ILLINOIS POLLUTION CONTROL BOARD
January 31, 1974

IN THE MATTER OF PROPOSED AMENDMENTS TO RULE 707 OF THE AIR REGULATIONS, DIESEL LOCOMOTIVE EMISSION STANDARDS	)	R72-3

OPINION AND ORDER OF THE BOARD (by Mr. Dumelle):

This Opinion and Order concerns the Amendments to Rule 707 of the Air Regulations adopted by the Board on January 31, 1974.

The matter before us was the proposed amendment of portions of Rule 707, Diesel Engine Emission Standards, of Part VII, Emission Standards and Limitations for Mobile Sources, of Chapter 2, Air Pollution Regulations. Rule 707 formerly read as follows:

Rule 707. Diesel Engine Emission Standards.

707(a) The visible emission standard in Rule 706 shall not apply to diesel engines.

707(b) Diesel engines manufactured before January 1, 1970, shall not be operated in such a manner as to emit smoke which is equal to or greater than 30% opacity except for individual smoke. Individual puffs of smoke shall not exceed 15 seconds in duration.

707(c)(1) Diesel engines shall be operated only on the specific fuels as specified in the engine manufacturers' specifications for that specific engine, or on fuels exceeding engine manufacturer's specifications.

707(c)(2) Persons liable for operating diesel engined fleets wholly within S.M.S.A. shall furnish to the Technical Secretary of the Illinois Air Pollution Control Board, once each year, proof that the fuel purchased and used in their operations conforms to Rule 707(c)(1).

707(d) All diesel engines operated on public highways in Illinois coming from out of the State shall conform to Rule 707(b).

707(e)(1) Diesel engines operated by any railroad in Illinois shall comply with Rule 707(b).

707(e)(2) Diesel engines operated by railroads shall not cause a nuisance or air pollution when being stored or on stand-by.

Chronology of Events

The amendments proposed concern limitations on emissions of smoke from diesel locomotives. A proposal was made originally by the Illinois Railroad Association (Association) to the Board on March 10, 1972 to amend the Rules and Regulations Governing the Control of Air Pollution, (old air regulations), and then reproposed September 5, 1972. The Association amendment repeals Rules 707(b), 707(e)(1), and 707(e)(2) and substitutes language included on their Exhibit A, shown below.

EXHIBIT A

Exhaust emissions from diesel-powered locomotives shall not exceed a density of thirty percent (30%) opacity except under the following conditions:

a. For a maximum of 60 consecutive seconds during acceleration and deceleration under load.

b. For a period of four consecutive minutes when a locomotive is loaded after a period of idle.

c. For a period of 30 consecutive minutes when starting a cold engine.

d. For periods of three consecutive and an aggregate of not more than ten minutes in any 60-minute period when a locomotive engine is being tested, adjusted, rebuilt, repaired, or broken in.

e. A malfunction of diesel equipment operating in interstate commerce which has been inspected and found to be in proper working order pursuant to existing federal regulations within the last 30 days.

At the first hearing, February 28, 1973 in Rock Island, the Association amended their proposal to make it more lenient, Amended Exhibit A, shown below.

AMENDED EXHIBIT "A"

Exhaust emissions from diesel-powered locomotives shall not exceed a density of forty percent (40%) opacity except under the following conditions:

a. For a maximum of 60 consecutive seconds during acceleration under load from a throttle position other than idle to a higher throttle position.

b. For a period of 4 consecutive minutes when a locomotive is loaded after a period of idle.

c. For a period of 30 consecutive minutes when starting a cold engine.

d. For periods of three consecutive and an aggregate of not more than ten minutes in any 60 minute period when a locomotive engine is being tested, adjusted, rebuilt, repaired or broken in.

e. For any diesel-powered locomotive which because of its age or design makes replacement parts unavailable.

The Illinois Environmental Protection Agency (Agency) then submitted its own proposed amendments, Proposed Amendment to Part VII of the Air Regulations, shown below, at the next hearing, March 16, 1973 in Chicago.

PROPOSED AMENDMENTS TO PART VII

EMISSION STANDARDS AND LIMITATIONS
FOR MOBILE SOURCES

Rule 702: Definitions

Diesel Fueled Locomotive - A diesel fueled vehicle designed to move cars on a railway.

Emission - The release into the atmosphere of contaminants.

Opacity - A condition which renders material partially or wholly impervious to transmittance of light, and causes obstruction of an observer's view. For the purposes of these regulations,

the following equivalence between opacity and Ringelmann shall be employed.

