Analytical Methodology and Resources for BMET & BME; to Evolve in Medical Research and Innovation

34TH SMBE SESSION

March 23rd –26th, 2025

Presenter:

Eleazar Tortal

WSLHD BME Dept.

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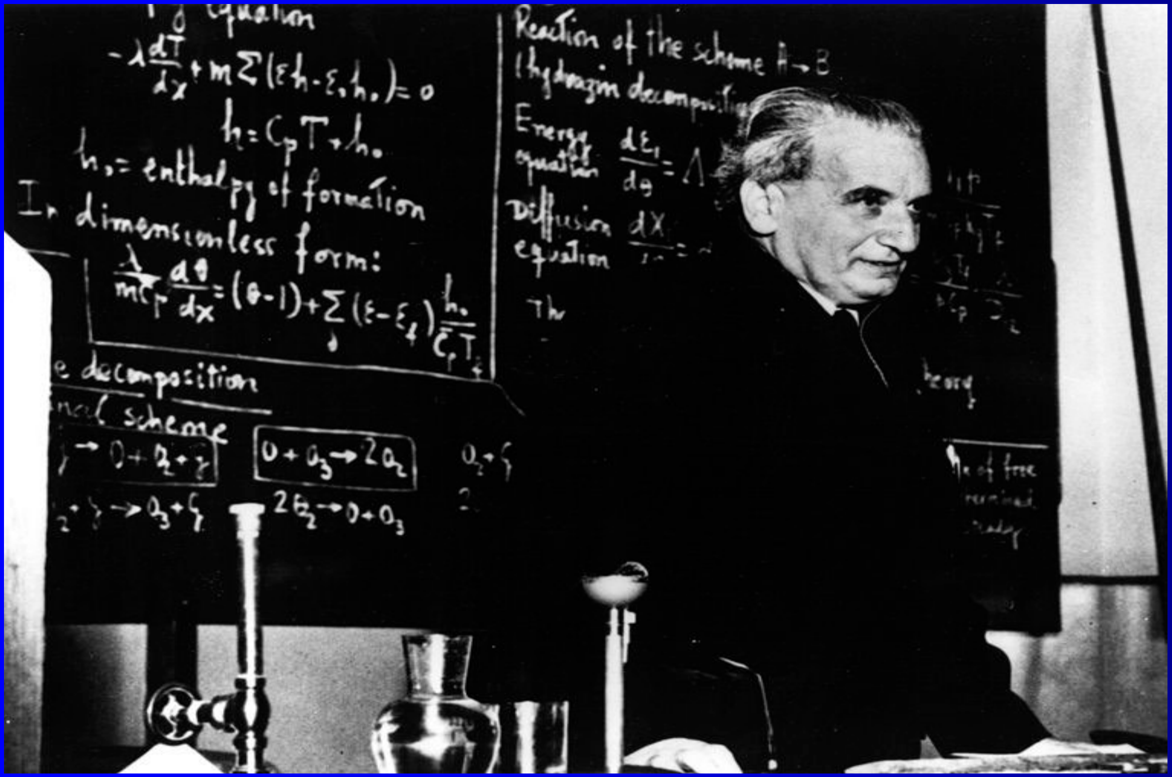
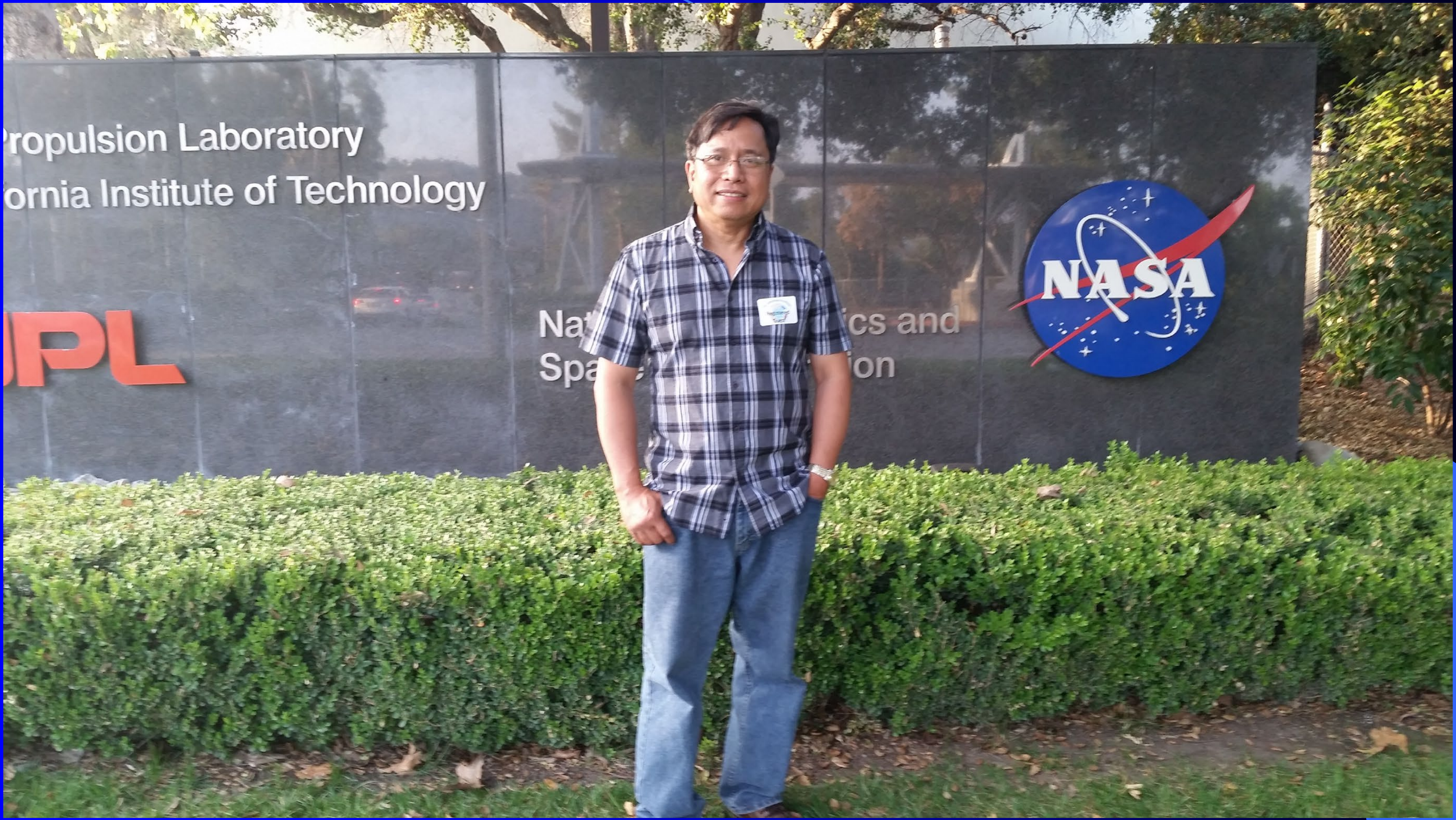
"Scientists study the world as it is, Engineers create the world that never has been."

Theodore von Karman

Founder of Jet Propulsion Laboratory (JPL) 1930's




Propulsion Laboratory
Institute of Technology
NASA


Southern California Edison
MONTEBELLO DISTR
EDISON INTERNATIONAL
Celebrating
125 Years
1886-2011

ENGINEER

- Technician
- Tech. Support
- Mentor
- Entrepreneur
- Manager
- Programmer
- Consultant
- Quality Assurance
- Philanthropist

CURRENT TECHNOLOGICAL TREND

1. THE INTRODUCTION OF ARTIFICIAL INTELLIGENCE

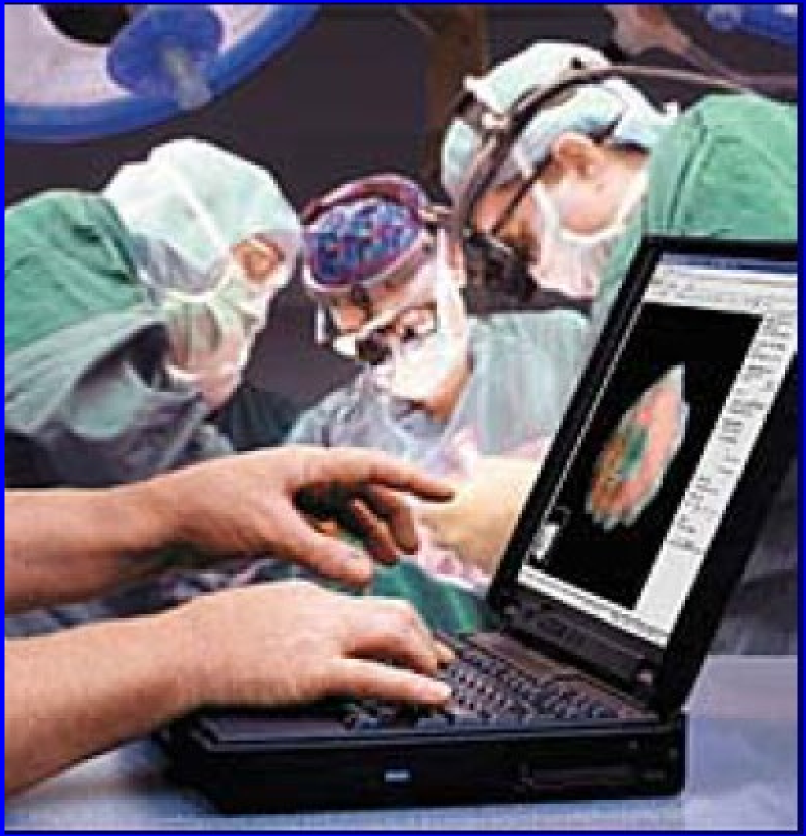
2. COMPUTERISATION AND NETWORKING

NEURAL NETWORK

- BIOLOGICAL
- ELECTRONICS

FUZZY LOGIC

Introduce by Lofti Zadeh in 1965 Fuzzy set of theories. It is employed to handle the concept of partial truth…



Computer aided surgery

Today’s modern surgical procedure are not only dependent on the surgeon’s own expertise and experience but also on Biomedical Engineers, computerised equipment and state of the art technology

CONTINUUM MECHANICS

1. STATIC – Can be linear or non-linear deals with static problems which the response is linear in the cause and effect sense.

2. DYNAMICS– Actual time dependence must be explicitly considered because of the calculation of inertia where forces requires derivatives with respect to actual time to be taken.

