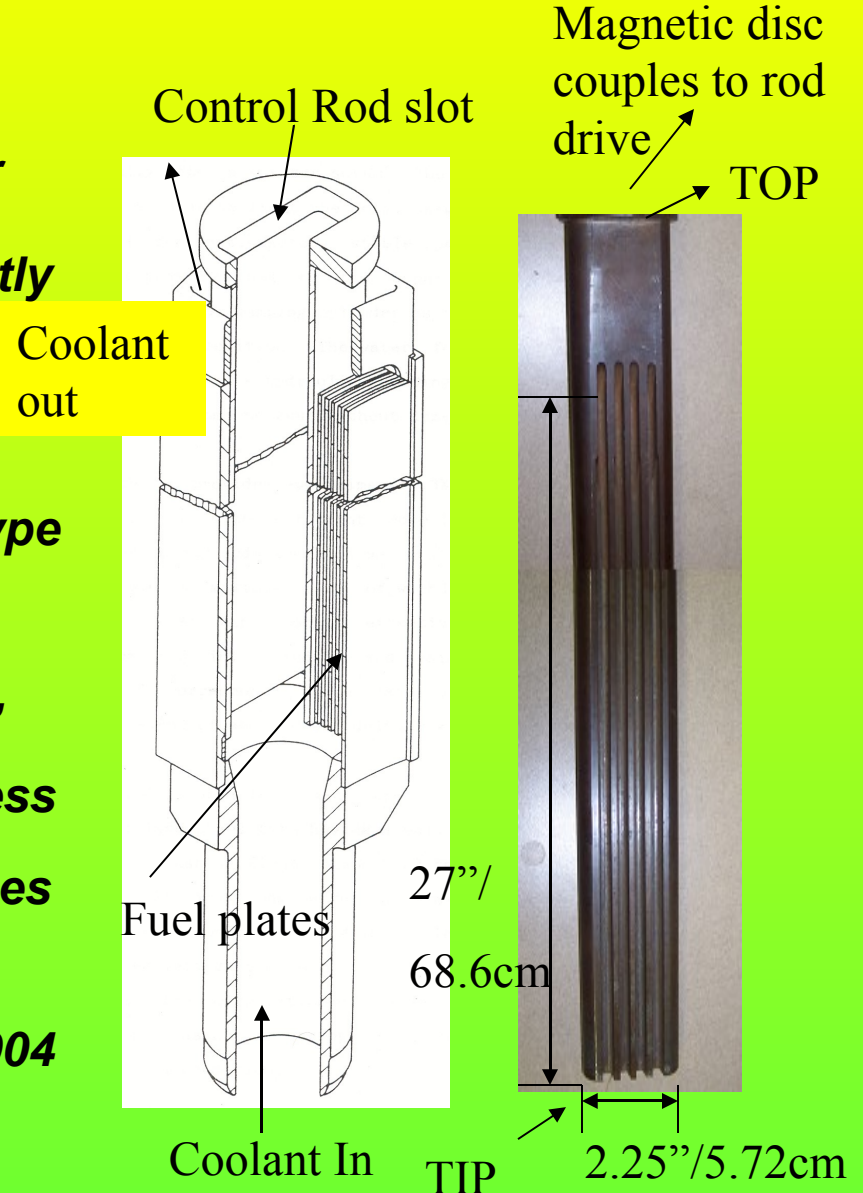
***Shreekanth Vadakattu\*\****

***\*work done as Director & SRO, University of Missouri-Rolla Reactor facility;  
currently at Kansas State University***

***\*\* MS Thesis, January 2005***

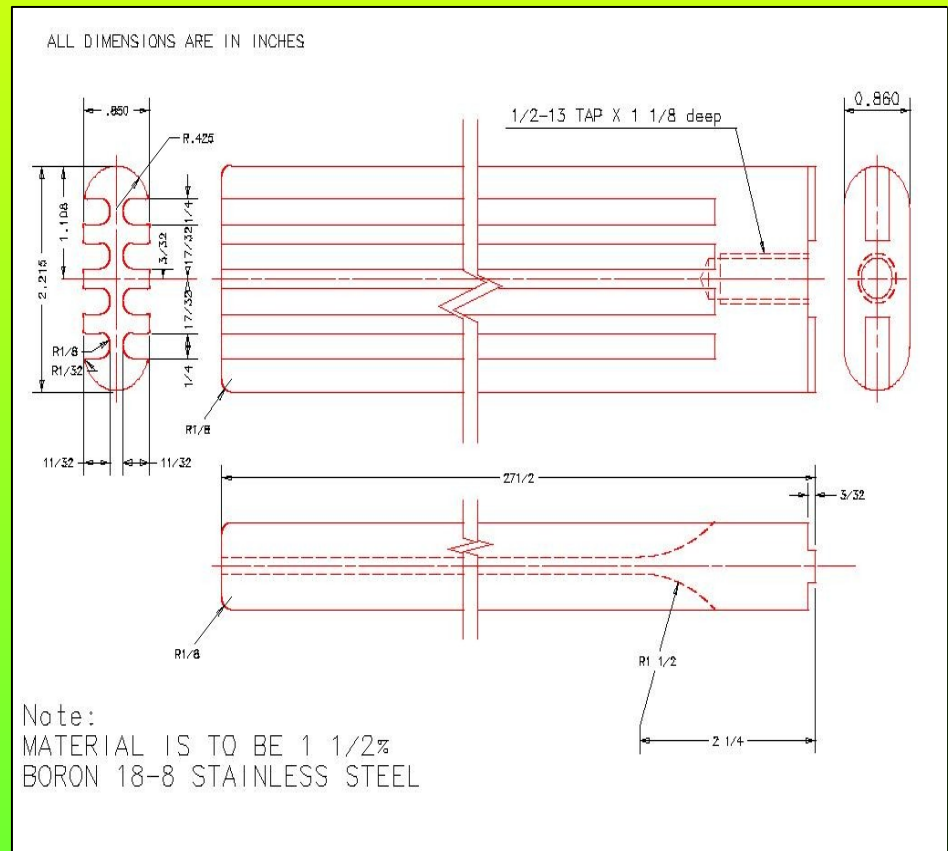
# UMRR Characteristics

- Operational since 1961; 1<sup>st</sup> nuclear reactor in Missouri
- Originally licensed at 10W; presently 200kW
- Switch from HEU to LEU in 1992; MTR (Material Test Reactor) plate type fuel
- Natural convection-cooled, pool-type reactor; non-pulse;  $\phi_{avg,th} \sim 10^{12}$  ns/cm<sup>2</sup>s
- One beam port  $\phi_{avg,th} \sim 10^6$  ns/cm<sup>2</sup>s, graphite thermal column, 2-pneumatic sample ports; core access & isotope production elements; sample rotator, various sample tubes
- Mainly for training and reactor laboratory classes
- Re-licensing application filed in 2004 for 20-year extension



# Control rod characteristics

- **Number of Rods used at UMRR: 3 safety and 1 regulating rod**
- **Dimensions of the rod:**
  - **Length – 27 inches (68.58cm)**
  - **Width – 2.25 inches (5.72cm)**
  - **Thickness – 0.875 inches (2.23cm)**
  - **Material – 18-8 borated stainless steel with 1.5-1.7% natural boron**



# *Introduction*

## *Traditional Inspection process*

- *Physical inspection using gauges performed by UMRR staff*
- *Subjective in nature; potential source of error*
- *Personnel radiation exposure during inspection.*

# *Introduction*

- ***Automation of inspection process***
  - ***Automation piecewise using state-of-the-art technologies.***
  - ***Minimizes personnel exposure during inspection; mandated under NRC license (ALARA)***
  - ***Potentially provides smaller error***
  - ***Provides archival quantitative results.***

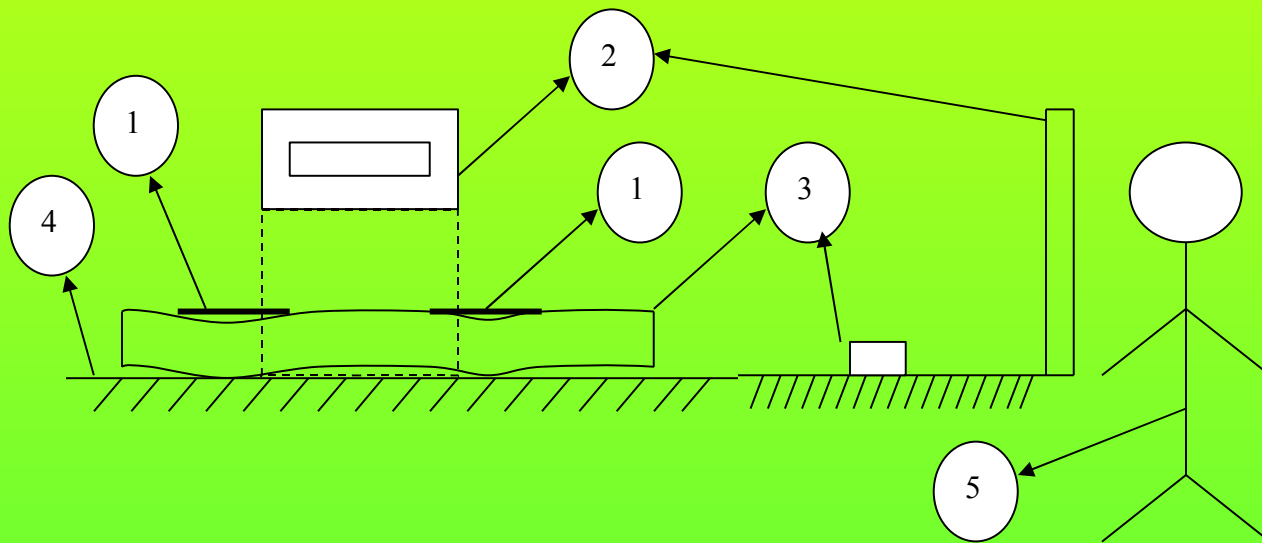
*Control Rod Inspection Process at  
UMRR*

