Comparative Analysis of Various Safety Standards on “Construction & Classification of Nucleonic Gauges”

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Abstract:
Various radiation sources are being used in Nucleonic Gauges (NGs) which find many non-destructive applications in industry to assure the quality of industrial products & optimize process parameters which permit measurements in adverse environmental conditions, in-corrosive media & also in non-invasive studies. Though, our society is benefitted from the applications of NGs, but may lead to potential hazard to health of radiation workers, public & environment if not handled/operated properly. Hence, compliances with National/International safety standards are essential during its manufacturing/design process to achieve the goal of built-in safety in addition to operational safety. In this paper, general & specific safety test requirements as specified in various National/International standards are analyzed and compared for different test parameters for various types of NG devices in respect of its design and quality aspects to bring out the equivalency in establishment of compliances with regulatory safety requirements for issuance of consents by National Regulatory Authority.

Keywords: Nucleonic Gauge, Standards, Radiation sources, Stray Radiations, Safety Requirements

Introduction: There are various applications of ionizing radiation in industry viz. tracer studies using sealed/unsealed sources; measurement of physical parameters in process industries using Nucleonic Control Systems (NCS)/Nucleonic Gauges (NG); radiography for Non-Destructive Testing and radiation processing of food and health care products. The NGs find many non-destructive applications in industry and widely used to assure the quality of industrial products and optimize processes. NGs are preferred as an appropriate choice over other methods as it permits measurements in adverse environmental conditions, in corrosive media & also in non-invasive studies. Our society is benefitted from the various applications of NGs, but may lead to potential hazard to health of radiation workers, public & environment if not handled/operated properly. Hence, compliances with National/International safety standards are essential during its manufacturing/design process to achieve the built-in safety. The types of radiation sources used in NGs include alpha, beta, gamma, neutron (e.g. $^{241}$Am; $^{85}$Kr; $^{90}$Sr; $^{137}$Cs; $^{60}$Co; $^{241}$Am-Be; $^{252}$Cf etc) with activity varies from several kBq to few GBq and X-rays in the energy range of 30 kV to 160 kV are also preferred depending upon its applications [1]. National standard should be consistent with International standards for NG devices as these standards are well collated, studied by the experts from various countries to develop the scientific basis for these standards. The deviations from the International standards with National standard may be justified and hence International standards form the basis for National Safety Standards. With the improved day by day modifications in radiation risk assessment & analysis associated with operation of NGs, criterions have been developed for the protection of radiation workers, public and the environment while it’s manufacturing & use and hence these Safety Standards have been developed. There are various National and International safety standards on “Construction & Classification of Nucleonic Gauge devices” as below:


More info about this article: http://www.ndt.net/?id=24362
Depending upon the types of NGs manufactured using various radiation sources; it has been categorized and classified for its use & operation from regulatory perspective. Particular emphasis is placed on built-in-safety while designing the NGs so as to minimize human intervention, control of stray radiation in and around the NGs, provision of safety features, reliability of the device and its components to withstand severe environmental conditions such as humidity and corrosiveness. General safety features/requirements for NG devices are analyzed and compared for different parameters such as checking integrity of radioactive source, indicators, interlocks, permissible streaming radiation levels etc. Few specific test requirements such as shielding integrity & adequacy tests, accidental tests, leak tests of the source etc. are also analyzed to verify the ability of the device to maintain radiological safety.

Methodology & Analysis:

The various applications of nucleonic gauges using radiation source in industries are level measurement in process column, thickness measurement of metal/plastic/papers, density/moisture measurement of materials, elemental analyzer in metal & cement industries, coal ash monitor etc[1]. There are two types of NG devices: fixed and portable type. The classifications & comparison for general safety features or requirements as well as specific tests requirements and recommendatory regulatory requirements of the NG devices are based on the various National/International safety standards.

Table-1 Features of various National/ International Standards

<table>
<thead>
<tr>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Whether applicable for Source based NGs</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>2</td>
<td>Whether applicable for X ray based NGs</td>
<td>Yes</td>
<td>Not specifically applicable but can be used analogously</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>3</td>
<td>Whether applicable for Fixed type of NGs</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>4</td>
<td>Whether applicable for Portable/Mobile type of NGs</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>5</td>
<td>Categorization of NGs</td>
<td>Not specifically categorized but applicable for all types of NGs</td>
<td>Category A: NGs with restricted beam Category B: NGs with Omni directional beam Category C: NGs with Stand Alone Source Housing</td>
<td>Category A: NGs with restricted beam Category B: NGs with non-restricted beam</td>
<td>Not specifically categorized but applicable for all types of NGs</td>
</tr>
</tbody>
</table>
1. General safety features and requirements for Nucleonic Gauging Devices:

i. **Radioactive Source Integrity:**
   The radioactive material used in NG device should be in the form of a sealed source. The tests requirements for sealed radioactive source are based on the compliances with AERB Safety Standard SS/3 [2]. Few specific tests that NG source has to undergo are Temperature, Pressure, Vibration, Impact, Puncture and Leakage etc. The leakage test is very important from radiation safety point of view and leak test on sealed sources should be performed periodically in order to ensure the containment of the radioactive material. This test can be conducted in various ways such as Immersion test, Gaseous Emanation test & Wipe test as well as by using some non-radioactive tests such as Helium mass spectrometer test & Bubble leakage test.

ii. **Indicators:**
   The installed NG device shall have ON-OFF indicators accomplished using both redundant electrical and mechanical indicators for shutter ON-OFF condition. All indicators should be clearly marked with symbols to clarify what device indicator reflects (e.g., “OFF” for green indicator, “ON” for red indicator). In case of failure of ON-OFF signals, the user should establish appropriate administrative controls to maintain proper operation of the signals else operation in the ON condition could result into a significant safety hazard to working personnel. In the event that ON/OFF indicators fail, the device shall remain in the OFF condition. For X-ray based NGs, yellow or amber warning light with the legend "HIGH VOLTAGE ON" should be placed on the control panel or adjacent to the X-ray tube housing. Such indicators are very useful to make aware the NG users & operating personnel about existence of radiations.

iii. **Interlocks:**
   Under normal conditions of use, there should be interlocks or barricades to prohibit the unauthorized encountering of radiation exposure. For conditions of infrequent use or where such interlocks or barricades are physically impossible, appropriate instructions & auxiliary shielding or proper administrative controls may be applicable. On X-ray gauges, interlocks should be incorporated to prevent accidental exposures to X-rays as well as high voltages associated with the X-ray tube & generator.

iv. **Labels:**
   Radiation safety labels should be provided for both radioactive source & X-ray based NGS indicating clearly presence of radioactive material or X-rays, located adjacent to NG device with a caution symbol, instructions and precautions for safe operation of the NG device. Where such labeling is not practical, there should be a durable, permanent label indicating the type and amount of radioactive material.

**NG Device Classification:**

Table 2 elaborates the list of specific tests condition and measurements to which NGs may be subjected and based on these results and analysis, the classification of each device type shall be determined by prototype testing for NG device. These standards do not apply to the measurement performance of the NG devices and applies only to radiation safety performance & considerations. The demonstration with all these tests shall be determined by
the ability of the device to maintain reasonable radiological safety. If the class of NG device as prescribed in applicable standard is lower than the class of sealed radioactive source then class of only source should be used for demonstration. The passing criterion after the evaluation of each required tests should be considered in determining the following factors:

1. Shielding integrity of NG device is unchanged / acceptable
2. No dispersal of radioactive material
3. Source capsule shall remain captive/intact in protective source housing
4. Chemical and physical form of the radioactive material is unchanged
5. External radiation levels shall not exceed the prescribed regulatory limits

2. Specific test requirements for NGs prescribed by various safety standards (SS):

Table-2 Test Requirements for the NGs

<table>
<thead>
<tr>
<th>Sr No</th>
<th>SS Tests</th>
<th>ANSI: HPS N43.8</th>
<th>IEC: 62598</th>
<th>ISO: 7205</th>
<th>AERB: SS-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>High and Low Temperature Test (Based on Operating Condition)</td>
<td>Applicable</td>
<td>Applicable</td>
<td>Applicable</td>
<td>Applicable</td>
</tr>
<tr>
<td>2.</td>
<td>Stray Radiation @ 5Cm (Shutter On &amp; Off Conditions)</td>
<td>Applicable</td>
<td>Applicable</td>
<td>Applicable</td>
<td>Applicable</td>
</tr>
<tr>
<td>3.</td>
<td>Stray Radiation @ 30Cm (Shutter On &amp; Off Conditions)</td>
<td>Applicable</td>
<td>Not Applicable</td>
<td>Not Applicable</td>
<td>Not Applicable</td>
</tr>
<tr>
<td>4.</td>
<td>Stray Radiation @ 100Cm (Shutter On &amp; Off Conditions)</td>
<td>Applicable</td>
<td>Applicable</td>
<td>Applicable</td>
<td>Applicable</td>
</tr>
<tr>
<td>5.</td>
<td>Fire Test-Accident/adverse condition Test (Not recommended for X-ray based NGs)</td>
<td>Applicable (Measurement with Dummy Source)</td>
<td>Applicable (Measurement with Dummy Source)</td>
<td>Applicable (Measurement with Source in non-operating position)</td>
<td>Applicable (Measurement with Dummy Source)</td>
</tr>
<tr>
<td>6.</td>
<td>Endurance Test (Shutter &amp; Source holder)</td>
<td>Applicable</td>
<td>Applicable</td>
<td>Applicable</td>
<td>Applicable</td>
</tr>
<tr>
<td>7.</td>
<td>Accidental-Drop Test (Not recommended for X-ray based NGs)</td>
<td>Recommended</td>
<td>Not Specified</td>
<td>Recommended</td>
<td>Recommended</td>
</tr>
<tr>
<td>8.</td>
<td>Impact Test (Not recommended for fixed NGs)</td>
<td>Recommended</td>
<td>Not Specified</td>
<td>Recommended</td>
<td>Recommended</td>
</tr>
<tr>
<td>9.</td>
<td>Vibration Test</td>
<td>Recommended</td>
<td>Not Specified</td>
<td>Recommended</td>
<td>Recommended</td>
</tr>
</tbody>
</table>