DISCRETISATION METHOD

Static Analysis is based on discretisation method by which the continuum mathematical model is discretised in space i.e., converted to discrete model with finite number of degrees of freedom. Problems in statics may also be time dependent but with inertia forces ignored or neglected.

SPATIAL DISCRETISATION METHOD

- FINITE ELEMENT METHOD
- BOUNDARY ELEMENT
- FINITE DIFFERENCE
- FINITE VOLUME
- SPECTRAL
- MESHFREE

BOUNDARY ELEMENT METHOD

A numerical computational technique used to solve linear partial differential equation. This method is particularly useful in fields such as fluid mechanics, acoustics, electromagnetics, etc.

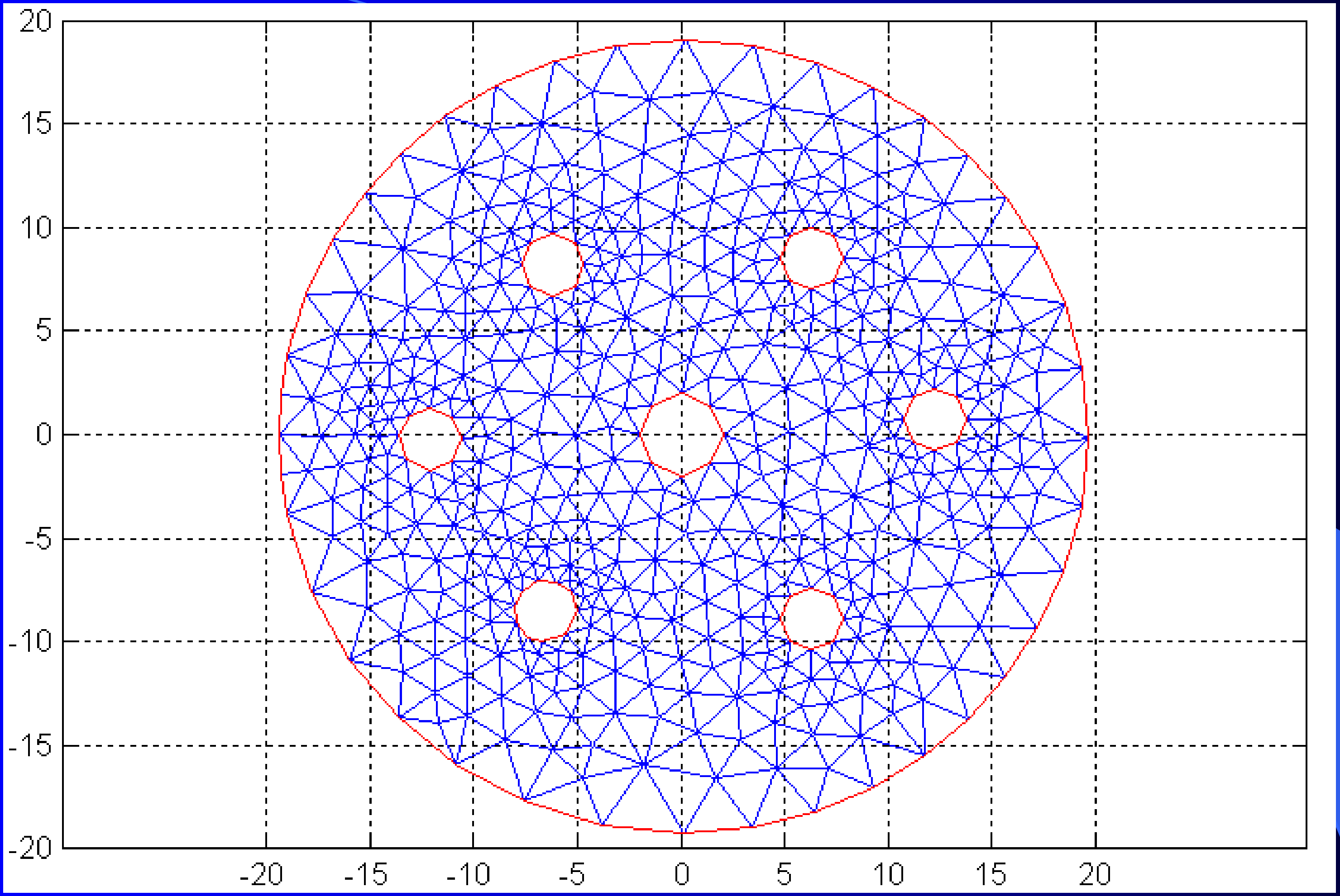
FINITE ELEMENTS

For non-linear problems, the dominance of finite element method is overwhelming!

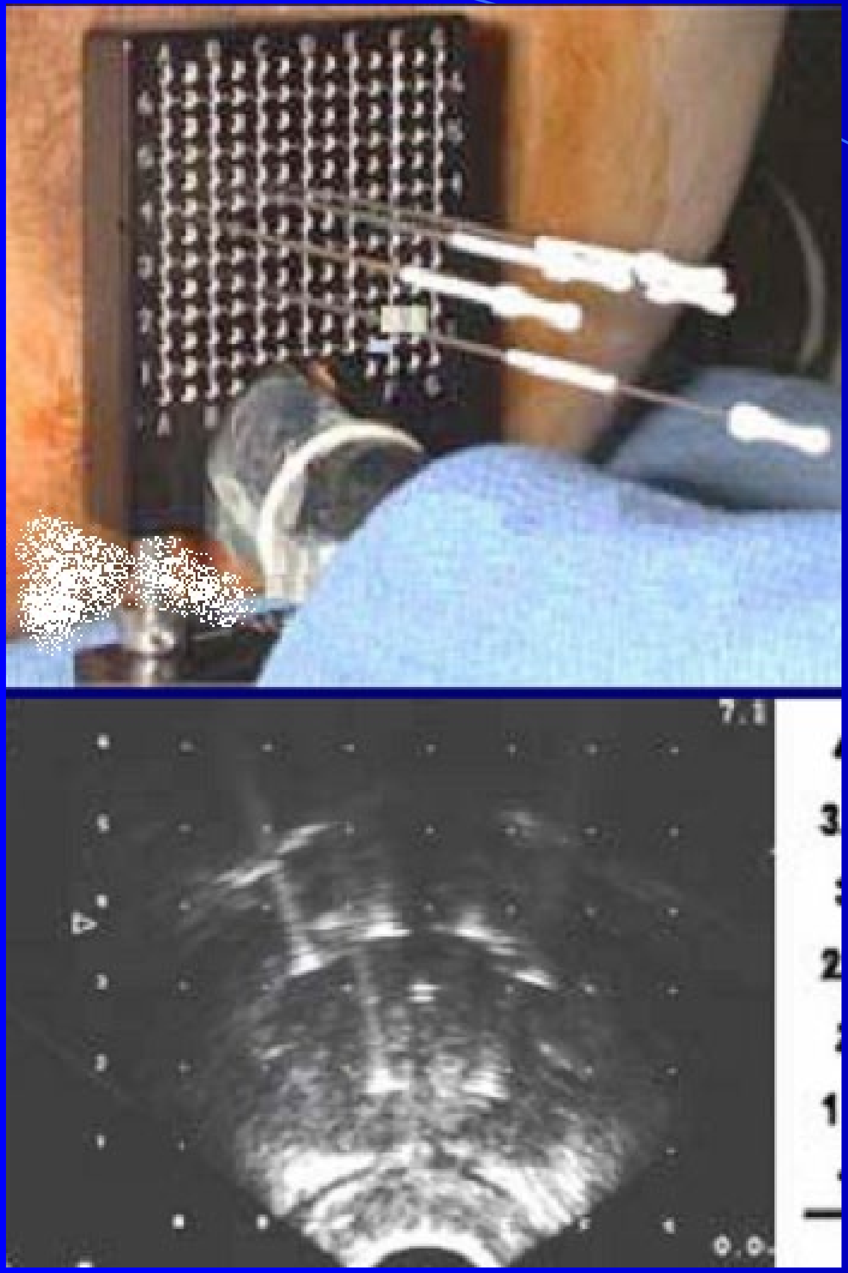
Aims and objectives

The broad aim of this presentation is to introduce back various mathematical tools and Engineers to be aware once again that they can create infinite possibilities by:

1. Developing numerical modelling and algorithms to accurately simulate the difficult physical system problem.
2. Creating database of intricate experiments by using collocation polynomials,
3. Developing numerical modelling using spatial discretization method.
4. Helping to provide practical method and technique to surgeons in effective optimisation of treatment to a particular disease.

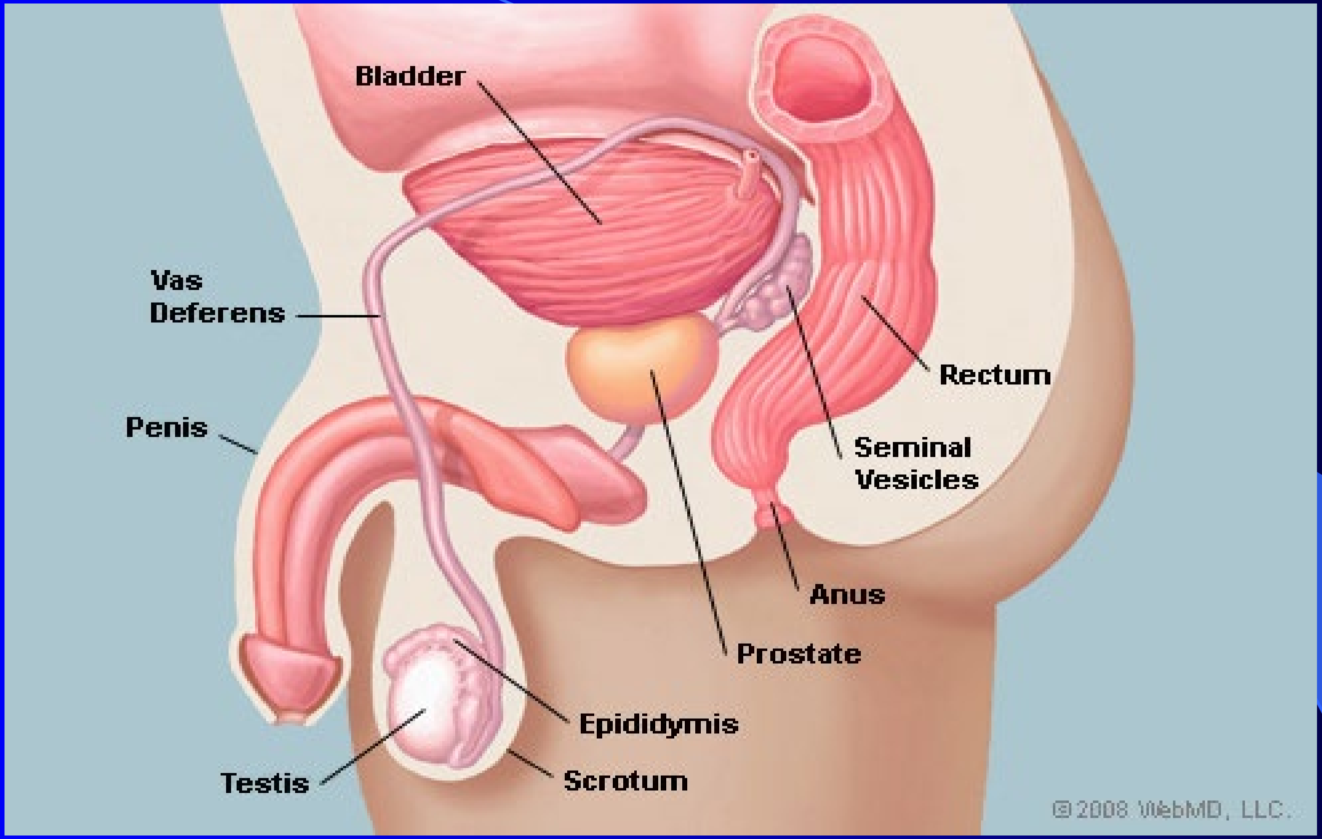


Finite number of sub-domains or elements. The functions defined over each finite element are called interpolation function