# *Why to perform inspection of control rod?*

- *According to the UMR Technical Specification 4.2.1(5) shim/safety rods shall be visually inspected annually for bowing, pitting and cracking to ensure whether they are capable of performing their function.*
- ***Inspection for Bowing:***
  - Bow on the control rod surface is mainly due to the ductile behavior, high temperature and high energy neutron bombardment and secondarily, temperature gradient.
  - Bowing is measured to ensure geometric accuracy or shape deviation (bow) of control rod surface and make sure it does not frictionally contact with the control rod channel when driven in or out of the fuel element.
- ***Inspection for Pitting:***
  - Pitting on the control rod surface may be due to bombardment of high energy neutrons and corrosion caused by impurities in coolant (Coolants is doubly de-ionized water).
  - Resistivity of the coolant water observed is 0.806 MΩ-cm.
  - Pitting is measured to check for physical degradation on the control rods.

# *Inspection process at UMRR*

- Control rods are retrieved from the reactor core and placed on to a measuring stand partially behind the shielding.
- This inspection task is performed using Standard Operating Procedures (SOP 302) for control rod inspection and recorded in permanent log book.
- After placing the rod on the measuring stand, bowing is measured by placing a level on the rod surface and moving feeler gauge blades between the level plates and the control rod surface.
- Pitting is visually inspected and noted in the permanent log book.

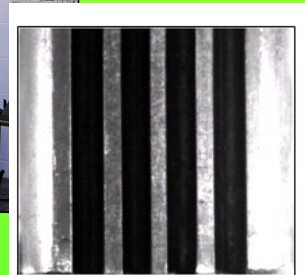
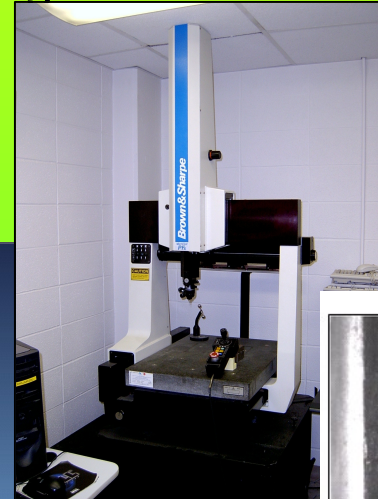


- 1. Level Plates**
- 2. Shielding**
- 3. Control Rod**
- 4. Measuring Stand**
- 5. Reactor Personnel behind shield**



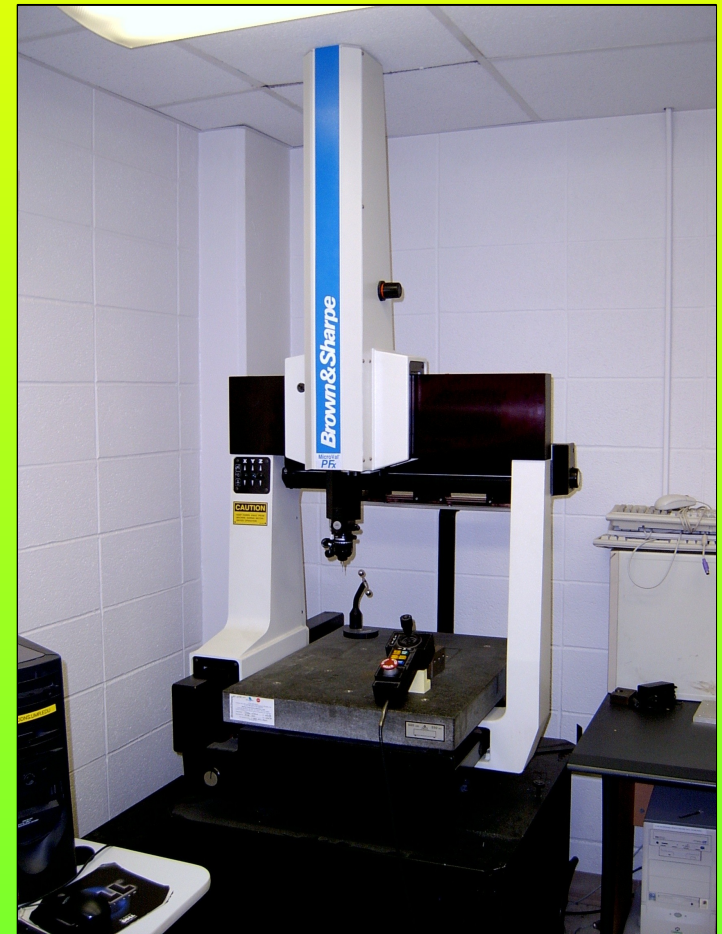
# Objective

- To stepwise automate annual control rod inspection task. Inspection tasks involve:
  - *Measurement of bowing using Coordinate Measuring Machine (CMM)*
  - *Evaluation of surface pitting of the control rod surface using Machine Vision technique.*
- Third Step (not done)
  - *Programming of a robotic arm to move Control Rod from the pool to measuring stand and inspect using machine vision.*



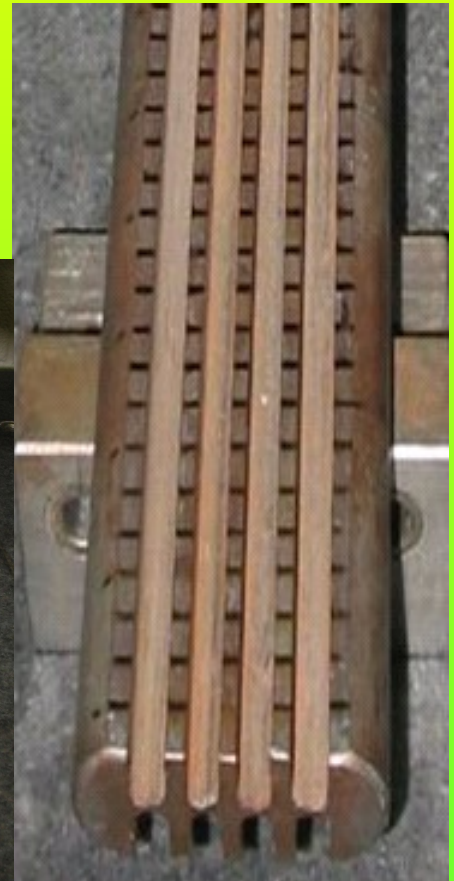
# *Bowing Inspection using CMM*

- **Coordinate measuring machines (CMM) are mechanical systems designed to move a measuring probe to determine coordinates of points on a work piece surface.**
- **CMM Specs:**
  - **Manufacturer: Brown & Sharpe**
  - **Series: Micro Val pfx**
  - **Measuring Range: 458x510x406 mm (18x20x16 inches)**



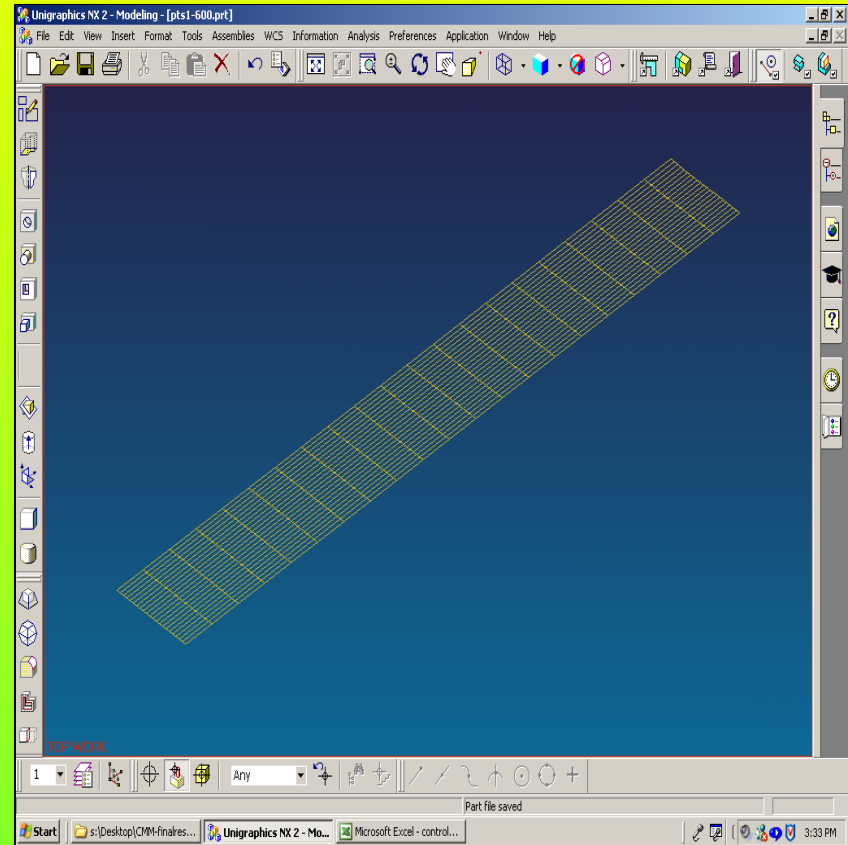
# *Inspection using CMM Continued..*

- To measure amount of bow on the control rod surface, many points are collected from the surface using CMM.
- The process of collecting points from any physical part to reproduce its features is called “reverse engineering”
- Reverse engineering requirements:
  - CMM (Brown & Sharpe) instrument
  - Touch Trigger probe system (Reinshaw M8)  
senses surface contour.
  - CAD Solid Modeling  
software to reproduce  
parts (UNIGRAPHICS NX2)



