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Project Summary

Porous Dike Intake Evaluation

Barry A. Ketschke and Richard C. Toner

A small-scale porous dike test facility was constructed and continuously operated for 2 years under field conditions. Two stone dikes of gabion construction were tested: one consisted of 7.5 cm stones; and the other, 20 cm stones. Approach velocity was set at 3 cm/sec. Using a test flume, laboratory studies were also conducted on the avoidance response of fish to a porous dike intake.

Flow through a porous dike, induced by a hydraulic head of about 61 cm, depended on the cross-sectional area (tidal height). Throughout the experiment, flow resistance changed, depending on the fouling. Increases in flow resistance resulted in lower flow rates at constant hydraulic head. Flow rates could be increased by backflushing the stone dike. Throughout the experiment, the porous dike showed a steady accumulation of silt and organic matter, but the flow rates tended not to decrease with time.

Analysis of field and laboratory data showed that the number of zooplankton is reduced passing through a porous dike by a combination of physical filtration and cropping. No zooplankton avoidance was substantiated. Analysis also indicated that the number of passively drifting larval fish is reduced passing through a porous dike by filtration or cropping. No conclusive field evidence was obtained to explain if actively swimming larval fish avoid passing through the dike; however, limited laboratory results suggest avoidance may occur. Results with juvenile and adult fish show that they avoid passing through a porous dike.

This Project Summary was developed by EPA's Air and Energy Engineering Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Several industries, particularly the steam-electric industry, have large requirements for cooling water. All cooling water systems, whether they recirculate the water (as in cooling towers) or not (as in once-through cooling systems), must have an intake system. These intake systems direct water, including the *aquatic organisms contained in the water*, into the industrial facility. The combination of screening, heat, mechanical action and, in some cases, chemicals added to the cooling water, can result in mortality to aquatic organisms.

The Federal Clean Water Act Amendments of 1972 ultimately require that all cooling water intakes be equipped with the *best technology available* to minimize the environmental impacts on aquatic organisms. After the Clean Water Act became law, the USEPA and the industrial users of cooling water began to examine and experiment with cooling water intake designs.

One method considered feasible was a rock (or porous) dike. Conceptually, the porous dike would be similar to a stone breakwater and surround the intake. All cooling water would then flow through the rock dike. By selecting a very low approach velocity, about 3 cm/sec (0.1 ft/sec), and relatively small stones, 7.5 cm (3 in.) to 20 cm (8 in.), it was theorized that the system could act as a physical barrier for large mobile aquatic organisms (e.g., fish) and as a behavioral barrier for small weak swimming aquatic forms (e.g., larval fish and microscopic animal plankton).

For a porous dike system to be considered a feasible intake, it was necessary to establish that it was in fact a barrier to aquatic organisms and that the system would maintain porosity and not clog.

The research covered in this report was designed to examine these two questions. Specifically, the research was designed to examine the ability of a porous dike to keep zooplankton, larval fish, juvenile fish, and adult fish out of industrial cooling water systems. A second objective was to examine the hydraulic characteristics and clogging rates of a porous dike.

Materials and Methods

General Procedures

All hydraulics, fouling, and field screening performance testing was conducted at a small-scale porous dike test facility, at Brayton Point Station, Somerset, MA.

The porous dike test facility (Figure 1) was a reinforced concrete and steel structure 6.4 m wide, 18.3 m long, and 6.1 m deep. The chamber was a concrete box, open at the top and front and divided into three cells by wooden timbers. Each cell was 1.8 m wide. A single axial flow pump in the back (downstream) end of the box drew water through the structure. At the front (upstream) end of the box, gabions were placed in the first and third cells. One cell had gabions filled with 7.5 cm stone, and the other had gabions filled with 20 cm stone. Each gabion was 1.8 m wide, 0.9 m high, and 0.9 m deep. They were placed on top of each other to form a wall approximately 4.3 m high. In the 20 cm test section, three rows of gabions made a 2.7 m thick section. In the 7.5 cm test section, two rows made a 1.8 m thick section. The center cell was sealed and not used. Flow was regulated by flow-control baffles. Approach velocities were initially set at about 3 cm/sec (0.1 ft/sec). The test facility went into full operation on July 16, 1979.