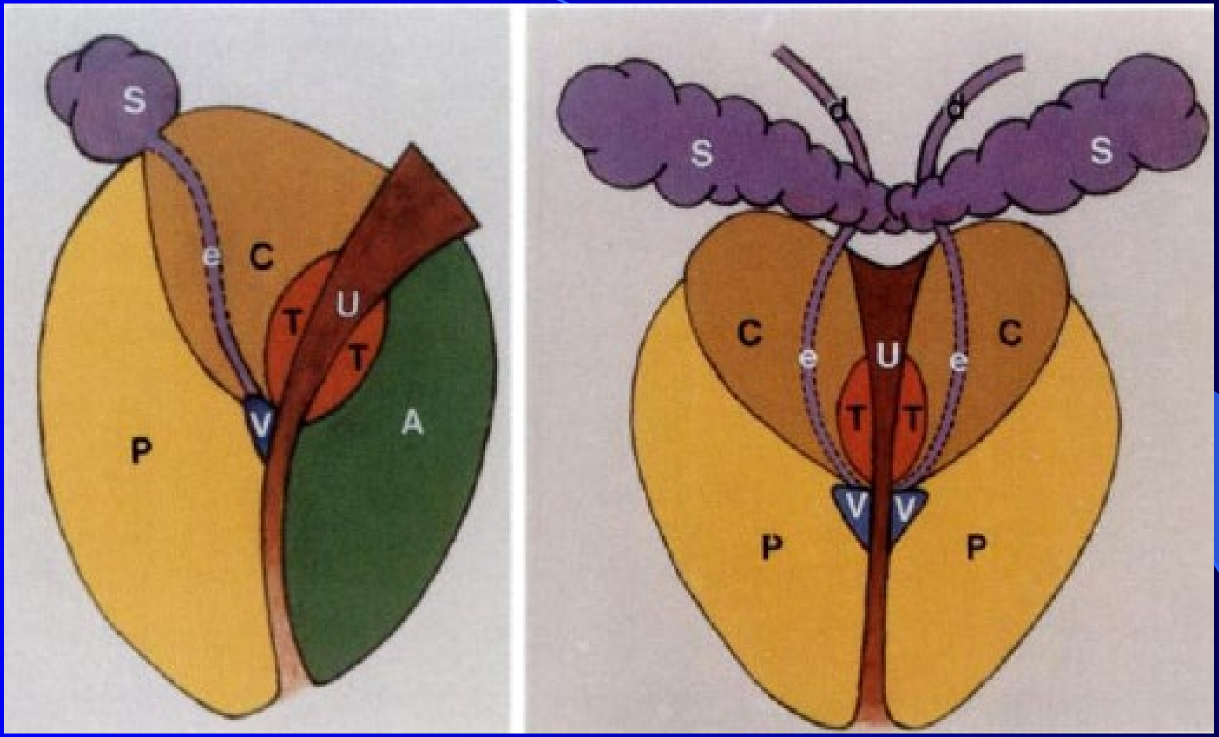


Brachytherapy of the prostate showing utilisation of needle probes and transrectal ultrasound

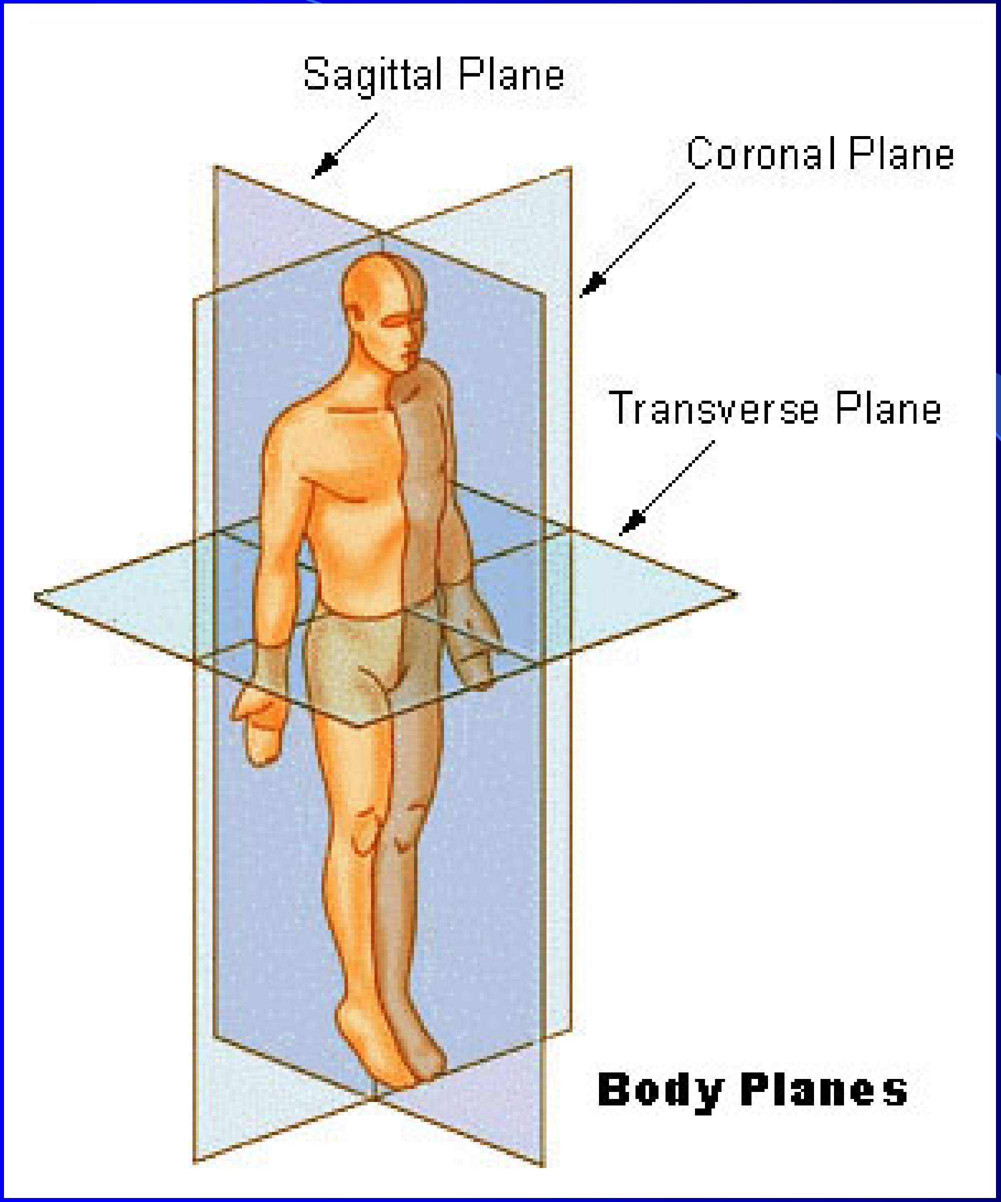
Prostate



A healthy adult prostate weighs about 20 – 25 grams (2/3 to 3/4 of an ounce). It is walnut shaped and it measures 4 x 2 x 3 centimeters (1.6 x 1 x 1.2 inches). It is divided into 2 lobes. It contains smooth muscle cells capable of contracting to expel the prostatic fluid.



Coronal view of the prostate (left) and midline sagittal (right). U is the urethra, S seminal vesicle, A anterior fibromuscular stroma, c central zone, e ejaculatory duct, P peripheral zone, T transition zone, V verumontanum


Sagittal Plane
Coronal Plane
Transverse Plane
Body Planes

KNOWN METHOD OF TREATMENTS:

- Prostatectomy
- Radiation Therapy
- Brachytherapy
- Cryotherapy
- Hormone Therapy
- Watchful Waiting

There are close to 26,000 new cases diagnosed and 1 in 6 men will develop prostate cancer in their lifetime, according to Prostate Cancer Foundation of Australia.

Each year 33,000 men die of prostatecancer in Australia.