# *Inspection using CMM Contd..*

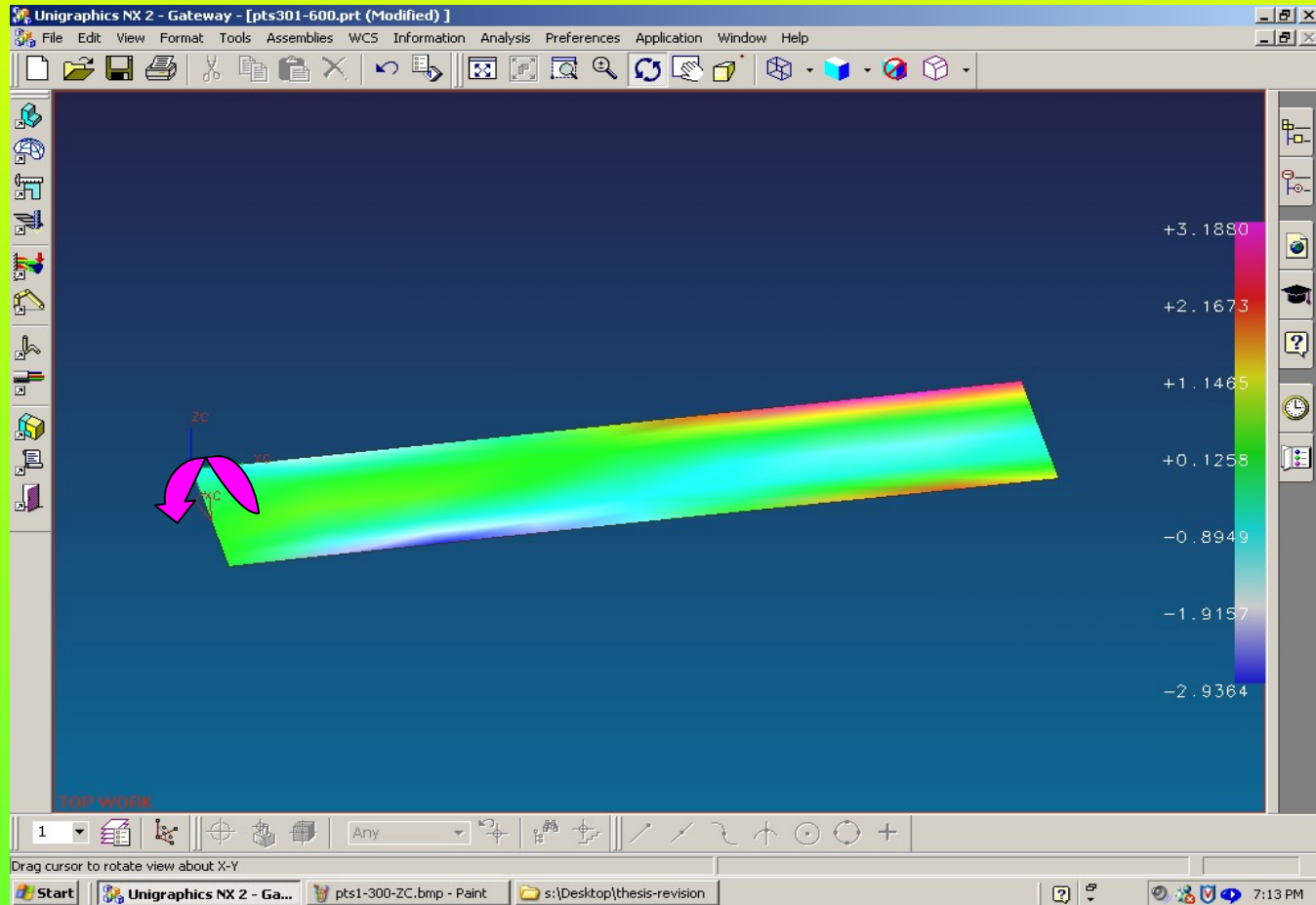
- **600 points were digitized which represents 15 inches of control rod in length.**
- **Points collected from the DMIS program are retrieved using CAD UNIGRAPHICS software.**
- **Surface is generated using “Free form feature”**
- **Slope analysis is performed on the surface to determine bow on the control rod surface.**





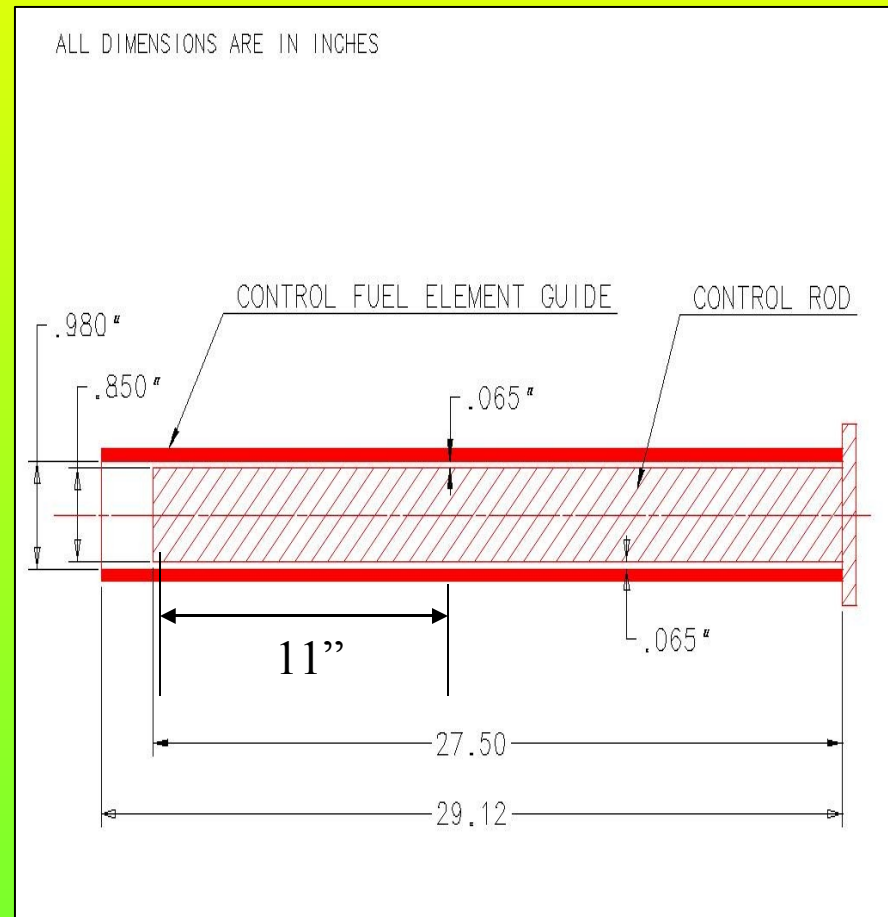
# Results

***Slope of the surface with respect to XC-Axis in degrees***



# Discussion

- **The width of the control rod is 0.850 inches (21.59 mm) and the inside width of the fuel element guide is 0.980 inches (24.89 mm).**
- **The maximum allowed tolerance between the fuel element guide and the control rod surface is 0.065 inches (1.65 mm) on either side of the control rod surface**
- **The maximum bow measured was 0.031 inches (0.787 mm) at 11 inches from the tip of the control rod which is well within the acceptable limit 0.065 inches.**



*Pitting Inspection on Control Rod  
Surface Using Machine Vision*

# *Pitting inspection using Machine Vision*

- *Since in-service control rod surface images were not available to estimate number of pits, applicability of machine vision technique was performed by simulating pits on steel coupons*
- *Pits are produced on steel coupon by immersing coupons in oxygen saturated de-ionized water at 30°, 50° and 70°C; de-ionized water is from reactor pool*
- *ASTM G-31 and G-46 standards for immersion corrosion testing, examination and evaluation of pitting corrosion respectively is followed*



# *Experiment Parameters*

- **Steel Coupon: SAE 1018 low carbon steel**
- **Coupon size: 25 X 25 mm  $\pm$ 1mm.**
- **Test solution: De-ionized water**
- **Test temperatures: 30°, 50° and 70°C (86°, 122° and 158°F)**
- **Aeration: Oxygen bubbled using sparger at a flow rate of 20 ml/min.**
- **Test duration: 24hrs for 30°C, 12hrs for 50°C, 8hrs for 70°C.**
- **Test cycles: 10 for each temperature**
- **Number of samples: 6 samples for each temperature range**
- **Cleaning Method: Using Nylon brush.**
  - **Bristle Diameter = 0.4 mm**
  - **Number of Bristle=3320 approximately**

# *Image Acquisition*

- *To study the pitting corrosion, images of the coupons are captured after each test cycle.*
- *To capture and analyze optical properties from the images, we setup the following system.*

