BARC/2009/E/015

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GOVERNMENT OF INDIA
ATOMIC ENERGY COMMISSION

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BHABHA ATOMIC RESEARCH CENTRE
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2009

BIBLIOGRAPHIC DESCRIPTION SHEET FOR TECHNICAL REPORT
(as per IS : 9400 - 1980)

01	*Security classification :*	Unclassified
02	*Distribution :*	External
03	*Report status :*	New
04	*Series :*	BARC External
05	*Report type :*	Technical Report
06	*Report No. :*	BARC/2009/E/015
07	*Part No. or Volume No. :*	
08	*Contract No. :*	
10	*Title and subtitle :*	A report on the aquatic dilution experiment carried out at discharge canal, KGS site
11	*Collation :*	19 p., 4 figs., 5 tabs., 1 ill.
13	*Project No. :*	
20	*Personal author(s) :*	1) T.K. Reji; P.D. Nayak; J. Sudhakar; T.L. Ajith; M.S. Vishnu; P.M. Ravi; J.P. James; R.M. Joshi; S.B. Naik; A.M. Kudtharkar; S.M. Gaonkar 2) P.C. Verma, D. Datta; Sudhir Dahiya; Brijkumar; Maduparna Datta 3) G. Sajeevan
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22	Corporate author(s) :	Bhabha Atomic Research Centre, Mumbai-400 085
23	*Originating unit :*	Health Physics Division, BARC, Mumbai
24	*Sponsor(s) Name :*	Department of Atomic Energy
	Type :	Government

Contd...

30	*Date of submission :*	June 2009
31	*Publication/Issue date :*	July 2009
40	*Publisher/Distributor :*	Associate Director, Knowledge Management Group and Head, Scientific Information Resource Division, Bhabha Atomic Research Centre, Mumbai
42	*Form of distribution :*	Hard copy
50	*Language of text :*	English
51	*Language of summary :*	English, Hindi
52	*No. of references :*	3 refs.
53	*Gives data on :*	
60	*Abstract :* Under Nuclear Power Corporation of India Limited (NPCIL), three units of (each of capacity 220MWe) Nuclear Power Stations are operational and one unit of similar capacity is under advanced stage of construction at Kaiga site. The radioactive liquid effluents generated in the plant are diluted with Condenser Coolant Water Stream (CCW) which is then discharged into Kadra reservoir through an artificially made discharge canal. The basic objective of the present study is to estimate the Dilution Factors at various locations of discharge canal and to understand the process of dilution and dispersion of radioactive effluent in the discharge canal. The strategy of the experiment involved the collection of samples from discharge canal lengthwise, breadth wise and depth wise immediately after the routine release of one of the batches of effluent stream into the CCW stream. No additional activity was released for the purpose of this experiment. The study compared the experimentally obtained Dilution Factor with that calculated based on the flow rates of CCW pumps and active liquid effluent discharge pumps. In the present conditions of experiment, Dilution Factor, based on flow rates of CCW pumps and Liquid Effluent Discharge pump, works out to be 8.11 E -05 while experimentally observed Mean Dilution Factor in the discharge canal works out to be (7.75±2.15) E-05. Hence this experiment clearly demonstrate the validity of the method of calculating dilution factor based on the flow rates of CCW line and that of Effluent discharge pump. The data analysis indicates that mass flow seems to be the major process of dispersion in the discharge canal. The tritium activity was found to be moving faster in the midstream as compared to that near the shore. The conclusions are drawn purely based on experimental results. This experimental data can be used for validation of aquatic dispersion models.	
70	*Keywords/Descriptors :* KAIGA-1 REACTOR; KAIGA-2 REACTOR; KAIGA-3 REACTOR; KAIGA-4 REACTOR; LIQUID WASTES; DISCHARGE CANALS; CONDENSER COOLING SYSTEMS; FLOW RATE	
71	*INIS Subject Category :*	S21
99	*Supplementary elements :*	