Hydraulic Performance

Hydraulic characteristics were measured by recording over the 2 years of operation the frictional losses through the stones or head loss (h) and the volumetric flow (Q) through the stones. Additionally, special hydraulic studies were conducted to address the efficiency of back-flushing and the relationship between increased head and volumetric flow.

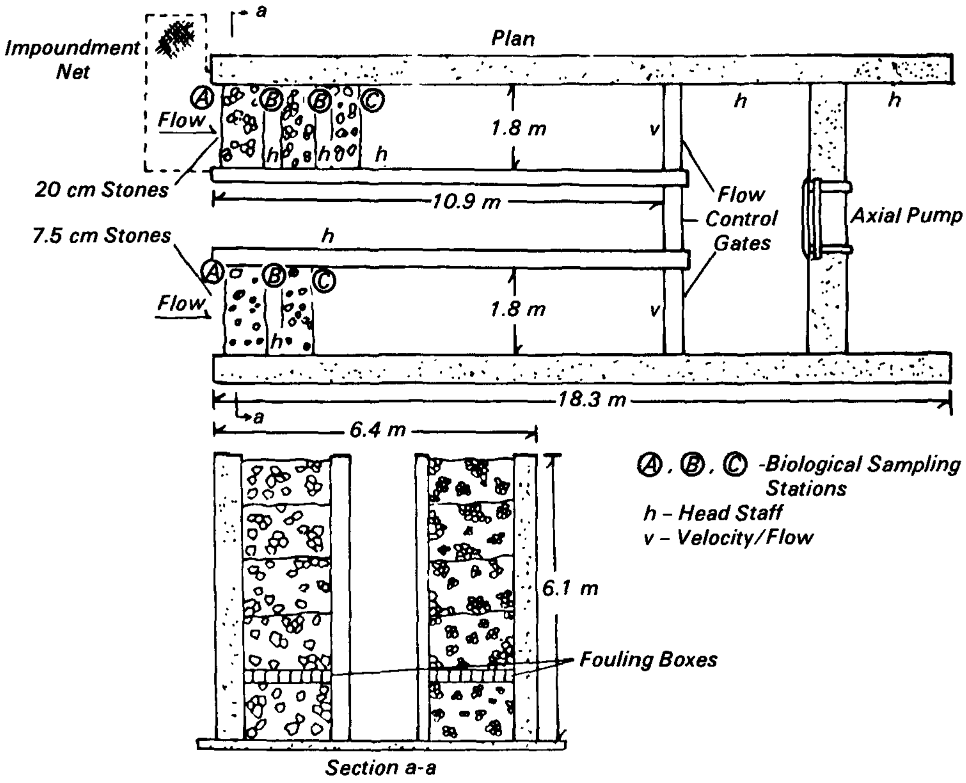

Figure 1. *Porous dike test facility.*

Head loss was measured by recording the water level at positions upstream of the gabions, downstream of the gabions, downstream of the flow control baffle, and downstream of the pump (Figure 1). Additionally, some measurements of h were made in the gabion slots.

Water level was measured with 4.6 m (15 ft) measuring staffs which were fixed to the walls of the test facility. In the gabion slots, water level was measured using a float and graduated rod. Head loss through the stones was calculated as the difference between the upstream water level and the downstream water level for each test station.

Volumetric flow was measured by recording the velocity of water passing under the known area of the flow control baffle gate. Velocity under the flow control baffle gate was measured in each test section at six fixed locations using a portable current meter. The current meter was fixed to a 6.1 m (20 ft) pole equipped with a mounting bracket which fit into a slot on the baffle gate. This setup ensured that measurements were made at the same depth and location on each survey.

Two backflush studies were conducted—in May 1981 and in July 1981. In both studies, the methodology was the same. At time zero, the flow volume and corresponding head loss values were measured throughout a tidal cycle. These flows and heads represented the initial or baseline values. After initial flows were measured, the upstream face of the 20 cm stone section was cleaned using a diver-operated pump. The speed of the gasoline-engine-powered pump was adjusted to yield a suction which penetrated no more than 5 cm (2 in.) into the dike. After this face cleaning, flow volumes and head readings were taken for comparison to the initial Q and h readings.

