6 Decades of His Majesty King Bhumibol Adulyadej's Graciousness

Department of Royal Rainmaking and Agricultural Aviation

Content

Preface

“Royal Rainmaking Technology” has been an excellent invention broadly recognized among scientists and organizations on weather modification in international and global levels.

Many international organizations granted the best awards, certificates, and honors to His Majesty King Bhumibol Adulyadej for his remarkable talent and intellectual.

An award which Thai people are most proud of is the UNDP Human Development Lifetime Achievement Award that Mr. Kofi Annan, the 7th Secretary-General of the United Nations, presented to His Majesty on 26th May 2006. His Majesty is the first person UN granted this award to in order to glorify him for his wisdom and all activities on developing quality of life and well-being of Thai people throughout his reign.

This honor award is presented to individuals who have demonstrated outstanding commitment during their lifetime to furthering the understanding and progress of human development in a national, regional, or global context. So Royal Rainmaking project is one of His Majesty’s works which successfully help people suffering from the drought, and brings them better lives.

Chapter 1

Prologue of Royal Rainmaking

Prologue of Royal Rainmaking

The 6 decade-long history of Royal Rainmaking started on 14th November, 1955, while His Majesty King Bhumibol Adulyadej was travelling from Nakhon Phanom Province to Kalasin Province. Passing through Sakon Nakhon Province and the Phuphan mountain range, His Majesty noticed distress and hardship of his subjects and farmers who lacked water for consumption and agriculture. His Majesty also learnt that, in wet season, flash flood from mountains damaged their crops and when the flood was gone, the land was dry.

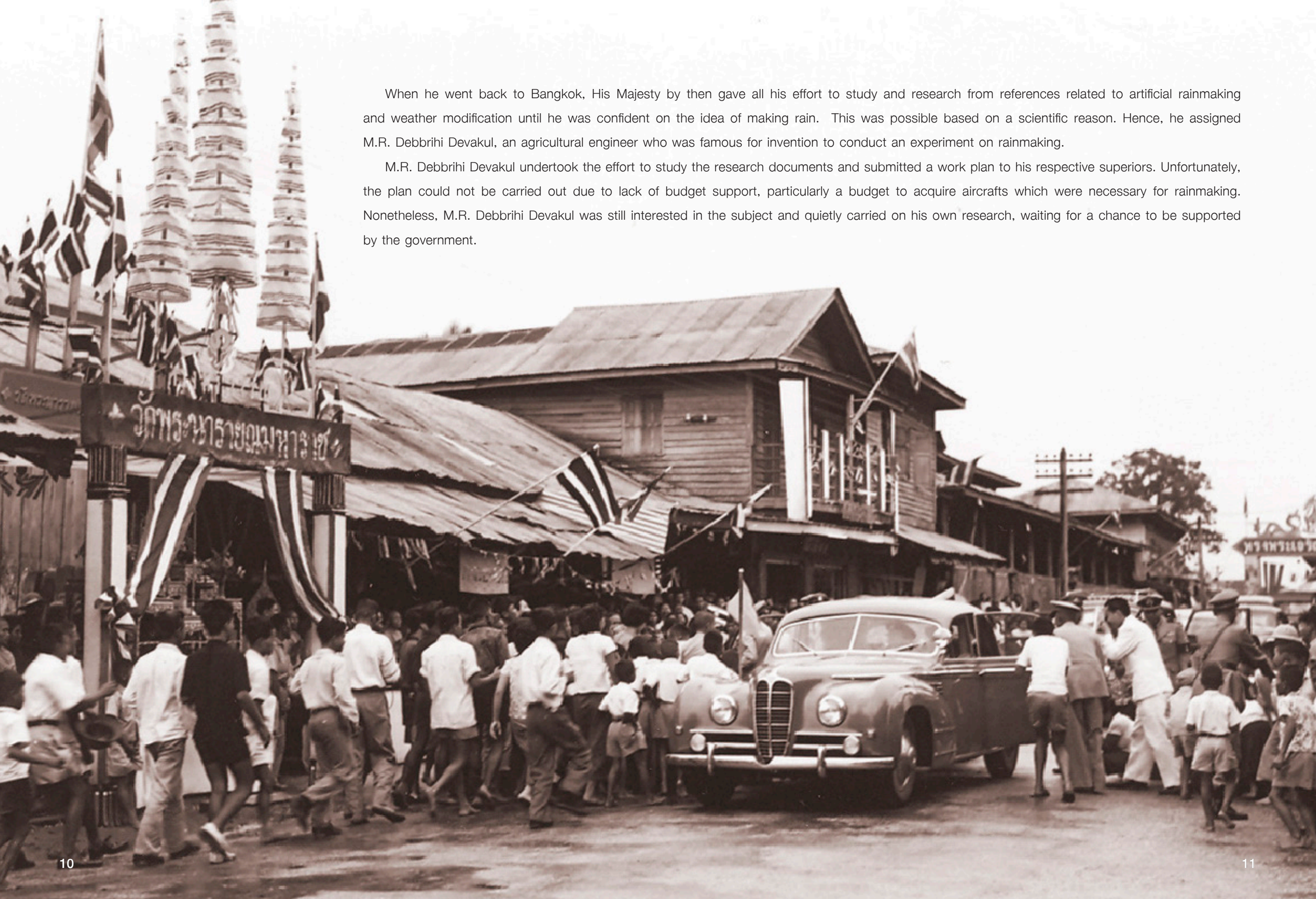
"...At that time, I looked up at the sky and saw that there were many clouds, but they were all blown past the arid land. The solution lies on how to make those clouds fall as rain in the locality..."

The Rainmaking Story written

by His Majesty King Bhumibol Adulyadej

When he went back to Bangkok, His Majesty by then gave all his effort to study and research from references related to artificial rainmaking and weather modification until he was confident on the idea of making rain. This was possible based on a scientific reason. Hence, he assigned M.R. Debbrihi Devakul, an agricultural engineer who was famous for invention to conduct an experiment on rainmaking.

M.R. Debbrihi Devakul undertook the effort to study the research documents and submitted a work plan to his respective superiors. Unfortunately, the plan could not be carried out due to lack of budget support, particularly a budget to acquire aircrafts which were necessary for rainmaking. Nonetheless, M.R. Debbrihi Devakul was still interested in the subject and quietly carried on his own research, waiting for a chance to be supported by the government.



In 1969, after a long continuous study for 14 years, the project of artificial rainmaking has proved successfully, Dr. Sawaeng Kulthongkhum, the Permanent Secretary of the Ministry of Agriculture and Cooperatives (MOAC), learnt that the Ministry had some small aircrafts under the responsibility of the Agricultural Aviation Unit which were being used for insecticide spraying. In response to His Majesty's idea, he revived His Majesty's initiative on rainmaking and put it into a real test. He assigned M.R. Debbrihi Devakul to prepare a rainmaking experiment project proposal. Subsequently, M.R. Debbrihi Devakul drafted a research and development project on rainmaking by means of cloud manipulation and submitted it to the Permanent Secretary, requesting permission to establish a Royal Rainmaking Operations Unit consisting of officers from various agencies under the MOAC, headed by himself, and supervised by the Permanent Secretary. M.R. Debbrihi's scheme was approved and the implementation started in June 1969.

The Theoretical Background

The first principle was to use an aircraft to seed substance (sea salt) into the atmosphere to absorb moisture, then to use cold formula substance (dry ice) to make moisture condense and coalesce (the initiative in weather modification for making rain).

Chapter 2

Visible Success

Visible Success

His Majesty King Bhumibol Adulyadej considered that it was possible to make artificial rain because it rains as a result of suitable humidity and temperature, as well as velocity and direction of wind. Therefore, he put a focus on cloud physics as an additional area of study.

2.1 The Initial Phase of the Royal Rainmaking Experiments

M.R. Debbrihi Devakul had started since July 1st, 1969 to prepare rainmaking experiments, by looking for a suitable test site, until he heard that there were condense clouds around the Khao Yai area in Pak Chong District of Nakhon Ratchasima Province. He went there to observe and inspect the ground weather conditions. After bringing back information to be analyzed in a laboratory, he was satisfied with the conditions. On July 20th, 1969, he started the first trial flight for chemical seeding in an attempt to induce rainfall on the area of Khao Yai National Park. He used a Cessna 180 one-engine aircraft loaded with dry ice. The aircraft was just a plain one used for insecticide spraying. There was no rainmaking equipment outfitted to the aircraft.

Application of dry ice had to be done by scooping it out through aircraft windows. Apparently, it was a very distressing operation. Once the aircraft window was opened for dry ice seeding, the strong wind would blow in, bringing back the dry ice inside the aircraft and at one time it got into M.R. Debbrihi's ears and damaged his eardrums. In spite of a great pain and suffering, he continued until the end of the operation. For this test, Nong Taku Special Army Airport, in Pak Chong District (of which the elevation was 1,500 feet above sea level) was used as the operational base. The method used in the operation was adopted from the method practiced in other countries (i.e. seeding granulated dry ice at the top of cumulus cloud). This type of cloud is a big rain cloud, in triangular shape, which looks like a hill from a side view. The top of a cumulus cloud shapes like a dome, or a cauliflower, with the colour as white as cotton wool. The base of the cloud is a straight horizontal line with dark shadows. It is a low altitude cloud which usually occurs at not higher than 6,500 ft. It is the most suitable cloud for rainmaking (another method used in the test was spraying water into a cumulus cloud). Approximately 15 minutes after the operation, the cloud was packed and became bigger. Its top was built up higher and the base of the cloud changed its colour from white to dark gray and rain seemed imminent. Unfortunately, rain could not be observed as mountains peaks obscured the view.