Opacity Percent	Ringelmann
10	0.5
20	1.0
30	1.5
40	2.0
60	3.0
80	4.0
100	5.0

Smoke - Small gas-borne particles resulting from incomplete combustion, consisting predominantly but not exclusively of carbon, ash and other combustible material, that form a visible plume in the air.

707(b) With the exception of Rule 707(e), diesel engines manufactured before January 1, 1970, shall not be operated in such a manner as to emit smoke which is equal to or greater than 30% opacity except for individual smoke puffs. Individual puffs of smoke shall not exceed 15 seconds in duration.

707(e) Visual Emission Standards and Limitations for Diesel Fueled Locomotives

(1) No person shall cause or allow the emission of smoke from any diesel fueled locomotive in the State of Illinois having an opacity greater than 30% for more than twenty (20) consecutive seconds.

(2) Rule 707(e)(1) shall not apply to:

A. Smoke which is caused solely by the presence of water condensate.

B. Emissions while the engine is being operated for testing incident to repair, break-in, and adjustment PROVIDED THAT:

(i) The diesel locomotive is not being tested within an enclosure such as a repair shop.

(ii) Any person who causes or allows the operation of a diesel fueled locomotive during a test period which would otherwise cause a violation of Rule 707(e) shall notify the Agency of the intended test. Thereafter, any such person shall comply with all reasonable directives of the Agency with respect to the intended test. In addition, any person subject to this Rule shall maintain such records and make such reports as may be required in procedures adopted by the Agency pursuant to Rule 107 of Part I of this Chapter and;

(iii) The granting of permission to operate during a test period shall be prima facie defense to an enforcement action alleging a violation of Rule 707(e).

Rule 709: Determination of Violation

Any violations of any provisions of Part VII of this Chapter shall be determined:

(1) by visual observation; or

(2) by the use of a calibrated smoke evaluation device approved by the Agency as qualified by Rule 106 of Part I of this Chapter; or

(3) by a test procedure employing an opacity measurement system as qualified by Rule 106 of Part I of this Chapter.

The remaining hearings, March 21, 1973, in Granite City, April 6, 1973 in Chicago, and April 16, 1973 in Chicago, were therefore held on the basis of considering both the Association Amended Exhibit A and the Agency Proposed Amendments to Part VII.

The following summary puts the various proposals into perspective.

Proposal	Basic Regulation	Exceptions
Original Regulation	smoke shall be less than 30% opacity	individual puffs not to exceed 15 seconds duration
Association Exhibit A	smoke shall not exceed 30% opacity	a) 60 second period during acceleration and deceleration b) 4 minute period following idle c) 30 minute period for cold start d) 3 minute period for testing and maintenance e) malfunction when engine had been inspected within past 30 days and found to conform with federal regulations

Association Amended Exhibit A	smoke shall not exceed 40% opacity	a)	60 second period durin acceleration
		b)	same as Exhibit A
		c)	same as Exhibit A
		d)	same as Exhibit A
		e)	locomotives for which replacement parts are not available
Agency Proposal	smoke shall not exceed 30% opacity	1)	puffs not to exceed 20 seconds duration
		2)	"smoke" composed solely of water vapor
		3)	locomotive testing provided certain conditions are followed

The issue therefore concerned both the steady state or basic level of visible emissions to be permitted plus the type and number of exceptions to the rule. Both the Association and the Agency agreed that some modification to the existing regulation was required, the Association claiming that the technology was not available (R. 3/21 p. 128) and the Agency saying that they could not support it (R. 3/21 p. 131). In both cases the proposals were more lenient than the existing regulation with the Association's proposal being the most lenient.

The Agency also proposed a new Rule 709, Determination of Violation, that would allow determination of emission level in terms of either opacity or Ringelmann number with or without the use of measuring devices or aids.

After reviewing the record the Board on December 6, 1973 ordered the publishing of the following as a Proposed Final Draft. Written comments on the Draft were invited until January 15, 1974.

Rule 702 Definitions

Add the following definitions:

Diesel Locomotive - A diesel engined vehicle designed to move cars on a railway.

Opacity - A condition which renders material partially or wholly impervious to transmittance of light, and causes obstruction of an observer's view.

Rule 707(b) - Revise as follows:
With the exception of Rule 707(e), diesel engines manufactured before January 1, 1970, shall not be operated in such a manner as to emit smoke which is equal to or greater than 30% opacity except for individual smoke puffs. Individual puffs of smoke shall not exceed 15 seconds in duration.

Rule 707(e)(1) and 707(e)(2) - Delete these rules and add new rules as follows:
707 (e)(1) No person shall cause or allow the emission of smoke from any diesel locomotive in the State of Illinois to exceed thirty percent (30%) opacity.

