Chapter 1

INTRODUCTION

1.1 Definition

Nondestructive Testing is an examination, evaluation or inspection of an object in *any manner* which will not impair the future usefulness of the object.

OR

Nondestructive testing is: the development and application of technical methods to examine materials or components in ways that do not impair future usefulness and serviceability in order to detect, locate, measure and evaluate discontinuities, defects and other imperfections; to assess integrity, properties and composition; and to measure geometrical characters. (ASTM E1316-92, Standard Terminology for Nondestructive Examinations).

Nondestructive testing (NDT) may be referred to as NDI (Inspection), and/or NDE (Examination or Evaluation). These all acronyms refer to the same general field of technology, the differences being determined mostly by the using industry.

In general, the field of NDT employs radiographic, ultrasonic, magnetic, particle, liquid penetrant, visual, thermal, acoustic, differential pressure, etc.

1.2 Purpose

Detect flaws (internal or external); measure thickness, density etc; determine structure or composition; measure or detect any of the object's properties.

1.3 Methods

Any physical phenomena can be employed for NDT, as long as it does the job.

Simple visual or listening, or could involve some form of electromagnetic energy or sonic or acoustic waves (vibrational energy).

1.3.1 Passive Methods

Visual inspection and acoustic emission

1.3.2 Active Methods

Some form of energy is made incident on the object and is monitored as it is *re-emitted* from the object.

Re-Emitted Signal

- transmitted
- reflected, refracted, scattered
- secondary emission (activation)

1.4 Electromagnetic Radiation

Electromagnetic radiation travels at a constant speed in vacuum = 3×10^8 m/s=$\lambda \times f$, where λ is the wavelength and f is the wave frequency.

λ ($\approx$), m	Radiation
$5\ 10^6$	60 cycle AC
10^5	electric waves
10^3 to 10^2	communications
1	television waves
10^{-2}	microwave
10^{-4} to 10^{-5}	infrared
10^{-6}	visible light
10^{-7} to 10^{-8}	ultraviolet
10^{-9} to 10^{-13}	x- and gamma- rays
10^{-14}	cosmic rays

1.5 Sound Waves (Vibrational Energy)

f ($\approx$), Hz	Wave
10^{-2} to 5	seismology, geological explorations, ocean waves
≤ 100	structural dynamics (macroscopic defects)
5 to 10^3	rotor dynamics
5 to 2×10^4	audible range for humans
10^3 to 10^5	mechanical failures (e.g. damaged bearings, leaks in pipelines, defects in aggregates)
50 to 10^6	acoustic emission (crack propagation)
10^2 to 10^6	signalling in water (sonar)
50 to 10^7	microscopic defects
10^5 to 10^8	Ultrasonics

1.6 Uses of NDT

- detect faulty material before forming or machining
- detect faulty components before assembling into product
- measure thickness or density or composition of material
- determine level of liquid or solid in opaque container
- identify and sort material
- discover defects developed during processing or use

One usually needs a fast, accurate and inexpensive technique, but usually only two of these characteristics are obtained; i.e a fast and accurate technique is usually expensive, while an inexpensive method is usually inaccurate if it is fast or is accurate but slow.

Objectives of NDT

- make products safe, reliable and more economical
- control and optimize manufacturing process

1.7 Motivations for NDT

- Unlike in destructive testing of a sample (small percentage), in NDT every product is inspected (more accurate results, more reliable).
- Avoid wasting time and money on defective raw material
- Pinpoint improvement needed to lower production cost by monitoring manufacturing processes.
- Costly equipment, nuclear reactors, high-performance military aircrafts, space shuttles), reliability not cost is the main concern.

1.8 Sensors

- Seeing: x-ray, microwave, infrared
- Hearing: acoustic emission, ultrasonics
- Touching: penetrant techniques (surface and surface connecting flaws)
- Smelling: sniffers (for detection of explosives)
- Taste: chemical tests

Old Ways

- Egg-candling (look at an egg in strong light so that staleness or fertility can be detected)
- Sonic test of metals (struck part with a hammer and flaws detected by the sound of a ring)

Such methods depend on whether the inspector's state of mind.

1.9 Basic Elements of NDT

Adapted from Harold Burger, Nondestructive Testing, U.S. Atomic Energy Commission, June 1967.

1. SOURCE (Transmitter): provide input energy.
2. MODIFICATION: source signal must change as a result of discontinuities or variations within the tested object.

3. DETECTOR (Receiver): capable of detecting change in source signal.
4. INDICATION: A means of recording or displaying the detected signal.
5. INTERPRETATION: of the indicators.

Example: X-ray Radiography

1. Source: x-ray generator.
2. Modification: change in density.
3. Detector: photographic film.
4. Indication: developing the film provides an indication and a record.
5. Interpretation: by a human observer.