When His Majesty heard about the experiment at Pak Chong and the trouble of the experiment team had encountered, His Majesty suggested changing the location to Bo Fai Airport in Hua Hin District of Prachuab Khiri Khan Province. His Majesty considered the location suitable for conducting the experiments because there were various types of topography such as mountains, highlands, plains, and the sea. Flooding which might result from the test would not pose a problem because excess

water could be quickly drained to the sea. Although the area was close to the sea and usually had a lot of clouds, it was often hit by drought. Another advantage was that there were many government agencies in the area, ready to facilitate the experiment, such as the Flight Control Tower of the Civil Aviation Department, the Meteorological Observation Station of the Meteorological Department, the Police Department's Radio Communication Station, the Centre of the Thai-Israel Rural Development Project, the Centre of the Khao Tao Village Development Project, etc. Also, transportation was convenient. One could travel from Bangkok to the operations site within 3- 4 hours, and it was easy to travel by car to follow-up the experiment's results in various locations in the area.

Since the first experiment in 1969, several experiments were done in dry fields where farmers took the opportunity to present their petitions to His Majesty asking for help. Although, farmers realized that rainmaking operation was still at its experimental stage, all hopes were still put on begging that perhaps at least the next experiment could be done in an area of drought. The experimental operation was made from time to time in farmers' fields and successfully brought in time water to their farms and crops.

2.2 Royal Activities on Rainmaking

As mentioned earlier, His Majesty had initiated the first rainmaking in Thailand, and had supported the work from the very beginning. His Majesty closely monitored the implementation at every step. When the Royal Rainmaking Unit faced some problems, His Majesty kindly gave suggestions to help solve the problems. For instance, His Majesty suggested to conduct a test at Hua Hin every month, in order to get all year round data on rainmaking. He also suggested research trainees, so that they would be able

to set up an operation plan suitable for local weather conditions. At times, His Majesty participated in the experiments and directed the operations. Before each operation, His Majesty would remind the officers in charge to study weather conditions as the first step. That was to avoid (inducing a subsequent depression) damaging crops and properties. His Majesty would encourage the operation if weather conditions were favorable in order to get more rainfalls. He warned the operators to be careful of chemicals which could be dangerous to users. Following are just some examples of his numerous activities regarding to Royal Rainmaking.

On August 20th, 1969, His Majesty, accompanied by His Royal Highness the Crown Prince (at present is His Majesty King Maha Vajiralongkorn Bodindradebayavarangkun) visited Bo Fai Airport at Hua Hin to observe the 5th Royal Rainmaking experiment. His Majesty kindly told the operation team to bear the burden because the work was very important in helping the unfortunate people to alleviate drought. His Majesty suggested the operation team to study the information and factors of surface weather conditions, such as surface relative humidity charts of the area, His Majesty also demonstrated to the operation team on how to increase surface relative humidity. To do that, His Majesty ordered a Palace fire truck to spray water up in the air. Then he went into where water was being sprayed, holding a hygrometer to measure humidity without worrying that his body would get wet. Apparently, the hygrometer showed the relative humidity at the same level as his prediction. Moreover, His Majesty suggested to increase the number of field observation units so that rainfall and other related information could be collected in greater detail.

Based upon that visit, the kind suggestions of His Majesty to the operations unit have been followed as scripture by the team and its successors up to the present time. These are:

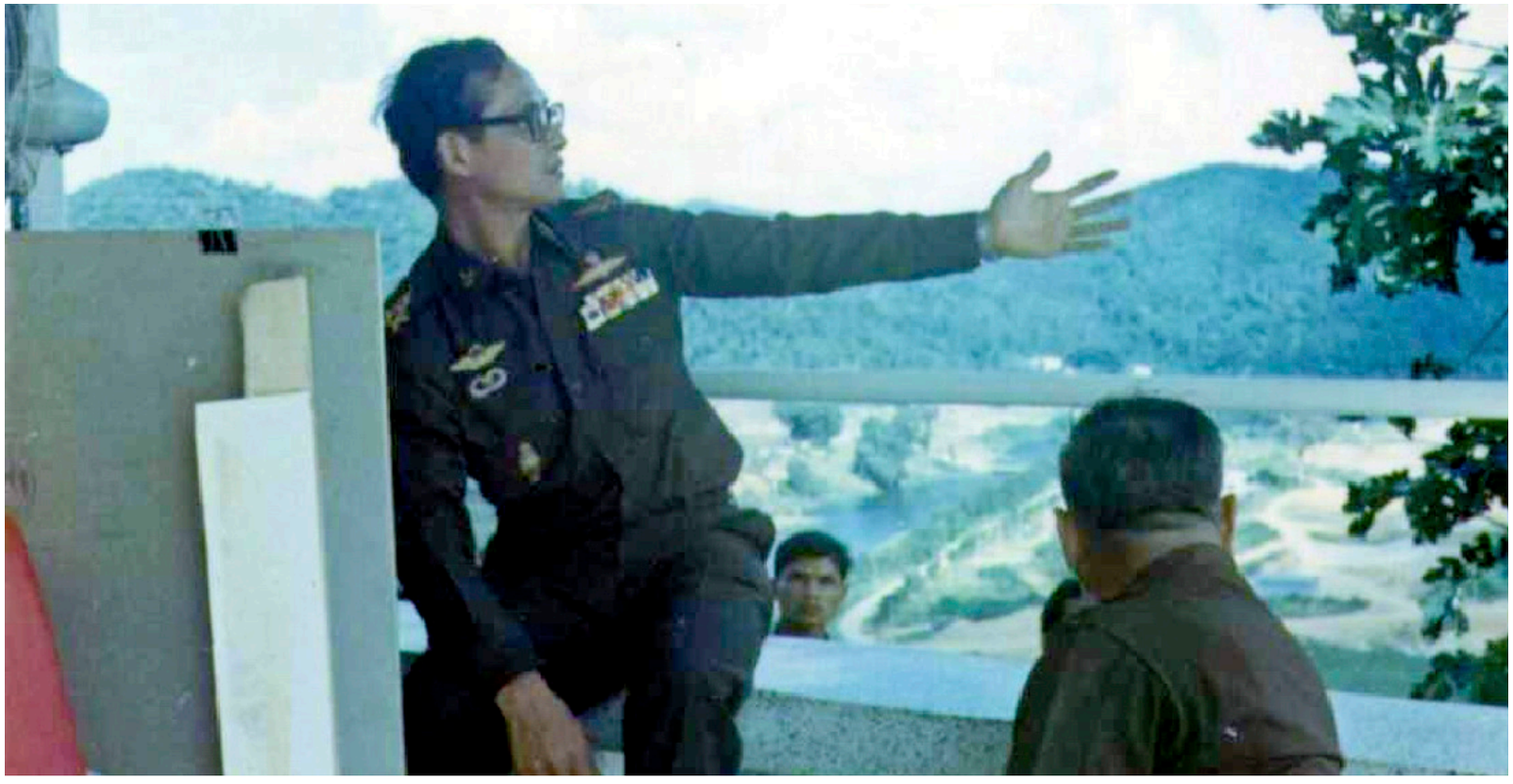
1. Research and study is an important work which never ends.
2. Ignoring critics diminishes the effort to develop.
3. Written records are to be kept.

On April 26th, 1971, His Majesty traveled to Bo Fai airport to observe rainmaking. At the airport, His Majesty awarded Royal Rainmaking wings to the working team as a sign of goodwill for them, His Majesty also blessed the new rainmaking aircraft which was the first one the MOAC procured with its allocated budget. On this occasion, His Majesty allowed three officials from Australia to follow him to observe the rainmaking experiment. His Majesty had conversations and exchanged opinions with them without formality. They very much appreciated His Majesty's kindness and praised him as an expert in the field of artificial rainmaking.

On October 19th, 1972, His Majesty directed the Royal Rainmaking demonstration at the Kaeng Krachan reservoir in Petchaburi Province to three representatives of the Singaporean Government. His Majesty was confident that the operation would result in rainfall above the reservoir. The Kaeng Krachan Reservoir was chosen as the target area because its topographic and weather conditions were similar to those of Singapore. Subsequently, they could adopt the appropriate rainmaking methods in Singapore. The Kaeng Krachan Reservoir was considered as the smallest and the most difficult target area that the operation team had ever met. The Police Department's aircraft and the aircraft of the MOAC were used in the demonstration. The Bo Fai Airport was used as the operation base. His Majesty directed the operation by means of radio communication from the Kaeng Krachan area. By his expertise, there was rainfall over the reservoir within 5 hours of the operation, to the excitement and impression of the Singaporean representatives.

During November 15th - 29th, 1972, His Majesty planed and directed the Royal Rainmaking from the Chitralada Palace through the Police Radio Network. The purpose of the operation was to increase water level at the Bhumibol Dam at the end of the rainy season, as its water volume was lower than usual. There was no depression to activate rain at the time but the relative humidity was high enough to encourage rainmaking. The MOAC's aircrafts were used in this operation and the dam's airfield was used as the operation base. The operation resulted in rainfall over the Dam and the catchment area on every operating day. The water volume was increased by about 620 million cubic metres, bringing up the water level of the Bhumibol Dam to 150 centimeters higher than the level before the operation. The electricity generated by this volume of water had a high monetary value.