707(e)(2) Rule 707(e)(1) shall not apply to:
A. Smoke resulting from starting a cold locomotive; for a period of time not to exceed 30 minutes.
B. Smoke emitted while accelerating under load from a throttle setting other than idle to a higher throttle setting; for a period of time not to exceed 40 seconds
C. Smoke emitted upon locomotive loading following idle; for a period of time not to exceed 2 minutes.
D. Smoke emitted during locomotive testing, maintenance, adjustment, rebuilding, repairing or breaking in; for a period of time not to exceed 3 consecutive minutes and an aggregate of 10 minutes in any 60 minute period.
E. Smoke emitted by a locomotive which because of its age or design makes replacement or retrofit parts necessary to achieve smoke reduction unavailable. These locomotives shall be retired at the earliest possible time.

Comments were received from two citizens during the comment period. Neither the Association nor the Agency submitted additional material.

Diesel Locomotive Design

Before discussing the issues a review of diesel locomotive design is necessary. The locomotive units are more properly called diesel electric units since they are comprised of a diesel engine connected to an electrical generator which in turn provides power for the electric drive or traction motors. It is the diesel engine portion of the locomotive which emits the smoke and causes the visual pollution. These engines are large size, multicylinder diesels, having horsepower ratings in the range of 1000 to 3600. They operate without a spark plug; depending on the compression of the air in the cylinder to reach the ignition temperature. The fuel and air are provided to each cylinder by a fuel injection nozzle operating along with a turbocharger or Roots blower which forces air into the cylinder. Both 2 cycle and 4 cycle diesel

engines are used, the difference being that on 2 cycle engines, every revolution of the engine includes a power stroke, whereas with 4 cycle engines every other revolution includes a power stroke. The air compressors attached to the engines are directly connected to the engine crankshaft in the case of the Roots blowers, or driven by the exhaust gases in the case of the turbochargers.

Operationally, the locomotive is equipped with either a continuously variable speed control or one that has a finite number of possible settings (notches). Typically the settings include notches 1 through 8, notch 8 being the maximum power setting, plus idle and dynamic braking. The notch settings establish the amount of fuel that is supplied by the fuel injectors to the cylinders (R. 4/6 p. 88) and thus the speed and power output from the diesel engine.

Locomotives can be classified as either line haul engines or switch engines, with switch engines being smaller and often older units (R. 4/6 p. 38). Approximately 15% of the locomotives in Illinois are switch engines (R. 2/28 p. 20).

In terms of total numbers of locomotives, there are roughly 2087 units operating in Illinois on a given day (R. 2/28 p. 20), 324 of which would be the older model switch engines (ibid). In statistical terms it is estimated that about 15,400 locomotives could enter the state during the course of a year (R. 3/21 p. 19) and thus be governed by the Board regulations. At present there are only two manufacturers of locomotives in the United States, the Electromotive Divison (EMD) of General Motors, and the General Electric Corporation (GE) (R. 2/28 p. 15) and the relative numbers of locomotives manufactured are 78% EMD, 7.5% GE, and 14.5% others (R. 3/21 p. 16).

Operating Characteristics

The visible emissions from locomotives are caused by the operating characteristics of diesel engines and by poor maintenance. Much testimony was given as to the smoke producing operational characteristics and the need for exemptions based on the following characteristics:

a) Acceleration - The problem concerns turbocharger lag. The turbocharger is not directly connected to the diesel engine but is powered by the thermal energy in the exhaust gas. The amount of air charged into the cylinder and available for combustion depends on the work performed by the turbocharger which in turn depends on the energy in the exhaust as mentioned

previously. In accelerating the locomotive, the operator chooses a notch setting which immediately determines the amount of fuel supplied through the fuel injectors. The amount of air supplied however, depends on the output of the turbocharger, and time is required before the turbocharger speed increases to match the increase in engine speed. During this time the air supplied by the turbocharger is not sufficient in terms of the amount of fuel supplied. The mixture is therefore fuel rich so that incomplete combustion occurs, and smoke is emitted from the locomotive. In addition, there are periods during acceleration when electrical circuits are switched, causing a momentary unloading of the engine and puffs of smoke.

b) Idle - An idling locomotive does not maintain the high engine temperatures necessary for efficient (smokeless) combustion. Unburned combustibles including carbon (soot) tend to accumulate in the engine and exhaust manifolds. Then when the engine is accelerated, these contaminants are emitted as smoke until the cylinders clean out and operating temperatures are attained. The duration of smoking following idle depends primarily on the duration of idling and the ambient temperature.

c) Cold start - Cold start refers to starting a diesel locomotive following a period of non-running such that the temperature of the engine is essentially that of the ambient. As mentioned previously, the diesel depends on compression of the air in the cylinder by the piston to raise the temperature past the ignition point. When the engine is cold, much of the heat generated by this compression goes into the cylinder walls and head; resulting in a lower temperature during ignition and a lower combustion efficiency. In addition, the cold wall causes the flame to be quenched when it reaches the cylinder wall so that some of the fuel does not ignite. Therefore during the exhaust cycle, this unburned fuel is emitted as a whitish smoke. (R. 3/21 p. 166). The quantity of smoke decreases as the engine warms up to its operating temperature, and the time required for warm up depends primarily on the initial temperature of the engine.