This face cleaning was designed to determine if the increased flow resistance was due to a surface fouling film. After the flow and head readings were taken, following the face cleaning, backflushing was initiated. Backflushing was achieved by turning the axial flow pump off. The facility was allowed to backflush for varying periods, up to 216 hours (cumulative). After each backflush, the pump was operated briefly, and the h and Q readings recorded.

The relationship between increased head differential and flow volume was examined by augmenting the flow rate of the axial flow pump with three gasoline-engine-powered pumps. Pumps were added in sequence to increase the head differential and the resultant flow measured.

Fouling Rate

The fouling rate was measured by the change in weight and void space of the gabions. The changes in gabion weight and void space were measured with fouling boxes, small removable sections of the gabions. Fouling boxes were 22 cm x 22 cm x 59 cm stainless steel boxes open at each end and filled with 7.5 cm or 20 cm stones. These boxes were in drawers between the bottom and next-to-bottom gabions on the upstream and downstream face of each test section at start-up. Prior to installation, the weight and displacement volume of each box was measured and recorded. Every 3 months, one box from the upstream face of each test section was removed and the weight and displacement volume measured and recorded. After each fouling box was removed, all biofouling was identified and measured. All non-living detrital material was collected and weighed.

Laboratory Screening Performance Tests

Laboratory screening tests for zooplankton, larval fish, and juvenile and adult fish were conducted in a T-shaped flume (Figure 2). Dimensions of the long arm of the T were 3.0 m x 0.5 m x 0.5 m. The short arm measured 2.4 m x 0.5 m x 0.5 m. Valves, between a 10 hp (7.46 kW) pump and the flume, controlled both current velocity and direction of flow. Velocity could be maintained between 0.5 and about 30 cm/sec (0.02 to 1 ft/sec). The flume was directly connected with fish holding facilities and a mechanical and biological filter system which permitted test animals to acclimate in the same water used in flume experiments. Light level and water temperature were also controlled.

Laboratory Zooplankton Screening Tests. Zooplankton tests were run in the flume with valve openings set to yield an equal volume of water flowing down each arm toward locations B and C (Figure 2). Under this arrangement, water flowed down the short arm (from location A): at the intersection, half the water flowed down the long arm; and the other half, down the short arm.

Live zooplankton of known species composition and number were placed in the flume at location A. Under test conditions, a small rock dike 51 cm thick made of 20 cm stones was placed in the long arm at the intersection. Under control conditions, the stones were removed.