From July 13th to August 26th, 1974, His Majesty kindly called for a special Royal Rainmaking operation, and participated in the operation which was carried out in the northeastern region by a working group of the MOAC. At that time, 16 provinces were stricken by drought as the beginning of rainy season was delayed. Farmers lacked water to prepare rice seedling and most of the seeds that had already been sown and germinated had not received enough water. Some farmers were not able to till their paddy fields for rice transplanting when their seedlings were ready to be transplanted. It was the largest drought area that the Royal Rainmaking Project had ever been undertaken. The total drought area of 17 million rai (2.72 million hectares), in those 16 provinces was reported. For the operation, 8 rainmaking aircrafts of the MOAC were used, supported by a large C-123 aircraft of the Royal Air Force, and 2 Porter aircrafts of the Police Department. The rescue operation lasted 45 days. His Majesty



had planned and directed most of the daily operations. Before the operations, farmers could transplant rice seedling in only 5% of the total rice planting area. After the operation, reports from every province under the operation revealed that farmers could prepare more seedlings, the dry seedbeds were saved, and rice transplanted area averagely increased by about 55%of the total rice planting area. In those provinces, transplanting could be done in almost all of the rice growing area.

His Majesty's Policy on the strategy to develop the King's Initiative Project for the "Royal Rainmaking Project"

1. His Majesty emphasized the need to develop and improve rainmaking methods based on more scientific approaches in designing, operating, monitoring and evaluating. His Majesty also emphasized the need to make use of computer technology in the study of cloud patterns and in operations to achieve the objectives of the project.

2. He stressed that weather modification or rainmaking is an important component in water resources management process. Its role is, for instance, to increase water in reservoirs, reduce pollution problems and increase water supply for public use.

3. He emphasized that full cooperation and coordination among participating agencies and organizations is the significant element in achieving the project's goal.

2.3 The Evolution

From 1969 to 1970, the first test of the Royal Rainmaking operation was launched by imitating the method used in other countries. Development of a method to achieve effective rainfall was done by means of experiences gained from observations and results of previous tests. The descriptions of methods characterized by chemicals used in the tests can be summarized as follows:

1. Seeding of granulated dry ice and spraying of plain water into clouds (the methods used in other countries).

2. Modification was made to method No.1 by using concentrated table salt solution instead of plain water.

3. Modification was made to method No.2 by applying it to make a cold curtain above a target area in order to attract rain clouds into the area, and increase rainfall.

- **In 1971**

Royal Rainmaking experiments were carried out to increase water volume of Ubonrat Dam in Khon Kaen Province and Bhumibol Dam in Tak Province. They were scheduled to operate every fortnight. However, there was a severe drought covering a large area that year and rice farmers submitted a petition to His Majesty to request for Royal Rainmaking. Since then, the MOAC has formed the Royal Rainmaking Unit to operate relief missions. Therefore, research and development of techniques for rainmaking were conducted alongside with rescue operations for farmers. The development progress of Royal Rainmaking methods during these years can be summarized as follows:

Early in the year, the method used by the Royal Rainmaking Project was the one from the first set of experiments (i.e. the use of dry ice and concentrated Sodium Chloride solution, and building of a cold curtain above target areas).

Later in that year, from October 31st to November 15th, 1971, Sodium Chloride (NaCl) in form of powder was first used in Royal Rainmaking operations at Petchabun Province. It is very dry table salt, finely ground into powder like flour. It was later called “Royal Rain Salt Flour” or “Formula 1”.

- **In 1972**

On January 7th, 1972, Calcium Chloride powder was successfully used in a trial to disperse fogs and clouds in the area of Chiang Mai and Mae Hong Son Provinces. The experiences gained from those trials were later adapted to be used in Royal Rainmaking operations. Furthermore, later in the year, concentrated Urea solution was tested in a Royal Rainmaking operation. It was used to attack clouds and force them to rain. Therefore, the chemicals used in the Royal Rainmaking operation in that year included:

- Sodium Chloride powder or Royal Rain salt flour (Formula 1)
- Dry Ice (Formula 3)
- Calcium Chloride powder (Formula 6)
- concentrated Urea solution

- **In 1973**

Urea powder was tested in operations and was later used to replace concentrated Urea solution (due to technical problems in spraying the solution). When Urea was applied together with other chemicals, it was proven to be more efficient. At the end of 1973, Calcium Carbide (CaC) powder was tested in the step of “triggering”. Therefore, the chemicals used in operations in 1973 were the same as in 1972, but the use of concentrated Urea solution was changed to Urea powder (Formula 4) instead.

- **From 1974 to 1976**

The chemicals used in Royal Rainmaking operations during these years were:

- Sodium Chloride powder or Royal Rain salt flour (Formula 1)
- Dry Ice (Formula 3)
- Urea powder/concentrated Urea solution (Formula 4)

- Calcium Chloride powder (Formula 6)
- Calcium Carbide powder (Formula 9)

- **From 1981 to 1982**

In mid 1981, Calcium Oxide powder (Formula 8) was tested for the “triggering” step. The chemicals used in the Royal Rainmaking operation during this period were the same as those used from 1977 to 1980.

- **From 1977 to 1980**

In mid 1977, the experiment using a concentrated solution of the mixture of Ammonium Nitrate and Urea was carried out (NH4NO3: Urea : water = 1 : 1 : 2). This solution could drop the temperature to between -5 °C and -7 °C, and was used in the step of “attacking step,” or to force the clouds to rain, and to increase rainfall efficiency. However, the technique of spraying a concentrated solution often created a technical problem. Therefore, Ammonium Nitrate in a form of powder or Formula 19 was tested and yielded successful results. Between 1977 to 1980, the chemicals used by the Royal Rainmaking Project were:

- Sodium Chloride powder or Royal Rain salt flour (Formula 1)
- Dry Ice (Formula 3)
- Urea powder/concentrated Urea solution (Formula 4)
- Calcium Chloride powder (Formula 6)
- Calcium Carbide powder (Formula 9)
- Ammonium Nitrate powder or concentrated solution (Formula 19)

- In 1983

Early in the year, an experiment was conducted to apply the concentrated solution of Formula T.1 (the solution derived from an electrolysis process resulting from a study made by MR. Debbrihi Devakul, a special advisor to the Institute of Royal Rainmaking Operations. The Formula T.1 solution is a chemical that reduces surrounding temperature and absorbs moisture. It was used in an experiments to “attack” rain clouds by stimulating them to rain and increase rainfall. Later in that year, the Formula T.1 was further tested in the form of fine powder, and yielded interesting results. Therefore, the Special Advisor continued his research to produce the chemical Formula T.1 on an industrial scale and he succeeded in so-doing in 1983.

The chemicals used in the Royal Rainmaking operation in 1983 were the same as the ones used from 1977 to 1982.

Since 1984, eight chemicals have been used up to now. These include:

- Sodium Chloride powder or Royal Rain salt flour (Formula 1)
- Dry Ice (Formula 3)
- Urea powder/concentrated Urea solution (Formula 4)
- Calcium Chloride powder (Formula 6)
- Calcium Oxide (Formula 8)
- Calcium Carbide powder (Formula 9)
- Ammonium Nitrate powder
- TI powder (Formula T.1)

At present, 3 main types of cloud seeding materials are used for rainmaking operation, i.e. endothermic (Calcium Chloride and Calcium Oxide), exothermic (Urea) and cloud condensation nuclei seeding materials (Sodium Chloride). The criteria for selection of seeding are the consideration of its their properties and daily atmospheric conditions.

2.4 Results Assessment of Experiments Achievements

In 1973, His Majesty assessed the results of artificial rainmaking experiments conducted from 1969 to 1972 and concluded that there were 3 steps of Royal Rainmaking Technology: triggering, fattening and attacking. The wordings used made it easy to understand, remember, communicate and report back to him.

Although, the final step of research had been reached in 1973, His Majesty still went on searching for a more efficient and precise attacking technology for instance, a technique called “Sandwich” that is to attack clouds to form satisfactory amount of rain over a target area. He also discovered an enhancement technique of dispersing Dry Ice flakes at an altitude of 1,000 feet under cloud bases in order to induce cloud bases to move lower so that rain would reach the ground in larger amount. Therefore, a technique to precisely drag a rain cloud and force it to yield rain over a target area and a technique to increase rain amount was improved and developed under the condition of local climatology and landscapes in relation to various times of the year throughout each season.

Chapter 3

Progress of The Development

Progress of The Development

Although the success of Royal Rainmaking operations has brought great benefits to the nation and its people, the Royal Rainmaking has continually developed, in the areas of methods and techniques, as well as organizational structure and personnel potential. In parallel, rainmaking operation has continuously and progressively been conducted in response to people's needs.

3.1 Royal Decree on Establishment of Bureau of Royal Rainmaking and Agricultural Aviation

Aircrafts played an important and essential role in Royal Rainmaking operations. Due to increasing scope of work, two supporting units were consolidated and upgraded on 15th September 1992 as the Bureau of Royal Rainmaking and Agricultural Aviation under the Office of the Permanent Secretary of the Ministry of Agriculture and Cooperatives.

One of the two units was the Aviation Section under the Agricultural Aviation Division which was responsible for all aircrafts. The other one was the Royal Rainmaking Section under the Royal Rainmaking Operations Office which was responsible for Royal Rainmaking.