सारांश

न्यूक्लियर पॉवर ॉरपोरेशन ऑफ इंडिया लिमिटेड (एनपीसीआईएल) े अंत ीत नाभि ीय बिजली घरों ी तीन इ ाइयाँ (प्रत्ये ी ामता 200 Mwe) प्रचालनरत हैं और समान ामता वाली ए इ ाई ा निर्मा ा ै ाा साइट पर प्र ात अवस्था में है। संयत्र में निर्मित रेडियोसि ्य द्रव बहि:स्राव ो संघनित्र शीतल जल धारा (सीसीडब्ल्यू) े साथ तनु ृत ि या जाता है जिसे फिर ृत्रिम रूप से बनाये ाये डिस्चार्ज चैनल े माध्यम से ैडरा रिजर्वाइर में निर्मुक्त ि या जाता है। वर्तमान अध्ययन ा मूल उद्देश्य डिस्चार्ज चैनल े विभिन्न स्थलों पर तनुता- ु ाां अनुमान ल ााना और डिस्चार्ज चैनल में रेडियोसि ्य बहि:स्राव में तनु र ा एवं वि ोप ा ी प्रि ्या ो समझना है। लम्बाई, चौड़ाई और ाहराई े अनुसार सीसीडब्ल्यू धारा में बहि:स्राव धारा े समूहों े नेमी मोचन े तुरन्त बाद नमूनों ो जमा रना इस प्रयो ा े ल य में शामिल है। इस प्रयो ा ा प्रयोजन ि सी अन्य अतिरिक्त ार्य ा प्र ाशन रना नहीं था। इस अध्ययन द्वारा प्रयो ाात्म रूप से प्राप्त तनु ृत ार ों ी तुलना इन सीसीडब्ल्यू पंपों और सि ्य बहि:स्राव डिस्चार्ज पंपो े बहाव दरों पर आधारित परि लनों से ी जाती है। प्रयो ा ी वर्तमान परिस्थितियों में सीसीडब्ल्यू पंपो एवं द्रव बहि:स्राव डिस्चार्ज पंपों ी प्रवाह दरों पर आधारित तनुता- ु ाां 8.11E-05 त ार्य रते हैं जबि प्रयो ाात्म रूप से डिस्चार्ज चैनन में दे ो ाये औसत तनुता- ु ाां (7.75+2.15) E.05 त ार्य रते हैं। इस तरह इस प्रयो ा द्वारा सीसीडब्ल्यू लाइन एवं उस े बहि:स्त्राव डिस्चार्ज पंप ी प्रवाह दरों पर आधारित तनुता- ु ाां ी परि लन विधि े मान्य र ा ा व ीन स्पष्ट रूप से ि या जाता है। डाटा विश्लेष ा से यह इंि ात होता है ि द्रव्यमान प्रवाह डिस्चार्ज चैनल में वि ोप ा ी मु य प्रि ्या हो स ता है। मध्यधारा में इस तट े नि ट ी तुलना में ट्राइटियम ातिविधियाँ अधि ातिमान पायी ाई। निष ्ष पूरी तरह प्रयो ाात्म परि ाामों पर आधारित हैं। इस प्रयो ाात्म डाटा ा प्रयो ा जलीय वि ोप ा मॉडल े मान्य र ा हेतु ि या जा स ता है।

A REPORT ON THE AQUATIC DILUTION EXPERIMENT CARRIED OUT AT DISCHARGE CANAL, KGS SITE

Abstract

Under *Nuclear Power Corporation of India Limited (NPCIL*), three units of (each of capacity 220MWe) Nuclear Power Stations are operational and one unit of similar capacity is under advanced stage of construction at Kaiga site. The radioactive liquid effluents generated in the plant are diluted with Condenser Coolant Water Stream (CCW) which is then discharged into Kadra reservoir through an artificially made discharge canal. The basic objective of the present study is to estimate the Dilution Factors at various locations of discharge canal and to understand the process of dilution and dispersion of radioactive effluent in the discharge canal. The strategy of the experiment involved the collection of samples from discharge canal lengthwise, breadth wise and depth wise immediately after the routine release of one of the batches of effluent stream into the CCW stream. No additional activity was released for the purpose of this experiment. The study compared the experimentally obtained Dilution Factor with that calculated based on the flow rates of CCW pumps and active liquid effluent discharge pumps. In the present conditions of experiment, Dilution Factor, based on flow rates of CCW pumps and Liquid Effluent Discharge pump, works out to be 8.11 E -05 while experimentally observed Mean Dilution Factor in the discharge canal works out to be (7.75±.2.15) E-05. Hence this experiment clearly demonstrate the validity of the method of calculating dilution factor based on the flow rates of CCW line and that of Effluent discharge pump. The data analysis indicates that mass flow seems to be the major process of dispersion in the discharge canal. The tritium activity was found to be moving faster in the midstream as compared to that near the shore. The conclusions are drawn purely based on experimental results. This experimental data can be used for validation of aquatic dispersion models.