- *Optical Unit*

- *Camera lens (NIKON 50 mm lens)*
- *Light bulb (75 watts)*
- *Mini Environmental Quality meter-850070(Light meter)*

- *Image sensing unit*

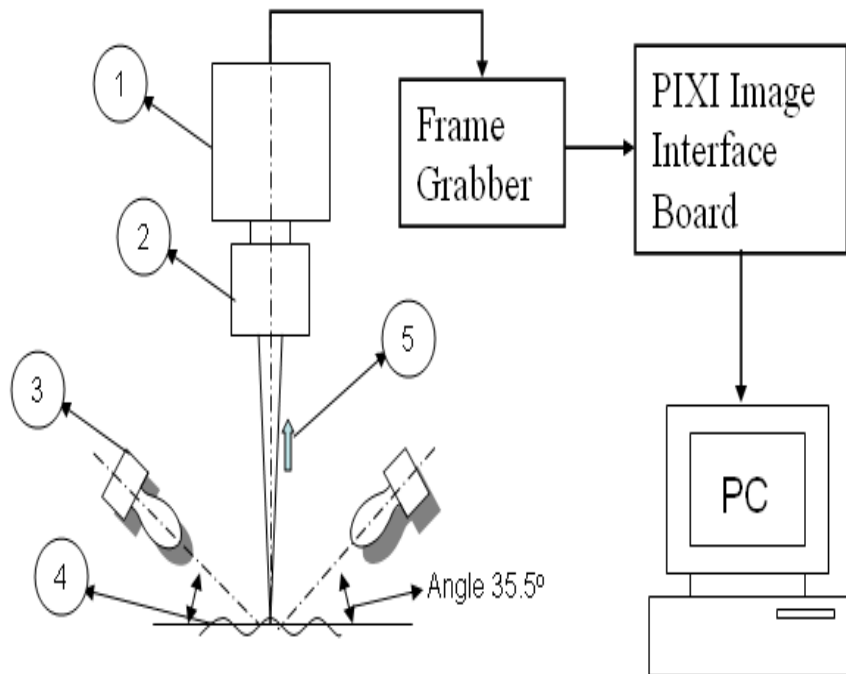
- *CCD camera (768 X 494) (Sony SR75 Model)*

- *PCI Imaging Board for Camera Link from EPIX Inc technologies*

- *XCAP-Standard software from EPIX Inc technologies*

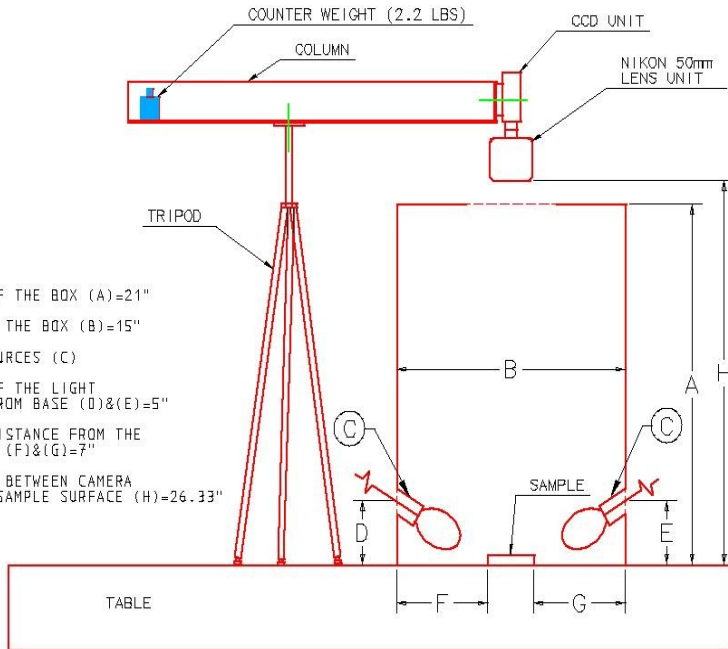
- *PC*

# *Experimental Setup*



# Experimental setup

ALL DIMENSIONS ARE IN INCHES



HEIGHT OF THE BOX (A)=21"

WIDTH OF THE BOX (B)=15"

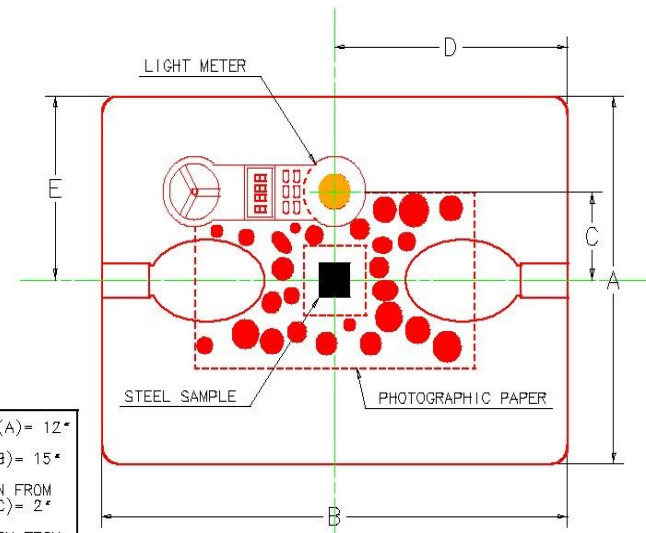
LIGHT SOURCES (C)

HEIGHT OF THE LIGHT SOURCE FROM BASE (D)&(E)=5"

SAMPLE DISTANCE FROM THE BOX WALL (F)&(G)=7"

DISTANCE BETWEEN CAMERA LENS TO SAMPLE SURFACE (H)=26.33"

ALL DIMENSIONS ARE IN INCHES



LENGTH OF THE BOX (A)= 12"

WIDTH OF THE BOX (B)= 15"

LIGHTMETER POSITION FROM THE STEEL SAMPLE (C)= 2"

LIGHT METER POSITION FROM SIDE OF THE BOX (D)= 7.5"

SAMPLE POSITION FROM THE BOX WALL (E)= 6"

# *Image Processing Steps*

- Capture images using machine vision setup
- Perform Image Analysis Using MATLAB
- Blob Analysis Using XCAP-Std software

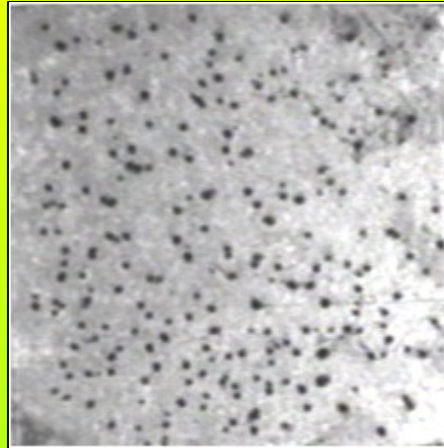
# *Blob Analysis Parameters*

- ***Blob analysis recognizes blobs based on the input values set for Minimum Blob width, Maximum Blob width, Minimum blob height, Maximum Blob height***
- ***These parameters are set by the user to locate size of the blob or pit (in pixel) on the image.***
- ***The input values that can be set range from 2 (pixel) for Minimum blob width and height and 9999 (pixel) for Maximum blob width and height.***

<b><i>Blob Analysis Parameters</i></b>	<b><i>Values set for</i></b>
<b><i>Minimum Blob width</i></b>	<b><i>2 pixel (0.02mm)</i></b>
<b><i>Maximum Blob width</i></b>	<b><i>50 pixel (0.5mm)</i></b>
<b><i>Minimum blob height</i></b>	<b><i>2 pixel (0.02mm)</i></b>
<b><i>Maximum Blob height</i></b>	<b><i>50 pixel (0.5mm)</i></b>

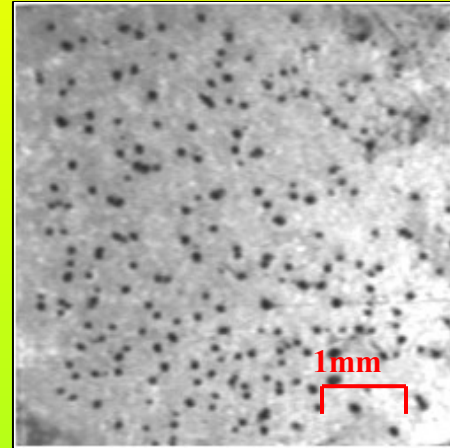
# *Image analysis Contd...*

RGB  
Image



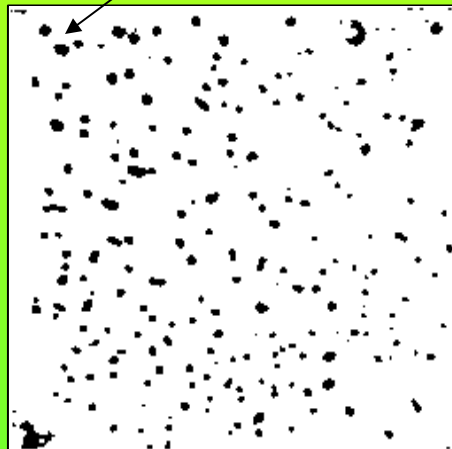
(A)

Grey  
Scale  
Image



(B)

White background



(C)

White background as  
Pits (blobs)



(D)