The scope of work of the Bureau of Royal Rainmaking and Agricultural Aviation has increased to include the following:

1) Royal Rainmaking operations to increase water volume in reservoirs for the use of farmers and other people in the adjacent areas

2) Studies and researches on weather modification technology, development and other related areas

3) Aviation support for conservation of natural resources and environment, agricultural operations or any related operations conducted by other government agencies

4) Establishment of eight Royal Rainmaking Operation Centers responsible for basins, covering twenty-five main basins

A former Director-General, Mr.Warawut Khantiyanan, recalled the period of time when the Royal Rainmaking Research and Development Institute had already become the Bureau of Royal Rainmaking and Agricultural Aviation, with six central units, equipped each with aircrafts, a scientist team and officers, providing services in response to petitions requesting

"The requests for Royal Rainmaking usually came from the same areas where droughts were recurrent; such as Nakhon Ratchasima or Chaiyaphum in the Northeast or from the lower and the upper North. However, it took a long time (almost one month) for the requests to arrive at the office. What we did was to set an annual rainmaking plan and approach strategy. When it was time, we started our operation by temporarily setting up an operation unit without receiving the petitions. After having finished the operation, we moved to another province.

None of us had a baggage. Instead, we used the sacks containing substances to pack clothes and got in a car to continue carrying out our missions."

The next evolution of the operation, as quoted by the former Director-General, was the division of responsible zones. In spite of the division, the operators still had to return to the central unit after completing their mission.

"The set up tents were not suitable for storing substances. So, we sought a permanent location and found a deserted building on the airfield. We then asked for a permission to use it for that purpose. Whenever it was time for an operation, unit left without a baggage, as items to be used had already been placed. Since, the operators had only three months to take a rest, and had to work continuously during the remaining nine months, we came up with an idea of establishing regional centers which are now being located in Chiang Mai, Nakhon Sawan, Khon Kaen, Rayong and Surat Thani."

In 1992, the Office of Royal Rainmaking and Agricultural Aviation had additional scientists and the work system was well-organized with modern technology. Government official's positions increased from sixty at the initial stage to almost five hundred.

3.2 Royal Rainmaking Operation for Forest Fire Suppression and Drought Mitigation

In the current decade, drought disasters increasingly have a devastating impact on the country's economy and people's livelihood namely the Todaeng Swamp Forest Fire in 1998 and the drought crisis in 1981.

Swamp Forest Fire Control by Royal Rainmaking

In Thailand, there are two big swamp forests located in

Narathiwat Province: Bajo and Todaeng swamp forests covering the area of 260,000 rai (104,000 acres). In 1998, the most severe drought in Thailand's history, in conjunction with the deforestation and the burning of the reserved forest, resulted in a devastating forest fire at Todaeng.

As the forest ground had been covered with fossils, wood, and leaves for a long time, most of them submerged in water and created a thick layer covering the ground. Water in the swamp prevented those fossils from fully decomposing. When the severe drought occurred and the underground water was lower, the fossils became the underground fuel and ignited fire from under the ground.

Todaeng Swamp Forest fire situation

1st stage : On 16th March 1998, swamp forest fire occurred in the area of Charayor village, Palemus Sub-district, Su-ngaiKolok District, Narathiwat Province. Officers in charge could control the fire in this village on 1st April 1998.

2nd stage : Swamp forest fire occurred on 10th April 1998 in the same area of the first stage and 3 other areas : Kokyai Village (100 rai or 40 acres), Pooyo Village (320 rai or 128 acres) and Kokkala Village (11,400 rai or 4,560 acres).

The forest fire in the 2nd stage was severe and it also spread to the nearby areas where it was hard to control. The Todaeng Swamp Forest fire was hard to extinguish because the features of the swamp forest are different from those of other kinds of forests in other regions of Thailand.

The methods used to extinguish this fire were, for example, pumping water into the swamp forest, extinguishing fire at the main area, creating fire forest barriers by Backhoes and spraying water from helicopters. However, these methods could control the fire from spreading to nearby areas. The officers encountered

a number of problems that obstructed them to completely extinguish the fire at that time.

His Majesty was concerned about the Todaeng Swamp Forest fire situation. The fire did not only destroy the fertility of the reserved forest but also the ecosystem of the swamp forest. It caused air pollution of which the smoke severely harmed people's health in the surrounding areas. As those above-mentioned methods could not control the fire, ignited from underground, His Majesty provided the advice to do a special Royal Rainmaking operation along with the aforementioned methods. He advised Royal Rainmaking officers to use dry ice to induce humidity into the area so that it would rain over the target area and the mountains nearby which were the water resources of Todaeng Swamp Forest.

Drought Crisis and Super Sandwich Techniques

Droughts frequently occurred in Thailand. El Nino phenomenon was the essential cause of the severe drought from 1999 to 2000. Thailand had faced severe crises: critical water levels in dams, crop losses, forest fire and saline water intrusion into Chao Phraya River due to the lower level of water in the river. The government announced measures to save water and reduce cultivated areas during that period. People suffered from the lack of water for consumption. Furthermore, the government warned farmers to restrict cultivated area of dry season rice. Thai farmers were concerned and panic.

Due to His Majesty's concern over the poverty of his people, he closely followed the drought situation and the extreme weather conditions in 1999. His Majesty suggested to set up, since the end of January 1999, special rainmaking operation teams in Nakhon Sawan and Phitsanulok to solve the drought problem in upper central river basin, Chao Phraya River Basin and lower northern river basin.

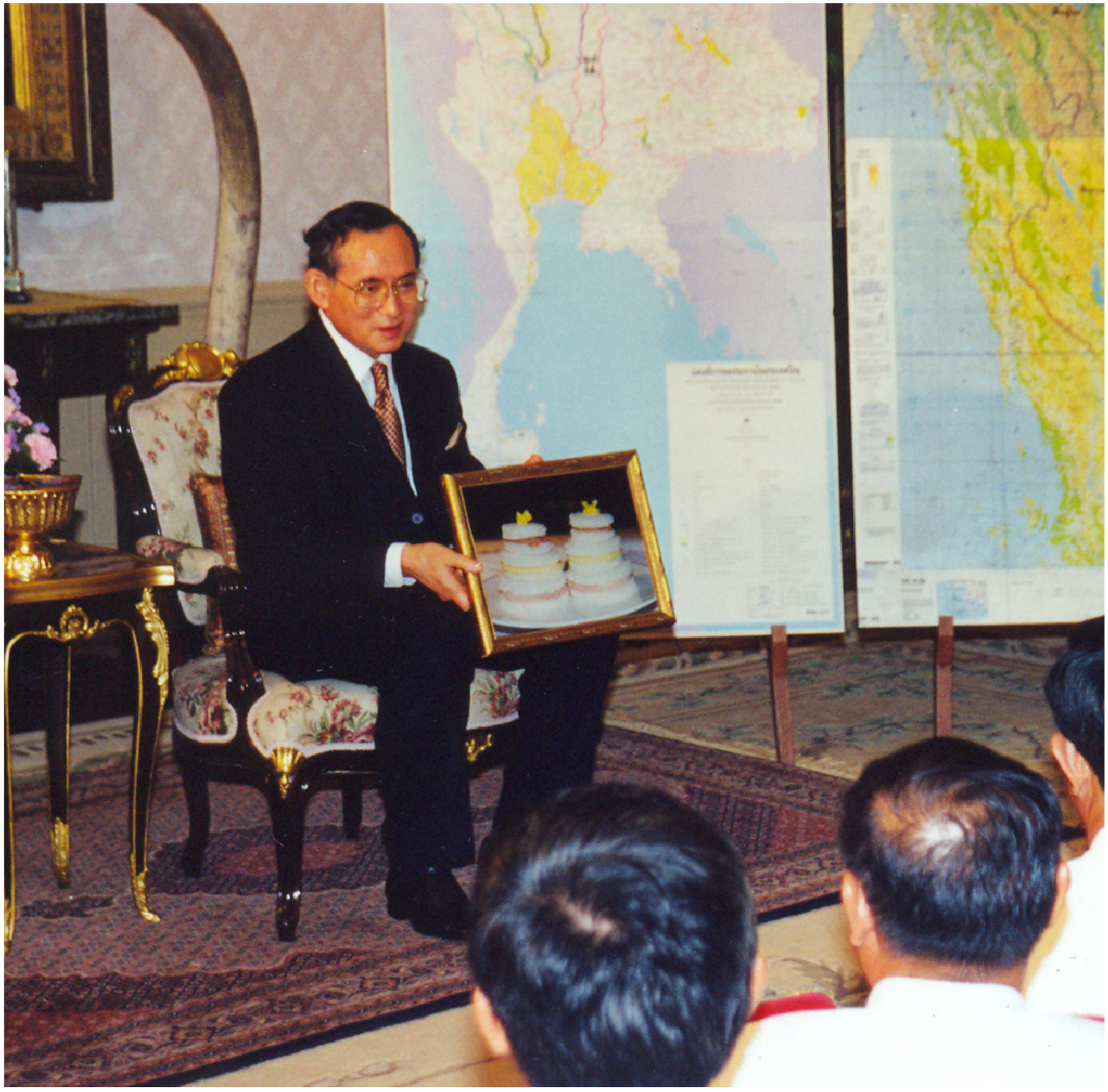
His Majesty also improved the Royal Rainmaking method by developing a new technique of weather modification called, 'Super Sandwich Technique' which was to attack both warm and cold clouds at the same time.