The above operating characteristics are cited by the Association as requiring the first three exceptions listed in Amended Exhibit A. The other two exceptions in the Exhibit pertain to periods of maintenance and the lack of available parts.

Allowable opacity

The first issue to be decided is the opacity to be permitted for the visual emissions under steady state operation. The Association proposed an opacity not to exceed 40% (Amended Exhibit A) while the Agency proposed an opacity not to exceed 30% (EPA Ex 1); the existing regulation stated that the opacity shall be less than 30% (Air Regulations, Rule 707(b), 707(e)(1)). An

explanation of opacity is included later in this opinion. It is enough for now to know that opacity is a measure of the number density of particulates and droplets in the smoke. Opacity is given in terms of the percentage of incident light that is blocked by the smoke so that 30% opacity means 30% blockage or 70% transmission.

The Association witnesses presented somewhat conflicting testimony as to the necessity for a 40% opacity limit. Testimony was received from several witnesses that the railroads could not comply with the existing regulations, but could, in almost all cases meet the Association proposal (R. 2/28 p. 18; 75; R. 3/16 p. 43-44; 128-131). However, cross examination revealed that the main problem with the regulation had to do with the transient periods of operation where excess smoke is emitted for the reasons described previously. Dr. Burkhard of GE thought that a 30% opacity limit would be appropriate for GE engines in Illinois (R. 3/16 p. 88) and had previously suggested this figure, with exceptions, during hearings in Connecticut (R. 3/16 p. 51). Dr. Burkhard, however, felt that the Agency proposal, 30% opacity with exceptions of 20 seconds duration, could not be met by GE engines during acceleration, based on tests conducted at the Marion facility (R. 3/16 p. 60). Mr. Smith stated that "under steady state conditions a large percent of locomotives could meet the EPA proposal," and further, "I am referring to some of the older locomotives which would not be able to meet them." (R. 4/6, p. 33). Mr. Smith also discussed the combination of a 30% steady state opacity limit with exceptions:

Q. Then taking the railroads proposed amendment, would it be agreeable to you if everything was changed except the 40% was changed to 30% and the same exceptions listed, then do you think every railroad could meet a standard such as this?

A. Looking at the locomotive fleet that is on most railroads, and I am generally familiar with what other people have, we could not meet the standard, particularly with the older locomotives.

Q. The older are the ones with these five exceptions, if that exception was included, exempting the older locomotives, could the regulation be met, 30%

A. No, not at all times, no sir.

Q. What times wouldn't it be able to?

A. At higher attitudes and a change of loading... (R. 4/6, p. 34).

Mr. Adik spoke of the operation of suburban locomotives, that is, those used for hauling commuter trains. These locomotives also pull an auxiliary power unit to supply electricity and air conditioning to the passenger coaches. It is his opinion that the main locomotive used in suburban operations would be able to meet a 30% opacity limit on a steady state basis but that the auxiliary unit could not (R. 4/6 p. 92-95).

The Agency position on the 30% opacity limit is based on emission tests conducted by the Southwestern Research Institute (SWRI) on three locomotives (EPA Ex. 2). The tests of visual emissions, summarized by the Agency in EPA Exhibit 11, showed that over duty cycles consisting of idle, eight notch settings, and dynamic breaking, no steady state emission level exceeded 30% opacity and no transient period of excess smoke exceeded a duration of 20 seconds. Summary results of the SWRI tests are given in the following two tables.

TABLE 1 SUMMARY OF LOCOMOTIVE STEADY-STATE SMOKE DATA (Ref. Table 8 of EPA Ex. 2)

Condition	Average % Opacity EMD Switch Engine	Average % Opacity EMD Line Haul		Average % Opacity GE Line Haul	
		Transverse	Longitudinal	Transverse	Longitudinal
Idle	1.5	1.7	2.2	3.7	6.7
Dynamic Brake	---	2.0	3.8	4.0	8.2
N1	2.8	2.1	2.3	4.9	8.9
N2	3.2	4.5	5.2	14.8	28.0
N3	2.7	11.2	22.8	15.1	29.2
N4	2.0	11.1	22.0	12.1	25.8
N5	2.0	12.1	21.4	9.8	19.5
N6	1.9	9.1	18.4	6.4	13.0
N7	2.2	5.5	11.2	4.6	9.0
N8	2.8	6.4	10.0	4.8	9.2

Notes: N refers to notch setting.