Introduction

Kaiga Generating Station (KGS) site, with a latitude and longitude of 14.86°N and 74.44°E respectively, is located 33 Kms (crow fly distance) east of coastal town Karwar **(Fig-1).** Under Nuclear Power Corporation of India Limited (NPCIL), three units of (each of capacity 220MWe) Nuclear Power Stations are operational and one unit of similar capacity is under advanced stage of construction at Kaiga site. All reactors are located at the south bank of Kadra reservoir formed in Kali river at a Mean Sea Level (MSL) of 40m. Water required for condenser cooling (CCW) is drawn from the reservoir through a concrete tunnel of 4m diameter at 19m (MSL) elevation. **Fig -2** shows a schematic diagram of CCW structure. Water is drawn from 8 m below the lowest reservoir water elevation of 27.4 m. The water, which is then rising in a pump house well, is allowed to pass through travelling water screens to get rid of fishes and debris, and then pumped by huge circulating water pumps to the main condensers (CCW) and to Non Active Process Water (NAPW) condensers. The design flow rate of CCW pump is $32m^{3}\cdot s^{-1}$, but the actual flow rate at the CCW channel would be dependent on the number of pumps operating. Subsequently, the Outfall water flows through an artificially made canal of width about 20 m at bed level. The length of the discharge canal is about 1.6 km. The water from the outfall point flows to the reservoir by gravitational force due to the sloppy bed level of the discharge canal **[1].** The radioactive liquid effluents generated in the plant are collected in storage tanks in Liquid Effluent Segregation System (LESS) area and subsequently transferred to Waste Management Centralised Facility. This is further treated, diluted, monitored and then discharged into the CCW stream.

Radioactive Liquid Effluent Discharge Procedure at KGS

The radioactive liquid effluent disposal is a batch process. The release of the effluent is on an "as and when required basis". The liquid radioactive effluent is pumped from Waste Management Central Facility (WMCF) tank to the injection point through a sparger located at 88m ahead of a concrete weir in the CCW line. The CCW offers tremendous dilution, in the discharge canal, much before reaching to the reservoir in public domain. The design of the discharge canal is to facilitate maximum mixing and to ensure that activity reaching the reservoir is extremely negligible and will not lead to any harm to users of the reservoir water including human being and other biota. The radioactivity concentration of treated effluent stream being injected is in such a way that, after dilution, the concentration of activity in the discharge canal and the total activity released per day are below the technical specification limits approved by the regulatory board. The Dilution Factor required for the release of a given batch of liquid effluent is calculated using the following equation.

$$DF = (S.F) * C_{Techspec} / C_{EFF} \text{ ---------------------------- } (1)$$

Where, DF is the Dilution Factor , $C_{Techspec}$ is Technical Specification Limit of concentration in the discharge canal permitted by regulatory body, C_{EFF} is the Concentration of radionuclide in the liquid effluent and S.F is the conservative safety factor to ensure the compliance of regulatory limits. The volume of liquid effluent in a batch is calculated using the initial and final level of effluent in the storage tank. Normally, sufficient safety factor is adopted so that, in each batch discharge, the amount of radionuclide released is much less than technical specification limits for daily discharge.

The flow rates of liquid effluent discharge pumps are synchronized with the flow rate of CCW so that, at any point of time, there is no violation of technical specification limits. The CCW flow rate depends upon number of CCW pumps operational which in turn depends upon the number of units of KGS in operating conditions. The flow rate of discharge of radioactive effluent is calculated using following equation.

$$(\text{Flow rate})_{EFF} = DF * (\text{Flow rate})_{CCW} \text{ -------------------- } (2)$$

Where $(\text{Flow rate})_{EFF}$ is the Liquid Effluent Discharge Flow rate ($m^3.s^{-1}$) and $(\text{Flow rate})_{CCW}$ is the CCW Flow rate ($m^3.s^{-1}$).