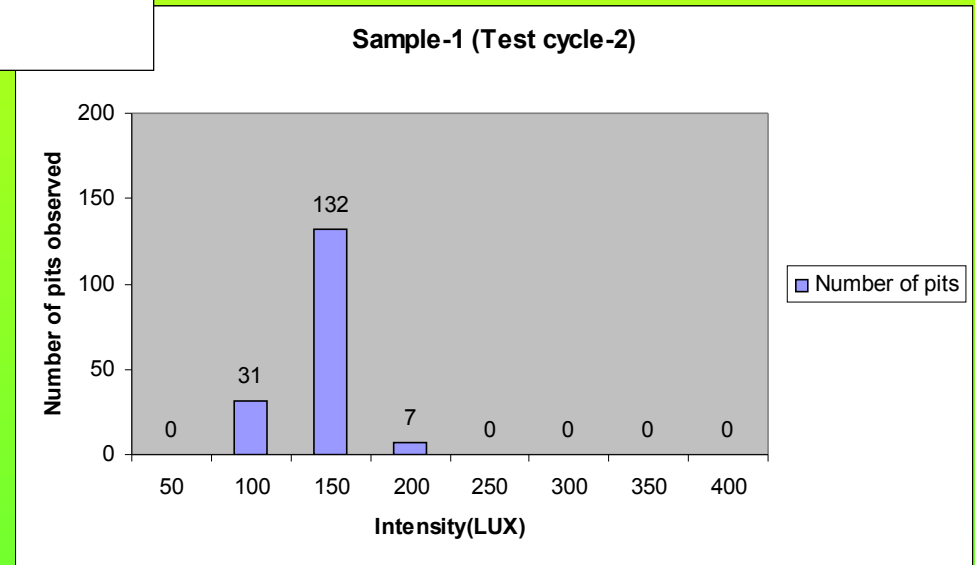
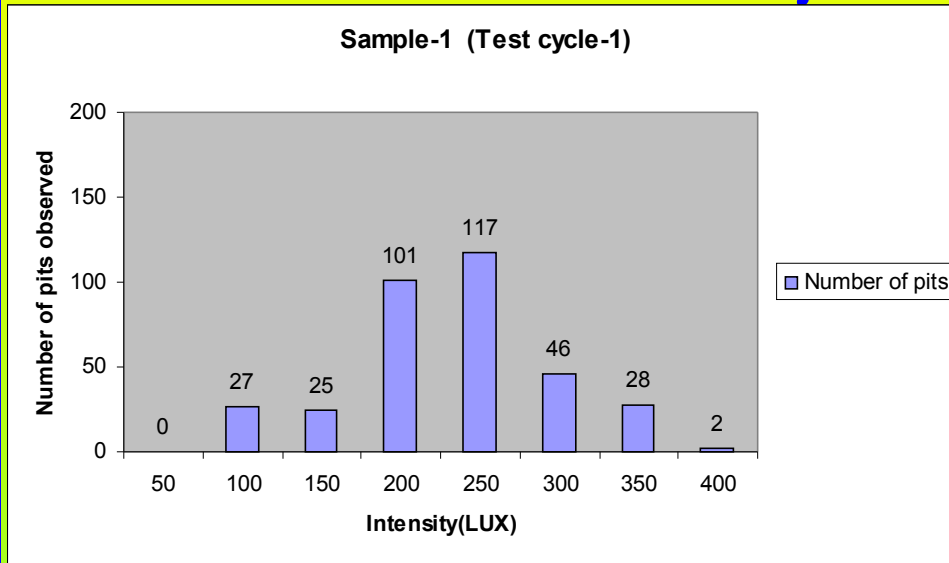
# *Results*

## ● *Light intensity versus number of pits*

- *Blob analysis is performed on the captured images after each test cycle to estimate number of pits.*
- *Light intensity versus number of pits helps in selecting the image showing maximum number of pits.*
- *Image with maximum topological information; i.e. maximum number of pits is sought.*