Australian Government
Cancer Australia

Deaths

Survival

Prevalence

24,217

Estimated number of new cases of prostate cancer diagnosed in 2022

27%

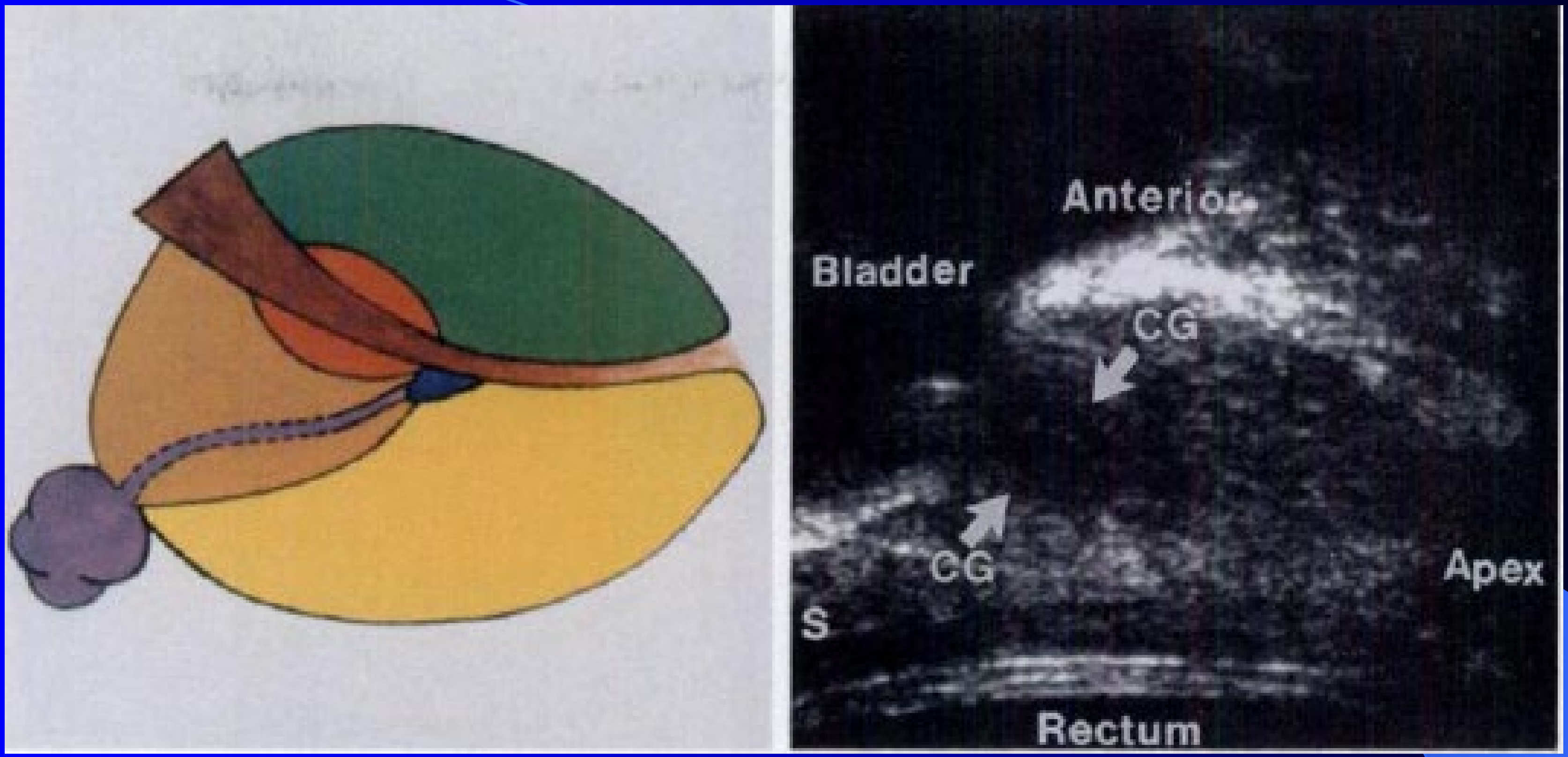
Estimated % of all new male cancer cases diagnosed in 2022

3,507

Estimated number of deaths from prostate cancer in 2022

13%

Estimated % of all male deaths from cancer in 2022



Sagittal scanning of the prostate. To obtain sagittal and parasagittal scans, probe is placed in rectum and rotated clockwise and counter-clockwise

Experimental Results

Table 1.

Ice ball diameter for the 3-mm probe during the 30 min freezing in °C

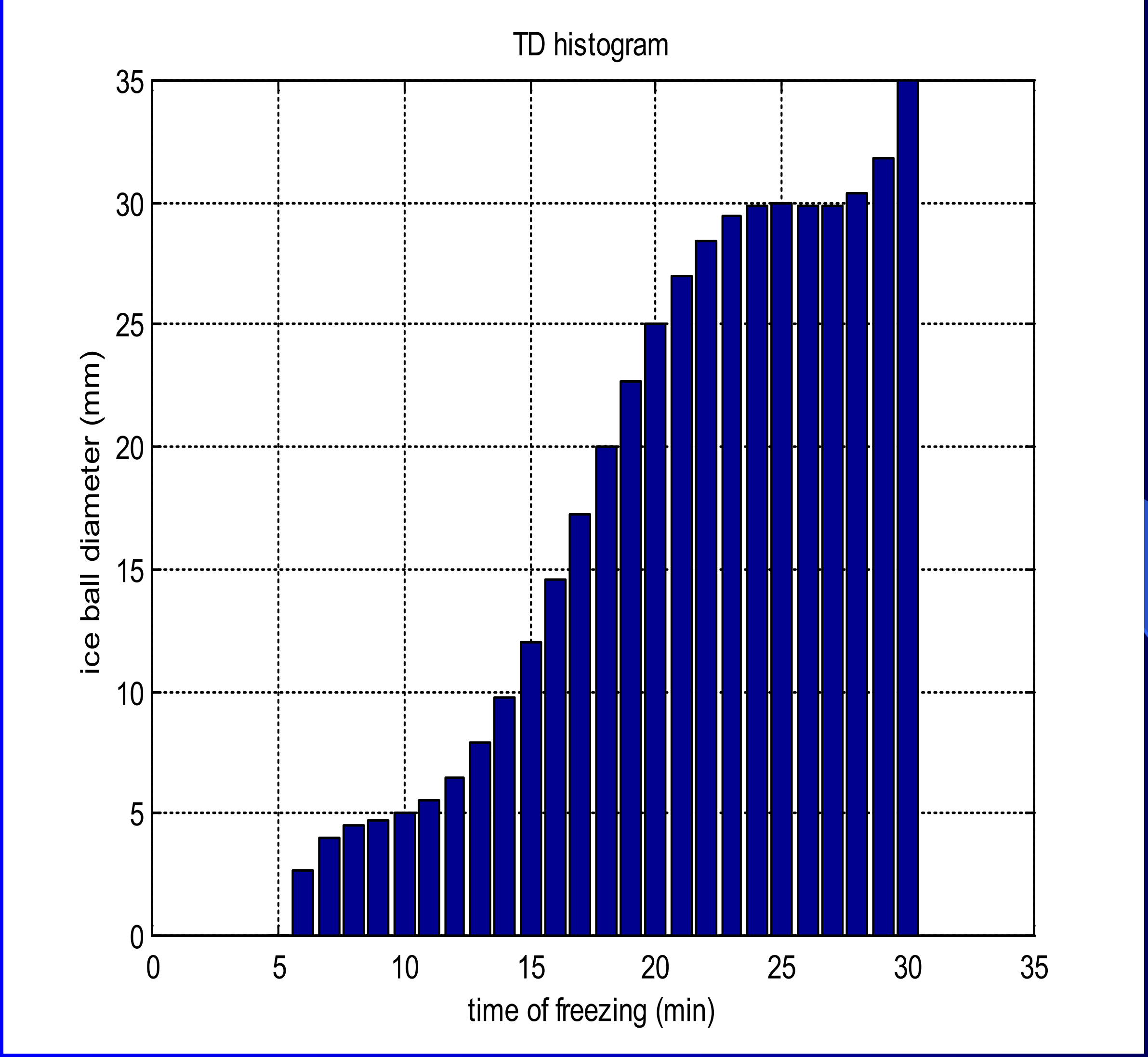
Shape of the ice ball

time	ice ball diameter (mm)	probe temp.
5	0	-6
10	5	-60
15	12	-140
20	25	-150
25	30	-185
30	35	-195

Table 2.

Temperatures (°C) at 5 mm, 10 mm, 15 mm and 20 mm radius from the probe tip centre during the 30 min freezing

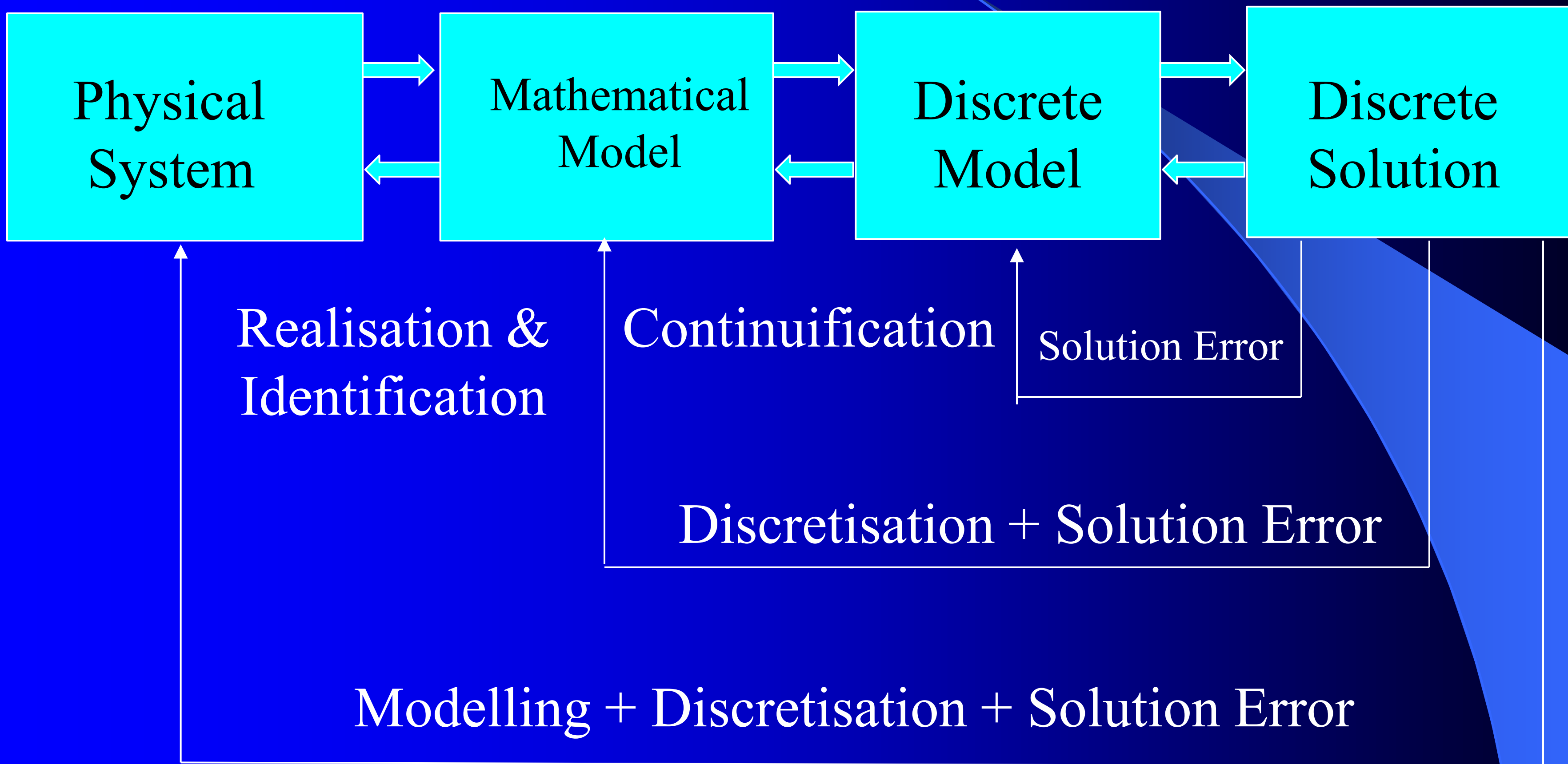
ice (d) mm	T1 @ 5 mm	T2 @ 10 mm	T3 @ 15 mm	T4 @ 20 mm
0	22	23	23	23
5	20	22	23	23
12	10	16	21	22
25	-16	-7	12	14
30	-25	-15	4	7
35	-37	-25	-8	-2