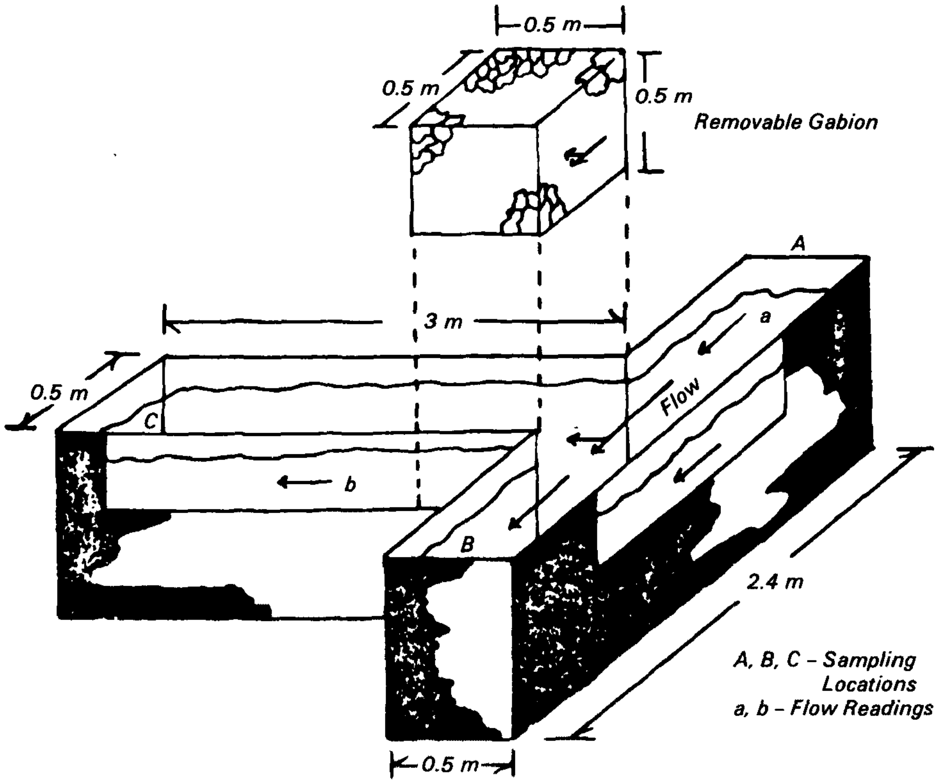

Figure 2. *Laboratory test flume.*

The zooplankton introduced into the short arm at location A were captured downstream of the intersection in both the long (C) and short (B) arms. Current velocity was maintained at 3 cm/sec.

All preserved samples were analyzed by microscope as to type and number of species present. All density data were converted to the ratio of the number captured over the number introduced before gabion and after gabion. These ratios were used in a paired t-test to determine whether any differences exist between the control and experimental conditions.

Laboratory Fish Screening Tests. Experiments designed to assess the porous dike concept were conducted with the T-shaped flume (Figure 2). A small rock dike, 51 cm thick and made of 20 cm stones, was constructed where the long arm of the flume joined the short arm. The rocks were carefully packed between stainless steel racks or gabion so that channels through which water could flow unimpeded did not exist along the sides or bottom of the flume. Rock panels affixed to the walls alongside the gabion gave the appearance of a continuous rock wall along the back of the forward chamber. In certain experiments, rocks, similar to those in the dike, were widely scattered on the bottom. In others, 10 to 15 mm gravel was spread in a single layer on the bottom. Water current was directed from A to B (Figure 2) across the face of the rock. Approximately half the volume passed in front of the stone dike, and the other half passed through the dike.

To ensure that the behavior of test animals was not influenced by an observer, a viewing screen was constructed around the face of the short arm.

Current velocity was generally maintained at 2, 3, or 6 cm/sec (0.07, 0.1 or 0.2 ft/sec) measured at 1 m downstream of the rock dike. Velocities under 3 cm/sec were measured by timing the movement of dye or a neutrally buoyant, water-filled table tennis ball since both flowmeters were insensitive to such low velocities.

Light was generally maintained at 65 lux provided by 4 incandescent lights mounted above the small arm of the flume. Two additional incandescent lights provided about 45 lux above the long arm. A rheostat was used to reduce light levels; for 24-hour studies, a timer incorporating a twilight period was used.

Since water temperature in the flume continually increased, due to friction between the water and flume surfaces as well as pump work, temperatures were maintained within 2.5°C of the initial acclimation temperature by exchange with cooler, ambient seawater or exchange between the flume and a separate insulated reservoir containing two cooling units.

The basic experimental procedure consisted of introducing small fish or larvae into the short arm of the T at location A and recording their behavior for periods of from 30 minutes to several hours. Before release, each sample of fish was acclimated in the current for 20-30 minutes in either a screened 8-liter pail or screened 1-liter beaker with removable bottom.

An additional study was conducted to observe the filtering capacity of the stone in the porous dike test facility. A fouling box containing 20 cm stone was removed from the test facility at Brayton Point, transferred to the flume, and placed at the intersection. The leading edge of the box was fitted into a wooden panel cut to fit the exact dimensions of the box mouth so that all water flowing down the long arm of the flume passed through the box. A small 0.33 mm mesh net with cod end was tied to the back edge of the box to catch all material passing through it. Flow rate through the box was set at 3 cm/sec.

Samples of preserved larval winter flounder and labrid eggs were released at the face of the box while the flume was operating. Flow was maintained for 7 minutes at which time the flume pump was shut off, the net removed and washed down, and the sample preserved until counted.

Field Screening Performance Tests

All field screening tests for zooplankton and larval, juvenile, and adult fish were conducted at the porous dike field test facility (Figure 1).

Field Zooplankton Screening Tests. Zooplankton field studies were conducted on 90 days between July 1979 and July 1981.