For rectangular stacks transverse and longitudinal refe to the short and long dimensions respectively.

Idle values are averages of 24 data points, the remaini values are averages of 8 data points.

Table 2 LOCOMOTIVE EMISSIONS DURING ACCELERATION TRANSIENTS
(ref. Table 13 of EPA Ex 2)

Unit	Ratio of Peak Value to Final Value (1)	Peak Duration, Seconds (2)
EMD Switch Engine	10	5
EMD Line Haul Engine	10	4
GE Line Haul Engine	10	16

(1) Peak value essentially 100% opacity.
(2) Duration in excess of steady-state opacity.

In terms of applicability of the test data for the three locomotives, the Agency witness stated that the tests are the only hard data available concerning visual emissions, and that the EMD units tested are the only two series of engines produced at present by EMD. (R. 4/16 p. 93-94). In terms of recent maintenance, the EMD switch engine was overhauled in September 1971, the EMD line haul engine was overhauled in December 1968 and had maintenance performed January 1972, and the GE line haul had maintenance performed at the beginning of the tests (EPA Ex. 2 Appendix E).

In addition to the SWRI tests, the Agency presented information from EMD concerning their locomotive emission reduction program (EPA Ex. 9). This program involves developing low emission, including no visible emission, engine components and retrofitting them to the EMD units. The specific improvements being retrofitted and used in the new units include cylinder liners having larger intake ports for more efficient air intake, redesigned pistons (fire ring) that allow better exhausting, and improved (low sac) fuel injector nozzles that decrease the amount of unburned or partially burned fuel (EPA Ex. 9). The visible emissions resulting from EMD testing at their McCook, Illinois headquarters reveals the following existing and anticipated smoke emission data at full power for both the Roots blown and turbocharged locomotives.

1. Roots blown engines

	Year	Improvement	Visual Emission (Ringelmann No.)	Equivalent (1) Opacity (%)
	1971	-	1.5	19
	1972	large port cylinder liners	1.2	12
mid	1972	low sac injectors	0.8	10
	1973	fire ring pistons	0.3	4

2. Turbocharged engines

Year	Improvement	Visual Emission (Ringelmann No.)	Equivalent (1) Opacity (%)
1971	-	1.0	12
1972	large port cylinder liners	0.8	10
1972	low sac injectors	0.5	6
1975	fire ring pistons	0.3	4

Note: (1) Equivalent opacity derived from Ringelmann Number using the following relation reported by EMD in petitioner's exhibit 16.

Ringelmann	Equivalent Opacity
0	0%
1	12%
2	26%
3	37%

These improvements developed by EMD for their current production models can be retrofitted to earlier model engines built by EMD (R. 2/28 p. 91).

The conclusion we find from the previous evidence is that most of the engines on a steady state basis can meet an opacity limit of 30 percent, the exception being some older units manufactured by neither GE nor EMD used mainly for switching operations where in any case there is very little steady state operation (R. 3/16 p.34). We therefore require locomotives to meet the 30% opacity limit proposed by the Agency.

Exceptions to the Opacity Limit

Exceptions a)through c)in the Association proposal pertain to operating characteristics of diesel electric locomotives. The Association witnesses stated that these exceptions were necessary. However, documentation was sparse as to specific needs.

a) Cold starts- The exception requested for cold starts specifies a duration of 30 minutes, however, no data was presented documenting the need for 30 minutes. Dr. Burkhard knew of no correlation between the ambient temperature and the length of time for cold start, but was of the opinion that 30 minutes would be a fair estimate of the warm up period required at zero degrees ambient temperature (R. 3/16 p. 95-96). Mr. Williams discussed the problem of starting a cold engine and said that "in all likelihood if you're out in a zero ambient, it would not start at all." He further was of the opinion that a cold start exemption of 30 minutes would be necessary at ambient temperatures below 30 degrees (R. 2/28 p. 92-94). In discussing suburban type operations, Mr. Adik said that on a cold day, as much as 20 minutes would be required to bring the locomotive up to its operating condition (R. 4/6 p. 86).

The question is not strictly how much time is required to reach operating conditions but, rather, how long does it take following a cold start before excess smoking clears up. On this point the railroad witnesses were vague. The smoke emissions decrease from start as the engine warms up but after the 30 minute period the emission level is in question (R. 4/6 p. 127). The opacity could be greater than normal during the entire 30 minute period (R. 4/6 p. 41). The Agency did not attempt to rebut the cold start issue except through the cross examination of Association witnesses.