. TD histogram of the collocation polynomial

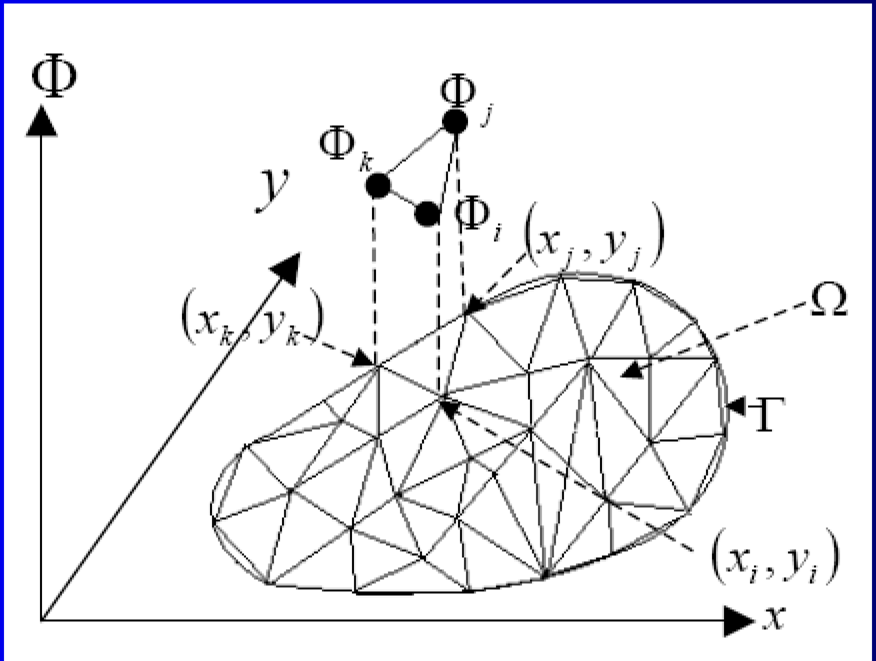
showing 30 steps for every 1 min division

A Simplified View of the Physical Simulation Process, Reproduce to Illustrate Modelling Terminology



FINITE ELEMENT METHOD

The basic idea of the finite element method is to divide the solution domain into a finite number of elements. In the finite element procedure, once the element mesh for the solution domain has been decided, the behaviour of the unknown field variable over each element is approximated by continuous function expressed in terms of nodal values.



The shape function in terms of global coordinates of the three node triangular element shown in Figure 4 can be derived by assuming an interpolation function, writing the interpolation function as a matrix equation and giving the boundary conditions in terms of the nodal point values of Φ [13].

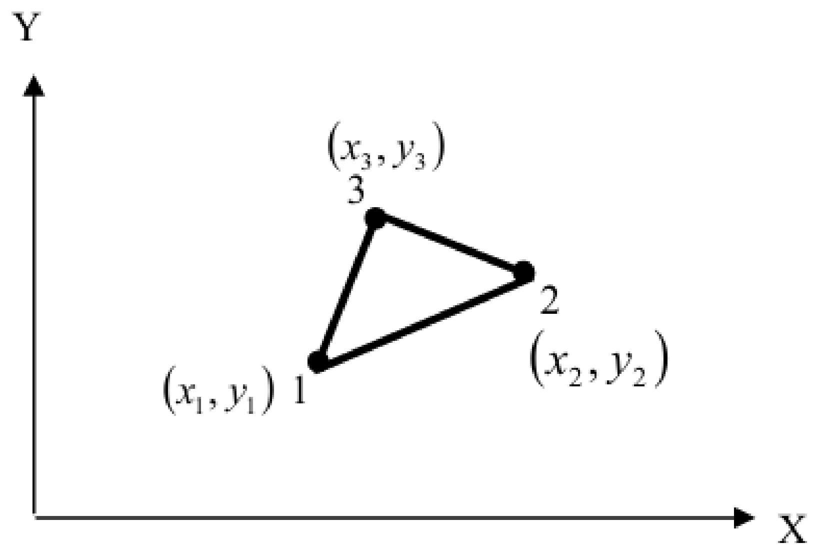


Figure 5. Three-node triangular element

The interpolation function to represent the unknown quantity could be written as [13]:

Matrix representation of the area of a triangular shape

$$N_1 = \left[(x_2 y_3 - x_3 y_2) + x(y_2 - y_3) + y(x_3 - x_2)\right]/2A$$
$$N_2 = \left[(x_3 y_1 - x_1 y_3) + x(y_3 - y_1) + y(x_1 - x_3)\right]/2A$$
$$N_3 = \left[(x_1 y_2 - x_2 y_1) + x(y_1 - y_2) + y(x_2 - x_1)\right]/2A$$

$$A = \frac{1}{2}\det\begin{bmatrix} 1 & x_1 & y_1 \\ 1 & x_2 & y_2 \\ 1 & x_3 & y_3 \end{bmatrix}$$

By expressing the constant in terms of the coordinates of the element's nodes and the nodal values of   yields:

$$\Phi_i = \beta_1^{(e)} + \beta_2^{(e)} x_i + \beta_3^{(e)} y_i$$

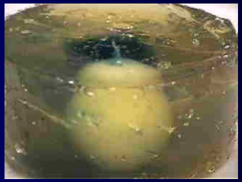
$$\Phi_j = \beta_1^{(e)} + \beta_2^{(e)} x_j + \beta_3^{(e)} y_j$$

$$\Phi_k = \beta_1^{(e)} + \beta_2^{(e)} x_k + \beta_3^{(e)} y_k$$

$$\phi^{(e)}(x, y) = \frac{a_i + b_i x + c_i y}{2\Delta}\phi_i + \frac{a_j + b_j x + c_i y}{2\Delta}\phi_j + \frac{a_k + b_k x + c_k y}{2\Delta}\phi_k$$

Where, Δ = the area of the triangular element
and where,

$$a_i = x_j y_k - x_k y_j,\ b_i = y_j - y_k,\ c_i = x_k - x_j$$



The complete representation over the whole domain which contains M elements is:

$$\Phi(x,y) = \sum_{e=1}^{M} \Phi^{(e)}(x,y) = \sum_{e=1}^{M} \lfloor N^{(e)} \rfloor \{\Phi^{(e)}\}$$

where, N is the shape function given by:

$$N_n^{(e)} = \frac{a_n + b_n x + c_n y}{2\Delta} \qquad n = i, j, k$$

$$T^{(e)}(x,y,z,t)=\lfloor N(x,y,z)\rfloor\{T(t)\}$$

$$\frac{1}{\alpha}\frac{\partial T}{\partial t}=\nabla^2 T+\frac{Q}{k}$$

where, $\alpha = k/\rho c$ is termed the thermal diffusivity where ρ is the density of the medium, c is the specific heat of the medium and k is the conductivity tensor expressed as matrix, Q is the rate of heat flow by Fourier

Heat Conduction Equation

$$\frac{\partial u}{\partial t} = k\nabla^2 u$$

Where, ***u(x,y,z,t)*** is the temperature at position ***(x,y,z)*** in a solid at time ***t*****,** constant ***K*****,** called diffusivity, is equal to $k/\sigma u$ where the thermal conductivity k**,** the specific heat σ and the density μ are assumed constant.

The Laplacian of ***u*** $= \nabla^2 u = \frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}$ **.** The problem of solving $\nabla^2 u = 0$ inside a region ***R*** where *u* is some given function on the boundary of ***R*** is often called Dirichlet.problem

PDE Specification

Parabolic:

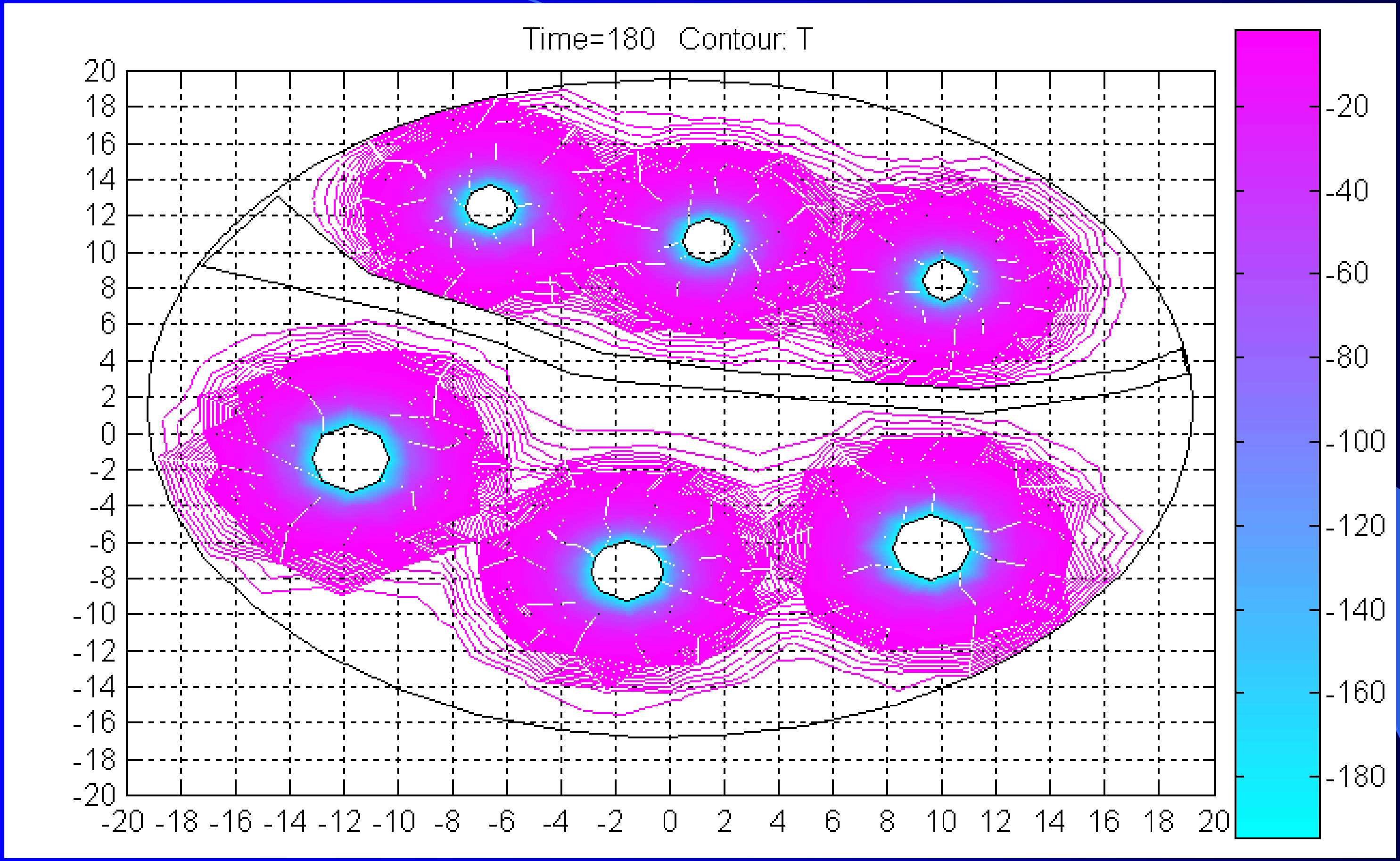
$$\rho c T - div\left(K\, grad(T)\right) = Q + h(\Delta T)$$