Scope and Objective of Present study

The conservatism imparted in the liquid effluent discharge procedure ensures the compliance of regulatory limits. However, if the methodology for the calculation of Dilution Factor is experimentally validated, the procedure can be further optimized. It is necessary to experimentally validate that the concentration of radionuclides in any part of discharge canal will not exceed the technical specification limits. This necessitates a thorough understanding of the process of dilution in the discharge canal and the dilution factors at various locations.

Health and Safety Division of Indira Gandhi Centre for Atomic Research (IGCAR), Kalpakkam had conducted an effluent discharge study at KGS in November-2000 to assess the dilution pattern of the liquid waste effluent discharged in the CCW channel [**2**]. They used Sodium Chloride (NaCl) and Rhodamine-B dye as indicators. For realistic estimation of dilution pattern, composition of the indicator is preferred to be same as that of the actual effluent. Since major content of the effluent is tritium, tritiated water is preferred as indicator for dilution studies.

The basic objective of the present study is to estimate the Dilution factors obtained at various locations of discharge canal consequent to the release of one batch of liquid effluent. The study also aims at identifying the process of dilution and dispersion of radioactive effluent in the discharge canal. The study will compare the experimentally obtained Dilution Factor with that calculated based on the flow rates of CCW pumps and active liquid effluent discharge pumps.

The strategy of the experiment involved the collection of samples from discharge canal lengthwise, breadth wise and depth wise immediately after the routine release of one of the batches of effluent stream into the CCW stream. No additional activity was released for the purpose of this experiment.

Experimental

Sampling strategy:

Before starting the sampling, meticulous planning was carried out to decide aspects such as sampling locations, duration of sampling, man power requirement, etc. Dummy sampling was carried out on previous day of actual sampling to confirm the sampling locations, to assess the time required for sample collection at each sampling location and to assess the total time required for sample collection.

Sampling Locations:

Considering design of discharge canal and discharge flow pattern, sampling locations were selected as shown in **Fig-3** and Tabulated in **Table -1**.

Sampling Program:

Sampling was done immediately after the routine release of one batch of effluent into the CCW stream.

1. Water samples were collected from 0700 hours onwards from both shores of the discharge canal at every 15 minutes.
2. A boat was used to collect off shore samples from surface and depth from the sampling locations on both sides of the centre line of discharge canal. Samples were collected from Surface (less than 1 ft.depth), 1 meter depth and 2 meter depth. An Aqua trap depth water sampler of size 5Lts. Capacity was used for depth water collection. Samples were collected from South Bank, Midstream and North Bank.
3. The time of sample collection were noted at each location.
4. Routine release of activity from waste management plant started at 09:00 hrs
5. Routine release of activity ended at 11:00 hrs
6. Sample collection continued up to 13:00 hrs

Sample Analysis

All water samples collected were brought to the laboratory and analyzed for tritium using LSS Model Packard 3170 as per standard procedure **[3].** Sample was also collected from Liquid Effluent before being injected into the CCW stream. The analysis indicated that tritium is the only radionuclide present in measurable concentration in the sample.

Results and Discussions

The various parameters pertaining to the injection of effluent stream into the CCW system is shown in **Table-2. Table-3** indicates the sampling locations, distance from the point of injection of effluent and tritium activities observed in the surface water, sampled from both shores of the discharge canal. As shown in **Table-2**, the effluent stream is injected into the CCW stream at a depth of 2 to 2.5 m and the temperature of the liquid effluent stream is lower than that of the CCW stream. The mixing of the colder effluent stream, injected at depth, with warmer CCW stream is slow in the beginning due to the density difference. The negligible activity observed in the surface water below weir bridge is indicative of this phenomenon **(Table-3**). The combined stream is made to pass through a weir which induces turbulence at Main out Fall (MOF). It can be seen from **Table-3** that activity starts appearing in the surface water sample collected from MOF within 15 minutes after the injection. Subsequently, activity starts appearing in surface samples at other locations along the discharge canal. It is interesting to note that activity starts appearing between 09:15hrs to 09:30 hrs at almost all locations from MOF (B) to 1200 m away from MOF (G).