Interpretation

- Experience Human Observation: relied on in many cases particularly those involving inspection of critical items (reactor fuel elements, aircraft or missile components).
- Comparison to some preset or standard value (level, thickness), used when high-production items are involved and for control purposes.
- Expert Systems: computerizing experience

Human judgement requires the observer to be aware of many of the basic principles involved. The objective of this course is to make you aware of the principles involved.

1.10 NDT Techniques

1. Visual methods (VI).
2. Penetrant Testing (PI).
3. Sonic: Ultrasonics Testing (UT), Acoustic Emission (AE).
4. Electromagnetic methods: Magnetic Flux Leakage, Magnetic Particle Inspection (MPI), Eddy Current (EC), Resistance Methods.
5. Thermal methods.

6. Microwaves.
7. Radiography (x-ray, gamma-ray and neutrons).
8. ⋯

A summary explanation of some of these methods is given below (adopted from the Autumn 1992 issue of Consensus, Standards Council of Canada).

1.10.1 Penetrant Testing

Canadian General Standards Board (CGSB) Standard 48-GP-9M

A surface method used for both ferrous and non-ferrous materials.

A coloured, penetrating dye (often fluorescent) is applied to the part under test and seeps into cracks or other surface openings.

The test part is washed and a blotting agent is applied which draws the dye from the surface opening to produce a two dimensional, visible indicator of its location.

It is easy, but not very sensitive to very small and inaccessible defects. Chemistry of penetrants must not affect material, not easily reproducible, depends on human judgment.

1.10.2 Ultrasonics

CGSB Standard 48-GP-7M

High frequency sound waves are used to inspect both internal and surface defects in fine-grained castings, forgings, welds and extrusions as well as non-metallic materials.

Sound waves are generated in the test material by a piezoelectric crystal and their travel through the material is monitored.

Interference of the sound beam path, caused by discontinuities in the material, indicated on a CRT display.

Ultrasonics do not penetrate void and require therefore air-gap free materials.

1.10.3 Acoustic Emission

No standards available yet

Piezoelectric transducers are used to listen to the high frequency acoustic waves emitted due to the sudden release of energy caused by crack growth, plastic deformation or phase transformation.

Sensors are mounted on the outside of the test object on the outside of the test object and stress in the form of pressure, compression, tension or torsion may applied. Acoustic emissions are amplified, filtered and processed (e.g. ring-down counting) for interpretation. Static defects cannot be detected by this method.

AE is passive, gives only indication of increase in stress (Kaiser effect).

1.10.4 Eddy Current

CGSB Standard 48-GP-13M

Used to detect surface and near-surface flaws in electrically conductive materials. Smaller circular currents (eddy currents) are generated in the surface of the test material by a test coil. The eddy current flow is disrupted by the presence of discontinuities which changes the electrical impedance of the test coil.

Any changes are amplified and indicated on the eddy-current instrument. Since eddy currents are affected by metallurgical properties as well as defects, this method can be used for material sorting and hardness and conductivity measurements. It is also widely used in the aircraft and nuclear industries.

1.10.5 Magnetic Particle Testing

CGSB Standard 48-GP-8M

A surface method used for detecting surface and near-to-surface discontinuities in ferro-magnetic materials. The test material is magnetized and coloured iron fillings (often fluorescent) are poured onto the surface. The north/south pole created by a crack or other defect will attract the iron fillings and provide a visible indication of the defect's location.

1.10.6 Microwaves

No standards available yet.

The phase shift and change in amplitude of microwaves is utilized in NDT. Microwaves are not affected by void but are completely reflected on metal surfaces. Best suited for non-metals, particularly, ceramics where ultrasonics is not effective.

1.10.7 Radiography

CGSB Standard 480GP-4M

A method for detecting internal discontinuities in castings, forgings, and weldments.

A special film is placed beneath the test material and x-rays and gamma-rays are used to penetrate through the material to the radiographic film.

Areas of different material densities are recorded on the film, indicating any cracks, voids, porosity or inclusions.

X-ray and gamma ray is most sensitive for metals. Neutron radiography works best with hydrogenous materials.

1.10.8 Thermography

No standards available.

The thermal conductivity or radiative properties of a material are used to test for thermal insulation, bonding or contact between parts, locating hidden objects and for overheating of electronic components and transmission lines.

The most common technique employs an infrared television camera which produces a temperature profile or thermogram of the object under test.

1.10.9 Miscellaneous Techniques

- Lasers for surface imaging (holography)
- Neutron activation analysis for composition measurements
- Magnetic resonance imaging, very special applications
- Vibration analysis
- Leak testing
- Visual inspection

Canadian NDT personnel are examined by an agency within the federal Department of Energy, Mines and Resources to requirements set out in CGSB Standards.