3. Classification Code for NGs:

It may be noted that tests mentioned in serial no. 1 to 7 in Table 2 are used while designing the code classifications for NG devices to ensure the radiation safety performance in operating & accident conditions as stipulated in respective Safety Standards. There are
several additional special & recommendatory tests to be conducted on NG device such as Impact, Vibration, Corrosion, Pressure, Explosion, Water Immersion tests etc to withstand special environmental and stringent hazard conditions of use. On the basis of evaluations and results obtained for each tests as mentioned in Table 2 in accordance with the limits prescribed by these respective standards for the various types of NG devices, a typical correlation has been established to derive a specific classification code for NG devices in each National/International Safety Standards which is shown below:

3.1: **ANSI HPS N43.8**

![Figure 1: ANSI Classification Code for NG devices](image)

Figure 1 illustrates the classification code prescribed by ANSI Safety Standard [3] for minimum test requirements to be conducted on NG device containing radioactive source as well as machine generated source (X-ray). First eight digits of the classification code imply for the test requirements to check High & Low temperature and external stray radiation level measurement under shutter On & Off condition at distance of 5 cm, 30 cm & 100 cm using maximum activity of radionuclides with all filled slots subjected to actual normal operating conditions which are categorized under total ten classes starting from class code digit ‘1’ to ‘9’ and last a special class code ‘S’ which should be used under stringent hazard conditions of use. X-ray tube based NG devices should be tested at maximum Voltage potential (kVp) & corresponding Current (mA). All these tests are prescribed for NGs (Portable & Fixed) containing all types of radionuclide (Alpha, Beta, Gamma & Neutron) and X-rays. Letter ‘R’ denotes for presence of radioactive source and letter ‘X’ should be used if NG containing machine generated source (X-ray). Last digit of the classification code denotes compliance with fire accident condition where NG device with dummy source is subjected to undergo fire (heat) test for a fixed time period which is categorized under total nine classes. Class code digit ‘1’ in the classification designation indicates that ‘No test’ is required to perform under specific test category of normal operating & accident conditions. It may be noted that fire accident test is not applicable for machine generated source based NGs (X-rays).
3.2: IEC 62598

Figure 2: IEC Classification Code for NG devices

Figure 2 illustrates the classification code prescribed by IEC Safety Standard [4] for minimum test requirements to be conducted on NG device containing radioactive sources. This IEC code can be analogously used for X-ray based NGs. First & second class code in the classification imply for the safety standard revision and NG category respectively. Class codes from third to eight denotes test requirements to check external stray radiation level under shutter Off & On condition at distance of 5 cm & 100 cm using maximum activity of radionuclides with all filled slots and High & Low temperature tests subjected to actual normal operating conditions which are categorized under total seven classes starting from class code digit ‘1’ to ‘7’. X-ray NG devices should be tested at maximum Voltage potential (kVp) & corresponding Current (mA). All these tests are prescribed only for fixed NGs containing all types of radionuclide (Alpha, Beta, Gamma & Neutron). Last letter of classification code denotes compliance with fire accident condition where NG device with dummy source is subjected to undergo fire (heat) test for a fixed time period which is categorized under total five classes. Code digit ‘1’ in the classification designation for ‘stray radiation’ measurements indicate that radiation levels are exceeding the prescribed limits and that for ‘temperature test’, it indicates that ‘No test’ is required to perform under normal operating condition. It may be noted that fire accident test is not applicable for machine generated source based NGs (X-rays).