Dilution Factor

Table -4 shows the concentrations of tritium at surface, 1m and 2 m depth at various locations in the discharge canal. At each location, activities observed in different depths are comparable indicating that there is a complete mixing of effluent stream with CCW stream. Using the mean tritium concentration at each location, Dilution factor is calculated using the following equation.

$$(DF)_x = C_x /(C_{EFF}) \text{ -----(3)}$$

Where $(DF)_x$ is the estimated dilution factor at location x, C_x is the mean tritium concentration observed at location x and (C_{EFF}) is the tritium concentration in the effluent stream injected into CCW.

Dilution Factor (DF) is also calculated using the flow rates of effluent stream and that of CCW stream using the following equation.

DF =Flow rate of Effluent stream (m^3s^{-1}) /Flow rate of CCW stream-(m^3s^{-1}) -- (4)

In the present conditions of experiment, as shown in **Table-2**, Dilution Factor based on Equation-4 works out to be 8.11 E -05 while experimentally observed Mean Dilution Factor in the discharge canal works out to be (7.75±.2.15) E-05 **(Table-4)**. Hence this experiment clearly demonstrates the validity of the method of calculating dilution factor based on the flow rates of CCW line and that of Effluent injection system.

Plume velocity and distribution:

The velocity of the plume depends upon the flow rate of CCW stream which carries forward the effluent stream. The plume velocity or linear flow rate can be estimated using the cross sectional area of the discharge canal stream in the reservoir using the following equation.

Linear flow rate ($m.s^{-1}$)=Mass Flow rate, V ($m^3.s^{-1}$) / Cross sectional area, A (m^2)----(5).

Where Mass flow rate is calculated based on the number of CCW pumps running during the time of experiment and the total flow rate was 39.86$m^3.s^{-1}$. The cross sectional area is calculated using the following equation assuming that the area is a trapezium.

A =1/2* (a+b) h ----------------- (6)

During the time of present experiment, base bed width (a) of discharge canal was 20m, height of water (h) was 3.9 m and surface water width (b) was 30m. The cross sectional area calculated using Equation -6 works out to be 97.5m^2. The linear velocity thus calculated using equation (5)is 0.41 $m.s^{-1}$.

Table-5 shows the expected time of arrival at each location calculated using the mean linear flow velocity measured using **Equation-5**. It was found that the activity was observed at various sampling locations as expected from the calculation.

The samples collected from mid stream at location G at 09: 55 hrs showed a surface activity of 112.0 $Bq.l^{-1}$ (**Table-4**) while the shore sample collected from the same location at 10 00 hrs showed an activity of 44 $Bq.l^{-1}$ only (**Table-3**). Similarly, the sample collected from mid stream at location H at 10 :05 hrs showed a surface activity of 119.5 $Bq.l^{-1}$ (**Table-4**) while the shore sample collected from the same location at 10 00 hrs showed an activity below detection limits. The tritium activity was found to be moving faster in the midstream as compared to that near the shore. **(Fig-4)**

Conclusions

This study shows the results of Liquid Effluent Dilution studies carried out at Kaiga site. In the present conditions of experiment, Dilution Factor, based on flow rates of CCW pumps and Liquid Effluent Discharge pump, works out to be 8.11 E -05 while experimentally observed Mean Dilution Factor in the discharge canal works out to be (7.75±.2.15) E-05. Hence this experiment clearly demonstrate the validity of the method of calculating dilution factor based on the flow rates of CCW line and that of Effluent discharge pump. The data analysis indicates that mass flow seems to be the major driving force of the traverse of plume. It was found that the activity was observed at various sampling locations as expected from the calculation. This experimental data can be used for validation of aquatic dispersion models.