Straight forwardly, for ease of understanding, this process comprising 6 steps (Triggering - Fattening- Attacking by Sandwich Technique – Enhancing - Attacking Cold Cloud by Silver Iodide (AgI) Seeding - Attacking by Super Sandwich Technique), was briefed completely in a form of a beautiful cartoon in one page and given to the Royal Rainmaking academicians as a guideline. This computer-drawing called, 'the Royal Rainmaking Technology' was applied to help unfortunate people to alleviate drought. The intelligence and generosity gained respect and admiration from his subjects toward their King.

The successful Royal Rainmaking operation of two operation teams in resolving drought in 2000 and the monitoring of Royal Rainmaking technology team confirmed the success in preventing and coping with drought Subsequently, the Bureau of Royal Rainmaking and Agricultural Aviation was granted to use and publicize the Royal Rainmaking Technology so as to provide helps to unfortunate people.

3.3 Royal Rainmaking Technology Transfer and International Exchange of Knowledge

According to the aforesaid great success of Thailand, many foreign countries have requested for the Royal Rainmaking technology to be applied in their homelands. They have also requested for Thai experts to transfer the knowledge in their countries, and at the same time, sent their scientists to be trained in Thailand. Those countries were : Jordan, Indonesia, Malaysia, The Philippines, Sri Lanka, Bangladesh, Oman, Qatar, Mongolia and Tanzania. Sometimes, Thai scientists were also invited for



an exchange of the Royal Rainmaking technology in other countries like U.S.A., Canada, New Zealand, Australia, Japan, and China. As a result, these exchanges of technology led to research and development projects with Canada and U.S.A.

The great success of Thailand in Royal Rainmaking operation has drawn invitations from the World Meteorological Organization (WMO) to send Royal Rainmaking experts to join the meetings of expert team on weather modification since 1979. This makes the Royal Rainmaking to play an important role in weather modification at an international level. Moreover, Thailand has been registered since 1982 by the WMO under the United Nations in the group of weather modification countries.

In 1984, the ASEAN Sub-committee on Climate Change and the WMO agreed to grant designate Thailand as a center of weather modification in the tropical region, and reconfirmed it the designation in 1994. This has enhanced Thailand to play a more active role on weather modification at an international level.

3.4 Joint Venture Research with USA on AARRP

With reference to His Majesty's Policy on the strategy to develop "Royal Rainmaking Project", it is necessary to develop and improve rainmaking methods based on more scientific approaches for designing, operating, monitoring and evaluating. Subsequently, there were the research project to provide statistical analysis for conclusive proof of the effectiveness of rainmaking.

Thailand's Applied Atmospheric Resources Research Program (AARRP) was launched from 1994 to 1999 as a joint project of the Royal Thai government – RTG (Bureau of Royal Rainmaking and Agricultural Aviation, Ministry of Agriculture and Cooperatives) and the U.S. government (U.S. Agency for International Development, USAID). The goal of AARRP was to provide RTG with the capacity to conduct scientifically sound field experiments to quantify water augmentation potential of warm and cold rainmaking technique in accordance with randomized floating single target design.The Bhumibol Dam catchment in the Northwest of Thailand was the site of the project field studies and experimentation.

The following table concisely gives the result of the evaluation of the cold-cloud seeding with ejectable Silver Iodide flare near the tops (temperatures -6 °c to -10 °c) and the warm tropical convective clouds with Calcium Chloride particles.

Efficiency of rainmaking is higher than natural rainfall	Cold-Cloud (%)	Warm-Cloud (%)
1. Rain volume rate	48	109
2. Benefit area	17	64
3. Rainfall lifetime	5	11

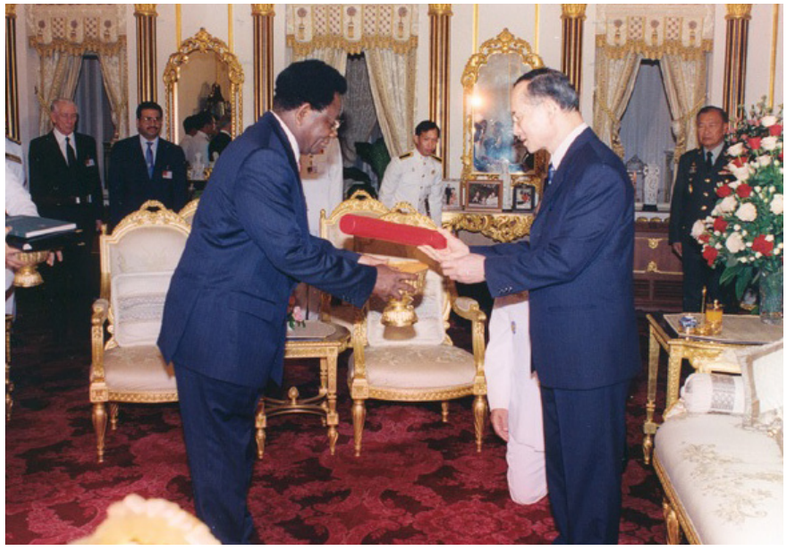
In conclusion, the evaluation of this program has provided statistically significant evidence that rainmaking produced 48% of cold-cloud and 109% of warm-cloud more than rain produced by their unseeded counterparts. That is the seeding of cold cloud by ejecting Silver Iodide and the seeding of warm convective clouds by ejecting Calcium Chloride particles. In early 1994, Royal Rainmaking scientists and US experts presented the AARRP's achievement to the 6th World Meteorological Conference in Italy. In February 1999, the WMO honored Thailand to host the 7th WMO Scientific Conference on Weather Modification in Chiang Mai.

3.5 Patents and Awards for Royal Rainmaking

Patents for Royal Rainmaking

In 2001, the Royal Rainmaking Project was granted a patent by the Department of Intellectual Property, Ministry of Commerce of Thailand and other organizations in other countries.

In 2005, the European Patent Office issued the patent for "Weather Modification by Royal Rainmaking Technology" to His Majesty. The patent was issued on behalf of 30 countries in Europe, 10 of which also granted their national patent for the same innovation. Later in 2006, His Majesty was also granted patent by the Hong Kong Special Administrative Region of the People's Republic of China.



Awards for Royal Rainmaking

"Royal Rainmaking Technology" has been an excellent invention broadly recognized among scientists and organizations on weather modification at international and global levels. International organizations granted the best awards, certificates, and honors to His Majesty for his remarkable talent and intellectual ability as follows:

- **1997 :** Plate and Certificate of Honor from the World Meteorology Organization-WMO
- **2000 :** Thai government praised His Majesty as "Father of Thailand Technology", and set 19th October as Thailand's Technology Day
- **2001 :** Trophy of "Diplôme D'un Concept Nouveau de Dévéloppement de la Thailande" from Brussels Eureka Fair 2001: 50th Anniversary of the World Exhibition of Innovation Research and New Technology

: Trophy of Special Prix for His Majesty of Thailand from Belgian-American Chamber of Commerce and Industry (BACCI)

- **2002 :** Thailand's Cabinet praised His Majesty as "The Father of Royal Rainmaking", and set 14th November as the Father of Royal Rainmaking Day
- **2006 :** Thailand's Cabinet praised His Majesty as "The Father of Thailand's Invention"
- **2006 :** UNDP Human Development Lifetime Achievement Award from United Nations
- 2007 : The international Federation of Inventor's Associations (IFIA) and Korea Invention Promotion Association (KIPA) praised His Majesty as "The Father of World Invention"
- 2007 : Trophy of Global Leader on Intellectual Property from the World Intellectual Property Organization - WIPO

Chapter 4

The Great Accomplishment

The Great Accomplishment

4.1 Royal Decree on Establishment of the Department of Royal Rainmaking and Agricultural Aviation

As the workload of the Bureau of Royal Rainmaking and Agricultural Aviation (BRRAA) has further increased, the BRRAA continued adjusting its organizational structure and expanding its missions. The Cabinet concurred, on 25 January 2013 to upgrade the status of BRRAA to **"the Department of Royal Rainmaking and Agricultural Aviation"** or **"DRRAA"**. In so-doing, the DRRAA had an urgent mission to adjust its organizational structure and set a five-year master plan of DRRAA missions. The Department set up afterwards Regional Rainmaking Centers for decentralization and integration with provincial and local organizations, and increased the number of Royal Rainmaking units under the control of the Regional Centers to enhance efficiency in operations as well as precision and speediness of Royal Rainmaking.

Nowadays, the DRRAA takes part in setting integrated policies, strategies and work plans with related organizations in the water management of the country and performs as a center of ASEAN and the world leading organization of weather modification.These missions are challenging for a government agency like the DRRAA to continue working on the royal initiative project for which His Majesty had devoted himself in conducting research and experiment on the Royal Rainmaking technology. As a result of His Majesty's devotion, the DRRAA, equipped with its Royal Rainmaking centers, new technology as well as knowledgeable and skilled officers could put into practice, His Majesty's initiatives finally help alleviate droughts and disasters for the Thai people.

4.2 Enhancement of Royal Rainmaking Operation Efficiency

To cope with the increasing missions, the DRRAA was obliged to increase its working potential and performance in terms of personnel, technology, equipment, and essential tools. It has also sought for cooperation with other public organizations, the private sector, and the general public.