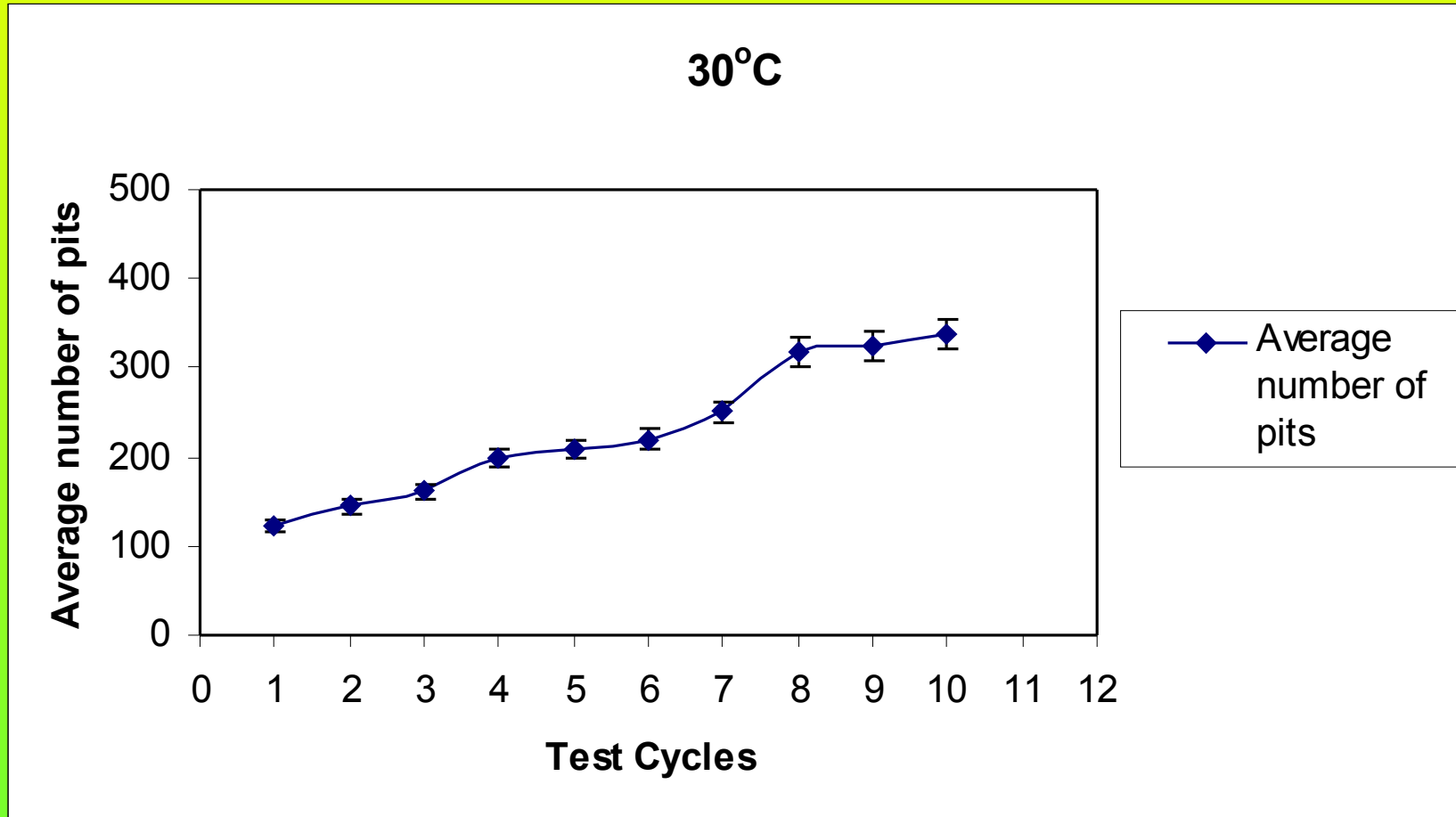


# Light intensity Versus number of pits for Sample-1 at 50°C

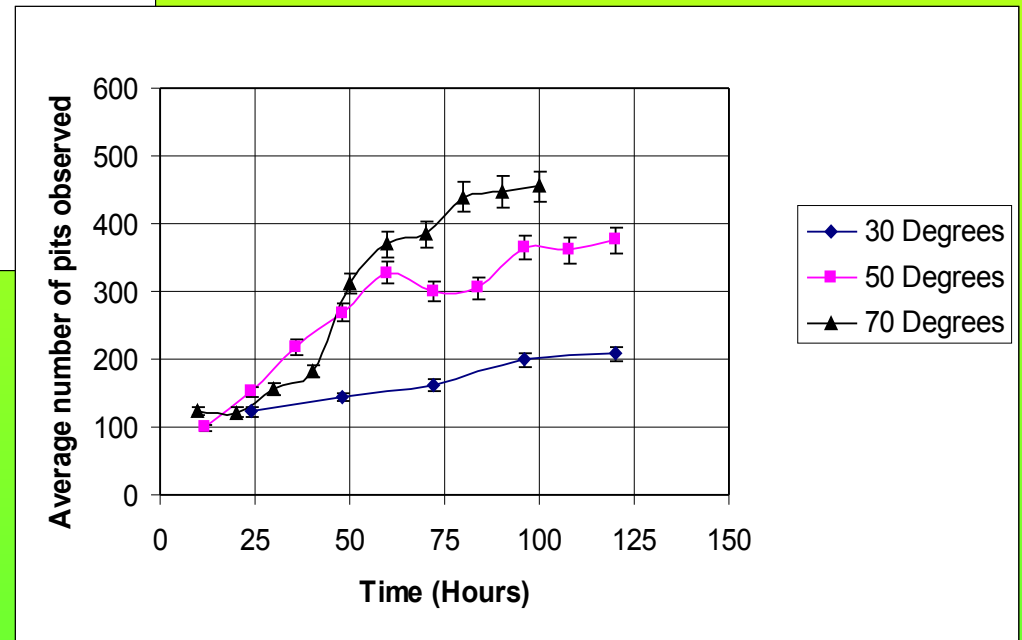
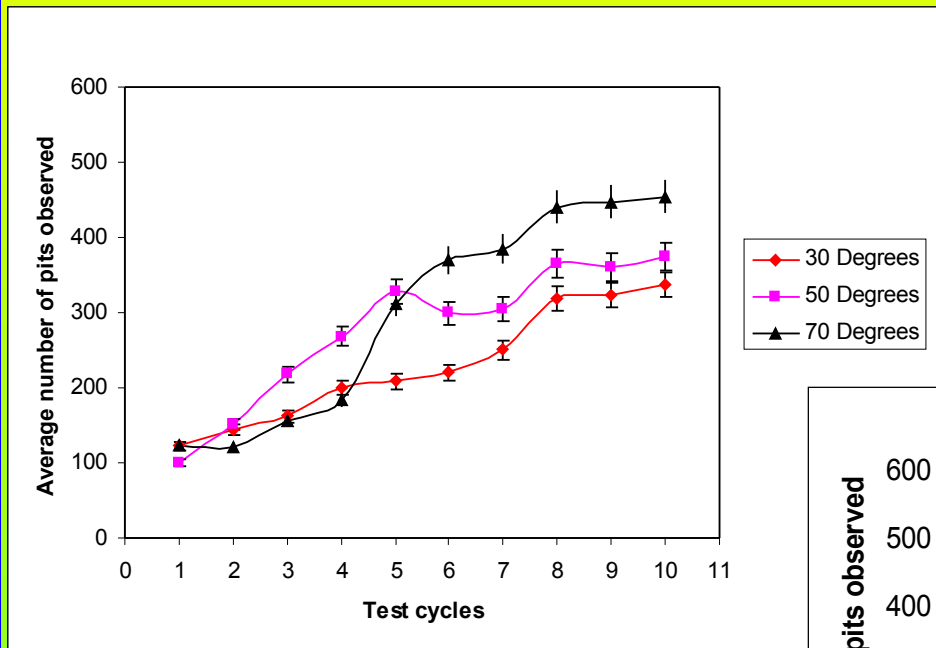


# *Average Number of pits versus Test cycles*

Average number of pits observed at 30°C



# Average number of pits observed at 30°, 50° and 70°C



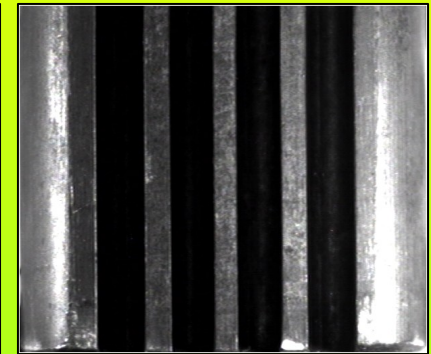
# Discussion

- **Machine vision technique is applied on the (un-irradiated) control rod surface.**
- **Images of the tip of the control rod is captured at 50, 100, 150, 200, 250, 300, 350 and 400 Lux.**

50 Lux



100 Lux



150 Lux

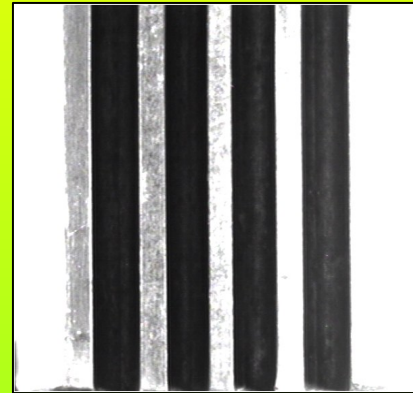


200 Lux

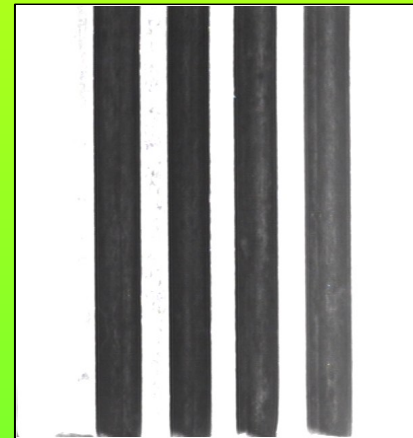
## *Discussion Continued...*

- *Blob Analysis is performed on the images to estimate number of pits.*
- *Light intensity versus number of pits is plotted to identify the image with maximum number of pits.*
- *Image captured at 150 Lux revealed maximum number of pits (37)*

250 Lux



300 Lux



350 Lux



400 Lux

# *Conclusions*

- *State-of-the-art technologies such as CMM and machine vision can be used to automate control rod inspection process*
- *Simple reverse-engineered surface generated after annual inspection can be compared from year-to-year; thereby reveal bowing trend of the control rod surface with accumulated in-core service time.*
- *Plotting number of pits versus light intensity is needed to identify the light intensity that gives the maximum number of pits; the maximum and distribution provide useful topographic information.*

## *Conclusions Continued...*

- *Application of both CMM and machine vision can be applied on the actual control rods of the UMR Reactor; thereby all but eliminate subjective evaluation*
- *Application of CMM and machine vision facilitates IT-based data archiving and data comparison*
- *Although not shown here, it is possible to use a late-model, programmable robotic arm to perform the control rod to/from movements from the pool's surface*

## *Contact information*

***Akira Tokuhira***

***Mechanical and Nuclear Engineering***

***Kansas State University***

***Rathbone Hall***

***Manhattan, Kansas USA 66506-5205***

***E: [tokuhira@ksu.edu](mailto:tokuhira@ksu.edu)***

***T: +1-785-532-3429***

***F: +1-785-532-7057***



# *Procedure to capture images*

- *Method for capturing images is based on the optical reflective properties of the surface and principles of light scattering.*
- *After each cycle, coupon is placed inside the box on photographic paper to obtain best sharpness on the coupon surface, between two light sources and perpendicular to the lens so that light is reflected from the coupon surface.*
- *Images are captured under varied light intensity to reveal the surface topology of the coupon*
- *Since it is difficult to identify at which particular light intensity value the surface gives maximum topological information , eight different light intensities 50, 100, 150, 200, 250, 300, 350 and 400 Lux are chosen which is measured using Light meter.*
- *Light intensity measured using light meter.*

# *Image Analysis*

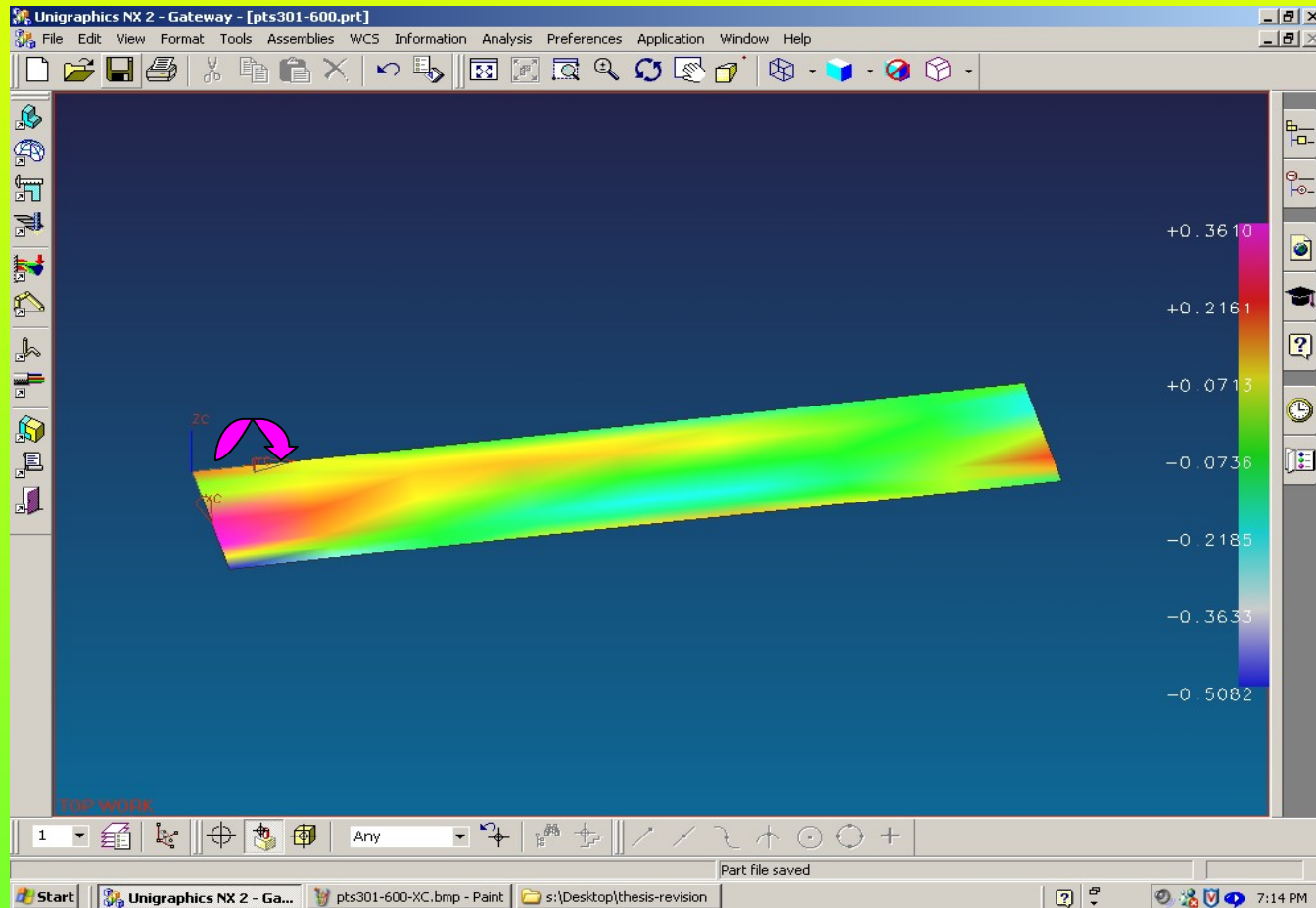
- *After capturing images at different intensities of light, XCAP-Std software is used to identify the image that reveal maximum number of pits.*
- *XCAP-Std has a Blob Analysis features which recognizes blobs as pits on the images and generates output report containing number of blobs.*
- *Blob Analysis feature in XCAP-Std identifies image blobs based on segmenting the image into foreground that is blob and background.*
- *Since the image captured is in RGB (Red, Green and Blue), filters available in XCAP-Std are not compatible with this format (RGB) and further blob analysis could not recognize between foreground and background in the image.*
- *To overcome this problem, image is converted into binary images (black and white) using MATLAB.*
- *By doing this all the black picture elements as foreground are identified as pits and background as white picture elements.*

