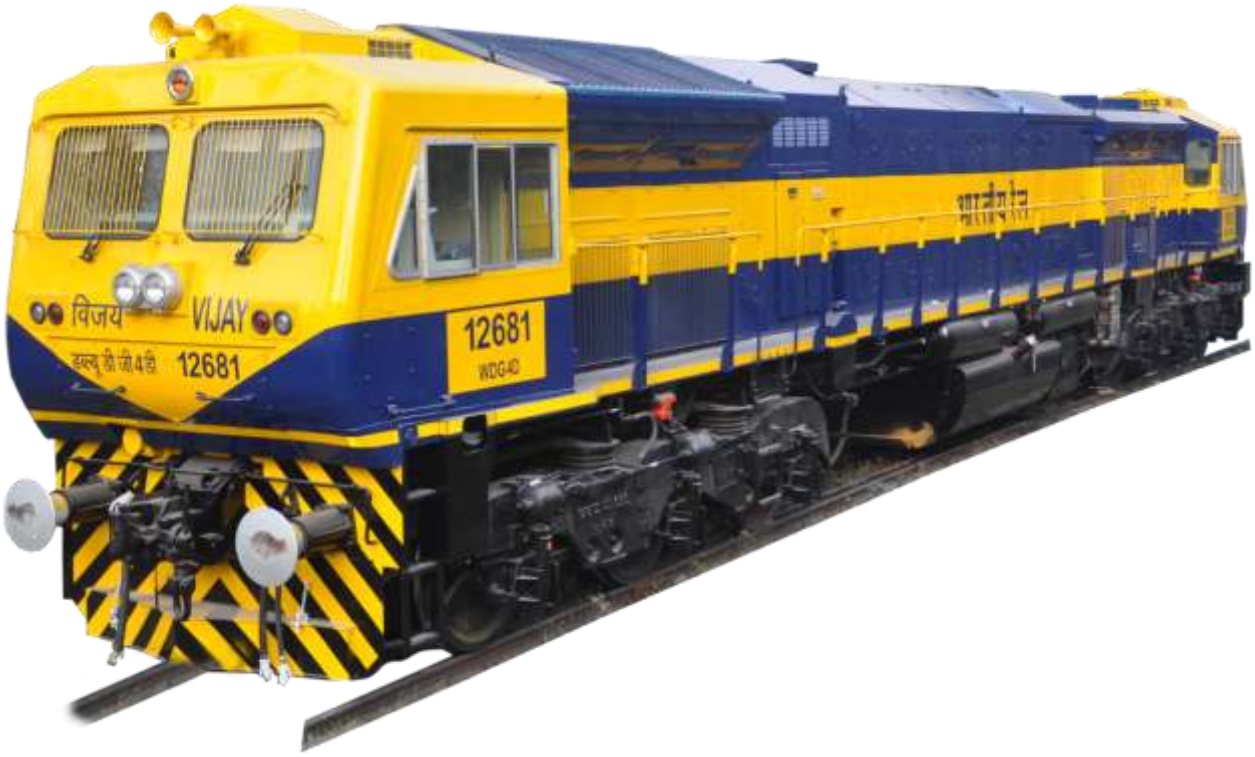
Interim Report

Exhaust Emission Benchmarks for Diesel Locomotives on Indian Railways



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Engine Development Directorate
Research Designs and Standards Organisation
Manak Nagar, Lucknow-226 011

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List of Abbreviations

ALCO	American Locomotive Company
BHP	Brake Horse Power
CO	Carbon monoxide
DLW	Diesel Locomotive Works
DLMW	Diesel Locomotive Modernisation Works
CPCB	Central Pollution Control Board
IIT	Indian Institute of Technology
IEA	International Energy Agency
UIC	International Union of Railways
FRA	Federal Railroad Administration
EMD	Electro Motive Division
ETC	Emission Test Car
FID	Flame Ionization Detector
FMS	Fuel Measurement System
gm/bhp-hr	gram per brake horse power - hour
HFID	Heated Flame Ionization Detector
HP	Horse Power
ICF	Integral Coach Factory
IR	Indian Railways
LHB	Linke Hofmann Busch
MEMS	Mass Emission Measurement System
Mg/m^3	milligram per meter cube
NMHC	Non Methane Hydrocarbons
NOx	Oxides of Nitrogen
PM	Particulate Matter
ppm	parts per million