One important consideration concerning cold starts is the frequency of occurrence. A diesel engine is frequently left idling when not in use. The reason for this was explained by Mr. Kotnour (R. 3/16 p. 159-160) "Well, I think that there is more damage in shutting them down....the contraction and expansion is so great that we have leaking heads or leaking seals. And secondly, I have yet to see a diesel get cold, a locomotive get cold that you can start." Very often a locomotive will run continuously for a month (R. ibid); in addition, leaving the engine running keeps the batteries charged and the air brakes set (R. 2/28 p. 39-40). Testimony from the Burlington Northern was that they hardly ever shut down an engine except for maintenance (R. 3/16 p. 132).

The conclusion on cold starts therefore is that the situation infrequently occurs, especially during cold months, but that some allowance should be made for excess smoke when cold starts do occur. As far as the specific duration of time to be allowed, the Association testimony seems to support a duration of 30 minutes, a duration not successfully rebutted by the Agency, which we therefore adopt.

b) Acceleration - Another Association exception would allow 60 seconds of excess smoking when accelerating a locomotive except from idle. Mr. Smith testified that there are normally eight notches so that if the engine accelerates through the notches, with two or three seconds to stabilize the engine in each notch, then 16 to 24 seconds are required to reach speed on a notch by notch basis. He then stated that observations showed that 52 to 58 seconds were required before the smoke cleared (R. 2/28 p. 38-39). The difference between the 16 to 24 second figure and the 52 to 58 second range is however not clear from the record. Dr. Burkhard in testimony to other states suggested an exemption period of 40 seconds during acceleration for GE locomotives, rather than the 60 seconds proposed by the Association (R. 3/16 p. 39). He was uncertain about the period the turbocharger lags behind the engine but stated that GE is working on a retrofit device to change the turbocharger lag; and in addition the fuel governor so that the engine does not get excess fuel (R. 3/16 P. 69-71).

When accelerating a regularly loaded train out of a yard, the operator normally runs the engine at the maximum throttle, notch 8, until speed is reached and then backs off on the throttle (R. 3/16 p. 147). The emissions could be reduced by accelerating at a slower rate but the speed reduction required to reduce the emissions to 30% opacity is not known (R. 3/16 p.154). It was also felt to be impractical to reduce emissions during acceleration of a commuter train by gradually increasing the throttle from notch to notch rather than accelerating at maximum power (R. 4/6 p. 87-89).

The type of engine makes a difference during acceleration. All EMD turbocharged engines have mechanical linkages such that at low engine speed the turbocharger is directly connected to the engine. As the engine speeds up the turbocharger declutches and then runs off the engine exhaust (R. 4/16 p. 147). This tends to decrease the turbocharger lag during acceleration. In addition, Roots blown engines emit lower opacity smoke (during acceleration) than turbocharged engines because the lag between engine and compressor is reduced (R. 4/16 p. 142).

The SWRI test data for sequential operation showed that no periods of excess smoke during transients between notches exceeded 16 seconds and that emissions within a notch did not exceed 30% opacity. The duty cycle is shown in Table 3 to this opinion.

Table 3 LOCOMOTIVE EMISSSIONS TEST SEQUENCE
(ref. Table 1 of EPA ex. 2)

Mode	Notch or Condition	Mode	Notch or Condition	Mode	Notch or Condition
1	Idle	9	N7	17	N5
2	N1	10	N8	18	Dynamic Brake
3	N2	11	Idle	19	Idle
4	N3	12	Dynamic Brake	20	N4
5	N4	13	Idle	21	N3
6	Idle	14	N8	22	N2
7	N5	15	N7	23	N1
8	N6	16	N6	24	Idle

The record indicates that an excess smoking period of between 16 and 60 seconds duration can occur during acceleration. We find that a reasonable compromise is 40 seconds based on Dr. Burkhard's testimony and the SWRI testing.

c) Loading following locomotive idling - This proposed exception is necessary according to the railroads to allow the clearing from the cylinders of the material collected due to inefficient and incomplete combustion caused by the cooling of the engine during idle (R. 3/16 p. 40). The 4 minute duration specified in the exception is based on conducted tests according to Dr. Burkhard (R. ibid) but no data was produced. Mr. Smith testified that during switching operations, normally short periods of idle occur and so loading after idle would cause heavy smoke for around 5 to 10 seconds (R. 3/16 p. 215). Testimony concerning suburban operations, where locomotives normally pull under load following periods of idle, was that on very cold days it could take several minutes for the engines to reach reasonable operating temperatures (R. 4/6 p. 81-83), while on warm summer days little temperature decrease would occur during idle.