Where the divergence of ***A*** is defined by:

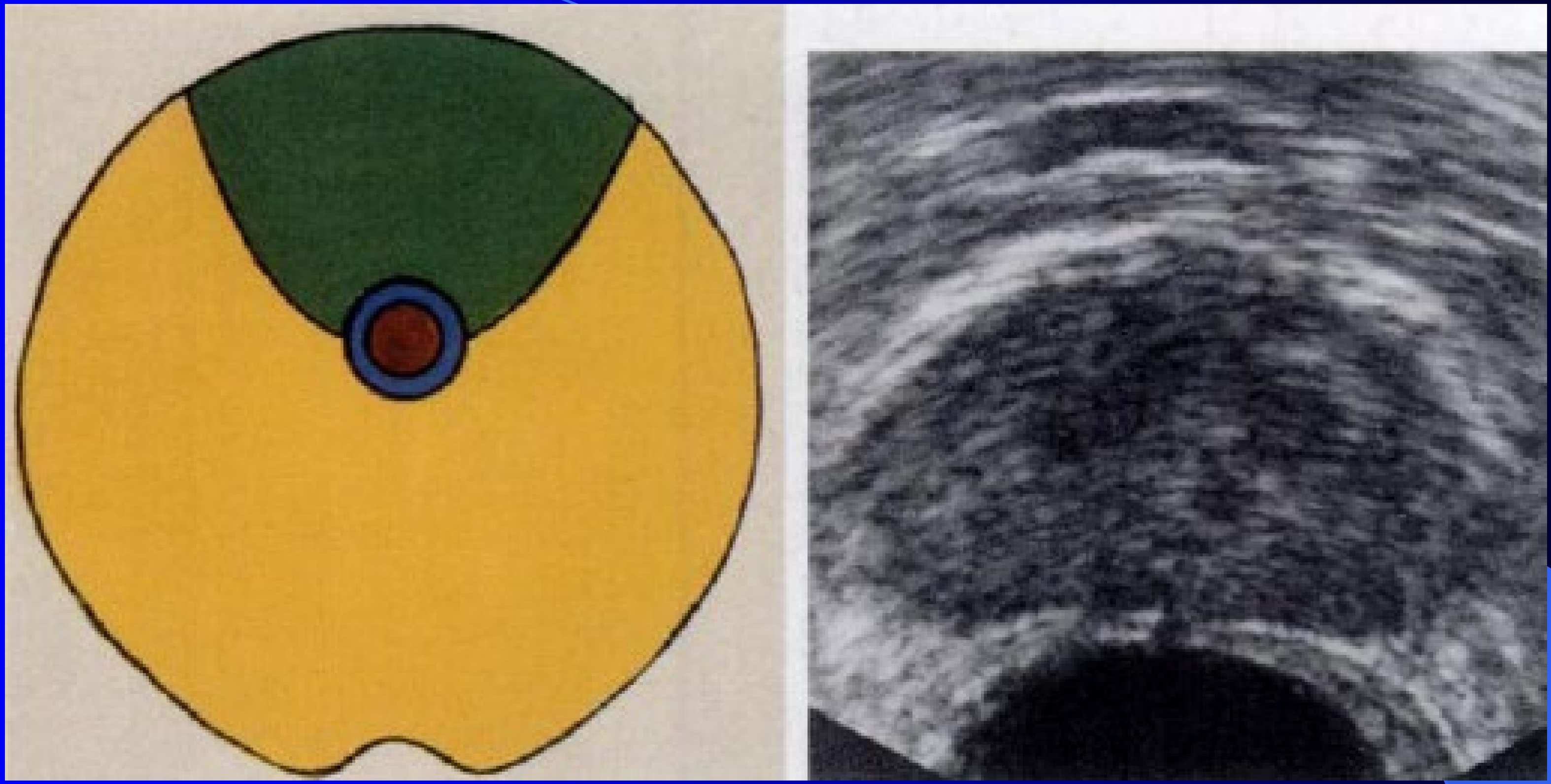
$$div\, A = \nabla . A = \left(i\frac{\partial}{\partial x} + j\frac{\partial}{\partial y} + k\frac{\partial}{\partial z} \right) . \left(A_1\, i + A_2\, j + A_3\, k \right)$$

$$= \frac{\partial A_1}{\partial x} + \frac{\partial A_2}{\partial y} + \frac{\partial A_3}{\partial z}$$

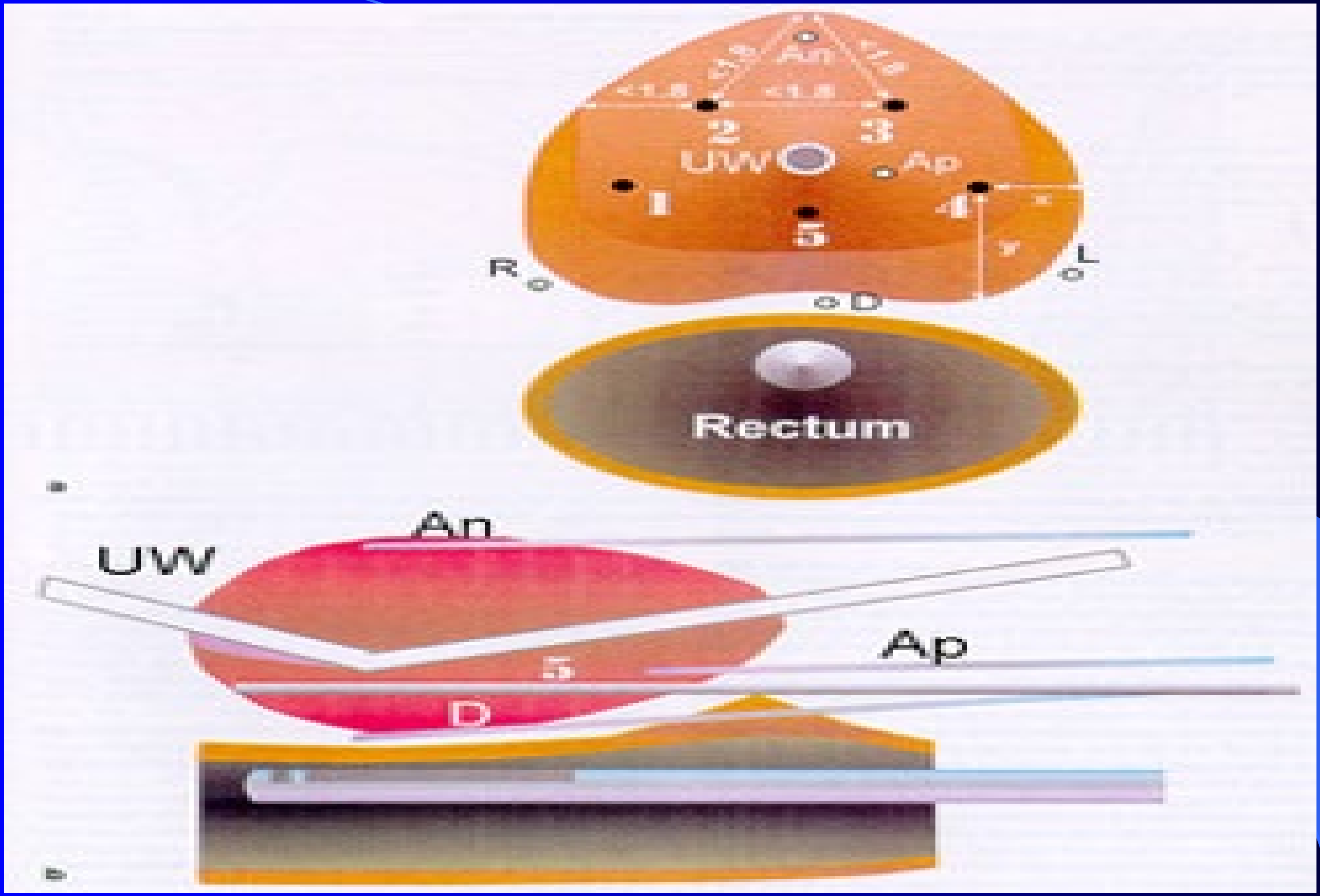
$$\frac{\partial}{\partial x}\left(k_x \frac{\partial T}{\partial x} \right) + \frac{\partial}{\partial y}\left(k_y \frac{\partial T}{\partial y} \right) + \frac{\partial}{\partial z}\left(k_z \frac{\partial T}{\partial z} \right) + Q = \rho c \frac{\partial T}{\partial t}$$