1. Synopsis:

The emission from diesel locomotives in India continues to be unregulated. Countries like US and EU have already enforced their mandatory locomotive emission standards and many others such as Canada and Australia are in advanced stage of finalizing them for implementation. India has pledged in the December 2015 Paris Agreement that it would reduce national emission intensity in tonnes CO2 per GDP unit by up to 20 to 25 percent by 2020 and up to 33 to 35 percent by 2030 when compared to the 2005 level. Target of reducing emission intensity is also articulated in the Twelfth Five Year Plan.

While the Indian Railways has been making consistent efforts for improving energy efficiency of indigenously manufactured Diesel locomotives and a substantial improvement in SFC has already been achieved, the need for inventorization of emission data with the objective of framing emission standards for our locomotives has long been felt. Indian Railways initiated action for setting up facilities required for capturing emissions data from diesel locomotives in 2007-08. An Emission Test Car (ETC) for in-service emission testing was commissioned in 2013. Sample data of exhaust emissions from diesel locomotives has been generated. Indian Railways has also issued a standard test procedure in consultation with CPCB and IIT/Delhi for monitoring emission performance of diesel locomotives in India. Meanwhile, Hon'ble National Green Tribunal (NGT), New Delhi in its order dated 14th March 2017 (OA No. 356/2013), has directed Indian Railways and Ministry of Environment, Forest & Climate Change to expedite issue of interim emission standards for the Diesel locomotives working on Indian Railways.

This report gives an overview of the existing diesel locomotive fleet profile on Indian Railways. It deliberates on the methodology and instrumentation quality used for capturing emissions data from the locomotives. It also explains in brief the compliance protocol proposed for certification, in-service and production line monitoring of the emission performance of diesel locomotives through their useful life. **The report concludes with an interim recommendation proposing emission standard benchmark for ALCO and HHP (EMD) type of locomotives**. It is important to recognize that there is significant uncertainty associated with the estimated locomotive emissions, especially given the inherent variability of limited amount of emissions data that is available on date. Indian Railways intends to refine the proposed standards in future as and when more emission data becomes available.

2. Introduction:

Railways form an important part of basic infrastructure required for region's economic growth. Various studies conducted in the past have established that rail transport offers a more sustainable alternative to most other transport modes, both in terms of energy use and carbon emissions per passenger-kilometer or tonne-kilometer, and is anticipated to continue to do so over the coming decades. Railway Handbook 2016 published jointly by IEA (International Energy Agency) and the UIC (International Union of Railways) reiterates that worldwide the rail sector has continuously reduced its specific energy consumption and CO2 emissions and confirms that the rail sector offers the most efficient land-based mode of transport per passenger-kilometer and tonne-kilometer compared to other modes of transport.

As per the world statistics presented in the Rail Hand Book 2016, the transport sector was responsible for emitting 7.5 billion tCO2 in 2013. The share of CO2 emissions from transport has continuously increased since 2010, rising from 22.7% in 2010 to 23.4% in 2013. In 2013, only 3.5 % of transport CO2 emissions were due to the rail sector, while railways transported 8% of the world's passengers and goods. The report emphasizes on the reduction in railway specific CO2 emissions over the period 1975-2013 from around 22 g / t Km to 14 g / t Km and 41 g / pkm to 16 g / pkm for freight and passenger services respectively. As per the Rail HandBook 2016 published jointly by IEA and UIC, the transport sector in India was responsible for 13.5% of total CO2 emissions in 2013 equal to 250 million tCO2, increasing its share by about 3.5 times from 1990. 9.7% of transport emission were generated by the rail sector (amounting to about 24.7 million tCO2). Rail's share of total transport activity was 12.6% for passengers transport and 33.3% for freight transport. The changes in the energy sources allowed for a reduction of the share of rail transport CO2 emissions from 24% in 1990 to less than 10% in 2013, while rail activity doubled in the same period (*source: Rail Handbook 2016*).