# *Inspection using CMM Contd..*

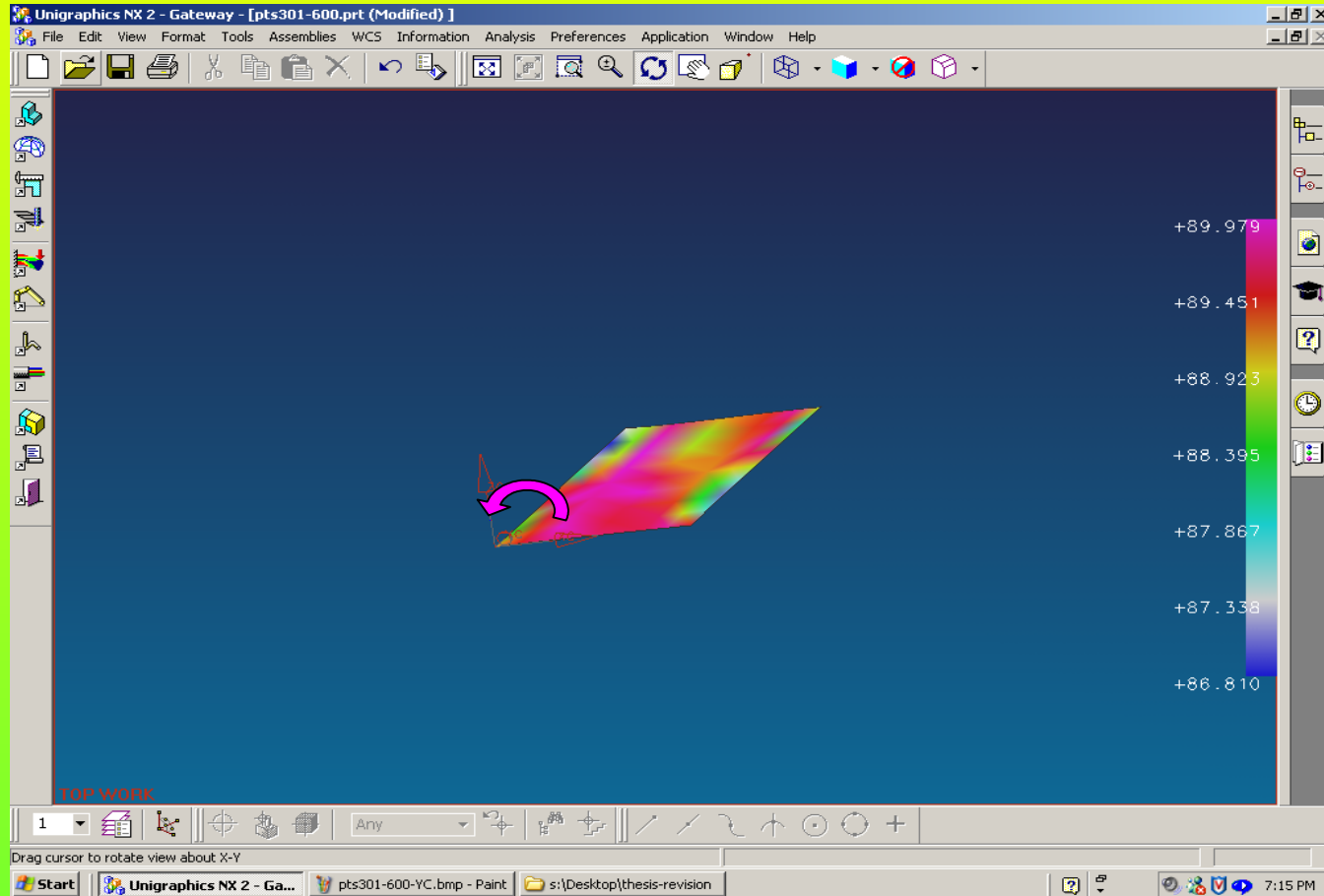
- 1) **The control rod is setup on two L-bracket on either ends of the rod to make it parallel to the granite work bench.**
- 2) **Before digitizing the points on the control rod with the probe, a grid of lines are drawn at a distance of 0.25 inches to locate points with the probe.**
- 3) **The digitized data (points) obtained from the CMM should be converted into the industry standard to use it in a solid modeling software. CAPPS-NT Version 5.1 is used for this purpose.**
- 4) **Point data is generated by taking one hit at a time. After each hit, part program is generated for that particular point in the DMIS program window of CAPPS-NT**



# *Slope of the surface with respect to YC-Axis in degrees*



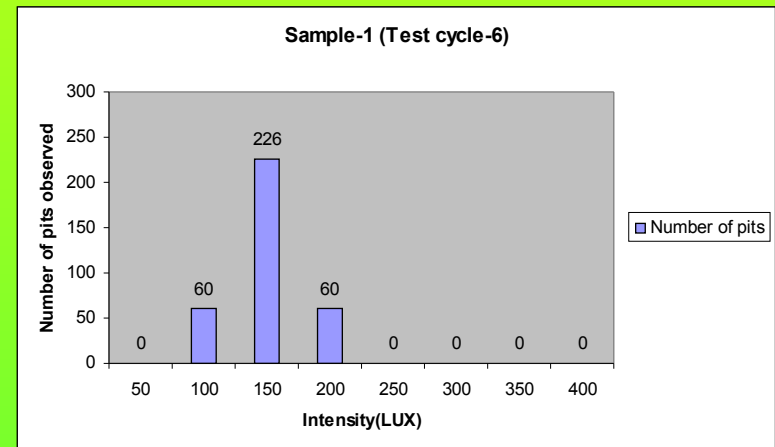
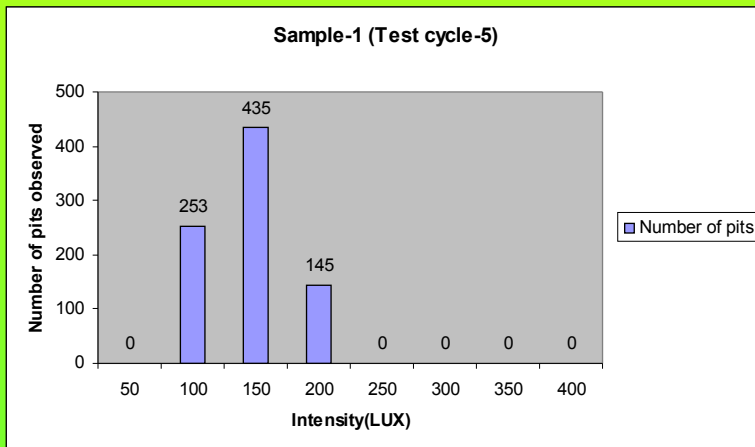
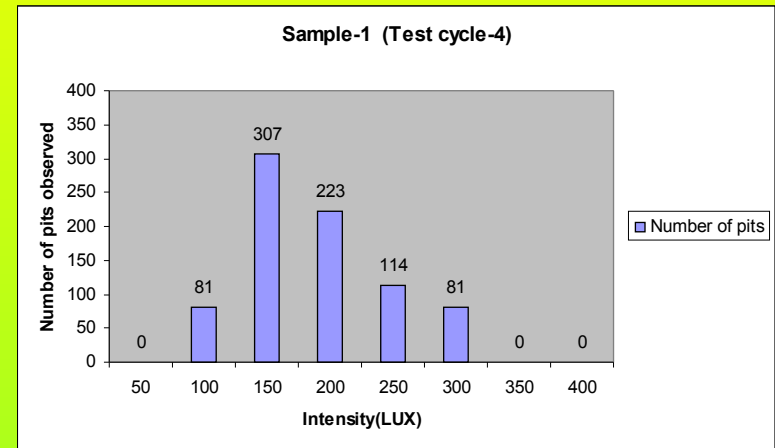
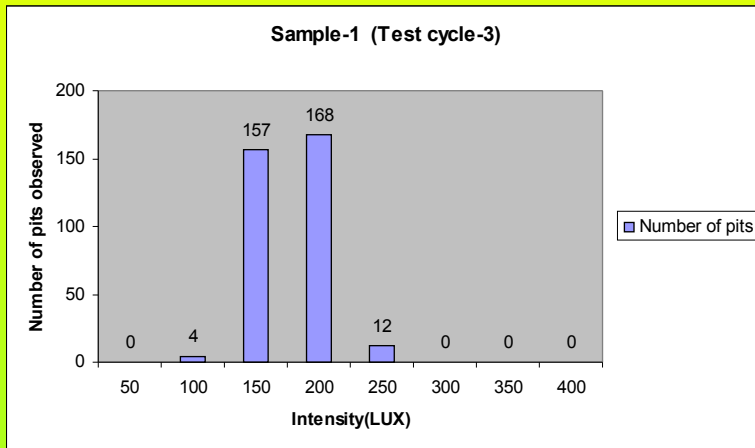
# *Slope of the surface with respect to ZC-Axis in degrees*