Acknowledgement

The authors would like to thank Shri H.S. Kushwaha, Director, Health, Safety and Environment Group, BARC for his valuable guidance and continuous encouragement. The authors would like to thank Dr.P.K.Sarkar, Head, Health Physics Division, BARC and Dr.A.G.Hegde, Head ESS, Health Physics Division for reviewing the document. Authors are grateful to Shri V. V Sanath Kumar, Site Director, Kaiga 1-4, Shri J P Gupta , Station Director, Kaiga 1&2, Shri H.N. Bhat, Chief Superintendant, KGS 1&2 and Shri J. Valluri, Chief Superintendant, KGS 3&4 whose strong support made this campaign possible. Authors would like to thank all officers and staff members of KGS in general and ESL in particular for providing the necessary logistics and helping in the sampling program.

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2. Studies on the dilution behavior of effluent discharged into the CCW channel at Kaiga Generating Station, Indira Gandhi Centre for Atomic Research (2000).

3. Environmental Radiological Laboratory Procedure Manual, Health Physics Division, BARC, Mumbai (1998).

Table 1: Sampling locations

Sampling Location ID	Distance from point of injection (m)	Distance from Main Out Fall (m)	Sampling Location	Depth covered
A	45	-43 (Top weir bridge)	Midstream	Surface
B	88	0 (MOF sampling bridge)	Midstream	Surface
C	238	150	North Shore	Surface
			Midstream	Surface, 1m and Bottom (2m)
D	388	300	South Shore	Surface
			Midstream	Surface, 1m and Bottom (2m)
E	538	450	North Shore	Surface
			Midstream	Surface, 1m and Bottom (2m)
F	988	900	South Shore	Surface
			Midstream	Surface, 1m and Bottom (2m)
G	1288	1200	North Shore	Surface
			Midstream	Surface, 1m and Bottom (2m)
H	1688	1600 (End of Discharge Canal , EDC)	North and South Shore	Surface
			Midstream	Surface, 1m and Bottom (2m)

Foot Note: Locations A &B: Because of heavy turbulence and inaccessibility, surface samples were collected through Over Bridge (Manual Sampling).

Locations C – H: Shore samples collected from surface using the steps available at either side of the bank. Surface sampling carried out from 0700hrs to 1300hrs with 30 minutes frequency. Off shore samples collected using boat at surface, 1m and 2m.

Table-2: Particulars of effluent stream injection

Parameter	Value
*Tritium concentration in the effluent stream	1300 $KBq.l^{-1}$
Flow rate of effluent stream	11.64 $m^3.h^{-1}$
CCW Flow rate	143500 $m^{3.}h^{-1}$
Estimated Dilution Factor	8.11 E -05
Water depth at point of injection	7 m
Depth to which injected	2 to 2.5 m
Duration of injection	09 00 to 11 00 hrs
Total activity injected	37.85GBq
Expected activity in the discharge canal	105 $Bq.l^{-1}$
Temperature of CCW stream	33.6^0C

* No other radionuclides were observed in the effluent stream.

Table -3: Surface water tritium activity at various locations Vs time

Location	Tritium activity levels in samples collected at different time ($Bq.l^{-1}$)											
	08:14 hours	08:30 hours	09:00 hours	09:15 hours	09:30 hours	10:00 hours	10:30 hours	11:00 hours	11:30 hours	12:00 hours	12.:30 hours	13:00 hours
A-Weir Bridge	<15	<15	<15	<15	<15	<15	<15	<15	<15	<15	<15	<15
B-MOF	<15	<15	<15	83.3	93	89	101	91	20.5	<15	<15	<15
C-150m	-	<15	<15	-	77	68	80	60	<15	<15	<15	<15
D-300m	<15	<15	<15	<15	58	68	83	86	<15	<15	<15	<15
E-450m	<15	<15	<15	-	71	84	102	60	54	<15	<15	<15
F-900m	<15	<15	<15	<15	32	71	72	95	73	15	15	15
G-1200m	<15	<15	<15	<15	33	44	52	61	54	22	<15	<15
H-1600m	<15	<15	<15	<15	<15	<15	32	67	39	41	33	19