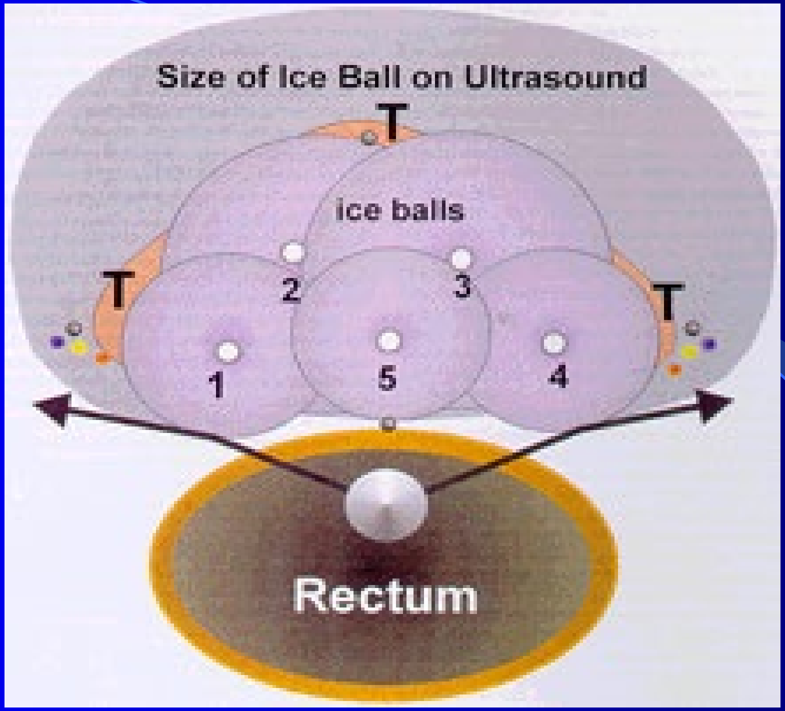
Ice depiction of prostate cryoablation using 3-3 mm diam. And 3-2 mm diam. probes. The contact temperature of the probes were set at –196 °C while the boundary temperatures of the prostate and the urethra are set at 0 °C



Axial imaging. In this orientation imaging, transducer is placed within rectum and withdrawn sequentially to obtain axial (transverse) images of the prostate. Image shows bilobed zone (in red)



A transverse view near the mid- gland of the prostate shows the locations of probes 1-5, anterior and posterior thermocouples, and urethra warmer.



Sound beams from the transducer (black arrows) strikes the the ice balls of probes 1 & 4 at an oblique angle casting a shadow that is larger than the partially coalesced ice balls. Tissue T which is invisible from the US transducer and is not lethally frozen can cause recurrence of the disease.

EXPECTED OUTCOME

- Develop optimisation algorithm for cryosurgery
- FEM imaging of the isotherms in cryosurgery
- Optimisation software in object oriented programming
- Database of probe thermal history
- Cryogenic procedure or methodology using the cryogenic prototype developed by applying all of the above

Simultaneous Optimisation of Cryoprobe Placement and Thermal Protocol for Cryosurgery

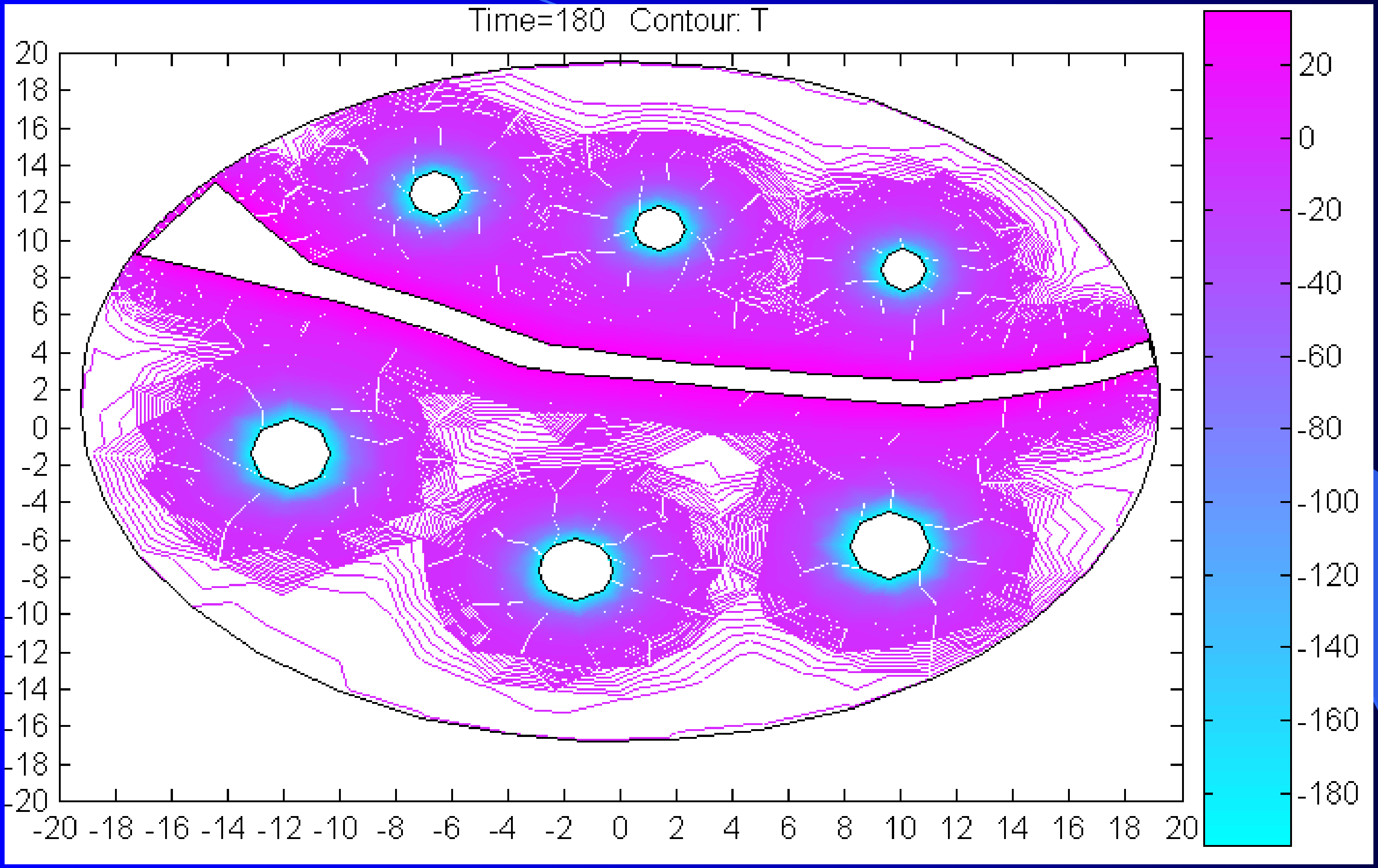
R Baissalov[1,2], G A Sandison[1,2], D Reynolds[3] and K Muldrew[4]

1 Department of Medical Physics, Tom Baker Cancer Center, Calgary, Canada T2N 4N2

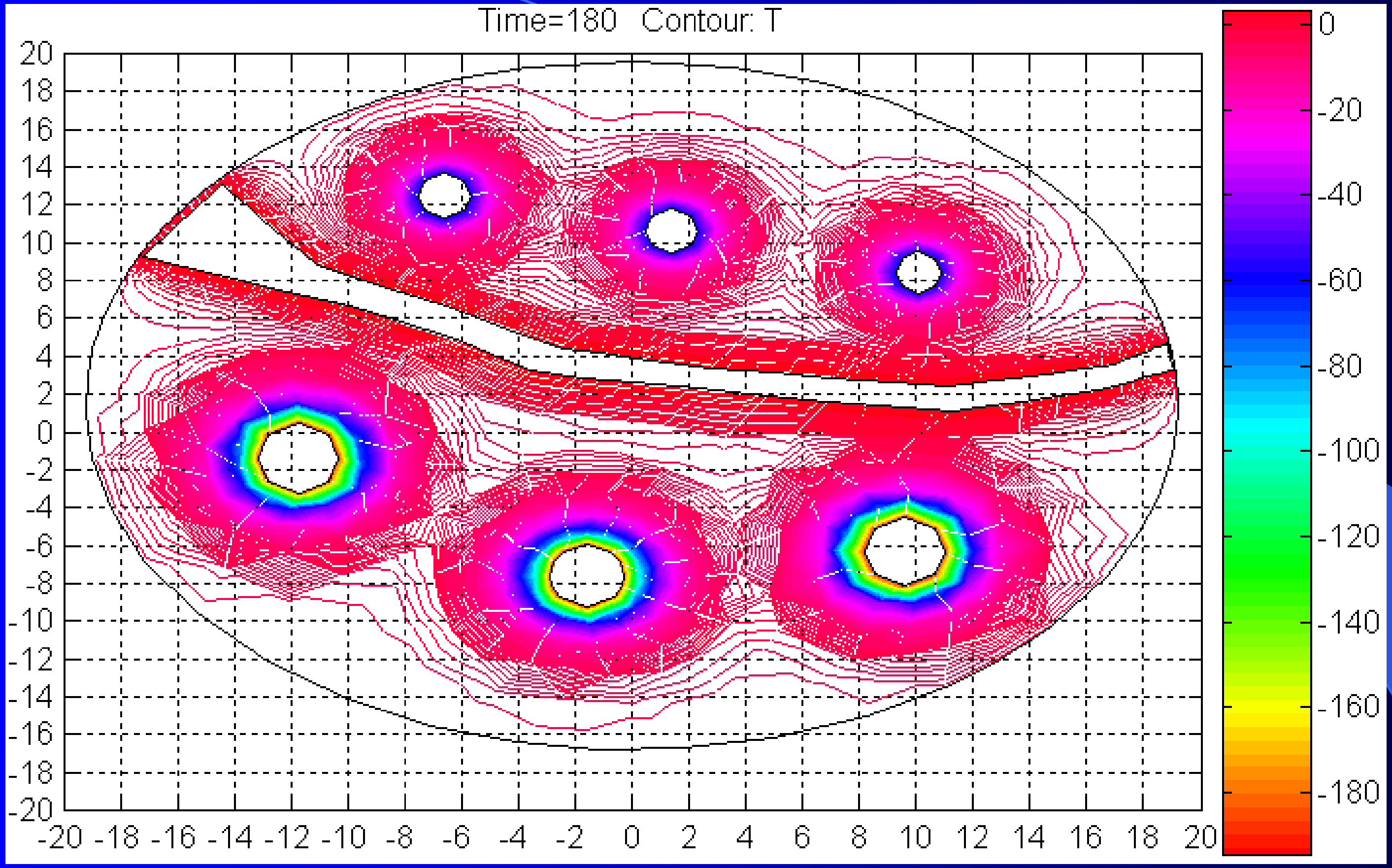
2 Department of Physics and Astronomy, University of Calgary, Calgary, Canada T2N 2N4