The Agency did not directly attempt to rebut this proposed exception. The inference is that the SWRI tests included idle periods in the duty cycle, Table 3 of this opinion, and as no transient periods of excess smoke emission exceeded 16 seconds, the Agency proposal of 20 second excursions was reasonable. The one basic problem with the SWRI tests, however, is that they were conducted in San Antonio, Texas in April 1972, a combination of place and time not representative of Illinois in the winter. In fact, according to Apendices A, B, and C of EPA exhibit 2,

the ambient temperatures were in the range of 70 to 100°F. so that during idle the engines probably did not cool off much. Our conclusions about the tests is that the data is applicable to steady state and acceleration conditions but not for cold start or loading following idle.

We therefore conclude, lacking more specific information, that exception (c) proposed by the Association for loading following idle should have a duration of two minutes.

d) Maintenance - Both the Association and Agency proposed that an exception be granted to locomotive emissions during repair, break in, and adjustment. The Association specifies time durations while the Agency would require notification and adherence with Agency directions prior to testing. The locomotives undergo periodic maintenance at minimum intervals of a month (petitioners ex. 4) but no evidence was given as to specific periods of excess smoking that occur during testing for maintenance. The exception presented is that contained in the statement of Dr. Burkhard to the State of Connecticut (EPA ex. 7) but was not supported with data by the Association. The Agency proposal seems unworkable to us because we cannot see them having the manpower to oversee and make suggestions before every locomotive undergoes maintenance testing.

We therefore adopt the Association's proposed exception for maintenance periods.

e) Lack of replacement parts - The issue here concerns the older locomotives used mainly in switch yards. Much testimony concerned the retrofitting of improved parts to achieve reductions in emissions. The locomotives today generally operate with lower emissions than those several years ago, lower emission levels being a by-product of improvements made in the efficiency of operation. In other words, improvements made to get lower fuel consumption by increased combustion efficiency have resulted in reductions in emissions (R. 4/6 p. 98). Owners of locomotives not manufactured by EMD or GE cannot get retrofitted parts since the manufacturers are no longer in business. In some cases there are no replacement parts either so that if the engine breaks down it cannot be repaired. Our order exempts those locomotives which are unable to retrofit to reduce their emissions. These locomotives are to be removed from service as soon as feasible. We do not intend that this exception protect smoky engines used instead of retrofitting other units or purchasing new units as necessary.

Enforcement

Much time was spent on a discussion of the enforcement of the regulation. The Association proposal is based on percent opacity while the Agency proposal bases the standard on opacity but would allow equivalent Ringelmann readings to be substituted.

The Ringelmann chart that has traditionally been equated to equivalent opacity is the following:

Ringelmann Number	Equivalent Opacity
0	0
1	20%
2	40%
3	60%
4	80%
5	100%

However, according to EMD the SWRI, through tests, has established the following equivalence between opacity and Ringelmann Number (petitioners ex. 16).

Ringelmann Number	Equivalent Opacity
0	0%
1	12%
2	26%
3	37%

This relationship according to Mr. Williams of EMD has been found to relate extremely well in the low end of the smoke scale (R. 4/16 p. 196). The Ringelmann chart was developed for varying shades of gray smoke. According to Dr. Chuan "a smoke which is completely black would have one set of correspondence between Ringelmann Scale and opacity while a white smoke would have a different set of correspondence." (R. 4/16 p. 27). Thus a locomotive engine which produces white smoke when the engine is cold due to unburned fuel droplets

and black smoke due to pyrolytic cracking of the fuel in fuel rich areas (R. 4/16 p. 75), could not be regulated based on a single equivalence between Ringelmann and opacity. In fact, the Agency would object to the use of Ringelmann alone since it would not allow enforcement of white smoke which emits from cold engines (R. 4/16 p. 95).

Opacity of a plume refers to the blocking of light transmission through the plume. In general the opacity is related to the number density and size distribution of particulates and liquid droplets in the plume. It is also related to the path length of the transmitted light, which is why the SWRI test results for rectangular stacks varied with the direction of measurement. The attractive features of opacity are the tie-in with emission density and the fact that opacity applies to emissions of all colors (R. 4/16 p. 118). Unfortunately opacity also results from the presence of water vapor which should be distinguished from that due to other materials (R. 4/6 p. 184-185).