Royal Rainmaking Volunteers

Royal Rainmaking volunteers get together as local voluntary groups aiming to help with distribution of water from atmospheric resources in the country to people. The groups are community organizations working closely with the DRRAA's staffs and farmers. Some of these volunteers are farmers in the Large Scale Farming Project and represent local farmers to submit requests for additional rain for their crops. Besides, these volunteers also give some information to farmers about water resources management and Royal Rainmaking activities in local areas.

Corporation with other internal and external organizations

With the kindness of His Majesty, the Royal Rainmaking Technology has been transferred to help people suffering from severe droughts in other countries such as Jordan, Qatar, the Philippines, Malaysia, Indonesia, Mongolia, Sri Lanka, Tanzania, and Singapore.

At present, the DRRAA has continually promoted international cooperation with many countries in terms of academy of science and technology about the Royal Rainmaking. In addition, the DRRAA has participated in international conferences on weather modification and atmospheric water management for preventing and solving drought problem.

Meanwhile, internal cooperation within the country has been achieved in order to increase efficiency in weather modification and intensive water management, with the Memorandums of Understanding (MOU) on topics covering scientific technology, research and development, integrated water resources management and aviation engineering. The MOUs have been signed with the involved agencies such as Defence Technology Institute, Thailand Institute of Scientific and Technology Research, Hydro and Agro Informatics Institute, Royal Irrigation Department, Royal Forest Department, Thai Meteorological Department, King Mongkut's Institute of Technology Ladkrabang, Faculty of Engineering of Kasetsart University, International Aviation College of Nakhon Phonom University, MRA Engineering & Marketing Co., LTD., and Civil Aviation Training Center

The DRRAA has constantly developed cooperative projects with foreign countries and organizations in terms of bilateral and multilateral collaborations aiming at formulating advanced approach to solve domestic and global water problems in a long term.

4.3 Enhancement of the Royal Rainmaking Technology

The significant mission of the DRRAA is to enhance His Majesty's wisdom on research and development of the Royal Rainmaking technology for a long period with his long vision through rational goals, strategies and vigorous work plan.

The DRRAA established a 20-year strategic plan to lead its own missions and combat challenges so as to increase its potential with utmost effectiveness in operating Royal Rainmaking task for water resources management, drought mitigation, and prevention of other natural disasters. In the meantime, the DRRAA has also been advanced in the Royal Rainmaking Technology through the following research and development projects:

1. Hail storm suppression by applying the Applied TITAN (Thunderstorm Identification Tracking Analysis and Nowcasting) Program. The program is used for a cold cloud operation to identify characteristics of rain groups and possibility of hail formation, and to help with decision making on Royal Rainmaking operation for hail suppression. Currently, the TITAN program is installed at radar stations located in the North and the Northeast, that are affected by hail storm every year.

2. Weather modification for suppression of haze which is mainly formed in cool or dry seasons. The weather modification operation is conducted by reducing temperature in the invasion layer by dispersing dry ice to contract air mass and make it move downward, allowing small molecule of haze and dust flows to move upward through the inversion layer to upper atmospheric level. Consequently, haze and dust in the air of the target areas decreases.

Moreover, the DRRAA has continually conducted academic research to support and enhance the efficiency of Royal Rainmaking operation as follows:

1. Application of Microwave Radiometer Profilers (MWRPs) which is a technology to continually monitor weather condition and help scientists to analyze major factors, such as, temperature, humidity, direction, wind speed, and air indices (i.e. K-index, SI-index, CAPE) to be used for evaluation and decision making to operate Royal Rainmaking.

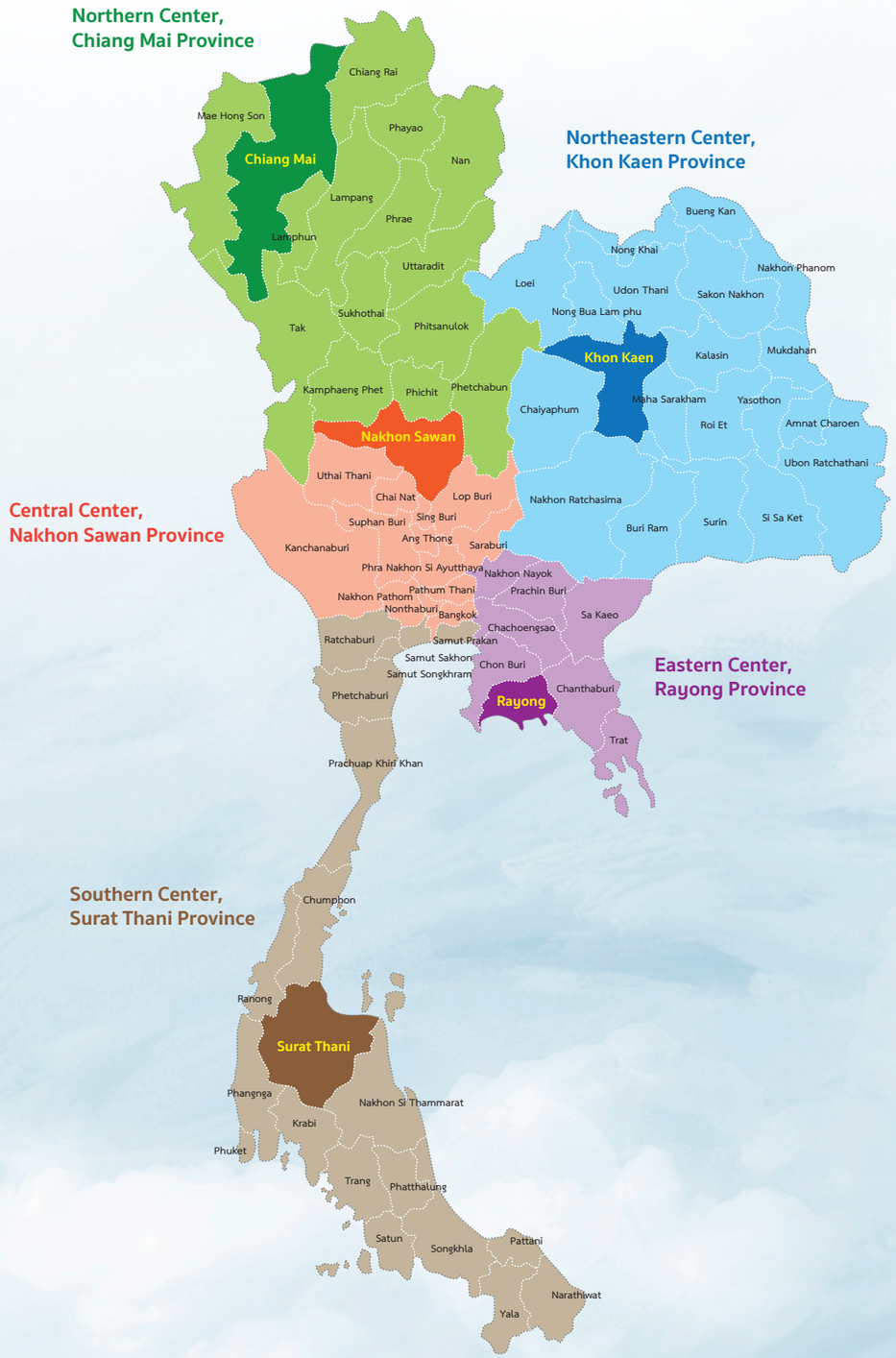
2. Development of Great Plains Cumulus Model (GPCM) or Program sonde 2 so as to accurately forecast the upper atmospheric climate. The program is accessible anywhere via internet system, and applicable for analyzing and planning of a daily rainmaking operation in a timely and effective manner.

3. Development of Mapping on Crop Water Requirement, using Remote Sensing and Geographic Information System (GIS) which is a technology to identify target areas, so as to enhance efficiency of Royal Rainmaking operation and enable evaluation of the operation productivity.

4.4 Abilities of Royal Rainmaking

Apart from capabilities of personnel, other major factors that contribute to the DRRAA's current potential are: equipment, scientific tools, data reporting system of scientific tools, and modern technology applied for Royal Rainmaking.