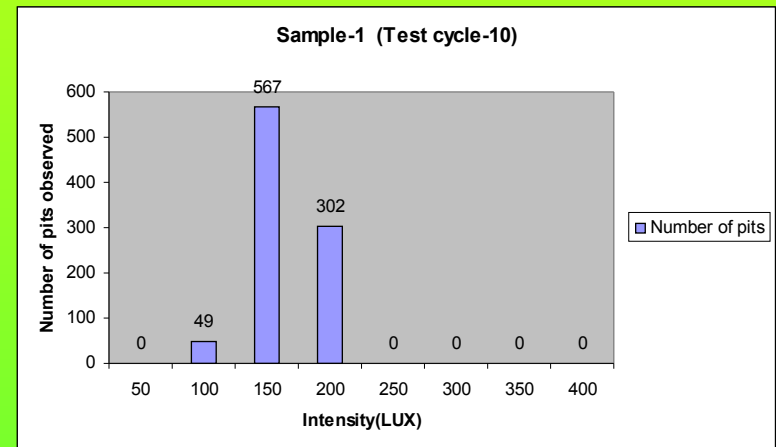
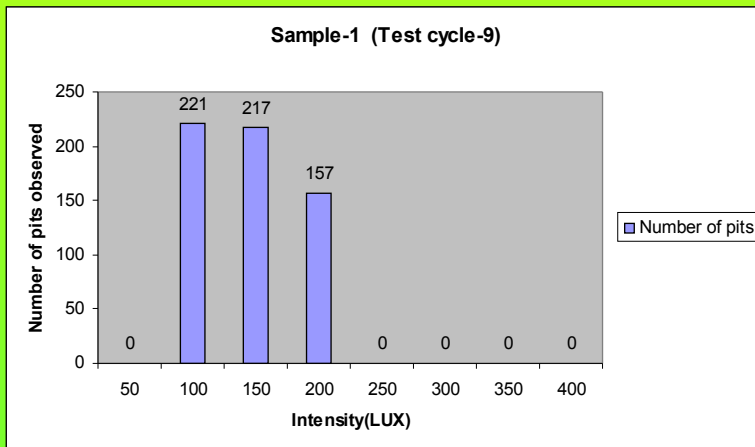
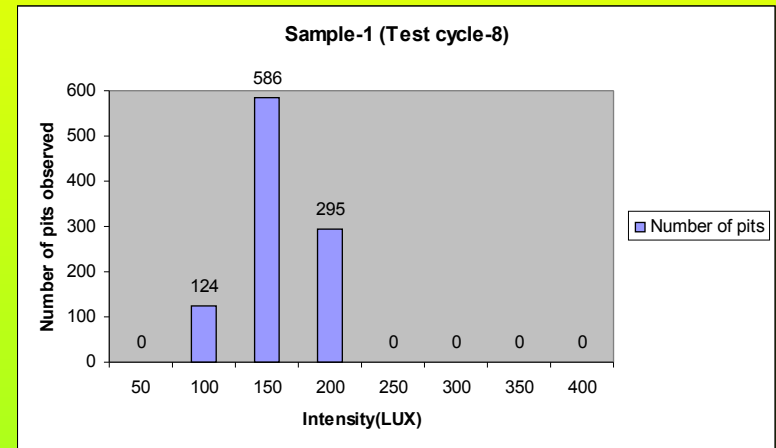
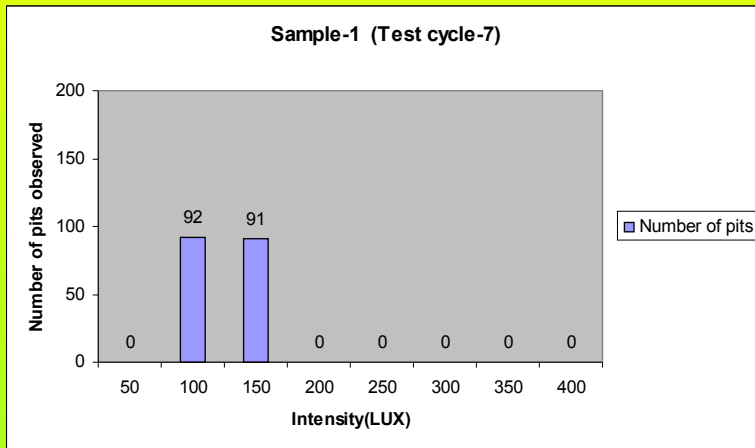
# *Past Investigations*

Authors	Pitting Corrosion experiment method	Purpose
Kong D Y	Immersion test of AISI 316L stainless steel in 3% NaCl aqueous solution at pH 2.5 and 5.0	To study topography of corroded areas using SEM and grey scale images
Bogaert- Alvarez R J	Immersion of 430, 304L, 316L and alloy 278 in 3.5 wt % NaCl aqueous solution made of 34 gm NaCl and 920 ml distilled water according to ASTM G61-86	Electrochemical noise experiment to establish relationship between Electrochemical noise, pit depth and pit density.

# Sample-1 50°C, Light intensity Vs Pits for test cycle 3-6

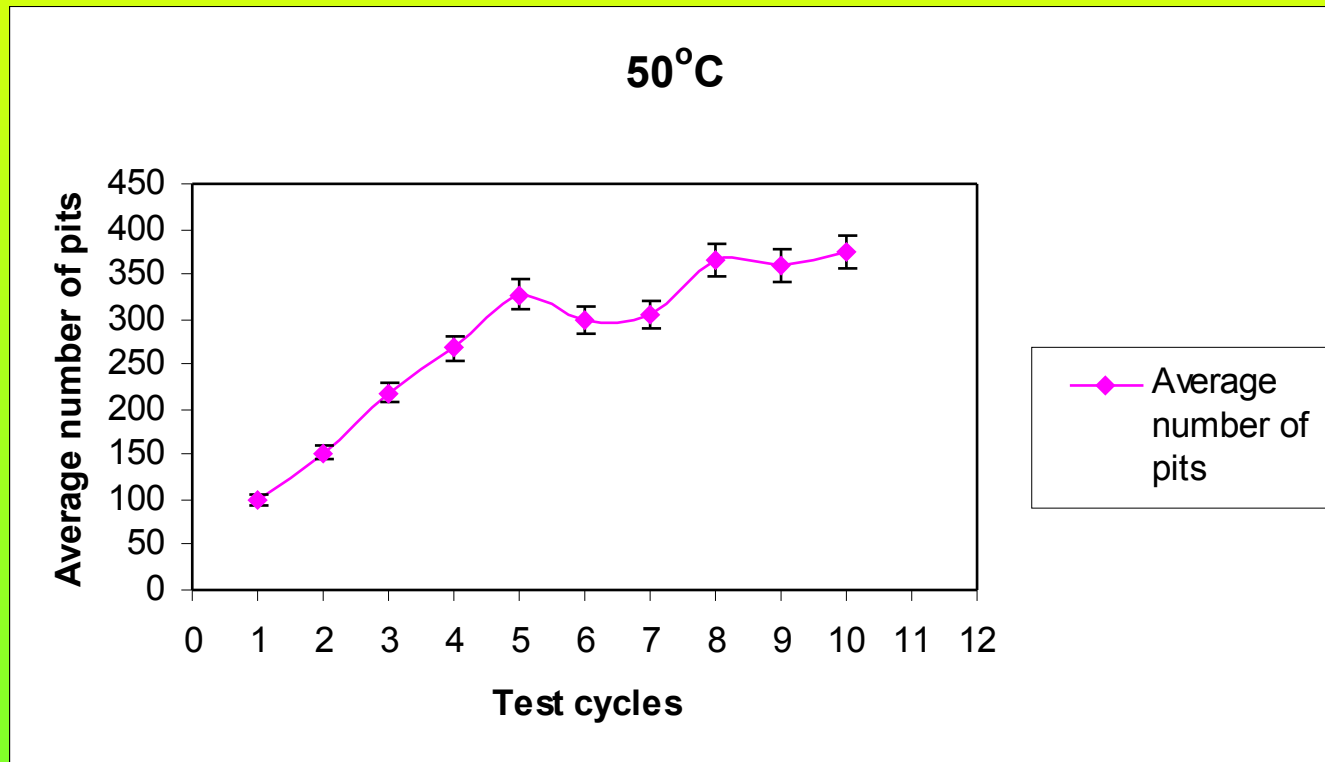


# Sample-1 50°C, Light intensity Vs Pits for test cycle 7-10





# *Average number of pits observed at 50°C*



# *Average number of pits observed at 70°C*