India is the country with the highest rail passenger activity with over 1 trillion passenger-km carried in 2013. This number is seven times larger than what it was in 1975. Similarly, freight activity increased with a factor of 5.5 between 1975 and 2013. Rail's specific CO2 emissions fell by 37% for passenger services and by 24% for freight services between 2000 and 2013. The share of CO2 emissions in India from fuel combustion by various sectors (for 2013) has been indicated in the report as under:

1. Manufacturing Industries & Construction – 47.1%
2. Residential – 16.2%
3. Others – 14.6%
4. Transport – 13.5%
5. Commercial & Public services – 5.9%
6. Energy Industry own use – 2.7%

(Source: Rail Handbook 2016)

(Source: Rail Handbook 2016)

The share of various modes of transport in the CO2 emissions is detailed as under:

1. Road transport – 80.9%
2. Rail transport – 9.7%
3. Aviation sector – 6.9%
4. Navigation – 2.5%

Indian transport modal share based on 2013 figures (ref: Rail Handbook 2016) is summarized as under:

	Passenger PKM	Freight TKM	Total TU
Road	86.1%	66.4%	82.3%
Aviation	1.3%	0.1%	1.0%
Navigation	N.A.	0.2%	N.A.
Rail	12.6%	33.3%	16.7%

Indian Railway is an environment friendly mode of transport and has been proactively making consistent efforts for improving the overall energy efficiency. As a result of the efforts put-in by railways, the Railway specific energy consumption over the period 2000-2013 has come down from 127KJ/pkm to 75 KJ/pkm for passenger and from 122 KJ/tkm to 92 KJ/tkm for goods services. During the same period the railway specific CO2 emissions have reduced from 15 to 9.2 g / pkm and from 16 to 12 g / tkm respectively (source: Rail Handbook 2016).

The rail sector is the most emissions efficient transport mode and it is for this reason that Railway projects do not require an environment impact assessment and a public consultation for an environmental clearance. All Railway Projects, with no exception, are totally exempted from seeking environmental clearance under Government regulations., but as a major transport mode we acknowledge our responsibility that further improvement is needed. Indian Railways had set CO2 target for saving 3.33 million tonnes of CO2 by 2020 (80% over the period 2011/12-2020/21) and Energy target of saving 4.05 billion kWh by 2020. As a part of action plan and sustainability targets commitments defined as Intended Nationally Determined Contributions (INDCs) during COP21 conference held in Dec 2015, efforts have to be made to increase the share of Railways in total land-based transportation from 36% to 45%. As a part of this effort, Dedicated Freight Corridors (DFCs) are being introduced across the country. In the first phase, two corridors are being constructed : Mumbai-Delhi (Western Dedicated Freight Corridor) and Ludhiana – Dankuni (Eastern Dedicated Freight Corridor). Further, as a part of measures intended to be taken for reduction in specific average CO2 emission from train operations & energy efficiency improvements, a number of energy efficiency measures undertaken has helped Indian Railways in achieving 19.7% improvement in Specific Fuel

Consumption for Freight service Locomotives and 21.1% improvement for Coaching Service Locomotives during the last 10 Years. Indian Railways is also installing solar power on its land and roof tops of coaches. The DFC is expected to reduce emissions by about 457 million tonnes of CO2 over a 30 year period. Worldwide railway community is aware that a shift towards sustainable transport is essential to achieve the internationally agreed goal of limiting change to a rise in average global temperature of no more than 2 degrees Celsius.