Royal Rainmaking Operation Centers and Provinces under responsibility



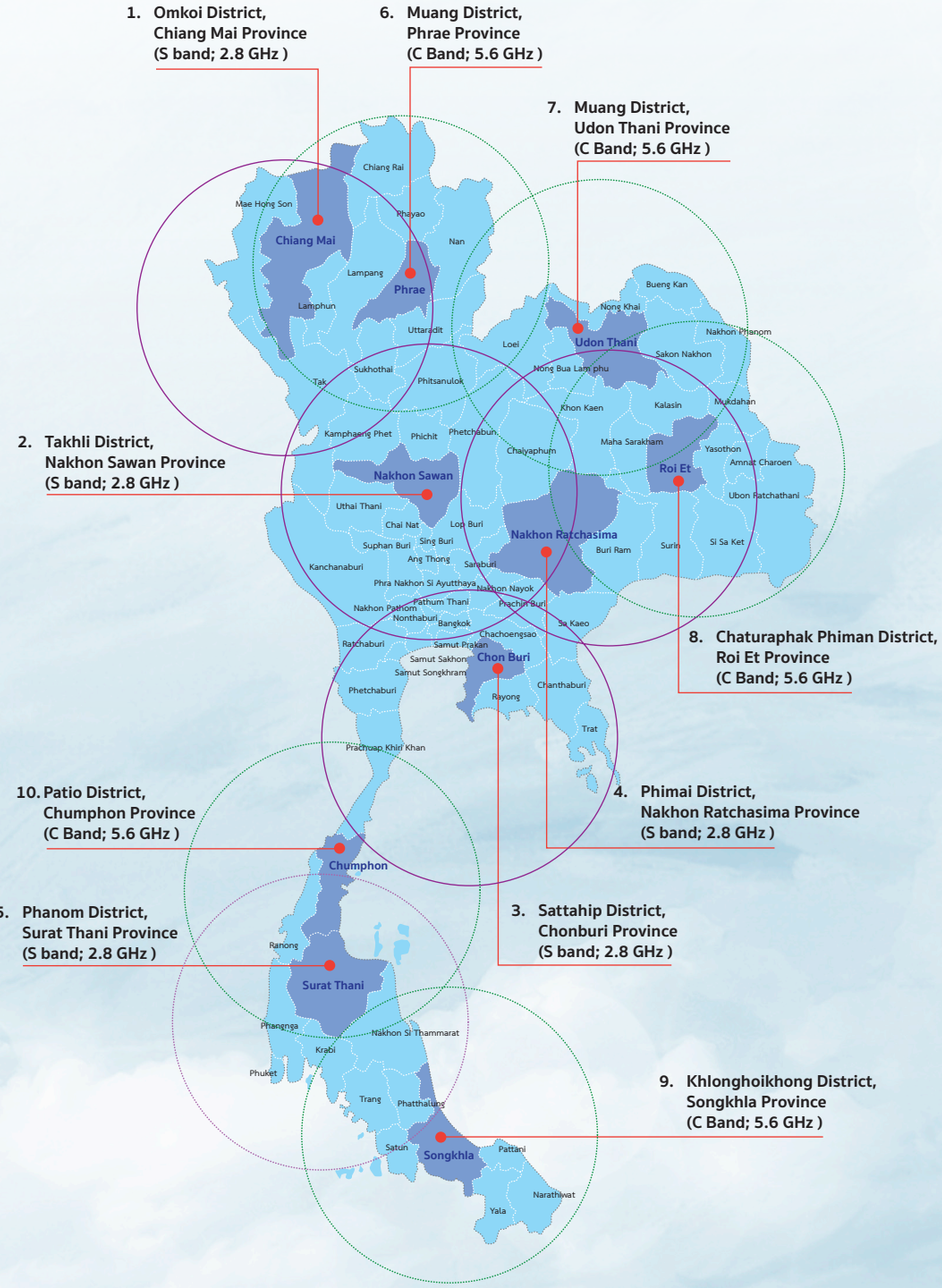
Royal Rainmaking Aircrafts

There are 2 types of aircrafts to support Royal Rainmaking operation services.

Type	Number of Engine	Loading Capacity (Kg)	Service	Total
1. Fixed-wing aircraft				
1.1 PorterPC-6/B2H2	1	500-550	warm cloud seeding	3
1.2 CessnaCaravan	1	700-800		10
1.3 CasaC-212	2	1,200		13
1.4 CN235-220	2	2,000-2,500		2
1.5 Super King Air 350B	2	-	- cold cloud seeding - research and development	3
2. Helicopter				
2.1 Ecureuil AS 350B	1	-	- survey and rainmaking evaluation - support Ministry's duties	2
2.2 BELL 206B	1	-		3
2.3 BELL 412 EP	2	-		1
2.4 BELL 407 EP	1	-		1
2.5 BELL 407 GXP	1	-		1

Weather Radar Stations

At present, the DRRAA has got 2 types of weather radars; fixed station radar (S band Doppler 2.8 GHz) and mobile radar (C Band Doppler; 5.6 GHz) A weather radar can detect cloud location, movement and intensity of the precipitation. This information is essential for planning rainmaking operation.



Seeding Substances

There are 3 main types of cloud seeding substances used for Royal Rainmaking operation, i.e. endothermic, exothermic and cloud condensation nuclei substances. The principle of seeding materials selection is the consideration of its properties and daily atmospheric conditions.

1. Endothermic substance

Endothermic is the substance that can raise its temperature by absorbing heat from the surroundings. Thus, the atmospheric temperature or cloud temperature will be cooled down. At present, 2 types of endothermic substances are being used in rainmaking operation: Calcium Chloride (Formula 6) and Calcium Oxide (Formula 8).

2. Exothermic substances

Exothermic is the substance that reduces its internal temperature by releasing heat into the surrounding to activate or enhance the formation and growth of clouds. At present, 3 types of exothermic substances are being used in rainmaking operations :Urea (Formula 4), Ammonium Nitrate (Formula 19) and dry ice (Formula 3)

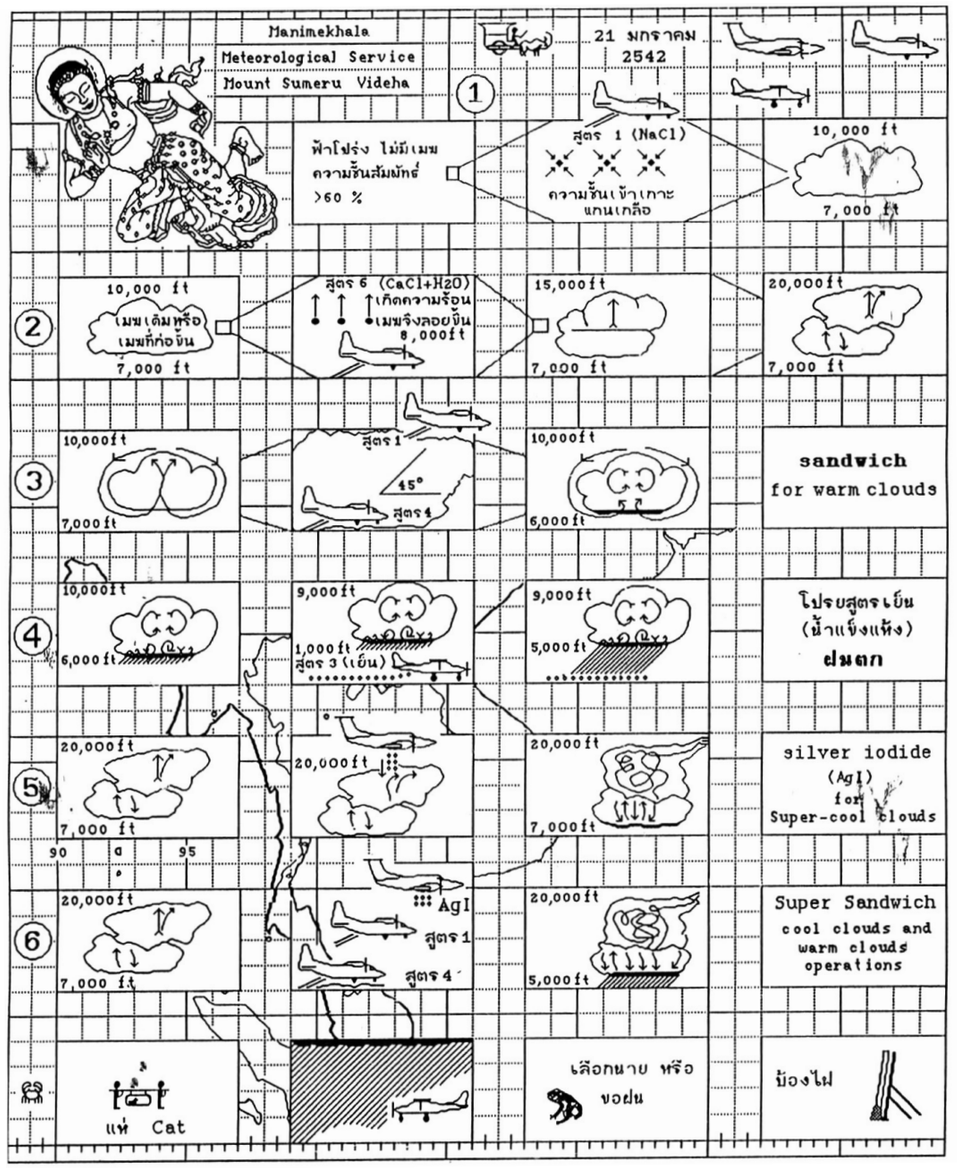
3. Cloud condensation nuclei substances

Cloud condensation nuclei or CCN provides the surface for water vapor molecules to condense into liquid form. At present, Sodium Chloride (Formula 1) is used as CCN substance for rainmaking operation.

Royal Rainmaking Technique

His Majesty had initiated the Royal Rainmaking operation and monitored the result of the experiments from daily reports.

He also studied scientific documents, closely observed weather conditions and phenomena on the atmosphere; no matter if an experiment was on-going or not. As a result of his devotion, he could progressively develop a process of cloud seeding. In 1973, His Majesty delivered the principle of cloud seeding to the officers and this principle has continuously been used until 1999. The warm and cold cloud seeding consists of 6 steps as follows:



Step I. Triggering

This step begins when the sky in the target area is clear or only a few cumulus clouds have formed in the morning and the average relative humidity is at least 60 percent. Powder of Sodium Chloride (NaCl), is dispersed from aircraft in the upwind side of the target area at the altitude of 7,000-8,000 ft. In order to activate cloud formation, each particle of Sodium Chloride acts as cloud condensation nuclei to absorb moisture and then change vapor into liquid or cloud droplets. The clouds can become bigger with the top reaching the altitude of 10,000 ft.