Evaluation of the effectiveness of a dike in reducing zooplankton entrainment was based on comparisons of the population density at locations upstream and downstream of, and within the dike. Sequential sampling was carried out during daylight at locations A, B, and C for both the 7.5 and 20 cm rock channels (7.5 A, 7.5 B, 7.5 C, 20 A, 20 B, and 20 C—see Figure 1) eight times each sampling day. Collections at each pair of locations (7.5 A—20 A, etc.) were made simultaneously using identical gear for both channels. Each sample was taken by pumping 500 liters of water through No. 30 (59 μm) mesh nets using gasoline-engine-powered pumps. To ensure that all of the water column was sampled, one-third of each sample was pumped from the bottom third of the water column, from mid-depth, and from the top third of the water column, and eight samples from each sampling location in each channel were combined into a single composite sample which represented the zooplankton population for that location. During the first year, sampling was conducted weekly, with 48-hour diel sampling once a month. During the second year, sampling was reduced to biweekly, with a 24-hour diel sampling once a month.

In the laboratory, each sample was reduced in volume to a concentration of 300-500 organisms/ml, and three 1 ml aliquots were removed and analyzed as to type and number of each organism present. To facilitate analysis, volumes were kept under 1,000 ml. If necessary, samples were split with a plankton splitter.

Data were analyzed for density differences.

Field Larval Fish Screening Tests. Ichthyoplankton densities on the upstream and downstream sides of the porous dike were sampled between August 1979 and July 1981 during March, April, May, June, July and August—when ichthyoplankton were most abundant.

Ichthyoplankton samples were taken with a gas-driven trash pump using 10 cm intake and discharge hoses and a 0.33 mm mesh plankton net. To improve the condition of ichthyoplankton, the last 2.4 m of discharge hose was increased to 15 cm diameter and the net was submerged. Pumping duration per sample ranged from 15 to 30 minutes depending on the abundance of ichthyoplankton in the samples. During each pumping period, the intake hose was moved at set intervals so that surface, mid-depth, and near-bottom were sampled equally.

Pumping volume was determined by recording the time necessary to fill a 757-liter box suspended in the same position as the sampling net. A tachometer, accurate to within ±2%, was used with the pump to ensure operational accuracy between sampling and calibration.

In 1979 and 1980, sampling was conducted 2 days per week, 1 day in the 7.5 cm channel, and 1 day in the 20 cm channel. In July and August 1980, sampling frequency was increased to 3 days per week to compensate to some extent for time lost when the facility was shut down for repair. In 1981, sampling was again conducted 2 days per week with 1 (March—mid-June) or 2 (mid-June—July) night sampling periods, in addition to the day periods.

On each sampling day, samples were taken at locations A and C (Figure 1). Generally 4 to 10 sets of samples were taken each day, depending on pumping duration. Although the original sampling design included collecting within the slots between gabions (B positions in Figure 1), a problem developed when the weight of stone caused the gabions to bulge into the slots. In the 20 cm stone channel, the slots were so narrow that the 10 cm hose could not be lowered into the water. Initially, sampling was possible at position B of the 7.5 channel, but only near high tide because the hose could not always be fitted far enough into the slot to reach water level. Beginning in May 1980, an additional intake hose was obtained for the B position of the 7.5 cm channel. This hose was worked into the slot and left in place so that the samples could be taken regularly at that position. Because the hose could not be raised or lowered in the slot, sampling was restricted to one depth—about 1.2 m above the bottom.

All samples were preserved in 10% Formalin and returned to the laboratory for microscopic analysis. Fish eggs and larvae were identified to the lowest distinguishable taxonomic category and counted.

Data were analyzed for density differences.

Field Fish Screening Tests. Field finfish experiments were conducted at the porous dike between September 1979 and July 1981, using the impoundment enclosures shown in Figure 1. The enclosures were constructed at 4.7 mm nylon mesh including a complete bottom, but were open where they joined the dike. Each enclosure was 4.3 m high. The mouth of each enclosure was held open by a metal frame which fit tightly within U-shaped slots in front of each channel. The offshore section of each net was held in place by a system of haul lines and anchor poles. The head ropes were fitted with floats and were pulled tight to keep them above high water.

Fish to be tested were collected by beach seine, otter trawl, lift net, or on the revolving screens at Brayton Point Power Station. Typically, the nets were set, a known number of test fish were released in each enclosure, and the system was left undisturbed for a period of time ranging generally from 24 to 72 hours. At the end of the test period, the nets were hauled, mouth first, and the fish remaining inside were counted and measured.