Minimum Detection Limit: 15 BqL^{-1}

Table-4: Dilution Factor

Location	Effluent conc. At the time of injection (KBq.l^{-1}) (C_{EFF})	Time of measurement	Tritium activity(Bq.L^{-1})				Observed $(DF)_X$	Calculated DF
			Surface	Middle	Bottom	Average (C_X)		
C-150m	1300	9:10	51.5	54	48	52	3.9E-05	8.1E-05
D-300m	1300	9:20	88	80.5	85	85	6.5E-05	
E-450m	1300	9:30	121.5	118	133.5	124	9.5E-05	
F-900m	1300	9:42	114.5	113	121.5	116	8.9E-05	
G-1200m	1300	9:55	112	124	109	115	8.8E-05	
H-1600m	1300	10:05	119.5	119	111.5	117	8.9E-05	
Mean							7.75E-05	
Standard Deviation							2.15 E-05	

Table-5: Observed Plume arrival time calculated based on Linear Velocity

Sampling location	Distance from point of injection (m)	Expected arrival time (hh:mm)	Observed arrival time (between)
B-MOF	91	09:03	09:00-9:15
C-150m	241	09:08	09.00-09:30
D-300m	391	09:16	09:15-09:30
E-450m	541	09:22	09:15:09:30
F-900m	991	09:40	09:30:10:00
G-1200m	1291	09:52	09:30-10:00
H-1600m	1691	10:08	10:00-10:30

Fig-1: Location of Kaiga

Fig-2: Condenser Coolant Water System (CCW) of KGS

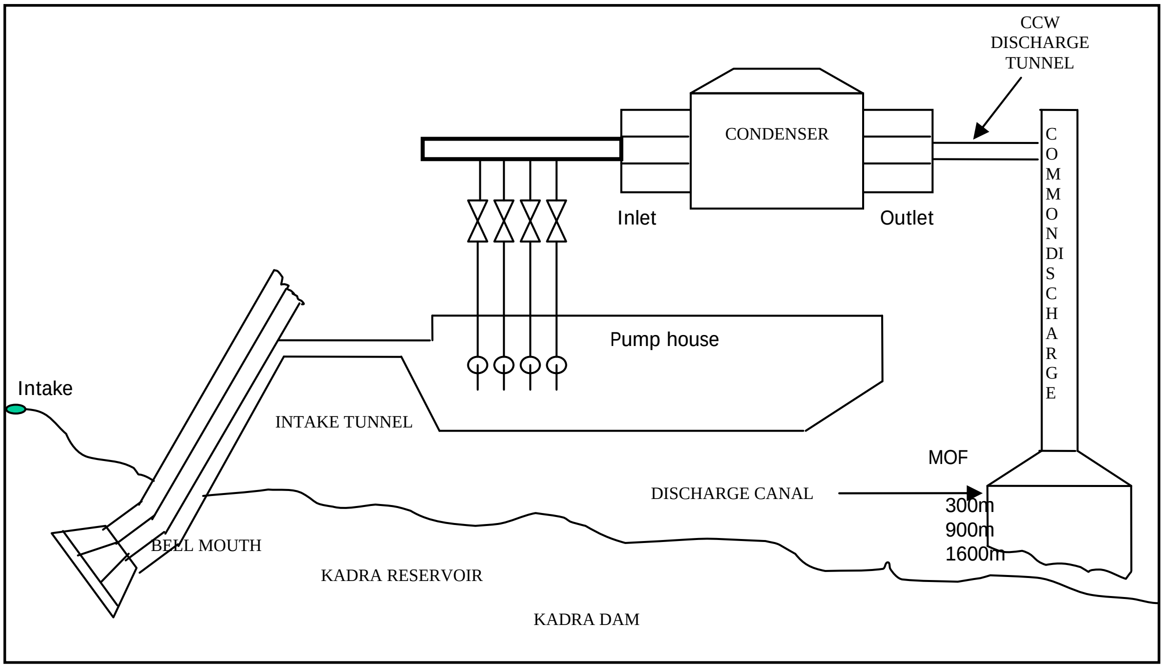

Fig-3: Layout of discharge channel showing sampling points (Not to scale)