Step II. Fattening

This step is to make the triggered clouds in the previous step and the natural clouds grow bigger. It starts when the cloud tops of the cumulus clouds formed in Step I reach the altitude of 10,000 ft. and an aircraft disperses powder of calcium chloride (CaCl2) into the clouds at the altitude of 8,000 ft. The heat from the chemical reaction of CaCl2 and moisture will expedite or enhance the updraft of air mass in the cloud. Therefore, the cloud growth increases continuously and the cloud top is higher than in the previous step. Its top can reach the altitude of 15,000 ft where it becomes ‘warm cloud’ (the temperature in the cloud top is higher than 0^0C). If the updraft is enough, the cloud top can develop until it reaches the altitude of 20,000 ft. where it becomes cold cloud (the temperature in the cloud top is below 0^0C).

Step III. Attacking

This is the case for warm cloud seeding which starts when the cumulus clouds formed in Step II move along with the wind approaching the target area and the cloud tops reach the altitude of 10,000 feet or higher. One aircraft disperses NaCl

at the top or the shoulder of the clouds (an attitude of 9,000 ft) on the upwind side. At the same time, the other aircraft applies urea at the altitude of 1,000 ft. above the base clouds. This results in two aircrafts flying simultaneously in parallel, making an angle of 45 degrees to the horizontal line. This flying technique is called ‘sandwich’. After seeding, raindrops in cloud become densely bigger and move lower to the cloud base. The cloud becomes mature and rain starts to drop but not so much.

Step IV. Enhancing

This step is to maintain Step III and enhance rainfall onto the ground. After operating step III, there may not be much rain because the atmosphere below the cloud base is drier and the temperature is higher than those in the cloud. Thus, the raindrops falling through the cloud base rapidly evaporate. This step is done by dispersing dry ice flakes (-78°C) at the altitude of 1,000 ft. below the cloud base to lower air mass’s temperature and increase relative humidity. This action will help reducing evaporation of raindrops. The rainfall rate gradually increases and a greater number of super-large raindrops reach the ground. This causes heavy rain which provides more amount of rainfall than that of natural rain.

Step V. Attacking Cold Cloud by Silver Iodide (AgI) Seeding

This step is operated when the cloud top formed in Step II reaches the altitude of 20,000 ft. This process is done by ejecting flares of AgI into the cloud top at the altitude of 21,500 ft. After operation, the amount of ice will be formed especially at the cloud top. Freezing of droplets enhances the release of latent heat, increases cloud buoyancy and updraft, and induces moister air into the cloud base. The ice will grow much bigger before melting into raindrops.

Step VI. Attacking by Super Sandwich Technique

This step is used when the cloud top in Step II reaches over the altitude of 20,000 ft. and the cloud condition is the same as that in Step V. Warm and cold cloud attacking techniques are used at the same time with at least 3 aircrafts. The cold cloud seeding aircraft ejects flares of AgI into the cloud top (at the altitude of 21,500 ft.) while the other two aircrafts use sandwich technique for warm cloud seeding, one dispersing NaCl at the mid-cloud level (about 10,000 ft), and the other one dispersing Urea at the cloud base level. The warm cloud seeding aircraft may disperse Dry Ice of Step IV in order to enhance rainfall. After seeding by the Super Sandwich Attacking Technique, the treated clouds start to produce heavy rain in large amounts for a prolonged period of time.

Chapter 5

Next Step “The Great Step of Royal Rainmaking Mission”

Next Step “The Great Step of Royal Rainmaking Mission”

Vision of the DRRAA is “In 2036, the DRRAA shall be the world’s leading organization in weather modification with the use of techniques developed by His Majesty King Bhumibol Adulyadej”, and the aim to protect agricultural areas and solve drought problem, add water into water sources and major reservoirs, mitigate natural disasters, and determine policy on atmospheric water management. The DRRAA also joins hands with other related agencies in national intensive water management, researches and development of weather modification technology, and provision of aviation and communication services. In so doing, the DRRAA encounters the following challenges like climate change and global warming that cause delayed rain, extensive agricultural areas, and changes of land use.

The DRRAA has, therefore, determined its working methodology to accomplish its missions and cope with the aforesaid challenges. That was to establish a 20-year strategic plan to enhance precision, speediness and efficiency of Royal Rainmaking operation and enhance standardization and timeliness of aviation operation. Strategies are also an essential tool to drive the DRRAA to successfully achieve its goals and visions. The strategies and work performance goals set for 5, 10, and 20 year-periods are as follows:

1. Strategy on prevention and mitigation of droughts and disasters
2. Strategy on enhancement of weather modification efficiency
3. Strategy on aviation management
4. Strategy on development of governmental management system

Appendix

Cooperation Project on Royal Rainmaking Technology between Thailand and Mongolia

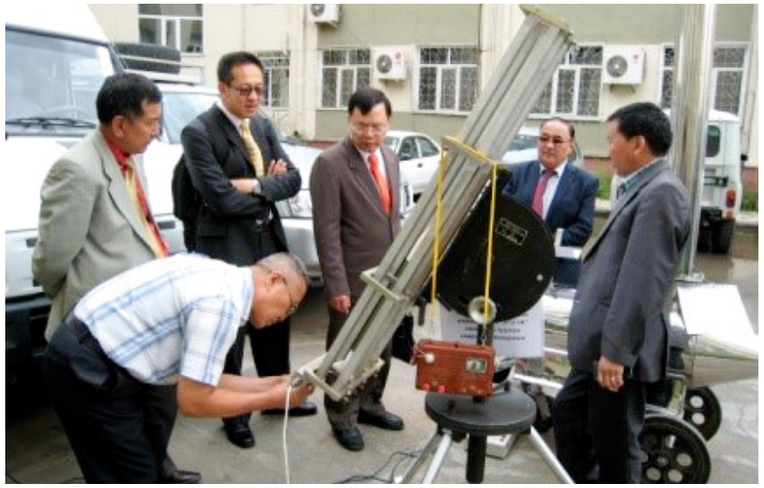
Cooperation Project on Royal Rainmaking Technology between Thailand and Mongolia

On 4th June 2014, Ambassador of Mongolia to the Kingdom of Thailand (H.E. Mr. Battumur Chimeddorj) informed the Office of His Majesty's Principal Private Secretary that the President of Mongolia requested Her Royal Highness Princess Maha Chakri Sirindhorn for supporting the arrangement of the training on Royal Rainmaking technology for the Mongolian representatives.

Subsequently, the meeting of 3 agencies (the Embassy of Mongolia in Bangkok, the Office of H.R.H. Princess Maha Chakri Sirindhorn's Projects and the Department of Royal Rainmaking and Agricultural Aviation or DRRAA) was held to discuss about the cooperation on Royal Rainmaking technology between Thailand and Mongolia. As the information regarding weather modification in Mongolia is not adequate, The Royal Household Bureau agreed with DRRAA to send experts to conduct a feasibility study for rainmaking technology in Mongolia.

On 5th– 9th July 2014, Thai expert team led by Dr. Surasri Kidtimonton, DRRAA Director-General, at that time was the Deputy Director-General, went to Mongolia to evaluate the possibility of rainmaking there. On this occasion, Thai expert team met Advisor to the President of National Security and Foreign Policy, the executives of National Agency for Meteorology and Environment Monitoring of Mongolia, Director of Weather Modification Department, and Director of Water Resource of Ministry of Environment and Green Development, in order to get more information about topography, weather, environment, weather forecast, water resources and water management in Mongolia.

On 18th September 2014, the meeting was held by the 3 agencies to follow up the progress of this cooperation.



In this connection, the DRRAA suggested that Mongolian representatives should come to Thailand for the study visit during June - July 2015. The Embassy of Mongolia in Bangkok would inform the government and involved agencies in Mongolia on the study visit project, then they would submit a request to the Office of H.R.H. Princess Maha Chakri Sirindhorn's Projects.

On 11th May 2017, H.E. Mr. Tugsbilguun Tumurkhuleg, Ambassador of Mongolia to the Kingdom of Thailand, visited DRRAA and discussed with Dr. Surasri Kidtimonton, Director-General of DRRAA, on the cooperation project. The embassy also submitted a letter to the Office of H.R.H. Princess Maha Chakri Sirindhorn's Projects on this matter.

On 1st August 2017, the Embassy of Mongolia sent a letter to seek for technical and financial support from DRRAA for organizing a study visit on Royal Rainmaking technology for 5 officials from the National Agency for Meteorology and Environment Monitoring 2017. Therefore, DRRAA conveyed the request to the Office of H.R.H. Princess Maha Chakri Sirindhorn's Projects. H.R.H Princess Maha Chakri Sirindhorn has graciously agreed to support the study visit project.

Approach to Cooperation on Rainmaking

Mongolia has applied weather modification technique by 1) Silver Iodide flare/canon ejecting and Silver Iodide burning from the ground. Therefore, an approach to cooperation between Thailand and Mongolia could be developed by exchange of knowledge and expertise on weather modification. Mongolia could adapt some techniques from the Royal Rainmaking technology for its cloud seeding operation, while Thailand will also adapt some of artificial rainmaking methods from Mongolia to Royal Rainmaking operation to enhance it to be most efficient.