3. Objective:

While the Indian Railways has been making consistent efforts in improving energy efficiency of indigenously manufactured Diesel locomotives and a substantial improvement in SFC (Specific Fuel Consumption) has already been achieved, the need for inventorization of emission data with the objective of framing emission standards for monitoring of exhaust emissions from our locomotives has long been felt. Efforts in this direction had already started in 2007-08 for identifying and defining technical specifications for acquiring proven technologies in the field of emission measuring instrumentation compatible to deal with the exhaust emissions from diesel locomotives in India. The Emission Test Car (ETC) for in-service testing for locomotive exhaust emissions was commissioned by Indian Railways in year 2013. The Emission testing facilities were also installed for measurement on the engine test beds at RDSO in the year 2007. Using the emission test car (ETC), exhaust emission data has been recorded for 23 in-service locomotives. Subsequently, to standardize the Test Procedure with the aim of avoiding variability and deviations in the recorded measurements, a "Monitoring Protocol for Exhaust Emissions Measurement of Indian Railways Diesel Locomotives using Emission Test Car" was issued in April-2015 by Indian Railways in consultation with CPCB and IIT/Delhi.

Meanwhile, Hon'ble National Green Tribunal (NGT), New Delhi in its order dated 14th March 2017 (OA No. 356/2013), has directed Indian Railways and Ministry of Environment, Forest & Climate Change to expedite issue of interim emission standards for the Diesel locomotives working on Indian Railways. In pursuance of Hon'ble NGT (National Green Tribunal) / Delhi's directive, this report proposing an interim Emission Standard for Diesel Locomotives on Indian Railways is being issued. It is important to recognize that there is significant uncertainty associated with the estimated locomotive emissions, especially given the inherent variability of limited amount of emissions data that is available on date. Indian Railways intends to refine the proposed standards in future as and when more emission data becomes available.

4. Fleet characterization, Data Collection & Analysis details:

a. Indian Railway Diesel locomotive fleet characterization:

SN	Loco types	EMD (HHP Locos)	
		ALCO Locos	
1.	Number of locomotives	EMD (HHP Locos)	2002
		ALCO Locos	3378
2.	Power rating(HP)	EMD (HHP Locos) ALCO locos	4000, 4500 2600, 3100, 3300
3.	Age Profile	EMD (HHP Locos) ALCO locos	1ST Loco manufactured in 2000 1st Loco manufactured in 1967. Production stopped in 2016
4.	Periodicity of major overhauls	EMD (HHP) Locos	6, 12, 18 years
		ALCO locos	8, 16, 18 years
5.	Cycle	EMD (HHP Locos)	Two stroke
		ALCO Locos	Four stroke
6.	Turbocharged	EMD (HHP) locos ALCO locos	Gear Driven on part loads & Gas Driven on rated loads Gas Driven
7.	Compression Ratio	EMD (HHP) locos ALCO locos	16 CR 11.75 CR
8.	Type of Fuel Injection	EMD (HHP) locos ALCO locos	Mechanical Unit Injectors (MUI) Jerk Pump System
9.	Type of propulsion system	EMD (HHP) locos ALCO locos	IGBT based AC-AC microprocessor based propulsion system Microprocessor based AC-DC
10.	Adhesion	EMD (HHP) locos ALCO locos	0.48 0.35
11.	Bogie arrangement	EMD (HHP) locos ALCO locos	Co-Co Co-Co
12.	Auxiliaries	EMD (HHP) ALCO locos	Motor Driven Radiator fans. All other auxiliaries are shaft drive. Shaft driven.
13.	Type of Heat Exchangers	EMD (HHP) locos ALCO locos	Mechanically Bonded Radiators with Forced draft flow of air (1,50,000 Btu/min) Mechanically Bonded Radiators with induced draft flow of air (1,20,000 Btu/min)
14.	Power assembly components	EMD (HHP) locos ALCO locos	Laser hardened Cast Liners with SS Rings Chrome plated liners, CI rings & CI liners with Chrome plated rings
15.	After-cooler design	EMD (HHP) locos ALCO locos	One after-cooler core each for left bank & Right bank One after-cooler core
16.	Type of suspension	EMD (HHP) locos ALCO locos	Primary – Coil , Secondary – Rubber Primary – Coil , Secondary – Rubber

b. Data collection:

RDSO has so far tested emission levels of 11 ALCO and 12 HHP type locomotives using mobile Emission Test Car (ETC). The methodology laid down by Indian Railways in consultation with CPCB (Central Pollution Control Board) and IIT / Delhi in the document 'Monitoring Protocol For Exhaust Emissions Measurement Of Indian Railway's Diesel Locomotives using Emission Test Car" has been followed to capture exhaust emission data from the locomotives. The emission levels of these locomotives have been co-related with their power, type and service life. The emission parameters were then compared with the benchmarks specified by US EPA for Diesel Locomotives working on American Railroads. It is worthwhile to mention that the emissions from a locomotive depend on many factors which amongst others include ambient (temperature & humidity), working duty-cycle, quality of fuel, quality of in-service maintenance, technology profile of the locomotive, in-service deterioration factors due to wear and tear etc. Considering wide variance in the ambient conditions and the service duty-cycles prevalent in US and India, comparing the exhaust emissions from the Diesel locomotives in India with the emission standards of US will not be logical. The effort is therefore to benchmark the exhaust emissions from Indian Diesel locomotives in service and define an emission standard taking due care to include compliance margins for variation in the ambient and manufacturing tolerances. It is also pertinent to point out that an overly stringent emission standard for Diesel locomotives in India may ultimately lead to non-compliance and negative modal shift from rail to road having serious impact on environment.

It is important to recognize that there is significant uncertainty associated with the estimated locomotive emissions, especially given the inherent variability of limited amount of emissions data that is available on date. Indian Railways intends to refine the proposed standards in future as and when more emission data becomes available.

5. Equipments Used for Data Collection:

a. Emission Test Car

Emission Test Car has been designed and developed by Indian Railways (Engine Development Directorate / Research Designs and Standards Organisation (RDSO)/Ministry of Railways). Locomotive exhaust emissions tests on Indian Railways have been performed using this Mobile Emission Test Car (ETC). The testing equipments are housed in a non-propelled LHB Hybrid Coach, manufactured at Integral Coach Factory / Chennai. Mass Emission Measurement System (MEMS) procured by RDSO and supplied by M/s HORIBA, Japan have been housed in this mobile test car. The mobile test

car also carries a portable Fuel Measurement System for measuring fuel consumption.