1.10.10 Techniques Covered in Course

1. Ultrasonics: powerful and widely used.
2. Acoustic emission: a passive technique.

3. Microwave: becoming more attractive.
4. Electromagnetic methods (MFL, MPI, EC): classical and useful.
5. Radiography: widely used and reliable.

Work Problems

1. In answering the question "What is Nondestructive Testing?", Harold Burger[1] states (not a verbatim quotation): "When you drop a coin in a vending machine to buy a candy bar, the machine subjects the coin to a number of tests to assure its genuineness. The coin is tested for size, shape and magnitude properties (and, in some machine for its weight and elastic properties), all in the few seconds between the time you insert the coin and the time your purchase pops out. These tests must be made quickly and in such a manner that the coin is still useful when the tests are finished. On this respect, the tests have much in common with many nondestructive tests made in industry."
   Speculate on the NDT methods used in the vending machine?
2. Explain how NDE can beneficially contribute to the following areas:
   (a) factor-of-safety in design.
   (b) safety in operating equipment and plant processes.
   (c) uniform quality in raw material.
   (d) conservation of raw materials.
   (e) economic benefit in equipment maintenance.
   (f) uniform quality of products.
3. In no more than 300 words describe an NDT that you encountered in industry. For this technique, identify the main elements of NDT (i.e. source, modification, detection, indication and interpretation), and explain where, when, why, and how this technique was used.

1.11 Graphs

[1] Nondestructive Testing, U.S. Atomic Energy Commission, June 1967.