3.3: ISO 7205

Figure 3: ISO Classification Code for NG devices
Figure 3 illustrates the classification code prescribed by ISO Safety Standard [5] for minimum test requirements to be conducted only for fixed types of NGs containing radioactive sources other than gaseous form. This ISO code is not applicable for X-ray based NGs. First two letters in the classification designation denote for Category and Sub-category of the NG device. Code class from third to eight no. in classification imply for test requirements to check external stray radiation level under shutter Off & On condition at distance of 5 cm & 100 cm using maximum activity of radionuclides with all filled slots and High & Low temperature tests subjected to normal operating conditions which are categorized under total six classes starting from code digit ‘0’ to ‘5’ (Special). Special Class test (Code-5) is to be carried out based on specific hazards of the installation and results for this test should never less stringent than test classification code digit no ‘4’. All these tests are prescribed only for fixed NGs containing all types of radionuclide (Alpha, Beta, Gamma & Neutron). Last digit of the classification code denotes compliance under adverse condition such as fire accident where NG device with source in non-operating condition is subjected to undergo fire (heat) test for a fixed time period which is categorized under total eleven classes.

### 3.4: AERB/SS-2

![AERB Classification Code for NG devices](image)

Figure 4 illustrates the classification code prescribed by AERB Safety Standard [6] for minimum test requirements to be conducted on NG device containing radioactive source as well as X-ray tube. There are total seven class codes which are denoted by digit ‘0’ to ‘6’. First six class codes digits in the classification designation imply for the test requirements to check external stray radiation level under shutter On & Off condition at distance of 5 cm & 100 cm using maximum activity of radionuclides with all filled slots and High & Low temperature tests subjected to normal operating conditions. Class code digit ‘0’ in the classification designation indicates that ‘No Test’ is required to perform under specific test category in normal operating condition & accidental condition. Class code digit ‘6’ which indicates conduction of special test for NGs designed for installation and use at elevated locations and in uncovered areas. Mostly special test includes water immersion test. All these tests are prescribed for NGs (Portable & Fixed) containing all types of radionuclide (Alpha, Beta, Gamma & Neutron) and X-rays. Letter ‘R’ denotes presence of radioactive source and if NG containing X-ray tube, letter ‘X’ should be used. To comply with accident conditions, classification code denotes the digit under fire test where NG device is subjected to undergo
fire (heat) test with dummy source for a fixed time period which is categorized under total eleven classes and letter ‘D’ denotes for conduction of ‘Drop test’. It may be noted that accidental fire test & stray radiation measurements under ‘Off’ condition are not applicable for X-ray based NGs and accidental ‘Drop Test’ is not applicable for neutron source NGs.

Conclusions:
Atomic Energy Regulatory Board has a mandate to enforce the radiation safety regulations with the objective and mission to ensure the use of ionising radiation and nuclear energy in India does not cause undue risk to the health of people and the environment. Overall radiation safety could be achieved through ensuring that NG equipment is designed and manufactured (built-in-safety) as per National/International Safety Standard and its safe operation during its use. To achieve the design safety aspects, AERB issues Type Approval Certificate to NG equipment after verifying the certified test results & necessary compliances/conformances with various Safety Standards to ensure the built-in safety of the NG equipment from radiation safety view point [7] and subsequently issues the consents after review of compliances with operational safety performance of the NG installation at user premises in accordance with Rule 3 (3) of Atomic Energy (Radiation Protection) Rules-2004 [8]. Built-in safety of the NG device is ensured by evaluating the results of performance of the prototype NG equipment demonstrated to AERB by authorized NG device Manufacturer/Supplier as well as safety review of technical documents in accordance with National/International standards. Here, general & specific safety test requirements as specified in various National/International standards are analyzed and compared for different parameters for various types of NG devices in respect of its design/construction, categorization and quality aspects to bring out the equivalency in establishment of compliances with regulatory safety requirements for issuance of consents by National Regulatory Authority. On the basis of analysis of these Safety Standards, it is concluded that AERB safety standard (AERB/SS/2) for NGs [6] is at par with all other Safety Standards as it thoroughly covers the design and manufacturing aspects for both types of NGs (Fixed and Portable) containing all types of radiation sources (Radioactive as well as X-rays).

References:

1. IAEA Technical Data on Nucleonic Gauges-2005 (IAEA Tecdoc-1459)
3. American National Standard on “Classification on Industrial Ionising Radiation Gauging Devices” (ANSI/HPS N43.8/2008)
4. IEC Standard on “Nuclear Instrumentation-Constructional requirements and classification of radiometric gauges” (IEC-62598/2011)