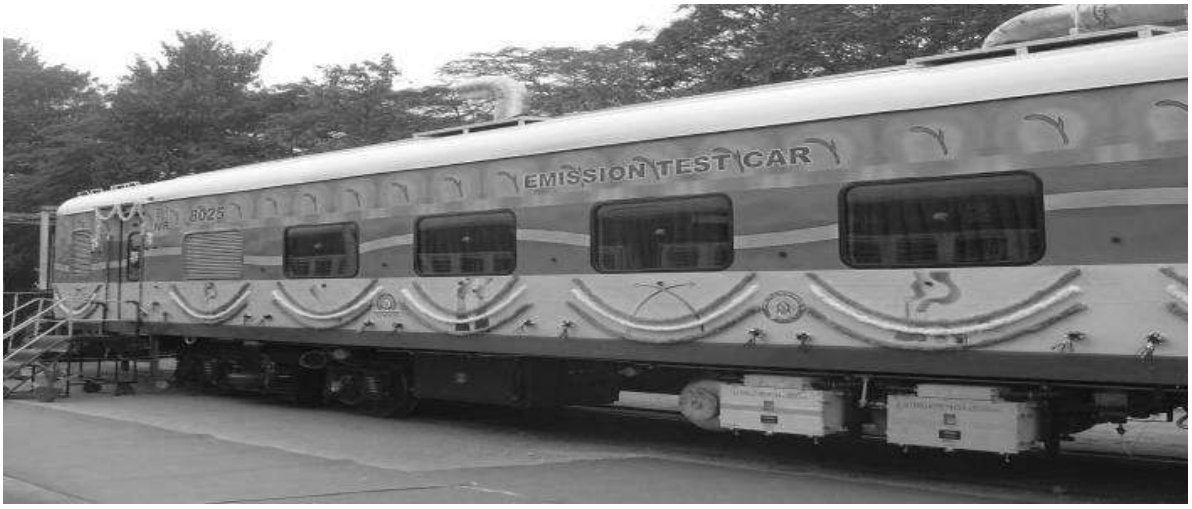

Figure 1: Outside view of emission test car

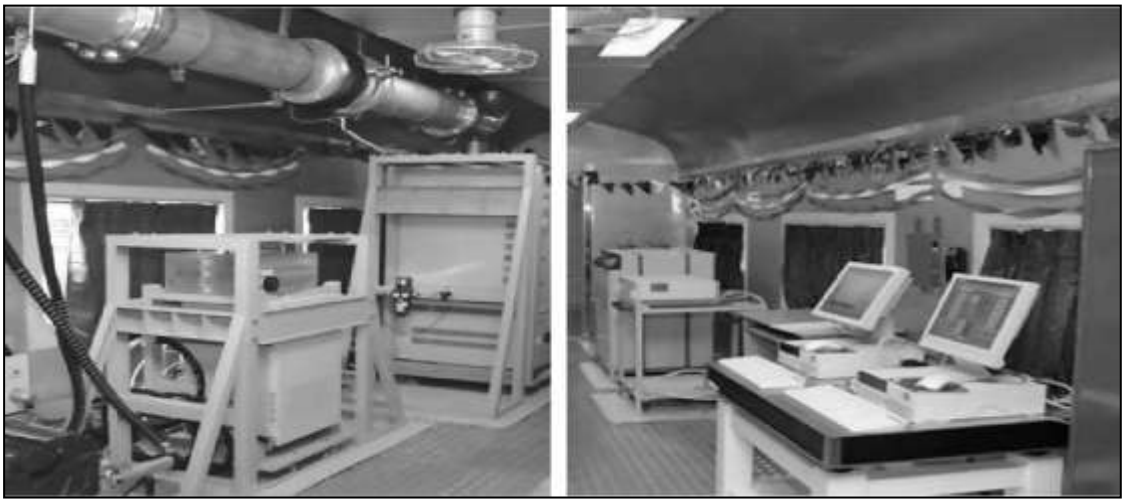

Figure 2: Internal view of MEMS room

Figure 3: Internal view of gas room

Figure 4: Internal view of DG set room

b. Technical Specification of Exhaust Emission Monitoring Equipments installed in Mobile Emission Test Car

S.N.	Equipment	Specification/Applicable ranges
1.	Carbon Oxides ($CO/CO_{2)}$ Analyzer Models: AIA-721A and AIA-722	These are module type analyzers installed in the analyzer rack (ANR) of MEXA-7100D. It uses Non Dispersive Infrared Detectors (NDIR) for measuring the concentration of Carbon Oxides (CO and CO_2). Range- CO(H)- 0-0.5 ~12 vol% CO_2 -0-0.5 ~ 20 vol% CO(L)- 0-50 ~ 5000 ppm
2.	Oxygen (O_2) Analyzer Model :MPA 720(MPD)	This is a module type analyzer which is installed in the analyzer rack (ANR) of MEXA-7100D.It measures the concentration of O_2 in exhaust gas using magneto-pneumatic method. Range-0-1 ~ 25 vol%
3.	Total Hydro Carbon (THC /CH4) analyzer models: FIA-725A and FIA -721HA	FIA -725 A and FIA-721 HA are installed in a separate type oven of MEXA 7100D.It measures the concentration of THC in exhaust gas by using Flame Ionization Detector (FID). Range- THC- 0-10 ~ 500, 1000 ~50000 ppmC THC/CH4- 0-50~2500,5000~25000 ppmC/ppm
4.	Oxides of Nitrogen (NOx) Analyzer model: CLA-755 A	CLA-755A is installed in a separate type oven of MEXA 7100D. It measures the concentration of NO and NOx in exhaust gas by using chemiluminescent method. Range-0-10 ~ 500, 1000 ~ 10000 ppm
5.	Soot Analyzer	Soot Analyzer is fitted in MEXA 1230PM and it measures soot by the diffusion charging method. Range- 0-15,75,150 mg/m^3 Dilution Ratio= 8/40/80
6.	SOF Analyzer	SOF Analyzer is fitted in MEXA 1230PM and it uses the dual FID method (two heated flame ionization detectors). SOF concentration is calculated as the difference between the signals from two FIDs, one FID using a sample line of 47^{o} C, and the other FID with a sample line of 191 ^{o} C. The equipment is used for R&D work and thus draws correlation with dilution tunnel and gravimetric method of measurement of Particulate Matter. Range- THC1- 0-10,20,50,100,200,500,1000,2000,5000, 10000 ppmC