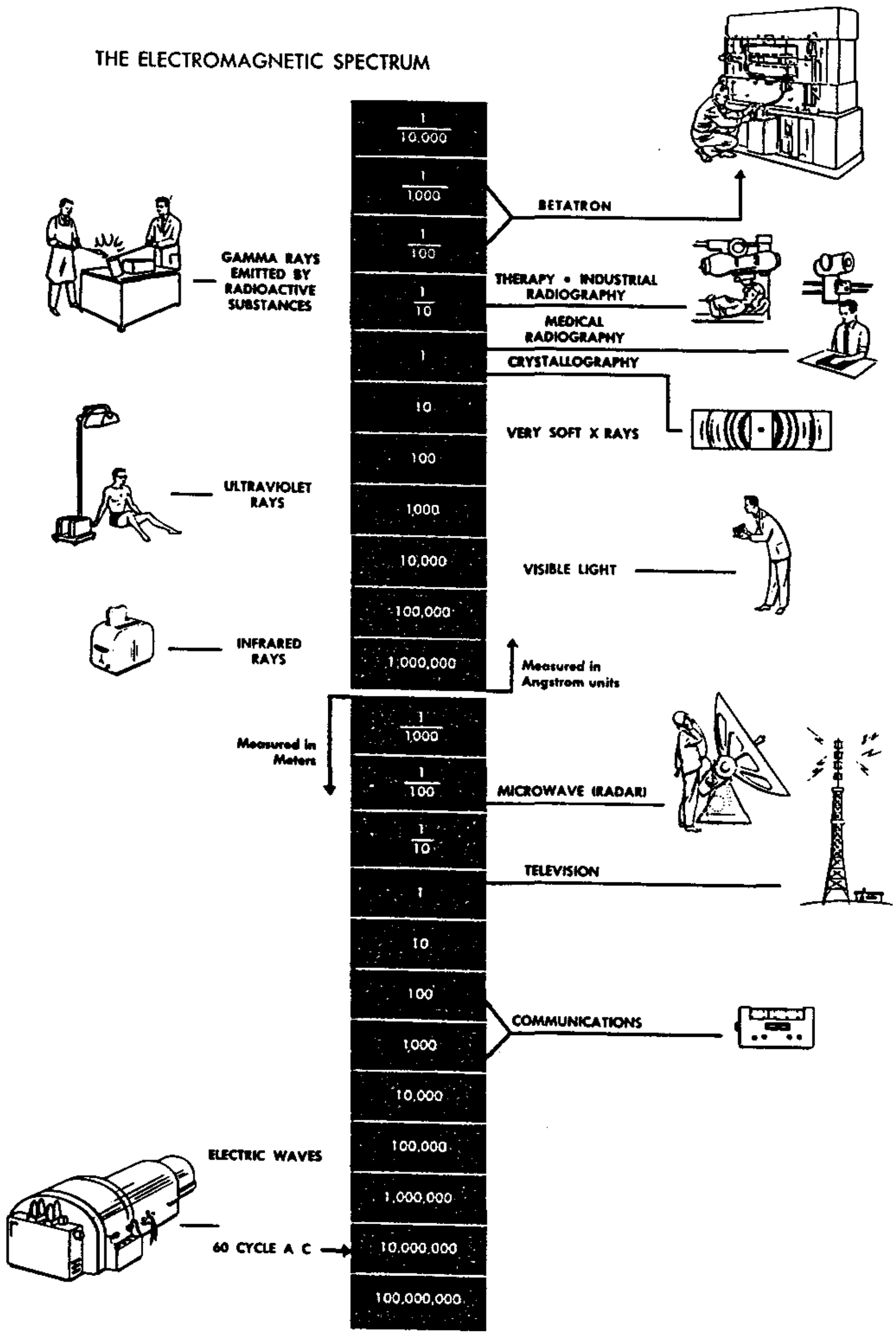

Figure 1.1: The Electromagnetic Spectrum

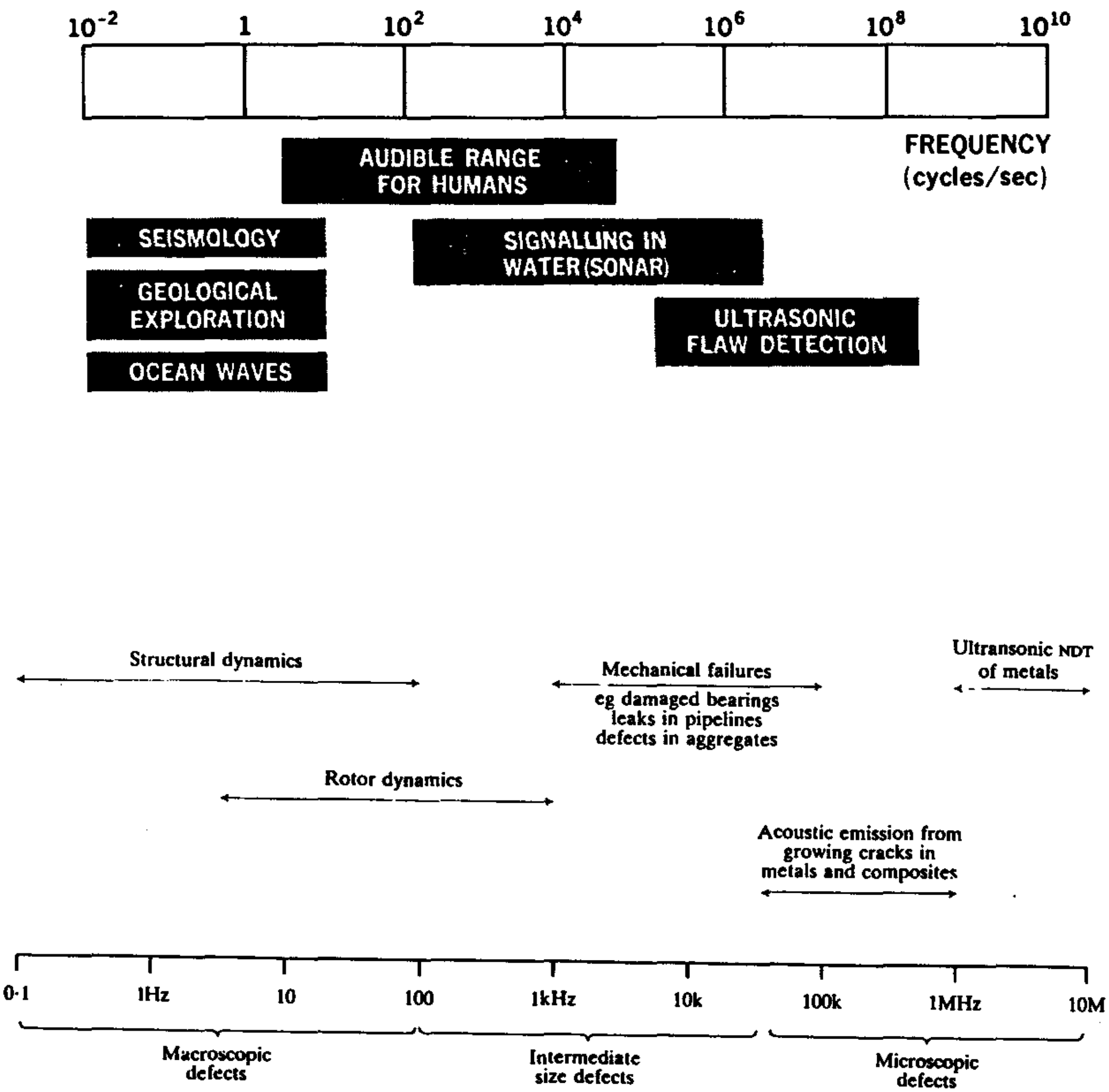

Figure 1.2: Mechanical Vibrations and Sound Spectrum