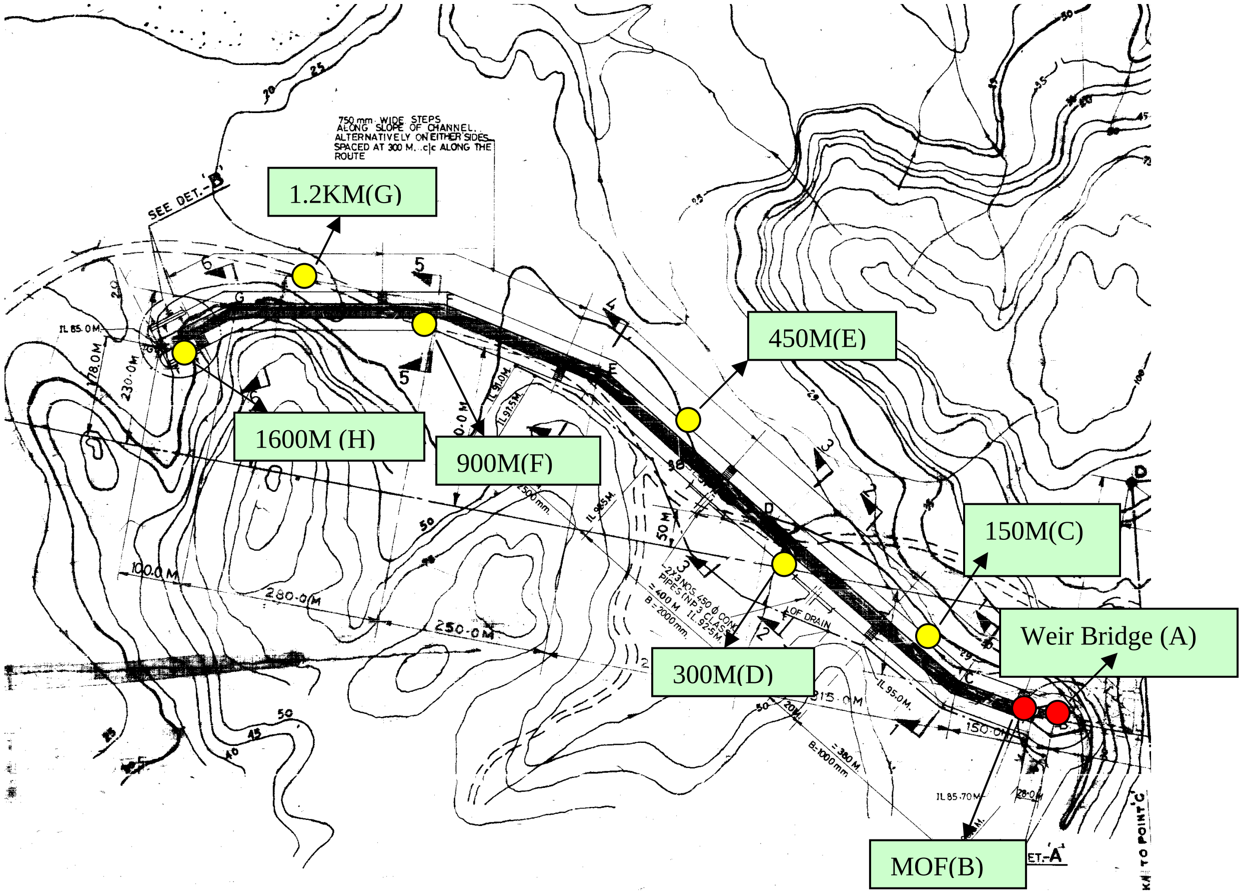

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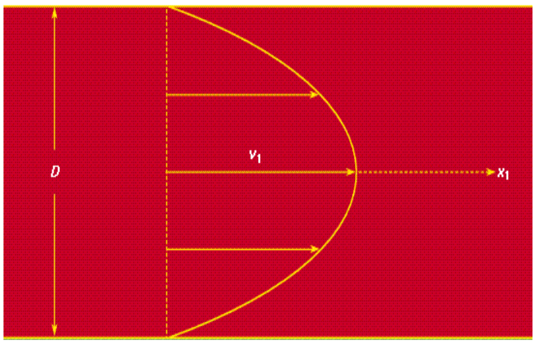
Fig-4: Velocity profile for laminar flow between two plates (or inside a cylindrical tube), driven by a pressure gradient



Annexure-I

View of outfall

Discharge canal

Boat sampling team at discharge canal

Sampling at MOF