		THC2- 0-10,20,50,100,200,500,1000,2000,5000, 10000 ppmC
7.	Celesco Smoke opacity meter	Celesco Smoke opacity meter is fitted in exhaust sampling line of Emission Test Car and its digital display is fitted in cabinet of MEXA 7100D. It measures the relative absorption of the smoke discharged from a diesel engine. Range- 0-100% Resolution- 0.1% Light Source- LED (green) Receiver- Silicon Photodiode
8.	Fuel Consumption Measurement Equipments	Diesel fuel consumption rate is measured on a mass basis using a mass flow meter. The fuel measuring system works on the principle of Coriolis measurement. Mass Flow Accuracy- ±0.05% of flow rate Repeatability- ±0.025% of flow rate Max Flow rate- 6800 Kg/h Min Flow rate- 5 Kg/h Pressure in Tube- 0-10 bar Burst Pressure- 377 bar
9.	Extension chimney piece for locomotive turbocharger exhaust	The extension chimney piece having a spout inside it is used for exhaust sample collection from turbocharger exhaust of locomotive. The internal diameter of this chimney piece is in the range of 27cm and spout diameter is 10cm, as used for Alco engine. The exhaust flow from the turbocharger chimney may vary from 2,000 kg/hr to 25,000 kg/hr from idle to 8^{th} notch in EMD and 1,500 kg/hr to 18,500 kg/hr in Alco. This extension piece is connected to the inlet of the sampling pipe with help of extension pipes.
10.	Extension pipes	Extension pipes are used for connecting extension chimney piece and inlet of exhaust sample line of Emission Test Car. Internal diameter of these pipes are in the range of 10 cm. Gaskets must be used at the joints between two extension pipes.
11.	Suction Blower	A suction blower, which has a capacity of 180 m^3/hour is used to suck exhaust emission and placed on the sampling pipe exhaust on the ETC roof connected at Gas room end.
12.	Oil free Scroll Compressor	An oil free scroll compressor is used which supplies oil free air supply to soot analyser for dilution and for purging of equipments.
13.	Tools	A kit containing the essential tools for connecting various components is to be provided.
14.	Heated transfer line	02 heated sample line, one for MEXA 7100D and another for MEXA 1230 PM is used.

6. Proposed Compliance Protocol:

A locomotive is supposed to comply to the emission standards for the whole of its useful life. Useful life can be defined based on total kilometers earned, MW-Hrs logged by the locomotive or time between overhaul/remanufacture. On Indian railway system, Railways has stipulated periodicity based on past experience and available data for maintenance of emission-critical power assembly components which include cylinder liners, pistons, piston rings, injectors, cylinder heads etc. Useful life of locomotives in India can therefore be defined as time-between-overhauls. For EMD locomotives, the typical useful life is 6 years and for ALCO locomotive family, the useful life is taken as 2 years. As per the standard freight duty-cycle to which a locomotive is subjected in use, a HHP diesel locomotive typically earns around 25000 MW-hrs while an ALCO locomotive earns around 8000 MW-hrs in its useful life.

Compliance program includes conformance to the emission standards at following stages (a) Certification (b) Production Line Test and (c) In-Use test. The certification test will conclude with the issue of certificate of conformance for a family of engine/locomotive. A family of engine/locomotive is defined as engines/locomotives having similarity in emission profile. The family includes engines / locomotives having similar emission-critical design configuration and performance parameters. Design configuration includes features like combustion chamber geometry, compression ratio, type of turbocharger, design of cylinder head, piston crown, valve placement, type of injector etc. Emission-critical engine parameters used to classify a engine/locomotive as a part of family include parameters like injection pressure, injection timing, engine speed (RPM) etc.