Fish were selected by size such that they were too large to escape through the enclosure meshes and yet small enough to enter the spaces between rocks of the dike if they chose to do so. During the winter months, tests were run whenever fish were available and weather permitted.

Since early in the study, it was not possible to determine whether missing fish had escaped or entered the stones. Therefore, a method of seining the downstream section of each channel was developed in July and August 1980. All fish introduced to the impoundments from that point on were finclipped so they could be easily identified if subsequently collected in the downstream channels.

The seine measured 3 m x 3 m, was constructed of 4.7 mm delta mesh, and was lashed along the vertical edges to two 3 m long wooden poles. The bottom edge of the seine was weighted with chain; the bottom of each pole was weighted with lead. To assist in hauling the seine over the length of the channel, haul lines were fixed to the top and bottom of each pole. To confine fish in the channels during seining, 4.7 mm mesh screens were constructed to slide down in slots fixed to the channel walls in front of the openings under the baffle gates. Generally, three seine passes were made whenever an impoundment test was conducted.

Conclusions

The results of studies of the hydraulic characteristics of flow through a rock dike demonstrated that a low flow velocity of 3 cm/sec can be induced and maintained by a relatively low hydraulic head of approximately 61 cm. Increasing hydraulic head and cross-sectional area result in increased volumetric flow through the stones. In tidal water, the decrease in flow due to decreasing depth is greater than would be predicted based on the reduction cross-sectional area, indicating higher flow resistance in the lower stone sections.

Flow volume induced by a relatively constant head varied throughout the experiment. Some seasonal trends were evident with lowest flows occurring during the warmest months. Flow volume increased both seasonally and in response to backflushing. Flow volume could be maintained by backflushing.

The major resistance to flow was in the upstream 0.9 m of dike. Organic matter and debris continued to accumulate within the stones through the 2-year experiment. About 70% of the fouling material was detritus, including organic debris. Variations in flow appeared to be corelated more to seasonal surface fouling, particularly hydroids and shelled forms, than to the accumulation of material within the stones. About 5 yd^3 (0.382 m^3) of silt and debris accumulated downsteam of the dike over the 2-year test period.

There was no difference in the hydraulic performance between the two stone sizes tested (7.5 cm and 20 cm). The fouling organisms in the two stone dikes showed some differences: the 20 cm stone diking had more larger shelled organisms, and the 7.5 cm dike had more small attached organisms.

The number of zooplankton per volume of water was reduced by passing through a porous dike. The amount of reduction was less during the colder months. The reduction was attributed to physical filtration and predation by the fouling community. No evidence, either in the field or the laboratory, could substantiate a zooplankton avoidance response.

The numbers of fish eggs and larvae per volume of water were reduced, in most cases, passing through the porous dike. The reduction in the density of passively drifting fish eggs was attributed to physical filtration and perhaps predation by the fouling organisms within the stones. The reduction in the number of passively drifting larvae such as winter flounder (*Pseudopleuronectes americanus*) was attributed to physical filtration and perhaps cropping. Winter flounder were shown to exhibit no directional swimming ability or avoidance response in laboratory test flume experiments; the reduction in density observed in the field was, therefore, attributed to filtration or predation. No conclusive evidence was obtained in the field to establish whether or not density differences for actively swimming larvae were due to avoidance or filtration/predation. Laboratory tests did show that some species of larvae exhibit a directional swimming ability and avoidance response.

Results of both laboratory and field tests have demonstrated that the porous dike is an effective barrier to juvenile and adult fish.

Recommendations

The role of filtration, predation, and avoidance in reducing the density of larval fish needs to be investigated further. This investigation could include an evaluation of the effect of flow path length on filtration capacity.

A larger scale test of a porous dike intake is also needed, to address the specific hydraulic design parameter needed for widespread commercial application. These studies could examine various structural designs that would capitalize on the localized fouling and backflushing potential.

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B. Ketschke is with New England Electric System, Westboro, MA; R. Toner is with Marine Research, Inc., Falmouth, MA.
Julian W. Jones *is the EPA Project Officer (see below).*
The complete report, entitled "Porous Dike Intake Evaluation," (Order No. PB 85-185 908/AS; Cost: $14.50, subject to change) will be available only from:
National Technical Information Service
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