3 Department of Computer Science, University of Calgary, Canada T2N 2N4

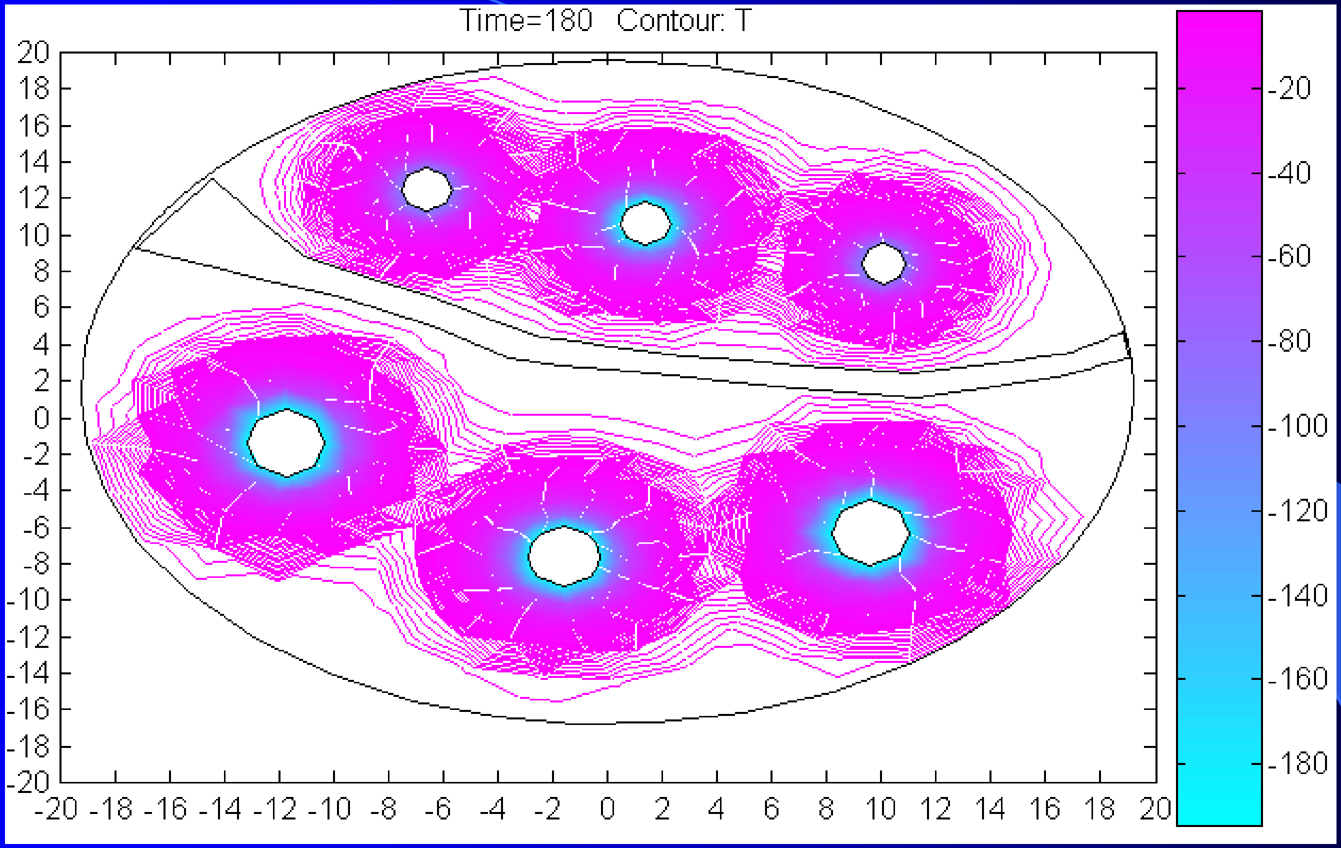
4 Department of Surgery, University of Calgary, Canada T2N 2T7



Temperature propagation of prostate ablation where the urethra temperature boundary is set at 37 °C



Ice ball depiction of prostate where the 2 mm probes are at –60 °C and the temperature of urethra is set at 5 °C



Ice ball depiction when the temperature set point of the 2 mm probes on the upper left and right of the anterior lobe of the prostate was set at –97 °C.

CONCLUSION

- The issues surrounding Cryosurgery were presented
- The numerical optimiSation method was introduced
- The thermal model using FEM implemented
- Cryosurgical procedure and equipment package implemented

Prototype Cryosurgical Machine

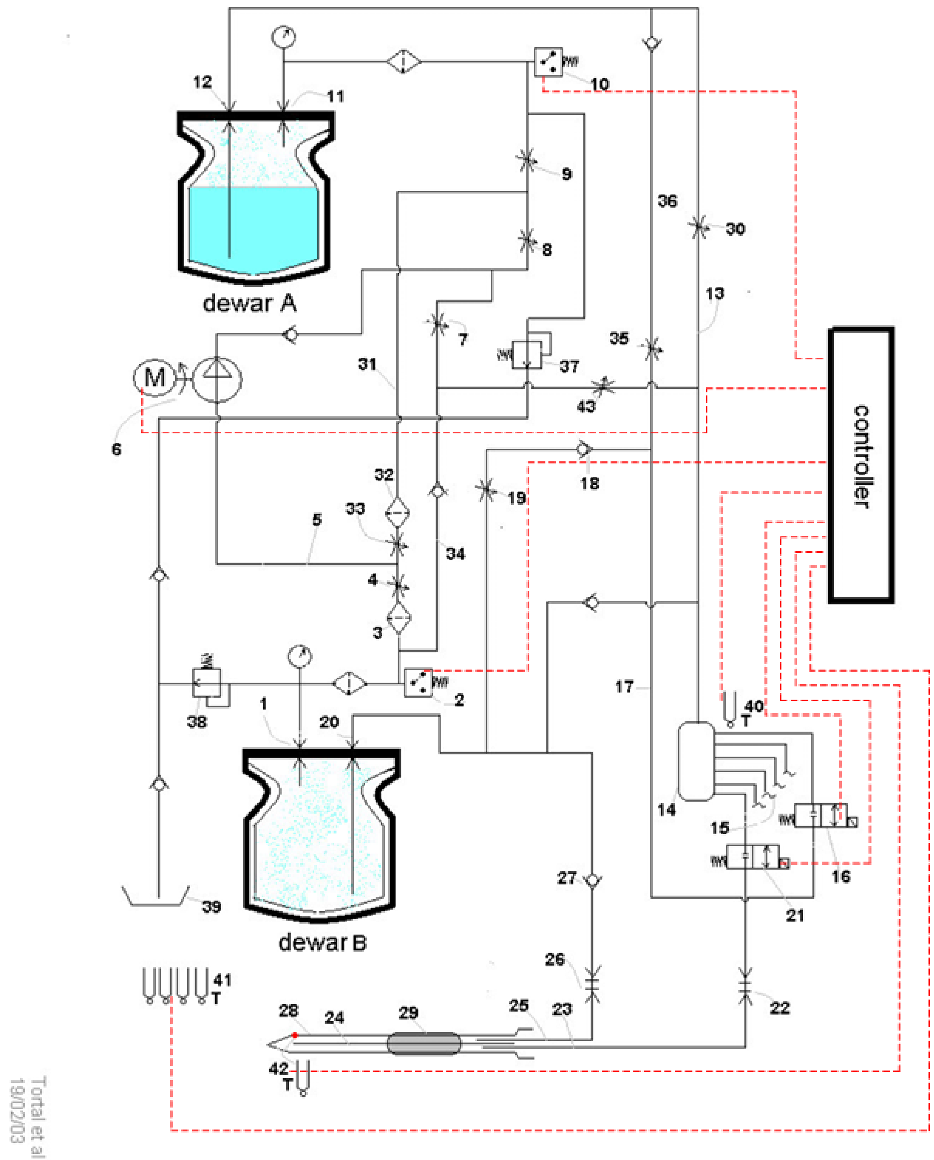


Figure 3. Cryogenic system flow diagram showing a cryosource that has a dual purpose of delivering and collecting the liquid nitrogen and vice-versa in a closed loop process system

End of Presentation
Thank You

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ELEAZAR R TORTAL
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Reference https://mga.ieee.org/resources/annual-statistics/55-resources/annual-statistics/419-the-annual-statistics-of-the-ieee-2020

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No. 5,906,209

Eleazar R. Tortal

Let it be known by the presence of this document
that the United States of America
has recognized this inventor's original creation
with the granting of a United States Patent.

Date: May 25, 1999

M C Henry
Attesting Officer

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TOPIC: MULTIPLE OBJECTIVE OPTIMIZATION IN CRYOSURGERY

SPEAKER: Eleazar Tortal, BSEE, M. Eng. (Hons), ALSR

LOCATION: Luminarias Restaurant, 3500 Ramona Blvd., Monterey Park, CA 91754

DATE & TIME: Wednesday, April 25, 2012. Lunch starts 11:30 AM; Talk starts 12:00 PM.

FOR RESERVATIONS: Please email your request to malak.shirkhani@sce.com by April 18, 2012. Please include your membership number.
Lunch is free for IEEE members. For Non-IEEE members: $15.
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ABOUT THE SPEAKER:

Mr. Eleazar Tortal, received the Proficiency certificate (1981) and B.S., Electrical Engineering degree (1986) from Technological University of the Philippines, Manila; Masters, M. Eng (Honors) (2004) from University of Western Sydney, Kingswood, New South Wales. He also studied Embedded Systems Design (2011) in UCLA, 211 Extension Bldg. Westwood, Los Angeles, California.

Eleazar has more than 15 years' experience as an Engineer, Lecturer, Researcher and presenter with several published papers at IEEE and other engineering and health care organizations. He has chaired biomedical session in the XVth International Conference on Mechanics in Medicine and Biology, Spore, 6-8 Dec.2006. He co-founded ALAY Scientific Research at Los Angeles where he is currently doing research on biomedical and renewable energy. He is also trying to find solution for current homelessness problem in the country through innovative technology. Some of his works includes:

- Design and patent of cancer therapeutic and cardiac corrective devices that has gained International Recognition for Innovative Medical Solution by Pan American Health Care Engineering (PAHCE) [available]: http://www.pahce.org/P7Summ06.htm, with supporting organizations e.g. ACSUP, ACCE, CMIA, EMBS, IEEE.
- Intuitive design of renewable energy e.g., "Omni-Hybrid Machine" which is a resultant combination of wind, solar, See beck effect and biogas.

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