Diesel Locomotive fleet on Indian Railways comprises of EMD type HHP Diesel locomotives and ALCO Diesel locomotives. While HHP locomotive uses standard 2 stroke EMD 16-710 G3B engine, the ALCO design uses 4 stroke 16 cylinder ALCO engine equipped with 251+ power-train configuration. Both of these designs have been adopted from the standard EMD and ALCO loco architectures working on American railroads. A large population of diesel locomotives equipped with EMD 16-710G3B and ALCO engines have been in service on various railroads worldwide. Considering the vast experience gained by American railroads with these types of diesel locomotives over past many years and work done by them in the field of controlling and reducing exhaust emissions from diesel locomotives, it is considered prudent to define a compliance protocol based on the practice being followed by US railroads for Diesel locomotive exhaust emissions.

Compliance procedures would include:

(a) Certification
(b) Production Line Test (PLT)
(c) In-use Test

(a) **Certification**: Certification can also be done on the basis of test data from engine on the test bed provided that the critical emission sensitive parameters like load, speed, engine-in air temperature, engine-in coolant temperature etc. is similar to that of the engines working on the locomotives. However, in such cases the first five locomotives from production line needs to be revalidated to assure validity of certificate of conformance.

(b) **Production Line Test**: Annual compliance will be required. To avoid unnecessary excessive burden of locomotive testing, the testing will have to done on one percent sampling basis per engine family (each family of locomotive) per year. Testing will have to be spread across the year to assure that PLT simulates all possible ambient conditions which may affect the emission performance of the locomotives. For a family of engine/locomotive being manufactured in very small numbers (less than 100 engines/locomotives per year) , one locomotive will be subjected to production line testing per year. In case the results averaged over 3 test cycles fail to comply with the family emission limits (FEL) / limits specified in the emission standard for that family, two additional locomotives out of the next fifteen locomotives will have to be tested subject to a maximum of ten locomotives in a year.

(c) **In-use Testing** : The focus of in-use testing is to verify the emission levels from locomotives which are nearing the end of their useful life. A diesel locomotive having served for 75% to 100% of useful life will be a candidate for In-use emissions testing. This verification again is to be done annually. A minimum of two well maintained diesel locomotives per year per family ,after having served for 75% or more of its useful life , will be subjected to In-use testing for verification of emission performance towards the end of their useful life. For each failing locomotive, two more locomotives would be tested upto a maximum of ten locomotives in a year.

7. Interim Recommendations for Emission Standards for Locomotives:

Based on the analysis of limited emissions data available with Indian Railways duly considering the emission profile at the time of manufacture and subsequent deterioration in the emissions profile of the locomotives in-use towards the end of their useful life, following Interim standards for exhaust emissions from the two family of locomotives i.e. HHP (EMD) and ALCO type diesel locomotives operating on Indian Railways is being proposed as under:

Type of locomotives	Carbon monoxide (CO) (g/bhp-hr)	Oxides of Nitrogen (NO_x) (g/bhp-hr)	Hydrocarbon (HC) (g/bhp-hr)	Particulate matter (PM) (g/bhp-hr)
ALCo type	3.0	17.0	1.00	0.45
EMD (HHP Locos)	1.4	9.0	1.00	0.35

(*Note: The limits of pollutants indicated in the table above are weighted duty-cycle average of the exhaust emissions from HHP and ALCO locomotives*)

It is important to recognize here that there is significant uncertainty associated with the estimated locomotive emissions, especially given the inherent variability of limited amount of emissions data that is available on date with Indian Railways. Indian Railways therefore intends to refine the proposed emission standards in future as and when more emission data becomes available.

The interim standards specified above will be applicable through the useful life of all the locomotives which have been newly manufactured, re-manufactured and in-service life between major overhauls.