The Agency would probably use the Ringelmann chart for black smoke or cases where there is a question concerning water vapor since the Ringelmann system neglects the presence of water vapor (R. 4/16 p. 97), and would use opacity for white smoke. It seems to us that the regulation should be based solely on opacity readings since they relate to quantity (actually density) of emissions. We recognize also that, except for cold engines, the presence of water vapor contributes little to opacity readings so that its effect is minimal.

A related issue concerning enforcement is the measuring device to be employed. The Association in their proposal did not specify a measuring device but during the hearings a railroad witness mentioned optical transmission meters as the best known means of measuring opacity (R. 4/16 p. 25). These instruments would have an accuracy of one percent and thus would minimize problems of enforceability (R. 4/16 p. 31). The problem with such an instrument is that for moving locomotives it would have to be mounted on the locomotive exhaust stack or else measurements could only be made on stationary locomotives (R. 4/16 p. 34). The only other possibility according to Dr. Chuan would be a lasar radar device which would allow remote measurements (R. 4/16 p. 36).

The Agency testimony was that certified smoke readers, that is, those that have attended and passed a course in smoke reading, are competent to judge the opacity of smoke. These observers are trained both on white smoke and black smoke to determine the opacity directly (R. 4/16 p. 179) without the use of aids such as a Ringelmann chart. The Ringelmann system was eliminated from the smoke school because both black and

white plumes were being observed (R. 4/16 p. 180). To pass the school the average error for 50 readings, 25 white plumes and 25 black plumes cannot exceed 7.5 percent with no single reading in error by more than 20 percent (R. 4/16 p. 177).

Our finding is that opacity measurements should be made preferably with an opacity meter but that visual observations by trained and certified smoke readers would be acceptable.

Specific Amendments

With the foregoing discussion in mind, the specific rule changes adopted by the Board can be summarized as follows:

Rule 702 Definitions

Definitions of diesel locomotive and opacity are necessary to set the regulations involving locomotives apart from other visual emission regulations.

Rule 707(b)

The language added separates regulations involving locomotives from regulations involving diesel engines.

Rule 707(e)(1)

This new rule sets the visual emission limit at 30% opacity for locomotives.

Rule 707(e)(2)

This new Rule establishes exceptions to Rule 707(e)(1) found necessary by the Board.

Rule 709 Determination of Violation

This rule specifies measurement either by trained observer or opacity measuring device. The rule is not intended to include the traditional Ringelmann charts due to the uncertainty in the record of the relation between Ringelmann number and percent opacity for various colors of smoke.

ORDER OF THE BOARD

The Pollution Control Board, after examining the Association's and Agency's proposed amendments, the transcripts of the five hearings, and comments submitted on the Proposed Final Draft, finds that an amendment to Emissions Standards and Limitations for Mobile Sources, Chapter 2, Part VII, Air Pollution Regulations is warranted. Therefore, the Board orders the following amendments to Chapter 2, Part VII. (Underlining indicates the amendments.)

Rule 702 Definitions
Add the following definitions:
Diesel Locomotive - A diesel engined vehicle designed to move cars on a railway.

Opacity - A condition which renders material partially or wholly impervious to the transmittance of light, and causes the obstruction of an observer's view.

Rule 707(b) - Revise as follows:
With the exception of Rule 707(e), diesel engines manufactured before January 1, 1970, shall not be operated in such a manner as to emit smoke which is equal to or greater than 30% opacity except for individual smoke puffs. Individual puffs of smoke shall not exceed 15 seconds in duration.

Rule 707(e)(1) and 707(e)(2) - Delete these rules and add new rules as follows:
707(e)(1) No person shall cause or allow the emission of smoke from any diesel locomotive in the State of Illinois to exceed thirty percent (30%) opacity.

707(e)(2) Rule 707(e)(1) shall not apply to:

A. Smoke resulting from starting a cold locomotive; for a period of time not to exceed 30 minutes.

B. Smoke emitted while accelerating under load from a throttle setting other than idle to a higher throttle setting; for a period of time not to exceed 40 seconds.

C. Smoke emitted upon locomotive loading following idle; for a period of time not to exceed 2 minutes.

D. Smoke emitted during locomotive testing, maintenance, adjustment, rebuilding, repairing or breaking in; for a period of time not to exceed 3 consecutive minutes and an aggregate of 10 minutes in any 60 minute period.

E. Smoke emitted by a locomotive which because of its age or design makes replacement or retrofit parts necessary to achieve smoke reduction unavailable. These locomotives shall be retired at the earliest possible time.

I, Christan L. Moffett, Clerk of the Illinois Pollution Control Board, hereby certify the above Opinion and Order were adopted on the 31st day of January, 1974 by a vote of 5-0.

Christan L. Moffett

Christan L. Moffett, Clerk
Illinois Pollution Control Board